Abuja Journal of Economics & Allied Fields, Vol. 12, No. 5, December, 2023.
Print ISSN: 2672-4375 Online: 2672-4324

# Impact of Electricity Sector Reform on The Efficiency of Electricity Distribution Companies (Dis Cos) in Nigeria.

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*Abstract*

*The essence of electricity sector reform is to improve the technical efficiencyof power utilities, thereby increasing access to reliable electricity and the productive use of electricity. In this light, this study examines the impact of electricity sector reform on the efficiency of distribution companies (DisCOs) in Nigeria. The study employs panel data from 11 DisCos between 2012 and 2020 and the Translog Input Distance Function of Stochastic Frontier Analysis (SFA) with Maximum Likelihood (ML) random-effects time-varying model of technical inefficiencies. In terms of the distribution of the inefficiency term, the truncated normal distribution, which allows the use of a single-step procedure to examine the impact of exogenous factors (electricity sector reform) on the inefficiency of the DisCOs is employed. The paper finds that electricity sector reform has a significant relationship with the efficiency of DisCOs. The presence of regulation further decreases the sub-sector's efficiency; however, private sector involvement in the sub-sector improves the distribution companies' efficiency. The impact of competition on DisCOs' efficiency is inconclusive. The study finds DisCOsto be highly inefficient despite sector reforms, with an average efficiency of 23 percent, which is remarkably low for a privatized industry. The paper therefore concludesthat electricity sector reform did not result in the desired efficiency gains of the DisCos. The study therefore recommends that more private sector involving is needed to improve the efficiency of the distribution sub-sector, with government involvement limited to supervisory or regulatory role.*

**Keywords:** Electricity Sector Reform, Efficiency, DisCOs, Stochastic Frontier Model, Translog Input Distance Function.
JEL Classification: L1, L51, Q38, Q43

## 1. Introduction

At the turn of the millennium, Nigeria embarked on one of the most ambitious power sector reform programmes in the world,costing inexcess of 3 billion dollars. The rationale for this reform,like most reforms, is not only borne out of poor performance ofdefunct state-ownedNEPA, occasioned by high energyandquasi-fiscal deficits,but also to improve the operational efficiency of privatized utilities (Ojiya et al., 2018; Sen et al., 2016a; Nworie, 2017a; KPMG, 2016; Allyne). Thisefficiency gainis only achievedthrough cost and collection efficiency, as well as the degree ofcontestability of the electricity market.This helps drive down energy prices while scaling up quantity and quality of services, thereby reducing operating losses and quasi-fiscal deficits of privatized power utilities (Musa, 2023; Sen et al., 2016b; Nepal & Jamasb, 2015).There is strong evidence in the literature suggesting that electricity sector reform improves efficiency in the sector, especially in developed countries (Joskow, 2006; Pollitt, 2004;Erdogdu, 2013a). Reforms impact has not produced desirable outcomes in developing countries, especially in Sub-Saharan Africa (SSA), where institutional weakness, a lack of political will, and technical and managerial expertise to drive reform programmes prevail (David, 2005; Nepal & Jamasb, 2015).

Despite nearly two decades of power sector reform in Nigeria, access to reliable electricity is still a mirage as inefficiencies persist across the electricity value chain (Musa, 2023; Abayomi, 2021). There is still huge underinvestment in distribution infrastructure, with attendant impacts on the quality of services and collection shortfalls (Tinuoye, 2017). The aggregate technical, commercial, and collection (ATC&C) losses, which range between 30 and 60 percent, are one of the highest in the world (Poudineh & Oyewunmi, 2018). Recent industry reports suggest that the DisCO with the lowest average ATC&C losses between 2015 and 2020 is EkoDisCO with 31 percent, which is significantly higher than theglobal benchmark of 8 percent, 22 percent for India, 6 percent for the US, 5 percent for China, and 4 percent for Japan, and Kaduna DisCOwith average ATC&C losses as high as 68 percent over the same period(Odje, 2021; Regy et al., 2021). The DisCos' ATC&C losses, although declining from 54 percentto 40 percent between 2015 and 2020,are still remarkably high to recover operating costs, and operate efficiently.

High ATC&C losses and a consequent lack of liquidity have a significant impact on the financial health of the electricity sector, given DisCOs'inability to collect enough revenue to remit for energy supplied.These billing and collection inefficiencies havetheir roots in consumers' unwillingness to pay for energy consumed, power theft, collection racketeering, and exorbitant estimated billing byDisCOs (Peng &Poudineh, 2018). Total revenue collected and remitted by DisCOs is only 20-30 percent of the total cost of electricity supplied, which is not only grossly inadequate to incentivize investment in distribution infrastructures but also investment in transmission infrastructures and gas supply(NERC, 2020).Between 2015 and 2016, only five out of 11DisCOs were able to meet cash calls to the market operator. This numberrose to 8 DisCosby the end of 2016 due to interventions from the CBN and World Bank;however, this did not solve the cash problems as illiquidity still persists in the sub- sector (FGN, 2015; CBN, 2020; World Bank, 2020). The country's quasi-fiscal deficits are also the highest in SSA, and cost recovery among power utilities is only second to Angola (Alleyne, 2013). It is against this background that this paper examines the impact of electricity sector reform on the technical efficiency of the DisCOs in Nigeria. Consequently, the study provides evidence- based answers to these questions: What impact does electricity sector reform have on the technical efficiency of DisCOs in Nigeria? How has the privatization of DisCOs impacted their efficiency? What impact does regulation haveon the efficiency of the DisCOs? And lastly, how has a competitive electricitymarket impactedefficiency in the distribution sub- sector?

Several studies exist in the reform literature on the impact of electricity sector reform on various economic outcomes (performance) in both developed and developing economies (Erdogdu, 2013a; Sen et al., 2016a, 2016b; Ojiya et al., 2018; Lemaire & Ragab,2020; Nepal et al., 2022; Li et al., 2022). Some studies focus on the impact of structural reforms on efficiency (Jiang, 2019; Bobde & Tanaka, 2020; Kamil et al., 2020; Ajayi & Weyman-Jones, 2021;and Nsabimana, 2022). Few studies examine the impact of electricity reform on the efficiency of power utilities in SSA (Olatunji, 2019; Njeru et al., 2019; Nsabimana, 2022). Most of these studies either employ econometric methods or data envelopment analysis (DEA) to estimate thetechnical efficiency of power utilities. Njeru (2019) uses the DEA to examine the technical efficiency of thermal electricity generators in Kenya; Olatunji (2018) employs the fully-modified OLS to explore determinants of productivity in the Nigerian Electricity Industry (NESI); and Nsabimana (2022) assesses the technical efficiency of the East African Power Sector using both the DEA and total factor productivity change (TFPC). However, econometric methods are less suitable when investigating technical efficiency, especially in industry, and the use of DEA and TFPC, although suitable, is non-parametric and relies on linear programming to determine firms' technicalefficiency (O'Donnell, 2018;Battese&Coelli, 1995; Nworie, 2017a; Musa, 2023). Furthermore, these methods do not involve specifying production functions in multi output-multi input models (Coelli et al., 2005).

This study fills both empirical and methodology gaps in the literature by employing stochastic frontier analysis (SFA) to examine the impact of electricity sector reform on the technical efficiency of electricity distribution companies in Nigeria. Empirical studies on reform's impact on DisCOs' technical efficiency, especially thosethat employ a multi output-multi input function to estimate the technical efficiency of power utilities in Nigeria, are either scanty or non-existent.Existing works on efficiency gains from reforms in this context are, at best, normative. This paper adds to this body of knowledge by using the SFA and Translog functions to estimate the technical efficiency of DisCOs, which is still a novelty in reform literature in Nigeria. In light of this foregoing discussion, this study finds electricity sector reform to have a significant influence on DisCOs' efficiency in Nigeria. While privatization of distribution networks has improved DisCOs' technical efficiency, regulatory quality has worsened their efficiency. The implications of the results are that the regulatory framework and tools are ineffective, and privatization of DisCOs has yielded the desired outcome of improving their technical efficiency. The conclusion of this paper will not only engender new thinking on energy policies in Nigeria but also have wider implications for energy policy formulations and implementations in SSA and developing economies, given the country's critical role in the West African Power Pool and the African continent at large.

The rest of this paper is summarizedas follows: Section 2 clarifies conceptual, theoretical, and empirical issues surrounding this study. Section 3 examines the composition of the data used, stylized facts, and descriptive statistics of the data. Section 4 looks at the methodological framework, specifically examining the building blocks of the Translog Input Distance Function. Section 5 presents and discusses empirical results as well as the policy implications that emanate from the findings. Section 5 concludes the study.

## 2. Electricity Sector Reform and Sectoral Efficiency in Nigeria

The roadmap for electricity sector reform in Nigeria started in 2001, following nearly four decades of NEPA's inability to provide reliable power to meet burgeoning energy demands,which prompted the need for sector restructuring to allow private participation in the electricity value chain (Musa, 2023; Tinuoye, 2017). The formulation of the National Electric Power Policy (NEPP) through the enactment of the Power Sector Reform Act, 2001, marks the beginning of private sector involvement in the power sector. In 2005,NEPA was corporatized into PHCN by the Bureau of Public Enterprises, which took over assets and liabilities prior to privatization and the conclusion of the sector reform(Arowolo & Yannick, 2018).However, the NEPP was abolished on August 8, 2005,to pave the way for the enactment of the Electric Power Sector Reform Act (EPSRA), 2005, and mark the beginning of power sector restructuring in Nigeria. The overarching objective of the EPSRA is to ensure a long-term electricity market where investors will operate in a competitive market structure and where the tariffs charged by service providers are determined by market forces (FGN, 2005).This leads to the unbundling of PHCN into 18 companies: 11 distribution companies, 6 generating companies, and the Transmission Company of Nigeria, which remains 100 percent owned by the government (Tinuoye, 2017).The Act also led to the establishment of theNigeria Electricity Regulatory Commission [NERC] as an independent regulator to coordinate the activities of the market and the Nigerian Bulk Electricity Trading Company [NBET] as bulk electricity off-taker (intermediaries) between the generating companies (GenCos) and the distribution companies(DisCOs),especially during the transitional stage of the electricity market (FGN, 2017). Furthermore,the multi-year tariff order (MYTO) takes effect on July 1, 2015, and prior to this, the DisCoswere granted licenses as privatized firms in 2013, with thegovernment having combined 40 percent stakes in each DisCo.

With no apparent improvement in the efficiency of DisCOs and the power situation in the country despite nearly two decades of sector reform, led to the passage of the Electricity Bill, 2022, by the Senate, repealing the EPSRA, and therefore providing a renewed legislative framework that will guide the post-privatization phase of the electricity industry (Atoyebi & Ayara, 2022). The bill intends to attract more investments and leverage the various gains of the privatization of the electricity value chain. Finally, new electricity bills which is passed on June 9, 2023, among others provide legal autonomy for the various states of the federation to generate, transmit, and distribute their own electricity provided they are covered by the national grid. The bill also allows individuals and firms to generate and distribute their own power, provided it is below one megawatt of electricity (FGN, 2022). These landmark billshave thepropensity to change energy poverty dynamics in Nigeria for many years to come.

The theoretical underpinning of electricity reform is drawn from standard microeconomic theory of efficiency, where societal welfare (total surplus) is maximized under a perfect competitive market and the presence of monopolieswill leads to deadweight loss (Begg et al., 2014; Sen et al., 2016b). Furthermore,the theory of natural monopoly holds that when firms have high fixed costs and average costs decline as output rises, efficiency can only be achieved when one seller serves a market (Greer, 2011; Begg et al., 2014). Jamasb et al. (2014) view reform as a combination of the establishment of energy policies, legislation, and institutionsgeared towards encouraging private participation and investments that will replace state-owned enterprises. Power reform ranges from subsidy removal, the establishment of cost- reflective pricing (low-level reform), to the corporatization of state-owned enterprises, vertical unbundling of this state-owned enterpriseinto competitive segments, and the introduction of an independent regulator to coordinate the activities of privatized entities (high-level reform). Bensch et al. (2016) argue that electricity reformentailsa combination of privatization, regulation, and competition with the view of improving technical efficiency in the sector, ultimately enhancing consumers' welfare, and guaranteeing returns on investment.They see privatization as a change in ownership rights of public utilities for public to private companies. The theoretical argument for privatization is that it leads to improvements in productive efficiency through labour productivity and high-capacity utilization (Zhang et al., 2008). Bade and Parkin (2013) posit that regulation entails "rules of the game" administered by a government agency (an independent regulator) to control tariffs, quantity and quality of service, and the entry and exit of privatized firms in an industry. Competition in the electricity market will not only engender private capital mobilization but also increase productivity through lowering operating costs and closing the price-cost gap

(Joskow, 1998).

On the other hand, Farrell (1957) in his submission on efficiency posits that it is a situation where a firm, given technical knowledge,is able to maximize output from a given amount of inputs or produce a given level of output using fewer factor inputs. Mankiw (2005) describes efficiency as the highest possible level of economic performance for a firm or industry where least combinations of factor inputs are used to achieve the maximum level of output.Efficiency can be categorized into technical, economic, and allocative efficiency (Dogan et al., 2018). However, this study focuses only on technical efficiency. Production is technically efficient if there is no other feasible combination of factor inputs that can produce more output without using additional inputsor use fewer inputs to produce the same level of output (Mas-Colell et al., 1995). Technical efficiency involves firms' ability to produce maximum outputs from a given production vector, and is measured by the output-input ratio (Coelli, 1996). Erena et al. (2021) state that, given technological innovation, technical efficiency is firm's ability to increase output level with a given level of productive inputs.

A host of empirical studies on the technical efficiency of power utilities exist in the literature. Li et al. (2022) use stochastic frontier analysis (SFA) to examine the technical efficiency of China's coal-fired power enterprises between 2010 and 2015, and found the average technical efficiency to be 81.8 percent. Jiang (2019), in a similar study, employs an input-oriented distance function and two-stage linear programming to examine the technical efficiency of thermal power plants in China and found disparities in technical efficiency among regions in China with efficiency gaps showing no signs of converging during the eleventh "five-year plan", and the twelfth "five-year plan," respectively. Kamil et al. (2020) measure the technical efficiency of power generating plants in Bangladesh using SFA (truncated normal distribution) and monthly data between 2013 and 2014. They therefore found the average technical efficiency to be over 90 percent, and the Sylhet combined cycle power plant's average technical efficiency to be 78.6 per cent. Aplethora of studies have also been done on the impact of structural reform on efficiency gains. Bobde and Tabaka (2020) employ the 2-stage DEA and bootstrap method and state-level panel data between 1995 and 2012, and found electricity reform (partial unbundle structure) to have a significant negative impact on technical efficiency. Their study also showsthat small-sized distribution sector experience efficiency gains following the reform of the electricity industry. Other studies have focused on institutional factors such as corruption, political support (Iman et al., 2018; Ajayi & Weyman-Jones, 2021; Musa, 2023) Ajayi and Weyman-Jones (2021) use a US state-level electricity generation dataset between 1997 and 2014, and found deregulation and political support to have a positive influence on technical efficiency, with average technical efficiency of 73.1 percent.

In spite of the avalanche of studies on the technical efficiency of power utilities, there are few empirical studies that estimatethe technical efficiency of power industriesin SSA and Nigeria in particular. Njeru et al. (2019) use SFA and DEA to examine the technical efficiency of thermal electricity generators in Kenya using a monthly dataset between July 2015 and December 2017 and found the average technical efficiency to be 71 percent with age and public ownership contributing to the sector's inefficiency. However, grid connections contribute to efficiency gains in the electricity industry. Nsabimana (2022) employs DEA and total factor productivity change (TFPC) to assess the technical efficiency of the East African power pool comprising Burundi, Ethiopia, Kenya, Rwanda, and Uganda between 2008 and 2017 and finds the average performance gap to be 20 and 22 percent for the generation model and the transmission-distribution model, respectively. The study also found that the generating industry exhibits a decreasing return to scale, while the transmission-distribution industry exhibits an increasing return to scale. Olatunji (2018) uses fully-modified OLS and time series data between 1996 and 2015 to analyze determinants of productivity in Nigeria and therefore found total factor productivity to be 29 percent, which is significantly below the global productivity benchmark of 80 percent. The study concluded that inadequate funding, vandalism, and a lack of technical and managerial expertise jointly contributed to low productivity in Nigeria.

There are also recent studies in the literature on the impact of electricity reform impact on sector efficiency(Nepal et al., 2022; Asanteewa et al., 2022). Nepal et al. (2022) use panel data econometrics for 18 non-OECD Asian and SSARC countries between 1990 and 2018 and found, while accounting for cross-sectional dependence, that electricity sector reform improves the operational efficiency of distribution networks through a reduction in energy losses. Asanteewa et al. (2022) employ SFA in 37 African countries between 2000 and 2017 and therefore found the electricity sector to have a positive correlation with installed capacity per capita, plant load factor, and technical network losses. In light of the foregoing discussion, the gap in the literature is evident, as studies empirically assessing the linkage between electricity sector reform and the technical efficiency of DISCOsin Nigeria arevirtually nonexistent. Moreover, previous studies have focused more on non-parametric DEA to estimate efficiency gains from structural reforms. This paper departs from existing literature by using the Translog Input Distance Function to measure the technical efficiency of the DISCOs in Nigeria. Nworie (2017), although employing similar methods in estimating the technical efficiencies of DISCOs in 33African countries, however, it uses two-stages approach to measuring technical efficiency. This study adds to the body of knowledge by using a truncated normal distribution, which allows a single-step procedure to examine the influence of exogenous factors (electricity sector reform) on DISCOs' inefficiency (Kumbhakar et al., 2015).

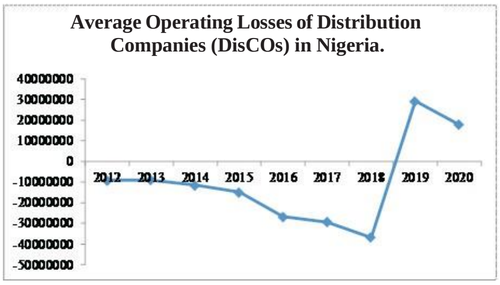
## 3. Data

This study uses panel data from 11 distribution companies from 2012 and 2020, collected from various secondary sources.This period is chosen because the unbundled distribution companies were officially transferred to private investors in 2013, althoughthey have been operational since 2012. Since this paper employs the multi input-multi output production function, this study collected data on output variables such as total sales or revenue, number of customers, and energy delivered from the annual reports and financial statements of each DisCO for the period under consideration. Input variables such as number of employees, operating expenditure, and distribution network proxy as distribution assets are collected from both the companies' annual reports and the NERC annual reports and quarterly performance reports of DisCOs. Exogenous variables such as average maximum peak load, public management and institution, and regulatory quality are sourced from the Transmission Company of Nigeria (TCN) and the World Bank Governance Indicators, respectively. In terms of the electricity sector reform variables, The study usesa dummy variable to represent the existence or otherwise of competition and unbundling in the Nigerian electricity sector reform. Privatization is measured by the percentage ownership stakes of private firms in each DisCO. These variables have been adopted based on the works of Jamasb et al. (2005) and Nworie (2017), as well as to capture the peculiarities of the Nigerian electricity industry (Musa, 2023).

In light of the foregoing discussion, it therefore becomes pertinent that the paper examines the stylized facts surrounding the Nigerian electricity industry as well as the descriptive statistics of the variables under consideration. Figures 2 and 3present data on the efficiency of the distribution sub-sector.

**Figure 1**

*The distribution sub-sector's average operating losses (2012- 2020)*



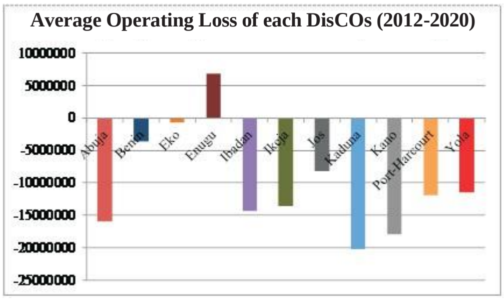

**Note:** The graph shows that the distribution sub-sector has been experiencing operating losses since privatization, except in 2019 and 2020. Copyright:Author based on data collected from Annual Financial Report of DISCOs between 2012 and 2020

While Figure 1 considers the average operating losses of the distribution sub-sector between 2012 and 2020, Figure 2 glances at the average operating losses of each DisCO in the same period. Figure 1 shows that the distribution segment has been operating at losses since privatization, except in 2019 and 2020, when average operating profit was achieved, albeit at a decreasing rate. Average operating losses increased by over 300 percent between 2013 and 2018. However, the industry achieves average operating profit in 2019 and 2020, although it falls in 2020 due to the impact of the COVID-19 pandemic on household and business energy consumption (Musa, 2023). This inefficiency can be attributed to non-cost-reflective MYTO regimes, electricity theft, and huge collection shortfalls (IBEDC, 2015).

Figure 2 shows that each of the distribution companies experience operating losses since privatization, except the Enugu Electricity Distribution Company, which achieves an average operating profit of 6.8 million naira over the nine-years period since privatization. However, Tables 1 and 2 look at the descriptive statistics of the technical efficiency model. Table 1shows the statistical properties of the variables under consideration.

**Figure 2**

*The average operating losses of each DISCO (2012- 2020)*




**Note:** The graph shows that each DisCO has been operating at a loss since privatization, except Enugu Electricity Distribution Company. Copyright: Author based on data collected from the Annual Financial Report of DisCOs between 2012 and 2020

We can see that the variables are widely dispersed, with a wide spread between minimum and maximum values. This means that the production data are not normally distributed, and there is a need to transform by finding the natural logarithm of the dataset before estimating the technical efficiency.

**Table 1**

*Descriptive statistics of the Translog Input Distance Function*

| Variable | Abv. | Unit of Measure | Mean | Std. Dev. | Minimum | Maximum | Obs. |
|---|---|---|---|---|---|---|---|
| **Number of Customers** | noc | Number | 765720.6 | 402907.9 | 240390 | 2150440 | 99 |
| **Total Sales (Revenue)** | rev | Naira (₦) | 5.20e-07 | 4.45e-07 | 4497995 | 3.15e+08 | 88 |
| **Energy Delivered** | end | KWh | 2225567 | 882850.7 | 543276 | 4756271 | 99 |
| **Operating Expenditure (OPEX)** | opex | Naira (₦) | 6.77e-07 | 3.47e-07 | 7332486 | 1.57e+08 | 88 |
| **Number of Employees** | nos | Number | 2249.8 | 971.9 | 799 | 5847 | 89 |
| **Regulatory Quality** | RegQ | Index | -0.83 | 0.906 | -0.96 | -0.66 | 99 |
| **Privatization** | Pri | Percentage (%) | 0.54 | 0.19 | 0 | 0.6 | 99 |
| **Unbundling** | Unb | Dummy | 1 | 0 | 1 | 1 | 99 |
| **Competition** | Com | Dummy | 0 | 0 | 0 | 0 | 99 |
| **Peak Load** | map | MWh | 319.81 | 128.57 | 85 | 670.71 | 99 |
| **Public Mgt & Institution** | PMI | Score | 2.81 | 0.32 | 2.8 | 2.9 | 99 |

**Note:** The table shows that the data are widely dispersed from their mean and, as expected from production data, are not normally distributed. Author Computation from Stata 16 based on theDisCO Annual Financial Report between 2012 and 2020

Table 2 shows the summary statistics of each DisCO, and the study uses the geometric mean rather than the arithmetic mean as was the case with Table 1. This allows the studymeasure the relative performance of each DisCO vis-a-vis others in the industry, in what is referred to in reform literature as yardstick regulation (competition). As shown in Table, Ibadan DisCO has the largest number of customers among distribution companies, followed by Abuja and Ikeja DisCOs with 1 million and nearly a million customers, respectively. This customer base (of Ibadan DisCO) is evident given the combined population of the franchise states and its proximity to Lagos, where people working in Lagos may reside within the franchise states due to the high cost of living in Lagos (Musa, 2023). Abuja DisCO collects the highest average revenue with 68 million naira, closely followed by Ibadan and Ikeja DisCOs with 66 million and 64 million naira, respectively. These Dis COs' revenue performance can be attributed to their operations in commercial, industrial, and federal government establishments, which pay their energy bills relatively more frequently (Musa, 2023). Ikeja DisCO receives the most electricity from TCN, followed by Ibadan and Abuja DisCOs. In a similar vein, Ikeja DisCO has the highest investments in distribution infrastructure and the largest operating cost among the DISCOs, with 172 million and 97 million naira, respectively, followed by followed by Eko and Abuja DisCOs for distribution assets and Ibadan and Abuja DisCOs for operating expenditure.

**Table 2**

*The geometric means for each DISCO between 2012 and 2020*

| DisCOs | No of Customers (Metered) | Total Sales (Revenue) '000 naira | Energy Delivered (KWh million) | Total Expenditure (OPEX) '000 naira | No of Staff | Electricity Distribution Assets ('000 naira) | Av. Daily Max. Load (MWh) |
|---|---|---|---|---|---|---|---|
| **Abuja** | 1020232 | 67977886 | 30854890 | 83760048.4 | 3196 | 81057492 | 400.5 |
| **Benin** | 890269 | 47124411.2 | 2167896.3 | 64840097 | 1959 | 52567272.7 | 263.5 |
| **Eko** | 441197 | 52423085.4 | 2794505.6 | 63752125.2 | 2136 | 127201176.4 | 388.1 |
| **Enugu** | 909929 | 58034259.6 | 2133164 | 64616169.3 | 2271 | 37482067.3 | 281.1 |
| **Ibadan** | 1720784 | 66204631.2 | 3302798.7 | 86398356.5 | 2776 | 99540680.3 | 448.1 |
| **Ikeja** | 960870 | 64764159.6 | 3398059 | 97332259 | 2857 | 172265417.3 | 534.7 |
| **Jos** | 474745 | 22507904.4 | 1209191.3 | 33752565.9 | 1363 | 39026096.1 | 167.3 |
| **Kaduna** | 508651 | 35140919.7 | 1784982.2 | 57843534.1 | 2620 | 16087333.4 | 240 |
| **Kano** | 517704 | 29817386.1 | 1677951.7 | 46200674.2 | 2093 | 26575768.1 | 307.1 |
| **PH** | 577658 | 38075728.9 | 1883016.4 | 59307282.3 | 1320 | 50970398 | 329.4 |
| **Yola** | 322034 | 10048335.9 | 819585 | 17181015.8 | 1025 | 1218359.3 | 119.4 |

Note: The geometric means of both the number of customers and the number of employees were approximated to the nearest whole numbers for computational convenience. Author computation from Stata 16 based on data collected from DisCO's Annual Financial Report between 2012 and 2020

Finally, Abuja DisCO has the highest average number of employees with 3196, followed by Ikeja and Ibadan DisCOs with 2857 and 2776, respectively. In terms of the average peak load received from TCN, Ikeja DisCO has the highest average peak load with 535MWh, followed by Ibadan and Abuja DisCOs with 448MWh and 401MWh, respectively.

## 1. Methodology

This paper employs stochastic frontier analysis to examine the impact of electricity sector reform on the efficiency of DisCOs in Nigeria. This technique is not only most suitable for estimating multi output-multi inputfunctions, but also given the inherent limitations of other efficiency estimation techniques. The DEA often used in the literature is non-parametric and relies on linear programming to determine a firm's efficiency. The corrected OLS, although parametric and easy to use, tends to over-estimate the efficiency frontier by capturing all variations in both actual and efficient outputs of firms in production inefficiency (Nworie, 2017). First developed from the famous works of Aigner et al. (1976) and then popularized by Meeusen and Van den Broeck (1977), the SFA is a parametric efficiency estimation technique that measures the efficiency and productivity of firms and industries (O'Donnell, 2018; Fare &Primont, 1995; Coelli et al., 2005). The central idea of the SFA is that deviations from the production frontier technology (considered "best practice") are influenced by factors outside the firm's control and might be attributed to measurement errors and other disturbances upon the frontier (Ajayi & Weyman-Jones, 2021). Aigner et al. (1976) specify SFA for a typical firm, and this can be written as:

$$y_i = f'(x_i) + e_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $e_i = v_i + u_i$. Eqn (1) can be re-written as;

$$y_i = \beta_0 + \beta_i x_i + v_i + u_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where $y_i$ represents the dependent variable, $x_i$ is the independent variable, $\beta_i$ denotes a vector of unknown parameters, $v_i$ is the symmetric (idiosyncratic) error term (i.e. statistical noise), and $u_i$ is the inefficiency term, such that, $v_i \sim N(0, \sigma_v^2)$; and $u_i \sim N^+(0, \sigma_v^2)$(Aigner et al., 1977). Eqn. (2) is known as the stochastic frontier model as outputs are bounded from above by the stochastic term $\exp(x_i'\beta + v_i)$, which can either be negative or positive, and hovers between the deterministic and efficiency terms (Musa, 2023). I employ the multi input-multi output production technology, and this production set is defined as[10]:

$$S = \{(x{:}\, q){:}\ x \text{ can produce } q\} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Eqn. (3) can be represented in input and output sets. I use the input distance function under the assumption that the DISCOs have more control over their input than their output. In terms of functional form, I employ the Translog input distance function since the objective of the study is to examine the impact of electricity sector reform on the efficiency of the DisCOs. Furthermore, it is assumed that price regulation will force the DisCOs to improve their technical efficiency by reducing input costs to produce the same level of output. This function was introduced by Christiansen et al. (2018), and it is the best analytical tool for determining efficiency gain, especially when dealing with multi input-multi-output production function. Another merit of this function over the Cobb-Douglas production function is its second order flexibility, which does not require price data or impose additional restrictions on the variables or model (Kumbhakar et al., 2015; Coelli et al., 2005).

In terms of its analytical framework, I use panel data time-varying inefficiency, where we assume that DisCOs learn from past mistakes, and as such, their efficiency changes over time (Coelli et al., 2005). If we assume our production technology in eqn. (3) is a multi outputs and multi input technology, our input distance function for panel data is given as:

## 5. Results and Discussion

In terms of empirical analysis, the study presents the results offindings in Table 3, with the view of providing answers to theresearch questions highlighted in Section 1. From Table 3, the result shows that the reform of the electricity sector have significant influence on the efficiency of the distribution sub-sector. Regulatory quality has a significant positive relationship with DisCOs' efficiency. A percentage increase in regulation

$$d_t^I(x_{it}, q_{it}, z_{it}) = x_{1it}\, D_I^t(x_{it}^*, y_{it}, z_{it}) \text{ .................... (4)}$$

Where $x_{it}^* = \frac{x_{it}}{x_{1it}}$, which represents a vector of normalized input. Eqn. (3.18) can be rewritten as:

$$-\text{Inx}_{1it} = \text{In}\, d_t^I(x_{it}^*, y_{it}, z_{it}) - u_{it} \text{ ..........................(5)}$$

Our Translog Input Distance Function is therefore given as:

$$-\text{Inx}_k = \alpha_0 + \sum_{r=1}^{r-R} \alpha_r \text{Iny}_r + \sum_{k-1}^{k-1} \beta_k \text{Inx}_k^* + \frac{1}{2}\left[\sum_{r=1}^{r-R}\sum_{s=1}^{s-R} \alpha_{rs}\text{Iny}_r \text{Iny}_s\right] + \frac{1}{2}\left[\sum_{j=1}^{j-K}\sum_{k=1}^{k-K-1} \beta_{jk}\text{Inx}_j^* \text{Inx}_k^*\right] + \left[\sum_{j=1}^{r-R}\sum_{k=1}^{k-K-1} \gamma_{rk}\text{Iny}_r \text{Inx}_k^*\right] + v_{it} - \text{In } D_I \text{ ... ... ... ... ... (6)}$$

Where $v_{it}$ is the statistical noise and the negative of the log of the input distance function $(-\text{InD})$ is the measure of efficiency. The technical inefficiencies can be defined as:

$u_{it} = f(t).u_i$, where $f(.)$ is the function that determines the time-varying inefficiencies. The transformation of the input distance inefficiency is given as:

$$x_1 = A \prod_m y_m{}^{\alpha_m} \prod_j \{x_j/x_1\}^{\beta_j \theta^{-1}} \text{ ........................................... (7)}$$

where the input-oriented technical efficiency is given as; $u = \ln\theta > 0$, which depicts the percentage of input overused owing to inefficiency (Kumbhakar et al., 2015).I also employBattese and Coelli (1995) ML random-effects time-varying effects model of technical inefficiencies, which is defined as:

$$TE_{it} = \exp(-U_{it}) = exp(z_{it}\delta - W_{it}) \text{ ...................................... (8)}$$

where $\alpha, \beta, \gamma, \delta$ are the unknown parameters to be estimated. These parameters have the propertiesf$(t) \geq 0$and $f(t) = 1$, which are either increasing or decreasing depending on the sign of $\delta$. I use the truncated normal distribution, which allows the use of a single step procedure to examine the influence of exogenous factors (electricity sector reform) $z_i$ on the DisCOs inefficiencies. This will be done by parameterizing the distribution function of the inefficiency term $u_i$ as a function of electricity sector reform, which is likely to affect the distribution companies' inefficiencies (Kumbhakar et al., 2015). The truncated distribution has a mean greater than zero, which means firms operate outside the production possibilities frontiers (Bee, 2016).[12]Given that assumptions, $v_i \sim N(0, \sigma_v^2)$; and $u_i \sim N^+(0, \sigma_v^2)$ are true for eqn. (6), then the maximum likelihood estimation of unknown parameters, $\alpha, \beta, \gamma, \delta$ is given as:

$$E({}^{u_{it}}/_{\epsilon_{it}}) = \mu_{it}^* + \sigma^* \left(\frac{\phi({}^{\mu_{it}^*}/_{\sigma^*})}{\Phi({}^{\mu_{it}^*}/_{\sigma^*})}\right) \text{ ..............................................(9)}$$

where $\mu_{it}^* = {}^{(\mu\sigma_v^2 - \epsilon_{it}\sigma_u^2)}/_{(\sigma_v^2 + \sigma_u^2)}$ and ${}^{\sigma_v^2\sigma_u^2}/_{(\sigma_v^2 + \sigma_u^2)}$. Let $\widetilde{u_{it}}$ presents the ML estimator of $u_{it}$. The associated estimator for the input-oriented technical inefficiencies is given as:

$$\exp(-\widetilde{u_{it}}) \text{ ........................................................... (10)}$$

quality will decrease the predicted sub-sector's efficiency by 0.19 percent. On the other hand, privatization of the DisCOs has a significant positive influence on their inefficiency. A percentage increase in the private sector's stake in the DisCO will increase their efficiency by 0.13 percent. The impact of competition and unbundling on the efficiency of DisCOs is inconclusive, as both variables happen to collinear. This result is unsurprising given the successive nature of the electricity reform steps taking place in Nigeria. Besides, although the sector reforms led to the unbundling of NEPA, the privatised firms in the distribution sub-sector (the DisCos) still have monopoly power in their respective franchise locations, and as such, there is no competition and electricity consumers do not have freedom to choose their electricity suppliers. In terms of the output variables, revenue has a significant negative relationship with operating expenditure; that is, a percentage increase in DisCOs' revenue will result in a 10 percent decline in operating expenditure, at 1 percent level. Furthermore, energy delivered by TCN to DisCOs, as expected, has a significant positive linkage with DisCOs' operating costs. In other words, one percent per kilowatt hour of electricity delivered to DisCOs will increase their operating expenditure by 19.3 percent. For input variables, the number of staff and distribution assets are both wrongly signed but have a significant relationship with operating expenditure. A percent increase in the number of staff will reduce operating expenditure by 7.84 percent. Furthermore, a one percent increase in distribution assets will result in a 3.2 percent reduction in operating expenditure. All second orders of output variables are significant, except number of customers, which is also insignificant at first order. The interactive effects are also insignificant except revenue and number of customers, which are significant at 10 percent level. Overall, the model is robust with a log-likelihood of 137.3, which is significant at the 1 percent level.

**Table 3**

*Input Distance Function: Impact of Electricity Reform and DisCOs' Efficiency*

Dependent Variable $\mathbf{In}\left(\frac{1}{\text{Opex}}\right)$

| Variable | Estimated Parameter | Coefficient | Standard error |
|---|---|---|---|
| **Constant** | $\alpha_0$ | $-31.15^{**}$ | 13.43 |
| **Innoc** | $\alpha_1(\text{Iny}_1)$ | 0.296 | 3.77 |
| **Inrev** | $\alpha_2(\text{Iny}_2)$ | $-10.10^{*}$ | 2.86 |
| **Inend** | $\alpha_3 \text{Iny}_3$ | $19.31^{*}$ | 5.29 |
| **Innoc$^2$** | $0.5\alpha_{11}(\text{Iny}_1^2)$ | 0.724 | 0.61 |
| **Inrev$^2$** | $0.5\alpha_{22}(\text{Iny}_2^2)$ | $1.59^{*}$ | 0.404 |
| **Inend$^2$** | $0.5\alpha_{33}(\text{Iny}_3^2)$ | $-3.17^{***}$ | 1.72 |

| | | | |
|---|---|---|---|
| Innoc * Inrev | $\alpha_{12}(y_1 * y_2)$ | −0.37 | 0.57 |
| Innoc * Inend | $\alpha_{13}(y_2 * y_3)$ | −0.27 | 1.05 |
| Inrev * Inend | $\alpha_{23}(y_2 * y_3)$ | 0.45 | 0.60 |
| Innos | $\beta_1(x_2^*)$ | −7.84* | 1.99 |
| India | $\beta_2(x_3^*)$ | −3.18* | 1.41 |
| Innos$^2$ | $0.5\beta_1(\mathrm{Inx}_2^{*2})$ | 0.04 | 0.344 |
| India$^2$ | $0.5\beta_2(\mathrm{Inx}_3^{*2})$ | −0.164 | 0.133 |
| Innos * India | $\beta_{12}(x_2^* * x_3^*)$ | −0.10 | 0.132 |
| Innoc * Innos | $\gamma_{12}(y_1 * x_2^*)$ | −0.0703 | 0.326 |
| Innoc * India | $\gamma_{13}(y_1 * x_3^*)$ | −0.77*** | 0.40 |
| Inrev * Innos | $\gamma_{22}(y_2 * x_2^*)$ | −0.10 | 0.132 |
| Inrev * India | $\gamma_{23}(y_2 * x_3^*)$ | −0.09 | 0.217 |
| Inend * Innos | $\gamma_{32}(y_3 * x_2^*)$ | 0.324 | 0.490 |
| Inend * India | $\gamma_{33}(y_3 * x_3^*)$ | 0.611 | 0.385 |
| Exogenous Factors | z − variables | | |
| Inmap | $z(\varphi_1)$ | 0.23* | 0.083 |
| RegQ | $z(\varphi_2)$ | 0.19*** | 0.103 |
| Pri | $z(\varphi_3)$ | −0.131** | 0.053 |
| Unbd | $z(\varphi_4)$ | – | – |
| Comp | $z(\varphi_5)$ | – | – |
| Tech.Efficiency | bc − t | 0.228 | |
| LogLikelihood | | 137.30* | |
| NoofObservation | | 89 | |
| NoofGroup | | 11 | |

Note: *critical values are significant at *1 percent **5 percent level; ***10 percent level. Competition and unbundling are collinear. Recall from eqn. (4)$x_{it}^* = \frac{x_{it}}{x_{1it}}$ the input index. Author computation from Stata based on data collected between 2012 and 2020 from NERC, TCN, and the Annual Financial Report of DisCOs.

The result also shows that the DisCOs have technical efficiency of 23 percent. This empirical result does not only answer our research questions but is also in line with the theory of efficiency and natural monopoly, which posit that when there is a huge fixed cost, market will be efficient. If served by a single seller (Greer. 2011). This result also corroborate the finding of Nworie (2017b) however, it contradict the submissions of Nepal (2022) and Asantewaa et al. (2022)

***Summary Statistics of DisCOs Technical Efficiency***

| Variable | Technical Efficiency. |
|---|---|
| Observation | 89 |
| Mean | 0.2283 |
| Std. Dev. | 0.1832 |
| Minimum | 0.1848 |
| Maximum | 0.2503 |

**Note:** The table shows that the distribution sub-sector has low technical efficiency. Author computation from Stata 16 based on data collected from the Annual Financial Report of DisCOs between 2012 and 2020

Table 4 shows the post-test result of the frontier model,which found average distribution companies' efficiency to be 22.8 percent. Furthermore, the low standard deviation from the mean efficiency suggests the individual DisCO's efficiency is not dissimilar to the industry's efficiency. Finally, the firm with the lowest technical efficiency has an efficiency level of 18.5 per cent, while the highest efficiency level in the industry is 25 percent. These empirical results further amplify the stylized facts presented in Table 2, showing almost all the DisCOs are operating at losses since privatization of the distribution sub-sector. Their inability to generate sufficient revenue (high collection losses) to settle financial obligations, especially energy delivered by TCN,is a principal contributor to their inefficiencies.The results also address the main objective of this study, which is the impact of electricity sector reform on the efficiency of DisCos in Nigeria.

Therefore, the policy implications arising from these findings are that the fact that improving regulatory quality further exacerbatesDisCOs' inefficiency suggests ineffective regulatory frameworks and tools that coordinate the activities of the distribution sub-sector.Privatization is found to be positively correlated with DisCOs' efficiency. This implies that the reform policy is yielding the desired outcome of improving the sector's efficiency. However, the government still has

40 percent stakes in each DisCO which carries attendant deadweight losses. Moreover, each DisCO operates as a monopoly in their respective franchise areas, which may also contribute to their inefficiencies. The inconclusive result obtained with respect to the impact of a competitive market is a pointer to the underdeveloped nature of the Nigerian electricity industry.However, this study has a number of limitations: one, the data on the distribution companies is very scanty, and the data has been pulled from various sources and various time periods, which means that data collection took as much time as the actual study. Another limitation of this study is the restriction of exogenous factors that influence inefficiency are restricted to the components of reform to reflect Nigeria's reform realities. Finally, the scanty nature of the data means there is missing or incomplete data, which may limit estimation outputs. This study can be further advanced by looking at the efficiency of other segments of the electricity sector, such as the generating companies (GenCOs) and the Transmission Company of Nigeria (TCN), for any generalization about the NESI to be more realistic. Furthermore, restriction of exogenous factors to key components of electricity reform to reflect Nigerian reform realities may have resulted in an omitted variable (misspecification). Studies that incorporate other standard reform steps such as independent power producers (IPP), choice of suppliers, corporatization, electricity legislation should also be advanced.

## 6. Conclusion

This studyexamines the impact of electricity sector reform on the efficiency of DisCOs in Nigeria using panel data from 11 distribution companies from 2012 to 2020. The paper employs the Translog Input Distance Function of the Stochastic Frontier Analysis and the Maximum Likelihood (random effect) time-varying model of inefficiency. In terms of the distribution of inefficiency, the study also uses the truncated normal distribution, which allows for a single-step procedure on the influence of exogenous factors (electricity sector reform) on DisCOs' inefficiency.The study therefore found regulatory quality to have a significant negative relationship with DISCOs' efficiency. The implication of this result is that the regulatory tools used by NERC have been ineffective in coordinating activities in the industry. Privatization is found to have a significant positive correlation with DisCOs' efficiency. This means that a percent increase in the private sector's stake in the DisCOs will improve theDisCos' efficiency. The wider implications of this findings is that the reform programme will yield the desired outcomes of improving the sector's efficiency if it is solely driven by theprivate sector. In other words, government participation in the distribution segment of the electricity industry should only be limited to a supervisory (regulatory) role. The impact of competition on sub-sector efficiency is inconclusive, which demonstrates the underdeveloped nature of the Nigerian Electricity Supply Industry (NESI). In light of this discussion, this study therefore recommends legislative bills that will strengthen the regulatory framework and institution of NESI and make it less susceptible to capture by political elites and organized industrialists (DisCOs), in order for NERC to have a significant impact on improving efficiency in the distribution sub-sector. There is also a need for further reform, especially in the distribution segment, where electricity consumers have the freedom to choose their suppliers, thereby eliminating the monopoly in DisCOs' franchise locations and its associated inefficiencies. This will make the market more contestable and help accelerate improvement in electricity access (reducing energy poverty), as well as foster the country's ambition of achieving universal access to electricity by 2030. These conclusions will also have wider implications for electricity sector reforms in SSA and developing countries.

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