

## Electricity Generation: Are Uganda's Electricity Generating Firms Efficient?

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### Abstract

*High tariffs and low access to electricity in Uganda remains a challenge despite surplus generation capacity. The excess generation is suggests inefficiencies in power generation. Most research has focused on demand side efficiency and limited attention is accorded to supply side technical efficiency, especially using Data Envelopment Analysis (DEA) and Tobit models. Therefore, the study extends DEA and Tobit model to evaluated technical efficiency and examine its drives of efficiency of generation companies in Uganda. Secondary data from Electricity Regulatory Authority (ERA) of Uganda from 2016 to 2023, for 36 generating firms, were analyses using an input-oriented Data Envelopment Analysis (DEA) and Tobit regression to examine the drivers of efficiency. Findings indicate that 22% of the firms are technically efficient while 67% are operating below 50% technical efficiency. This was attributed to aged technologies, high administrative or operation costs, and regulatory challenges. Plant size, workforce size, operations and maintenance costs, and energy source were found to be the major drivers of efficiency at generation level. The study extends the application of DEA approaches and Tobit model to firm-level generation side context. This shows that electricity is not efficiently generated in Uganda. Therefore, the responsible line ministry should put in place better rules and regulations that are performance based, adopt modern technology, and better management of workforce.*

**Keywords:** Technical Efficiency, Tobit Regression, & Data Envelopment Analysis (DEA)

### Introduction

Having access to energy is key for socioeconomic and long term development. This is highlighted under Sustainable Development Goal 7 (SDG 7), which ensures access to affordable, reliable and modern energy (United Nations, 2025). In recent years, electricity demand increased worldwide, especially in low-income countries majorly attributed to population growth, industrialization, and economic development (Ibrahim et al., 2023). Because of this increase in demand, countries have increased electricity generation to meet the demand. However, achieving universal access to energy does not only depend on increased electricity supply but also other factors, such as affordability, reliability, and sustainability of electricity services, which are related to cost-efficiency of electricity generation. High electricity tariffs remains a big challenges in many Sub-Saharan Africa despite surplus generation of electricity. This highlights largely that operational and structural inefficiencies still exist in electricity generation system. Therefore, energy efficiency remains a fundamental in improving the sector performance and sustainability of electricity supply. Research continue to show that using energy efficient practices can increase

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energy savings, reduce production costs and increase access (Pudleiner et al., 2017). Additionally, energy efficiency helps to reduce greenhouse gas emission for environmental sustainability (Fowlie & Meeks, 2020) and reduces over reliance on fossil fuels (Rodriguez-Lozano & Cifuentes-Yate, 2021; Pinto et al., 2023).

Worldwide, studies have largely used Data Envelopment Analysis (DEA) to measure efficiency. Dogan & Tugcu (2015) found that some G-20 countries are not equally efficient. Russia and China perform better in using their resource to generate electricity than other G-20 countries. Globally, efficiency levels range between 60% and 90% (Rodriguez-Lozano and Cifuentes-Yate, 2021). While some progress has been noticed in primary-to-final energy conversion, the way electricity is generated and used is still not efficient (Pinto et al., 2023). This means that energy is wasted both at generation and during consumption, making it difficult to attain the broader climate change target. Despite substantial energy reforms and capacity growth, electricity system is not yet efficient, especially in Sub-Saharan Africa (Agoundedemba et al., 2023; Asantewea et al., 2022). This is because people lack access to electricity, frequent power outages, system losses, and poor infrastructure development. This shows that the local energy resources, such as biomass, are not used efficiently, and renewable resources are not well integrated into the power system (Jingura & Kamusoko, 2017). According to René (2022), technical inefficiencies of up to 20% is observed in electricity systems in East Africa. These inefficiencies can be put as operational, institutional and structural, with limited incentives for performance improvement.

Uganda has an installation generation capacity of 1,346.6 MW and a peak demand of only 785 MW. This leaves surplus of 562 MW. Despite the excess, electricity tariffs remain among the highest in the region (MEMD, 2023), suggesting inefficiencies in the electricity generation process. Besides, access rate to electricity in Uganda remains at 53.4% (UBOS, 2024), below the regional average for developing countries. Thus, excess generation capacity is not translated into improved access or low prices, due to factors such as production costs, system losses, or scale inefficiencies. The Uganda's 2023 National Energy Policy and Draft Energy Efficiency and Conservation Bill has focused on improving energy efficiency majorly on demand-side interventions (e.g. in households, industry, transport), and limited attention is accorded to supply side. Therefore, this brings a policy gap, as inefficiencies at generation increases working costs and reduces plant reliability, which distorts reliability of supply and electricity tariffs. At electricity generation level, technical efficiency is influenced by different factors, such as energy source, the size of the plant, ownership structure, plant age, technology, and management systems (Nguyen et al., 2022; Benini & Cattani, 2022; Hou et al., 2022). Besides, Sengupta & Mukherjee (2022) and Bernstein (2020) have mentioned factors such as shortages in resources, delayed maintenance, and regulatory inefficiencies to affect firm performance. However, studies by Wasseh et al. (2023) and Hou et al. (2022) only considered the aggregated efficiency in the sector, with limited attention to operational dynamics of individual electricity generating companies. Therefore, firm-level inefficiencies remain underrepresented in the literature, particularly in developing countries. Therefore, the aim of the study is to extend the application of Data Envelopment Analysis and Tobit model to measure technical efficiency and its drivers in Uganda's electricity generating firms. Focusing on firm-level performance, in developing countries, the study fills the gap by looking at electricity generation efficiently that has been underrepresented in the literature. The results will provide evidence-based policy decisions to make electricity affordability, reliability, and sustainable in Uganda.

### **Theoretical Review**

The Efficiency Measurement Theory (Charnes et al., 1978) and adopted by Cook & Seiford (2009), gives a framework to assess how firms use their resources efficiently. The theory treats each generating firm as a single decision-making unit (DMU). While the model is flexible and can easily handle multiple inputs and outputs, it's limited in separating technical efficiency from scale inefficiency. The Scale efficiency theory (Banker, 1984) as used by Banker and Thrall (1992), posits that a decision-making unit (DMU) improves productivity by operating at its most productive scale size. The theory helps to identify whether the firm is inefficient because resources are poorly used or the firm is operating at the wrong plant size, good for cost-effective and sustainable infrastructure planning and widely used by many scholars, such as Fare et al. (1985), Banker et al. (1984), Cooper et al. (2006), and Bernstein (2020). It's capable of identifying the optimal scale of operation without exceeding resource limits, and distinguish between technical efficiency and scale efficiency. However, it is very sensitive to outliers in the data set.

### **Empirical Review of literature**

Factors influencing technical efficiency in electricity generation include firm ownership, plant age, and investment in infrastructure. A study in Kenya showed that state-owned (public) companies are less efficient than the private owned firms while new power plants performed better than the older power plants, especially in thermal power plants (Njeru et al., 2020). Adopting new modern technology, paying workers well, and installing advanced systems increases energy efficiency and reduces greenhouse gas emissions (Murty & Nagpal, 2020; Tillman, 2015). Even though technical efficiency seem to have improved, there is limited literature to understand how power plants operate efficiently in low-income and conflict-affected regions like sub-Saharan Africa, where energy infrastructure and regulatory governance challenges hinder progress (Alinsato et al, 2021). Recent research available has focused on manufacturing and consumer-side efficiency (Hou et al., 2022; Andor et al., 2021; Murty & Nagpal, 2020; Tillman, 2015), while limited effort is accorded to supply side (electricity generating firms). Understanding how power plants work efficiently at generation level in developing countries helps to improve access to electricity, affordability, support the adoption of clean and sustainable energy.

Workforce size and environment is one of the key factors that influence the firm performance. Working environment and conditions of work, such as work load and pay, which are related to labor management has positively influenced technical efficiency (Hou et al., 2022). Whereas having enough workers is very important, too many workers or using workers inefficiently increases labor costs and wastage of resources, which weakens overall firm efficiency (Njeru et al., 2020). Thus, balancing workforce size and output is important for efficiency. Power plants perform better when they appropriately spend and allocate their maintenance costs, especially if well planned and supported by management (Wai Foon & Terziovski, 2014). For example, thermal power plants with effective maintenance and operational practices achieve higher efficiency scores (Njeru et al., 2020). Furthermore, it is emphasized that effective operations and maintenance (O&M) practices, such as committed leadership, regular maintenance, and adequate investment in infrastructure, are positively associated with higher technical efficiency score (Wai Foon & Terziovski, 2014; Hou et al., 2022). However, older power plants, aging infrastructure, and public ownership are associated with lower efficiency (Njeru et al., 2020). Companies can be more efficient if they regularly maintain and operate their equipment well, allow market competition, and supporting fair business practices (Hou et al., 2022).

The available literature has mixed conclusions about the effect of firm age on efficiency. For instance, New power plants tend to be more efficient than the older plants (Sattar et al., 2013), especially thermal power plants in Kenya (Njeru et al., 2020). However, other studies found that how old a firm is or how fast it is growing does not determine efficiency (Megawati, 2019; Ekadjaja and Wijaya, 2021). Besides, studies show that different energy sources have different efficiency scores. Saglam (2018) found that geothermal power plants are efficient than solar thermal plants. In line with this finding, Mekuye et al. (2024) found that renewable energy sources, such as solar, hydro, and wind, are more efficient than fossil fuels. Therefore, efficiency of a power plant depends on how it operates and the energy source it's using to generate power. Recent research shows that the plant size determines how efficiently it will be. Although, the results are not always the same. For instance, Shumais (2020), Kusz et al. (2024) and Costa-Campi et al. (2015) found that bigger power plants tend to be more efficient than the smaller plants. The studies explained that bigger plants use their resources well and can benefit from the economies of scale. However, Megawati (2019) found that firm size has a negative influence on technical efficiency in manufacturing firms. In Austrian biogas plants, smaller plants were more inefficient than the bigger firms, with increasing returns to scale seen as firms grew bigger in size (Eder & Mahlberg, 2018). This was in line with study by Kusz et al. (2024), who also found that smaller plants are less efficient than the larger ones. Other factors, such as ownership structures, the adoption of solar PV technologies, the regulatory environment (Bernstein, 2020), and subsidies (Eder & Mahlberg, 2018) can significantly influence efficiency levels. Studies highlight that efficiency can significantly be influenced by firm size though with mixed findings and research remains contextually underrepresented.

### **Methodology and Approaches**

Quantitative research design is adopted in this study to measure the technical efficiencies of the generators and to examine its drivers. The design is suitable because it relies on numerical data and statistical models to measure technical efficiency and its drivers (Erena et al., 2021). The study focused on 50 electricity generating firms in Uganda as listed by Ministry of Energy and Mineral Development (MEMD, 2023). The companies included all power generating plants in the country, both government owned and private companies, participating in generation of power. This study used secondary data from Electricity Regulatory Authority's (ERA's) of Uganda website (<https://www.era.go.ug/index.php/stats>). This covered a period from 2016Q1 to 2023Q4, on generation statistics. The period was chosen because the data is availability for data period for all the companies and many started operating during that time. For data completeness and accuracy, steps were undertaken, including data cleaning (to address missing values and correcting anomalies), transformation of variables, and categorization or aggregation of data. Ultimately, only 36 electricity generating firms (utilities) were retained for further analysis using STATA software Version 15.

The study adopted a mathematical model of Data Envelopment Analysis (DEA), a non-parametric technique, particularly an Input-Orientation DEA model (Toloo et al., 2021; Tharwat et al., 2019; Ji & Lee, 2010). This model measures if a DMU can minimize (reduce) the inputs while keeping outputs constant (Piran et al., 2020; Khan & Karam, 2019). DEA models can also be split into returns to scale and variable returns to scale. Returns to scale. Charnes et al. (1978) proposes measuring efficiency of the DMUs assuming constant returns to scale (CRS). Variable returns to scale (VRS) efficiency measurement model (Banker et al., 1984) to measure efficiency under an assumption of variable returns to scale, allowing the breakdown of efficiency into technical and

scale efficiencies in DEA. At the second stage, using a Tobit regression Model, the values of Technical Efficiency (TE) derived were regressed on the input variables (regressors) to identify the factors influencing technical efficiency of generating firms. Therefore, the second stage model had the following form;

$$TE_i = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \dots + \beta_nx_n + \varepsilon_i \quad (5)$$

Where

- TE = Technical efficiency values*
- β<sub>i</sub> = coefficients of the variables, i = 1, 2, 3, ... n*
- β<sub>0</sub> = constant (Average technical value)*
- x<sub>i</sub> = independent variables of interest*
- ε<sub>i</sub> = the error term*

Therefore, the model specification is;

$$TE = \beta_0 + \beta_1 \text{number of employees} + \beta_2 \text{O\&M costs} + \beta_3 \text{Plant size} + \beta_4 \text{Energy source} + \beta_5 \text{Firma age} + \varepsilon \quad (6)$$

Where;

- TE = technical efficiency of firm i in year t,*
- β<sub>i</sub> = are variable parameters*
- ε = the error term*

The Tobit regression model is a vital tool in econometrics and various other fields for analyzing censored data (Karim & Salh, 2020), that provides a framework to understand both the occurrence and magnitude of outcomes when the dependent variable is subject to censoring. This model gives unbiased and consistent estimates, for deeper insights into the factors influencing the dependent variable (Michels & Musshoff, 2022; Sedeeq & Meran, 2022; Jacobson & Zou, 2024).

**Variable under the study and integration into the model**

According to Table 1, in measuring technical efficiency using DEA, Total revenues (TR) and Energy generated (TEG) were considered as output variables while number of employees (NE), and Operation and Maintenance Costs (O&M) as input variables. In tobit model estimation, Plant size, number of employees, operation and maintenance costs, energy source, and age, were considered as independent variables to establish factors influencing the technical efficiency in the DMUs.

**Table 1: Variables under study and the data source**

Variable	Symbol	Variable definition/ interpretation	Source of Data	Measurement units
Technical Efficiency	TE	Technical efficiency score of a generating firm (DMU)	Author’s compilation	Percentage
Total Revenue	TR	Total revenues generated in a year	ERA (Website)	UGX Million
Number of employees	NE	Number of employees of each generating firm (DMU) at the end of a year	ERA (Website)	Number
Operation & Maintenance cost	O&M	Total operational and maintenance costs (Salary, repair, raw materials, fuel etc.)	ERA (Website)	UGX. Million.
Power plant size	Psize	Installed capacity of power plant	ERA (Website)	MWh
Energy generated	TEG	Total energy generated by a firm	ERA (Website)	MWh
Energy source	Source	Source of energy	ERA (Website)	N/A

Age	Age	Years a power plant has been generation electricity	ERA (Website)	Years
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**Diagnostic tests**

For Data Envelopment Analysis, this is a non-parametric frontier model to measure efficiency of decision-making units (DMUs). Different diagnostic tests, such as normality, homoscedacity and multicollinearity, were done for consistent and reliable results. Adopting Shaprio-wilk test, the variables approximated a normal distribution while applying residual plots and Breusch-Pagan test, the variation in the error term was found to be constant (Homoscedasticity). Multicollinearity test were conducted using Variance Inflation Factor (VIF) to ensure no severe dependence among explanatory variables. The VIF values were above the threshold of 10, thus no severe multicollinearity among regressors.

**Results**

**Descriptive statistics**

From Table 2, the average energy generated in the period of study is 838,137MWh, average number of employees is 517 people per year, while average Operation & maintenance costs is UGX: 522,761.8 Million shillings.

**Table 2: Descriptive statistics of the variables**

Variable	Obs.	Mean	Std. Dev.	Min	Max
Total Energy Generated	36	838,137	2,384,326	18502.45	10,100,000
Number of Employees	36	517	567	56	3323
Operation & Maintenance	36	522,761.80	2,232,713	804	12,500,000

**Source:** Author’s computation

**Data Envelopment Analysis results**

The study adopted DEA as a benchmarking approach to evaluate the technical efficiency of the utilities. 36 power generating firms or utilities were analyzed, treating each firm as a Decision-Making Units (DMUs). The sample size is greater than 30 sample size, enough for analysis. A firm is considered efficient if there is any improvement in the input or output without affecting or harming (worsening) some other input or output (Koopmans, 1951),. In the same line, Alirezace and Afsharian (2010) explained that an efficient DMU in CRS model is also considered efficient in the VRS model. Using STATA software, technical efficiency scores were generated for each DMU. Although both CRS and VRS models were adopted in this study, results by VRS model (Banker et al., 1984) were considered consistent and reliable results for interpretation (See table 4). The scores in the table 3 were sorted depending on the ranks, considering those with high scores first (100%) to those less than 100% efficiency score.

**Technical Efficiency Score by firms**

According to Table 3, the study reveals that only 22% of the total electricity generating firms achieved 100% technical efficiency during the study period (2016-2023). However, a large portion, 66.6% of the electricity generating firms operate below average technical efficiency (50%), and 41.7% of these performing below 30% technical efficiency. 77.8% the electricity generating firms operate between 10% to 87% efficiency levels, indicating that power generation is still inefficient. Most electricity generating plants use workforce and maintenance and operation

resources more efficiently. However, Kikagati shows a large slack of 320.995 in O&M costs, which means that much is spent on maintenance than necessary for efficient operation. Slack values in total energy generated reveal that some power plants under-produce relative to their input use. Additionally, positive slack values in total revenues, shows that electricity sector could earn more revenue with current resource levels available. These inefficiencies make it difficult for the electricity sector to grow economically, because the energy supply is not used to its full capacity. Nevertheless, workforce deployment is being used efficiently, meaning labor is not wasted. Therefore, there is need for improvement in Uganda's energy generation system.

**From Table 3: Data Envelopment Analysis (DEA) results by generators**

No	Generators	rank	Efficiency Scores (theta)	islack (NoE)	islack (O&M)	islack (TEG)	islack (TR)
1	Bujagali	1	1	.	0	.	.
2	Emerging Solar Power	1	1	.	.	0	.
3	Isimba	1	1	.	0	.	.
4	Kabalega Hydromax	1	1	.	.	.	.
5	Kiira & Nalubaale	1	1	0	.	.	0
6	Nkusi (PA Technical)	1	1	.	.	.	.
7	Nyamwamba 2	8	1	.	.	482508	85891.8
8	SM Hydro	1	1	.	.	.	0
9	ACCESS Solar	9	0.872205	.	.	8445.4	.
10	UEGCL Namanve (Jacobsen)	10	0.859978	.	.	794843	.
11	Tororo Solar (North)	11	0.73972	.	.	205531	19032.9
12	Kakaka	12	0.502665	.	.	211697	34980.4
13	Tororo PV Power	13	0.410587	.	.	252063	33403.7
14	Hydromax Nkusi (Waki)	14	0.384575	.	.	.	0.000103
15	TIMEX Bukinda	15	0.383014	.	.	22029.5	.
16	ZIBA	16	0.371187	.	.	.	.
17	XSABO Solar	17	0.351845	.	.	20670.3	.
18	Nyamagasani 2	18	0.336801	.	.	124281	22614
19	Kilembe Mines Ltd (KML)	19	0.333675	.	.	.	20270.2
20	Sindila	20	0.32907	.	.	45506.1	8454.77
21	Ndugutu	21	0.309966	.	.	21288.7	2151.64
22	Rwenzori Hydro	22	0.295498	.	.	106949	11399.5
23	Siti 2	23	0.294499	.	.	184139	10856
24	Muvumbe Hydro (U) Ltd	24	0.282221	.	.	3320.49	.
25	Kikagati	25	0.263281	.	320.99	482241	156213
26	Achwa 1&2	26	0.26278	.	.	1924397	61033.9
27	Elgon Hydro SITI	27	0.248041	.	.	5963.84	.
28	Electromaxx (U) Ltd	28	0.233961	.	.	628906	.
29	Lubilia	29	0.224496	.	.	5883.99	.
30	Maji-Power Bugoye Ltd	30	0.219021	.	.	496033	38046.6

31	Kasese Cobolt Company Ltd	31	0.214418	.	.	.	.
32	Mahoma	32	0.194277	.	.	893.937	0.001457
33	Rwimi	33	0.165583	.	.	450381	39808.5
34	Ecopower - Ishasha	34	0.135528	.	.	85356.8	5863.01
35	AEMS-Mpanga	35	0.13504	.	.	482568	22481.6
36	Nyamwamba	36	0.10913	.	.	473205	135760

**Source:** Author’s computation

**Technical Efficiency Score by Firm Age**

From table 4, technical efficiency levels changes across firms, depending on the firm age. Older firms show high efficiency level (90%), with some inefficiencies in energy generation and revenue collections. Middle age firms are operating below average 47.5% and have significant slacks, meaning that they are not resources well, while new plants are more efficient (85.3%). Although, older and new plants are fairly efficient, they still need to use resources and manage revenue collection well.

**From Table 4: Data Envelopment Analysis (DEA) results by years of existence**

DMU	rank	Efficiency Scores (theta)	islack (NoE)	islack (O&M)	islack (TR)	islack (TEG)
<b>More than 10 Years of existence</b>						
Kiira& Nalubaale	1	1	0	.	0	.
Kasese cobolt	6	1	.	.	40234	1032561
Kilembe Mines Ltd	4	1	.	.	114710	253809
UEGCL Namanve	5	1	.	.	68489.2	1002357
Electromaxx (U) Ltd	10	0.503243	.	.	376389	1765226
Maji-Power Bugoye	8	1	.	.	934988	2796444
AEMS-Mpanga	9	0.580402	.	.	872040	2460420
Bujagali	1	1	.	0	.	.
Ecopower-Ishasha	7	1	.	.	40390	1205673
Kabalega Hydromax	1	1	.	.	.	.
<b>Between 6 to 10 years of existence</b>						
DMU	rank	theta	islack (NoE)	islack (O&M)	islack (TR)	islack (TEG)
Access Solar	4	0.872971	0.878974	.	.	8452.95
Elgon Hydro Siti	15	0.255685	31.7575	.	.	6229.47
Muvumbe Hydro (U) Ltd	14	0.294286	67.2663	.	.	3886.69
Rwimi	18	0.201675	.	.	61056.5	584857
Tororo PV power	7	0.457831	.	.	40198.4	288865
Tororo Solar (North)	5	0.803212	.	.	24147.4	232008
Hydromax Nkusi (Waki)	6	0.468206	270.579	.	3112.91	.
Isimba	1	1	.	0	.	.
Lubilia	17	0.23028	22.9882	.	.	6075.65
Mahoma	16	0.234984	18.9336	.	8329.77	21470.1

Nkusi (PA Technical)	1	1	.	.	.	0
Nyamwamba	19	0.137443	.	4707.81	72517.9	644913
Xsabo Solar	9	0.355957	15.4635	.	.	20803.6
Achwa 1&2	11	0.329057	.	5273.19	39965.8	2443198
Emerging Solar Power	1	1	.	.	.	0
Ndugutu	13	0.311675	.	.	2342.86	21852.7
Sindila	10	0.334802	.	.	9077.73	47480.9
Siti 2	12	0.322803	.	.	16467.7	212073
Ziba	8	0.411841	159.07	.	.	0.009758

**Between 1 to 5 years of existence**

DMU	rank	theta	islack (NoE)	islack (O&M)	islack (TR)	islack (TEG)
Timax Bukinda	1	1	.	.	.	.
Kakaka	5	0.720178	.	.	0.000604	2646.03
Nyamagasani 2	7	0.557648	.	.	0.00049	3602.88
Nyamwamba 2	1	1	.	.	0	.
Rwenzori Hydro	6	0.692551	.	.	.	4046.47
Kikagati	1	1	.	0	.	.
SM Hydro	1	1	.	.	.	.

**Source:** Author's computation

### Technical Efficiency by Energy Source

The results show that efficiency varies across the energy source (hydro, solar, and thermal) adopted for generation. The results show major differences in technical efficiency among electricity generating firms based on their energy source; Hydro, Solar, and Thermal. Hydropower plants exhibit low efficiency levels as compare to solar and thermal energy plants but still has high slacks in energy generation. These high slacks highlight inefficiencies in the capacity utilization of the plants. On another hand, generally solar plants perform better. For instance, firms, such as Access solar, XSABO solar, and Emerging Solar power operate at full efficiency, while Tororo PV Power (45.7%), Tororo Solar (North) (89.3%) show moderate inefficiencies, largely in revenue and energy output. However, their slack values are relatively low, suggesting fewer issues in resources utilization compared to hydropower firms. Besides, hydro power plants are more inefficient than solar power or thermal plants, highlighting the need for optimization and resource management improvements are necessary, especially for the hydroelectric sector.

### From Table 5: Data Envelopment Analysis (DEA) results by Energy source

Firms	rank	Efficiency Scores (theta)	islack (NoE)	islack (O&M)	islack (TR)	islack (TEG)
<b>HYDRO POWER PLANTS</b>						
Kiira & Nalubale	1	1	0	.	0	.
Kasese Cobolt Company Ltd	23	0.223963	.	.	.	0.023432
Kilembe mines Ltd (KML)	16	0.333675	.	.	20270.2	.
Maji-Power Bugoye	24	0.223068	.	.	41738.3	514608

AEMS-Mpanga	28	0.137962	.	.	26407.1	506996
Bujagali	1	1	.	0	.	.
Ecopower -Ishasha	27	0.150769	.	.	.	126639
Kabalega HydromaxX	1	1	.	.	.	.
Elgon Hydro Siti	19	0.278857	.	.	.	16535.2
Muvumbe Hydro (U) Ltd	18	0.296266	.	.	.	9790.3
Rwimi	26	0.172423	.	.	42136.9	478239
Hydromax Nkusi (WAKI)	11	0.389922	.	.	.	.
Isimba	1	1	.	0	.	.
Lubilia	21	0.259901	.	.	.	17499.4
Mahoma	22	0.228896	.	.	.	9660.43
Nkusi (PA Technical)	1	1	.	.	.	.
Nyamwamba	29	0.10913	.	.	135760	473205
Achwa 1&2	25	0.212023	.	.	.	1406978
Ndugutu	13	0.365141	.	.	.	39835.9
Sindila	12	0.372069	.	.	.	76603
Siti 2	17	0.327757	.	.	6900.16	231697
Ziba	10	0.398622	.	.	.	.
Timex Bukinda	9	0.447933	.	.	.	45340.8
Kakaka	8	0.530173	.	.	28916.1	238010
Nyamagasani 2	14	0.364199	.	.	14361.3	154940
Nyamwamba 2	7	1	.	.	85891.8	482508
Rwenzori Hydro	15	0.334243	.	.	5122.88	149862
Kikagati	20	0.263281	.	320.995	156213	482241
SM Hydro	1	1	.	.	.	0

**SOLAR POWER PLANTS**

Firms	rank	theta	islack (NoE)	islack (O&M)	islack (TR)	islack (TEG)
ACCESS Solar	1	1	.	0	.	.
Tororo PV Power	5	0.457831	.	2605.85	9503.42	22138.8
Tororo Solar (North)	4	0.893033	.	2524.95	1163.21	3772.15
XSABO Solar	1	1	.	0	0	0
Emerging Solar Power	1	1	.	.	.	.

**THERMAL POWER PLANTS**

Firms	rank	Efficiency Scores (theta)	islack (NoE)	islack (O&M)	islack (TR)	islack (TEG)
UEGCL Namanve (JACOBSEN)	1	1	.	0	.	.
Electromaxx (U) Ltd	2	0.720155	0.0002	31276.6	100306	133901

**Source:** Author's computation

**Analysis of the factors influencing Technical Efficiency using Tobit regression model**

**Hypothesis:** Adopting a Tobit regression model, this study was guided by the following hypotheses;

- i. Plant size has no significant positive effect on technical efficiency
- ii. Number of employees has no significant negative effect on technical efficiency
- iii. Operational & maintenance costs has no significant negative effect on technical efficiency
- iv. Firm age has no significant positive effect on technical efficiency
- v. There is no significant relationship between energy source and the technology efficiency

Table 6 shows the analysis results by a Tobit regression model of factors influencing technical efficiency in electricity generation in Uganda. Both CRS and VRS models were applied. However, in this study, the VRS model results were considered important and appropriate method to achieve the purpose of the study. The censored regression model under the CRS DEA framework shows that plant size positively and significantly boosts efficiency (Coef. = 0.31534, p-value = 0.000), while firm age shows a marginal positive effect (Coef. = 0.21829, p-value = 0.054). Conversely, high O&M costs significantly reduces efficiency (Coef. = -0.22257, p-value = 0.000), while workforce (number of employees) and energy source have negative but statistically insignificant impacts. The Tobit regression results under VRS DEA Model highlight key factors influencing technical efficiency (VRS\_TE). Plant size positively and significantly effects technical efficiency (Coef. = 0.41187, P-value=0.000), highlighting that larger plants perform better under VRS conditions. In contrast, number of employees negatively effects technical efficiency (Coef. =-0.19808, p-value = 0.017), showing potential inefficiencies from overstaffing. Similarly, high O&M costs significantly reduces efficiency (Coef. = -0.24001, P-value =0.000). This shows the need for cost-effective management practice. Energy source also has a negative and statistically significant impact, with solar energy (Coef. = -0.3245, p-value 0.051), showing a lower likelihood of inefficiency compared to hydro energy. This study considers the results by VRS model as the appropriate results for policy implication.

**Table 6. Tobit results under both CRS and VRS model**

<b>Tobit regression - CRS Model</b>				<b>Tobit regression - VRS Model</b>			
Number of Observation		36		Number of Observation		36	
Uncensored		32		Uncensored		28	
Left censored		0		Left censored		0	
Right censored		4		Right censored		8	
LR Chi2(5) =		32.11		LR Chi2(5) =		36.41	
Prob value>chi2=		0.000		Prob value>chi2=		0.000	
Pseudo R2 =		0.59397		Pseudo R2 =		0.7762	
<b>CRS_TE</b>	<b>Coef.</b>	<b>t-values</b>	<b>P-values</b>	<b>VRS_TE</b>	<b>Coef.</b>	<b>t-values</b>	<b>P-values</b>
Plant Size	0.31534	6.21	0.000	Plant Size	0.41187	6.3	0.000
Number of Employees	-0.05403	-0.77	0.448	Number of Employees	-0.19808	-2.52	0.017
O&M costs	-0.22257	-4.99	0.000	O&M costs	-0.24001	-4.75	0.000
Firm Age	0.21829	2	0.054	Firm Age	0.18192	1.5	0.143
Energy source				Energy Source			

Solar	-0.10529	-0.73	0.468	Solar	-0.3245	-2.03	0.051
Thermal	-0.21802	1.24	0.224	Thermal	-0.33381	-1.7	0.635
Constant	1.73138	4.65	0.000	Constant	2.85172	6.54	0.000

**Source:** Author’s computation

**Discussion of the Results**

The technical efficiency results indicate that 22% of the electricity-generating firms operate at full capacity, while 77.85 exhibited efficiency scores between 10% and 87%. Also other firms performed poorly, with 67% operated below 50% efficiency. These inefficiencies could be explained by inefficient input utilization, outdated technology and regulators constraints. Previous research studies show that regulation and energy policies can reduce energy sector productivity, because of using resources inefficiently and outdated technology (Ajayi et al., 2020). However, the challenges can be addressed through good regulatory reforms, investment in modern infrastructure system, and capacity building. Rahimi and Ipakchi (2010) explained that demand-side management and adoption of new technologies are key to optimizing efficiency in generation. Besides, incentive-based regulations can affect technical efficiency, especially in developing countries majorly with state-owned utilities (Bigerna et al., 2016). Because of experience, older firms are more efficient that the new ones but still have output inefficiencies. The new plants are face inefficiencies largely in workforce use and revenue collections. This aligns with Ahmed et al (2020), that older power plants have better efficiency because of experience and economies of scale. While Chen et al. (2019), indicated that younger firms are more efficiencies because they adopt modern technologies and lean operation.

The study noted that plant, workforce size, and O&M costs were the drivers of efficiency. This finding aligns with research by Rickels et al., (2020), that operational and maintenance costs lowers plant efficiency, especially in hydro plants. According to Owusu and Asumadu-Sarkodie (2016) solar and thermal power have higher efficiency because of lower maintenance costs and higher capacity utilization. The results are suggested the need for improved operational strategies to enhance efficiency in the electricity sector. Therefore, electricity generation efficiency can be improved by using better-managed and bigger power plants, optimizing workforce, minimized operating and maintenance costs, and using modern technology. Therefore, the study is emphasizing that the government or the stakeholders can support these improvements by putting in place regulations and policies, incentives such as tax breaks, and investment in research and development to promote more efficient power generation.

**Conclusion and Recommendations**

In Sub-Saharan African countries, power generating companies are still not operating efficiently. For example, Uganda’s energy sector has inefficiencies in electricity generation. Solar and thermal plants are more efficient than hydropower plants. Plant size, workforce size and O&M costs are the key drivers of efficiency. Older and new firms perform better, while mid-age-firms struggle, indicating the need for targeted support and efficiency-enhancing policies. From the conclusion and above results, the following recommendations are proposed.

- Policymakers must devise efficiency-driven regulations, such as incentives for firms adopt modern technology. The study recommends introduction of good principals, tax breaks, and efficiency audits for firms operate optimally. Besides, policies that support

diversification of Uganda's energy mix should be introduced, promoting hybrid systems like solar-hydro integration to improve overall efficiency.

- Electricity generating firms must promote efficiency by adopting predictive maintenance strategies, digital monitoring, and automation to minimize operational costs. Hydropower plants, which exhibit the most inefficiencies, should focus on resource optimization and benchmarking against efficient firms. There should be better and optimized workforce management practices through training programs, lean staffing, and process automation to improve productivity.
- Funding firms using performance-based lending model, through investors and financial institutions, should be prioritized. Financial support programs should be introduced to help firms in middle age struggling with efficiency. This will scale up operations and investing in cost-saving technology.
- Uganda's electricity regulation largely should reconsider focusing supply-side efficiency in generation. Therefore, the study recommends the integration of regulatory reforms; investment incentives; such as tax credits, low interest loans, grants/subsidies; and technological advancements is fundamental to improving electricity generation efficiency and ensuring sustainable energy growth.

## References

- Agoundedemba, M., Kim, C. K., & Kim, H. G. (2023). Energy status in Africa: challenges, progress and sustainable pathways. *Energies*, 16(23), 7708. <https://doi.org/10.3390/en16237708>
- Ahmed, B., Akbar, M., Sabahat, T., Ali, S., Hussain, A., Akbar, A., & Hongming, X. (2020). Does firm life cycle impact corporate investment efficiency? *Sustainability*, 13(1), 197. <https://doi.org/10.3390/su13010197>
- Ajayi, V., Dolphin, G., Anaya, K., & Pollitt, M. G. (2020). *The Productivity Puzzle in Network Industries: Evidence from the Energy Sector*. University of Cambridge, Faculty of Economics.
- Alinsato, A. S., Nkeudjoua, F., & Houenou, B. (2021). Technical efficiency of electric companies in sub-saharan africa. *Economics Bulletin*, 41(4), 2601-2611.
- Alirezaee, M. R., & Afsharian, M. (2010). Improving the discrimination of data envelopment analysis models in multiple time periods. *International Transactions in Operational Research*, 17(5), 667-679. <https://doi.org/10.1111/j.1475-3995.2009.00759.x>
- Andor, M. A., Bernstein, D. H., & Sommer, S. (2021). Determining the efficiency of residential electricity consumption. *Empirical Economics*, 60(6), 2897-2923. [https://doi.org/10.1016/S0377-2217\(01\)00101-1](https://doi.org/10.1016/S0377-2217(01)00101-1)
- Asantewaa, A., Jamasb, T., & Llorca, M. (2022). Electricity Sector Reform Performance in Sub-Saharan Africa: A Parametric Distance Function Approach. *Energies*, 15(6), 2047. <https://doi.org/10.3390/en15062047>
- Banker, R. D. (1984). Estimating most productive scale size using data envelopment analysis. *European journal of operational research*, 17(1), 35-44. [https://doi.org/10.1016/0377-2217\(84\)90006-7](https://doi.org/10.1016/0377-2217(84)90006-7)
- Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, 30(9), 1078-1092. <https://doi.org/10.1287/mnsc.30.9.1078>
- Benini, G., & Cattani, G. (2022). Measuring the long run technical efficiency of offshore wind farms. *Applied Energy*, 308, 118218. <https://doi.org/10.1016/j.apenergy.2021.118218>

- Banker, R. D., & Thrall, R. M. (1992). Estimation of returns to scale using data envelopment analysis. *European Journal of operational research*, 62(1), 74-84. [https://doi.org/10.1016/0377-2217\(92\)90178-C](https://doi.org/10.1016/0377-2217(92)90178-C)
- Bernstein, D. H. (2020). An updated assessment of technical efficiency and returns to scale for US electric power plants. *Energy policy*, 147, 111896. <https://doi.org/10.1016/j.enpol.2020.111896>
- Bigerna, S., Bollino, C. A., & Polinori, P. (2016). Market power and transmission congestion in the Italian electricity market. *The Energy Journal*, 37(2), 133-154. <https://doi.org/10.5547/01956574.37.2.sbig>
- Charnes, A., W. W. Cooper and E. Rhodes. (1978). "Measuring the Efficiency of Decision Making Units." *European Journal of Operational Research* 2, 429-444. [https://doi.org/10.1016/0377-2217\(78\)90138-8](https://doi.org/10.1016/0377-2217(78)90138-8)
- Cook, W. D., & Seiford, L. M. (2009). Data envelopment analysis (DEA)—Thirty years on. *European journal of operational research*, 192(1), 1-17. <https://doi.org/10.1016/j.ejor.2008.01.032>
- Cooper, W. W., Seiford, L. M., & Tone, K. (2006). *Introduction to data envelopment analysis and its uses: with DEA-solver software and references*. Boston, MA: Springer US.
- Costa-Campi, M. T., García-Quevedo, J., & Segarra, A. (2015). Energy efficiency determinants: An empirical analysis of Spanish innovative firms. *Energy Policy*, 83, 229-239. <https://doi.org/10.1016/j.enpol.2015.01.037>
- Dogan, N. O., & Tugcu, C. T. (2015). Energy efficiency in electricity production: A data envelopment analysis (DEA) approach for the G-20 countries. *International Journal of Energy Economics and Policy*, 5(1), 246-252.
- Eder, A., & Mahlberg, B. (2018). Size, subsidies and technical efficiency in renewable energy production: The case of Austrian biogas plants. *The Energy Journal*, 39(1), 185-210. <https://doi.org/10.5547/01956574.39.1.aede>
- Ekadjaja, A., & Wijaya, A. (2021). Factors affecting firm performance in manufacturing companies in Indonesia stock exchange. *Jurnal Akuntansi*, 25(1), 154-167. <https://doi.org/10.24912/ja.v25i1.730>
- Erena, O. T., Kalko, M. M., & Debele, S. A. (2021). Technical efficiency, technological progress and productivity growth of large and medium manufacturing industries in Ethiopia: A data envelopment analysis. *Cogent Economics & Finance*, 9(1), 1997160. <https://doi.org/10.1080/23322039.2021.1997160>
- Färe, R., Grosskopf, S., & Lovell, C. K. (1985). *The measurement of efficiency of production* (Vol. 6). Springer Science & Business Media.
- Fowlie, M., & Meeks, R. (2020). Rethinking energy efficiency in the developing world. *Review of Environmental Economics and Policy*, 1-37.
- Hou, Z., Roseta-Palma, C., & Ramalho, J. J. (2022). Technical Efficiency Improvements in the Portuguese Electricity Sector. *Available at SSRN 4181161*.
- Huang, G., He, L. Y., & Lin, X. (2022). Robot adoption and energy performance: Evidence from Chinese industrial firms. *Energy Economics*, 107, 105837. <https://doi.org/10.1016/j.eneco.2022.105837>
- Ibrahim, H. A., Ayomoh, M. K., Bansal, R. C., Gitau, M. N., Yadavalli, V. S., & Naidoo, R. (2023). Sustainability of power generation for developing economies: A systematic review of power sources mix. *Energy Strategy Reviews*, 47, 101085. <https://doi.org/10.1016/j.esr.2023.101085>

- Jacobson, T., & Zou, H. (2024). High-dimensional censored regression via the penalized Tobit likelihood. *Journal of Business & Economic Statistics*, 42(1), 286-297. <https://doi.org/10.1080/07350015.2023.2182309>
- Ji, Y. B., & Lee, C. (2010). Data envelopment analysis. *The Stata Journal*, 10(2), 267-280. <https://doi.org/10.1177/1536867X1001000207>
- Jingura, R. M., & Kamusoko, R. (2017). Temporal and spatial analysis of electricity generation from biomass sources in sub-Saharan Africa. *Cogent Engineering*, 4(1), 1296757. <https://doi.org/10.1080/23311916.2017.1296757>
- Karim, R. M. H., & Salh, S. M. (2020). Using tobit model for studying factors affecting blood pressure in patients with renal failure. *UHD Journal of Science and Technology*, 4(2), 1-9. <https://doi.org/10.21928/uhdjst.v4n2y2020.pp1-9>
- Khan, I. U., & Karam, F. W. (2019). Intelligent business analytics using proposed input/output oriented data envelopment analysis DEA and slack based DEA models for US-airlines. *Journal of Intelligent & Fuzzy Systems*, 37(6), 8207-8217. <https://doi.org/10.3233/JIFS-190641>
- Koopmans, T. C. (1951). An Analysis of production as an Efficient Combination of Activities. *Activity Analysis of Production and Allocation/Wiley*.
- Kusz, D., Nowakowski, T., & Kusz, B. (2024). The Capacity of Power of Biogas Plants and Their Technical Efficiency: A Case Study of Poland. *Energies*, 17(24), 6256. <https://doi.org/10.3390/en17246256>
- Megawati, E. S. D. (2019). Analisis Pengaruh firm size, firm age, leverage, dan growth Terhadap Kinerja Perusahaan. *Jurnal Paradigma Akuntansi*, 1(3), 666-674. <https://doi.org/10.24912/jpa.v1i3.5569>
- Mekuye, B., Mebratie, G., Abera, B., Yibeltal, A., Lake, A., & Tefera, A. (2024). Energy: An Overview of Type, Form, Storage, Advantages, Efficiency, and Their Impact. *Energy Science & Engineering*, 12(12), 5678-5707. <https://doi.org/10.1002/ese3.1937>
- Michels, M., & Musshoff, O. (2022). A tobit regression model for the timing of smartphone adoption in agriculture. *Heliyon*, 8(11).
- MEMD (Ministry of Energy and Mineral Development) (2023), Energy Policy for Uganda 2023
- Murty, S., & Nagpal, R. (2020). Measuring output-based technical efficiency of Indian coal-based thermal power plants: A by-production approach. *Indian Growth and Development Review*, 13(1), 175-206. <https://doi.org/10.1108/IGDR-05-2018-0058>
- Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, 3(1), 1167990. <https://doi.org/10.1080/23311916.2016.1167990>
- Nguyen, M. H., Le, C. V., & Atkinson, S. E. (2022). The production inefficiency of US electricity industry in the face of restructuring and emission reduction. *Journal of Economics and Development*, 24(4), 278-292. <https://doi.org/10.1108/JED-07-2022-0127>
- Njeru, G., Gathiaka, J. K., & Kimuyu, P. K. (2020). Technical efficiency of thermal electricity generators in Kenya. *International Journal of Energy Economics and Policy*, 10(3), 340-347. doi:10.32479/ijeep.9102
- Pinto, R., Henriques, S. T., Brockway, P. E., Heun, M. K., & Sousa, T. (2023). The rise and stall of world electricity efficiency: 1900–2017, results and insights for the renewables transition. *Energy*, 269, 126775. <https://doi.org/10.1016/j.energy.2023.126775>
- Piran, F. S., Lacerda, D. P., & Camargo, L. F. R. (2020). Data Envelopment Analysis (DEA). In *Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services* (pp. 49-76). CRC Press.

- Pudleiner, D., Jones, D., & Khan, A. (2017). Energy Efficiency Roadmap for Uganda, Making Energy Efficiency Count.
- Rahimi, F., & Ipakchi, A. (2010). Demand response as a market resource under the smart grid paradigm. *IEEE Transactions on smart grid*, 1(1), 82-88. 10.1109/TSG.2010.2045906
- Rickels, W., Quaas, M. F., Ricke, K., Quaas, J., Moreno-Cruz, J., & Smulders, S. (2020). Who turns the global thermostat and by how much? *Energy economics*, 91, 104852. <https://doi.org/10.1016/j.eneco.2020.104852>
- René, N. S. A. B. I. M. A. N. A. (2022). Benchmarking of the Electricity Sector in East Africa: An Assessment of Technical Efficiency. *East African Journal of Science, Technology and Innovation*, 3. <https://doi.org/10.37425/eajsti.v3i.462>
- Rodríguez-Lozano, G., & Cifuentes-Yate, M. (2021). Efficiency assessment of electricity generation from renewable and non-renewable energy sources using Data Envelopment Analysis. *International Journal of Energy Research*, 45(13), 19597-19610. <https://doi.org/10.1002/er.6959>
- Saglam, Ü. (2018, November). The efficiency assessment of renewable energy sources with data envelopment analysis. In *2018 Annual Meeting of the Decision Sciences Institute Proceedings, Chicago IL*.
- Sattar, I., Saeed, A., & Arshad, B. (2013). Is Experience or Fund Type Effect Matters in Firm Performance? A Study of KSE Listed Organization in Pakistan. *Research Journal of Management*, 1-9.
- Sedeeq, B. S., & Meran, B. W. (2022). The Use of Tobit and Logistic Regression Models to Study Factors that Affect Blood Pressure in Cardiac Patients. *Cihan University-Erbil Scientific Journal*, 6(2), 133-140. <https://doi.org/10.24086/cuesj.v6n2y2022.pp133-140>
- Sengupta, D., & Mukherjee, D. (2022). By-production of electricity and particulates: efficiency of Indian thermal power plants revisited. *International Journal of Energy Sector Management*, 16(2), 265-283. <https://doi.org/10.1108/IJESM-12-2020-0002>
- Shumais, M. (2020). Resource use efficiency of electricity sector in the Maldives. *The Journal of Asian Finance, Economics and Business*, 7(1), 111-121. <https://doi.org/10.13106/jafeb.2020.vol7.no1.111>
- Tharwat, A., El-Demerdash, B., & El-Khodary, I. (2019, January). Developing an input oriented data envelopment analysis model with fuzzy uncertainty in variables. In *Creative Business and Social Innovations for a Sustainable Future: Proceedings of the 1st American University in the Emirates International Research Conference—Dubai, UAE 2017* (pp. 117-122). Cham: Springer International Publishing. [https://doi.org/10.1007/978-3-030-01662-3\\_13](https://doi.org/10.1007/978-3-030-01662-3_13)
- Tillman, D. A. (2015). Improving Efficiency in Electricity Generation: A Technological Perspective. *Handbook of Clean Energy Systems*, 1-13. <https://doi.org/10.1002/9781118991978.hces202>
- Toloo, M., Keshavarz, E., & Hatami-Marbini, A. (2021). Selecting data envelopment analysis models: A data-driven application to EU countries. *Omega*, 101, 102248. <https://doi.org/10.1016/j.omega.2020.102248>
- United Nations (2025) The Sustainable Development Goals Report 2025. <https://unstats.un.org/sdgs/report/2025/The-Sustainable-Development-Goals-Report-2025.pdf>
- Wai Foon, S., & Terziovski, M. (2014). The impact of operations and maintenance practices on power plant performance. *Journal of Manufacturing Technology Management*, 25(8), 1148-1173. <https://doi.org/10.1108/JMTM-12-2012-0122>

- Wesseh Jr, P. K., Zhong, Y., & Hao, C. H. (2023). Electricity supply unreliability and technical efficiency: Evidence from listed Chinese manufacturing companies. *Energies*, *16*(7), 3283. <https://doi.org/10.3390/en16073283>
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.