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Benchmarking of the Electricity Sector in East Africa: An Assessment of Technical Efficiency

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Abstract

The electricity sector has globally been subject to reforms since the 1990s. The reforms consisted of unbundling vertically integrated monopolies and attracting the private sector with a view of improving quality of service (QoS) and technical efficiency. In some East African countries, however, the electricity sector remains vertically integrated. Controlling electricity losses has been difficult, resulting in poor QoS. This paper analyzes and compares the performance of the East African power sector with regard to QoS. A non-parametric approach, Data Envelopment Analysis (DEA) was used to estimate the technical efficiency scores and the Total Factor Productivity Change (TFPC) for productivity improvement under two models, generation and transmission-distribution (TD). Data comprising two outputs and three inputs was collected in Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda for the period 2008-2017. On average, the East African power sector exhibits performance gaps of 20% for the generation model, and 22% for the TD model. In the generation model, it exhibits Decreasing Returns to Scale (DRS) at a frequency of 34 out of 60, compared to 16 for Increasing Returns to Scale (IRS) and 10 for Constant Returns to Scale (CRS). However, in the TD model, IRS are the most dominant, with a frequency of 31 out of 60 compared to 19 and 10 for DRS and CRS respectively. Inefficiency is largely attributed to excess inputs, including high-voltage transmission line lengths and electricity losses, as well as a shortage of outputs, such as the number of customers. The study also shows a global productivity improvement, which is linked to efficiency change for the generation model and technological change for the TD model. Specifically, countries that have attracted the private sector into the generation and/or distribution sectors have improved their productivity compared to others with state-owned utilities.

Keywords: *East Africa, electricity sector reform, Data Envelopment Analysis, quality of Service, performance gap*

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Introduction

Since the 1990s, developing countries have engaged in the process of electricity sector reform. One of the main reasons of that reform is the low quality of service (QoS). Severe power outages lead to poor supply security, high levels of electricity losses, lack of financial resources to increase investments and expand access to electricity (Dertinger and Hirth, 2020; Mohsin *et al.,* 2021). The electricity sector reform, which has also been implemented in East African countries, has unfolded in several steps, including unbundling the state-owned power utilities and their privatization (Bacon, 2018; Dertinger and Hirth, 2020). The question is whether these reforms have increased the performance of the electricity sector.

Data Envelopment Analysis (DEA) is one of the benchmarking approaches used to compare the performance of entities that transform multi-inputs into multi-outputs. It is a non-parametric linear programming technique used to evaluate the performance of similar organizations known as Decision Making Units (DMUs). Each DMU is engaged in a transformation process using inputs to produce outputs without the information of market prices (Pereira de Souza *et al.,* 2014). A combination of inputs and outputs choice makes it possible to maximize the technical efficiency (TE) scores, a ratio of weighted outputs to weighted inputs. Various goals are assigned to the DEA models, such as finding the TE and identifying efficient and inefficient DMUs (Alizadeh *et al.,* 2020). To assign the performance values, the different DMUs are supposed to use the same inputs to produce the same outputs (Petridis *et al.,* 2019).

The DEA method has been used to compare the performance of different electricity sub-sectors, such as power generation (Jaraite and Di Maria, 2012; Njeru *et al.,* 2020; See and Coelli, 2012), transmission (da Silva *et al.,* 2019; Llorca *et al.,* 2016) and distribution (Barabutu and Lee, 2018; Bongo *et al.,* 2018; Petridis *et al.,* 2019). To date, though, very few studies address the entire electricity sector (Alizadeh *et al.,* 2020; Mardani *et al.,* 2017). Estache *et al.,* (2008) have examined issues relating to the quality and volume of data while Çelen (2013), Coelli *et al.,* (2013) and Xie *et al.,* (2018) addressed the small sample size of entities and the international comparability problems. Despite the vast number of studies benchmarking the electricity sector, very few have been conducted on utilities operating in African countries, e.g. Barabutu and Lee (2018), Estache *et al.,* (2008), Njeru *et al.,* (2020), Plane (1999) and Real and Tovar (2020).

This study addresses this gap by comparing the performance of the electricity sector in East Africa. Specifically, it compares TE scores and their determinants. It also compares the TFPC of different electric utilities. Given the management complexity of the electricity sector in East Africa, data is in this study aggregated at the country level. Instead of comparing the performance of individual firms, the paper focuses on the electrical industry. The analysis is conducted using two models, a generation model and a TD model. Finally, the study is based on our compilation of a detailed dataset concerning six countries, namely Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda, for a ten-year period from 2008 to 2017.

The rest of the paper is organized as follows: Section 2 briefly describes the DEA approach and presents the data. The results are presented in section 3 and discussed in section 4. Finally, the paper ends with a conclusion.

Material and methods

Data Envelopment Analysis

DEA was originally proposed by Charnes *et al.,* (1978) for DMU operating in CRS. The approach was extended to the variable returns to scale (VRS) by Banker *et al.,* (1984). It respects the assumptions developed by Färe and Primont (1995), such as free disposability, convexity and return to scale. It requires the use of linear programming methods and constructs a piece-wise linear envelopment frontier (Coelli and Perelman, 1999). All observed data points have to lie on or below the production frontier.

Let X represents $K\,x\,P$ matrix of input, and Yrepresents MxP output matrix where x_i and y_i are the input and output vectors for the P firms. The DEA input-oriented seeks to minimize the inputs and still remain within the feasible production set. It is defined as follows:

$$\max_{\theta,\lambda} \theta$$

$$\begin{aligned} &\text{s.t} \\ &-y_i + Y\lambda \geq 0 \\ &\frac{x_i}{\theta} - X\lambda \geq 0 \\ &N1'\lambda = 1 \\ &\lambda \geq 0 \qquad (1) \end{aligned}$$

Where $N1$ is a $Nx1$ vector of 1s, λ is an $Nx1$ vector of weights, θ the distance function. This one shows how much the input vector can be proportionally contracted without changing the output vector. θ_i takes a value between 1 and $+\infty$. $1/\theta_i$ is viewed as the proportional reduction in inputs by the i^{th} firm, without changing outputs.

Total Factor Productivity change

To analyze how to improve performance, the Malmquist DEA index developed by Färe *et al.,* (1994) was used. It measures the TFPC between two analyzed periods t and *t+1*. Suppose that $D_0^t(x^t, y^t)$ is the output distance function, i.e the reciprocal of the maximum proportional expansion of the output vector y^t given inputs x^t, the Malmquist DEA index can be written as follows:

$$M_o\,(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} X \left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} X \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)^{\frac{1}{2}} = EC^{t+1} X\, TC^{t+1} \quad (2)$$

Where the term out of the brackets Ec^{t+1} measures the efficiency change between t and t+1. On the other hand, the term in brackets TC^{t+1} measures the geometric mean of the magnitudes of technical change. While the Efficiency change captures the changes in relative efficiency over time (evidence of catching up the frontier), technical change shows evidence of innovation (shift in frontier). The Malmquist TFP index can take three values: $0 \leq M_o < 1, M_o = 1, M_o > 1$. A value greater than one implies an improvement in TFPC, while a value less than one indicates a deterioration in productivity over time. A value of 1, however, implies a status-quo between the two periods analyzed. To implement the DEA and Malmquist DEA index, we used the solver DEAP version 2.1 developed by Coelli (1996).

Data collection

The data was collected in two stages. Initially, some data was collected physically through a visit to the different countries. The main institutions visited are REGIDESO in Burundi, the Electricity Regulatory Authority (ERA) in Uganda, Ethiopian Electric Power (EEP), Ethiopian Electric Utility (EEU) in Ethiopia, and Tanzania Electric Supply Company Limited (TANESCO) in Tanzania. In these countries, the data was supplied by designated officials within the various departments of the utilities, with the exception of Uganda, where the ERA summarizes all electricity sector data and publishes it on its website. Data on the electricity sector in Kenya was obtained through the Kenya Power Lighting Company (KPLC) website, including annual reports from 2008 to 2018. This website summarizes all data related to power generation, transmission, and distribution. Secondary data for the electricity sector in Rwanda were obtained through three sources: the 2012 and 2018 national energy policies, energy statistics found at the Rwanda Utility Regulatory Authority (RURA) website, and some studies such Bimenyimana *et al.,* (2018) and Meera *et al.,* (2016).

The electricity sector has been restructured in some countries, giving rise to two or more companies with different functions. In other countries, a single company performs all generation, transmission and distribution activities. Thus, the power sector in East Africa is complex. Performance comparisons require harmonization with respect to inputs and outputs. This is why the study compares performance through a generation model and a TD model. The common feature of these models is the use of electricity delivered (GWh) and the number of customers as outputs. Electricity losses (GWh), treated as imperfect substitutes for other capital and operational expenses, are a common input to both models. These are the technical and non-technical losses obtained by the difference between the electricity purchased and the electricity delivered. Installed capacity (MW) is specific to the generation model, while the high-voltage transmission line length (Km) is an input for the TD model. In this study, output and input data are aggregated at the country level. Table 1 summarizes output-input variables, while Table 2 shows the Pearson correlation at the level of 5%.

Results

Table 3 summarizes the technical efficiency scores and their change. The performance gap of 22% in the TD model is higher than 20% in the generation model. Comparing to other countries, Kenya and Rwanda have small performance gaps, indicating that technical efficiency scores are close to 100%. Rwanda is doing better in the generation model, while Kenya is in the TD model. Burundi and Tanzania perform relatively well in the generation model compared to the TD model, with a performance gap of 20% and 37% respectively for Burundi, and 18% and 40% respectively for Tanzania. Uganda performs relatively better in the TD model than in the generation model with a performance gap of 18% and 32% respectively. In contrast, Ethiopia has a higher performance gap in both models, the higher one being in the generation model (40% and 32%).

Table 1. Summary of input-output variables

Variable	Units	Obs	Mean	St.Dev.	Min	Max
Installed Capacity	MW	60	1280.10	1350.14	54.85	4831.76
HV line length	Km	60	2943.37	2406.01	322.00	8772.64
Electricity Losses	GWh	60	896.39	76.86	36.43	2902.10
Electricity Delivered	GWh	60	3090.05	2611.21	161.72	8585.94
Customers	10000	60	114.18	115.70	48.11	618.23

Table 2. Pearson correlation between outputs and inputs

	Electricity Delivered	Customers	Installed capacity	HV Lines	Electricity Losses
Electricity Delivered	1				
Customers	0.8604*	1			
Installed capacity	0.7686*	0.6226*	1		
HV Lines	0.9234*	0.7281*	0.8439*	1	
Electricity Losses	0.8745*	0.7126*	0.8446*	0.9401*	1

Using the classification made by Norman and Stoker (1991), replied to by Barabutu and Lee (2018), Ervural *et al.,* (2018), and Mbangala and Perelman (1997), Kenya and Rwanda are classified as moderately efficient, the TE scores being above 90%. Burundi and Tanzania are marginally efficient in the generation model, while Uganda is marginally efficient in the TD model. Finally, Ethiopia is inefficient in both models. In terms of performance change, Burundi and Kenya have a negative average growth rate (-0.7%) in the generation model. The highest change for Ethiopia (8.5%) is due to the large variance in TE scores over time. In the TD model, all countries observe a positive change in TE scores. The highest change in Tanzania is also due to their high variance, as shown by the min and max.

Table 3. Technical efficiency scores

Country	Mean	Std. Dev.	Min	Max	Change
	Generation model				
Burundi	0.802	0.113	0.571	1.000	-0.7%
Ethiopia	0.598	0.201	0.304	0.886	8.5%
Kenya	0.942	0.051	0.867	1.000	-0.7%
Rwanda	0.949	0.059	0.843	1.000	2.1%
Tanzania	0.819	0.065	0.676	0.898	3.2%
Uganda	0.682	0.100	0.545	0.852	1.8%
	TD model				
Burundi	0.672	0.149	0.502	1.000	2.9%
Ethiopia	0.675	0.161	0.375	0.849	3.3%
Kenya	0.963	0.040	0.878	1.000	0.6%
Rwanda	0.929	0.081	0.790	1.000	2.8%
Tanzania	0.606	0.126	0.353	0.767	10.8%
Uganda	0.811	0.113	0.630	1.000	5.6%

Table 4. Nature of return to scale

Country	Generation model			TD model		
	IRS	DRS	CRS	IRS	DRS	CRS
Burundi	9	0	1	9	0	1
Ethiopia	0	10	0	0	10	0
Kenya	0	8	2	4	1	5
Rwanda	3	1	6	3	0	7
Tanzania	0	9	1	5	4	1
Uganda	4	5	1	9	0	1
Total	**16**	**34**	**10**	**31**	**19**	**10**

Table 5. Average input excess and output shortages

Variable	Burundi	Ethiopia	Kenya	Rwanda	Tanzania	Uganda
	Generation model					
Electricity delivered	4	0	0	0	0	0
Customers	129	15	4634	0	0	3423
Transmission lines length	0	923	0	0	0	53
Electricity Losses	6	1	2	0.17	285	60
	TD model					
Electricity delivered	8	0	0	2	0	0
Customer	488	3358	216864	0	0	2986
Installed capacity	0	332	0	0	169	0
Electricity losses	4	99	13	0	115	118

Table 6. Total Factor Productivity Change

Country	Generation model			TD model		
	EC	TEC	TFPch	EC	TEC	TFPch
Burundi	0.987	1.003	0.99	0.971	1.009	0.98
Ethiopia	0.965	1.004	0.969	0.964	1.025	0.988
Kenya	1	0.981	0.981	1	1.025	1.025
Rwanda	1.001	1.044	1.045	1	1.075	1.076
Tanzania	1.04	0.986	1.026	1.052	1.005	1.057
Uganda	1.024	0.981	1.005	1.016	1.042	1.058
Mean	1.003	1	1.002	1	1.03	1.03

Note: EC: efficiency change, TEC: technological change, TFPch: total factor productivity change

The inefficiency of the electricity sector in East Africa can also be analyzed through the nature of returns to scale. The results are shown in Table 4. In the generation model, the East African power sector exhibits DRS at a frequency of 34 out of 60, compared to 16 for IRS and 10 for CRS. However, in the TD model, IRS are the most dominant, with a frequency of 31 out of 60 compared to 19 for DRS and 10 for CRS. Returns to scale reflect the increase in outputs resulting from an increase in inputs in the same proportions. In the case of DRS, any increase in inputs in the same proportions results in a less proportional increase in outputs. On the other hand, in the case of IRS, any increase in inputs in the same proportions corresponds to a greater proportional increase in outputs. Both IRS and DRS reflect inefficiency. Only decision-making units operating at CRS are considered efficient. Efficient decision-making units in the generation model are also efficient in the TD model.

The nature of returns to scale is generally related to the size of the electricity sector (Badunenko and Kumbhakar, 2017). For example, the electricity sector in Ethiopia, Kenya and Tanzania, when not efficient, admits DRS, especially in the generation model, as their installed electricity capacity is larger than that of Burundi, Rwanda and Uganda. The power sector in Burundi and Ethiopia appear to be the least efficient. Burundi with the lowest installed capacity power sector exhibits IRS at a frequency of nine out of ten in both models. On the other hand, Ethiopia with the largest installed capacity, transmission line length and delivered electricity exhibits DRS at a frequency of ten out of ten. However, Rwanda for which the electricity sector exhibits CRS at a frequency of six and seven out of ten respectively in the generation and TD models appears to be the most efficient in the region. It is a best practice from which other countries can draw inspiration to increase their performance. Both IRS and DRS characterize the firm's inefficiency. Inefficiency in the power sector was also found in the case of utilities operating in the Southern African Power Pool by Barabutu and Lee (2018); Estache *et al.,* (2008) and Real and Tovar (2020). According to Ritten *et al.,* (2018), the DRS may discourage firms from expanding their activities to meet the demand. On the other hand, IRS could create barriers to the market entry for new firms in the electricity sector.

Discussion

What explains the inefficiency of the electricity sector in East Africa?

The inefficiency of a firm is defined by comparing it with its peers. Specifically, the comparison can be made using input and output slacks. The presence of slacks enables one to assign a rank for each firm compared to the peers. Inefficiency can be attributed to both economic outputs and inputs. Input slacks indicate unused resources, while output slacks are related to deficiency in expected output (Bongo *et al.,* 2018; Wang and Feng, 2015). Table 5 shows the input excess and output shortage. For the case of output, Burundi, Kenya and Uganda have the highest shortage in customers. Given the inputs and considering the generation model, these countries could increase the number of customer respectively by 129, 4634 and 3423 each year. Burundi has also a shortage in the electricity delivered which could increase by 4 GWh each year. The shortage in customer becomes higher with the TD model for five of six countries except Rwanda. Considering this model, Burundi, Ethiopia, Kenya, Tanzania and Uganda could increase annually their customers respectively by 488, 3358, 216865, and 2986.

For the case of input, Ethiopia displays excess in transmission line length by 332 km and 923 km yearly respectively in the generation and TD models. This excess become 53 km for Uganda in the TD model. Electricity losses are a common input inefficiency source for all countries. In Burundi for example, the excess in electricity losses exceeds delivered electricity shortage (6 MWh vs 4 MWh). By comparing the two models, the excess in electricity losses reduces from the generation to the TD model for Burundi (6 vs 4 MWh), Rwanda (0.17 vs 0 MWh), and Tanzania (285 vs 115 MWh). However, this excess becomes higher by switching from the generation to the TD model in Ethiopia (1 vs 99 MWh), Kenya (2 vs 13 MWh), and Uganda (60 vs 118 MWh). Electricity losses constitute a part of the production that is not sold. Electricity losses lead not only to loss of turnover, but also to reduced profits. The inefficiency in electricity losses could be attributed to demand growth in developing countries over the supply capacity (Nsabimana, 2020). On the other hand, the poor investments and the dilapidated networks resulted in increasing both technical and non-technical losses.

The theory of input and output inefficiency was first used by Leibenstein (1979), who qualified it as X-efficiency. More specifically, X-inefficiency refers to under-utilization of resources, which lead to increased costs or decreased profit and revenue (Kumbhakar and Tsionas, 2021). The under-utilization of input leads also to lower input productivity. Leibenstein (1979) developed several aspects of inefficiency, such as input-specific inefficiency and neutral inefficiencies. Input-specific inefficiency can be attribute to labor and capital. On the other hand, neutral inefficiency, also called managerial efficiency, is related to output inefficiency.

Have reforms in the electricity sector improved performance?

Table 5 compares the improvement in total factor productivity change (TFPch) through the Malmquist index. At the aggregate level, the TFPch is 0.2% and 0.3% per year for the generation and TD models respectively. An improvement in TFPch is observed in Kenya, Rwanda, Tanzania and Uganda. These countries have attracted private investment through Independent Power Producers (IPPs) that operate mainly in the generation and/or distribution sectors. Rwanda stands out as a model country in terms of TFPch, with an annual growth rate of 4.5% and 7.6% per year respectively in the generation and TD models. In Uganda, Tfpch is also linked to change in efficiency and technology. Its electricity sector improved by an average of 5.8% per year in the TD model and 0.5% per year in the generation model. The poor improvement in the generation model is linked to the decline in innovation. For Tanzania, the productivity improvement is 2.6% and 5.7% for the generation and TD models respectively, which is largely related to efficiency change. Kenya improves its performance in the TD model and declines in the generation model. A decline is observed in Burundi and Ethiopia in the two models. These countries are characterized by a state-owned electricity sector. Although Ethiopia unbundled its electricity sector, the two created electricity utilities are entirely under state monopoly.

Private sector participation in the electricity sector improves its performance. This is consistent with the results of Bagdadioglu *et al.*, (1996), Barabutu and Lee (2018), Çelen (2013), and See and Coelli (2012). Imam *et al.*, (2019) pointed out that privatization would reduce bureaucratic rigidities in the operations and management of utilities when the control of politicians and civil servants changes. According to Gore *et al.*, (2019) and Valasai *et al.*, (2017), private sector participation reduces the political interference that is prominent in the state-owned utilities, which results in higher electricity losses, such as electricity theft. On the other hand, Eberhard *et al.*, (2018) illustrate that poor governance prevails when a utility is state-owned and vertically integrated. The high level of bureaucracy in state-owned utilities hinders the decision-making process, especially with regard to investments to be made.

Conclusion

This study benchmarks efficiency of the electricity sector in six Eastern Africa countries. It is based on a unique dataset collected physically in these countries. It uses the DEA approach to estimate the technical efficiency scores and the TFPC. The benchmarking is performed using two models, generation and TD. Under CRS DEA model, the overall performance across the six countries show a performance gap of 20% and 22% for the generation and TD models respectively. The electricity sector in Rwanda and Kenya is moderately efficient. Uganda is also catching up, especially in the TD model, as well as Burundi and Tanzania in the generation model. Ethiopia is the worst performing of the six countries, despite the huge investments made.

The electricity sector in East Africa is vulnerable to electricity losses. Not controlling them limits output expansion, such as access to electricity. As a result, a large number of countries experience high inefficiency in both electricity losses and customer numbers. On the other hand, the countries that have attracted IPPs have improved their TFPC more, through efficiency and technology change. As suggested by Balza *et al.,* (2020), private participation in the electricity sector should be involved in competitive activities such as generation and distribution. The high technical efficiency associated to the private sector is attributed to the adoption of new technologies and managerial practices. Private investments should be directed towards untapped renewable electricity sources, such as solar, wind and geothermal energy.

The study contributes by comparing the performance of the electricity sector in East Africa, through two models. Other studies could compare the performance of one of the electricity sector components, where data is available, such as power generation companies. They could also compare performance in terms of renewable energy adoption. The main limitation of this study is related to the low data coverage. It could be extended to East African Power Pool member countries for which comparable data are available.

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