Quality performance gaps and minimal electricity losses in East Africa

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Abstract

The electricity sector in East Africa is characterized by high levels of electricity losses while regulatory policies have been implemented in order to reduce these losses. Generally, such policies modify the inputs, (for instance higher transmission capacity), the outputs (for instance improved billing), or the technologies. In this paper, we tackle the electricity loss reduction question under a new angle by estimating minimal electricity losses. These minimal electricity losses are computed non-parametrically maintaining the inputs, the outputs, and the technologies constant. Minimal losses are then compared to actual losses to construct quality performance indicators. Our main result is to show that on average, for given electricity generation processes, electricity losses could be reduced by 8%, representing approximately \$60 millions of yearly savings.

Keywords: Minimal electricity losses, quality performance gap, window analysis, East Africa.

JEL Codes: C67, Q40

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1 Introduction

The electricity sector in East Africa is characterized by high levels of electricity losses negatively impacting the utilities, the customers, and the society as a whole. Reducing electricity losses is therefore a major objective for policy makers and regulators in that part of the world. Solutions like detection equipment for electricity fraudsters, upgrading the electricity network, expanding inspections, and increasing the use of prepaid meters are available. These solutions, generally, require modifying the inputs, the outputs, or the technologies of the electricity generation processes. That is, new investments are needed. In this paper, we tackle the electricity loss reduction question under another angle. We compute potential minimal electricity losses while maintaining the electricity generation process, i.e. the inputs, the outputs, and the technologies, unchanged. Putting this differently, we look for potential electricity loss reduction without requesting new investments. Using a detailed and tailored database for six East African countries over a 10-year period, we find that a potential reduction of 8% for the electricity losses is possible while maintaining the inputs, the outputs, and the technologies constant. This represents a net saving of \$60 millions per year.

An important aspect of the quality of service (QoS) for an electricity distribution system is the continuity of supply. A lack of continuity results in power outages which cause inconveniences and costs to consumers and firms. On top of power outages, the transmission and distribution (T&D) of electricity generate power losses. T&D losses can be attributed to technical and non-technical factors. Technical losses (TLs) are the losses that occur within the transmission and distribution network due to the cables, overhead lines, transformers and other substation equipment that are used to transfer electricity. Non-technical losses (NTLs) correspond to the electricity consumed but not paid by the consumers. This absence of payment by the consumers can be attributed to the inability of the electricity distribution company to collect its debts, the illegal connections to the network, electricity theft and frauds (de Souza Savian et al., 2021, Jamil & Ahmad, 2019). The electricity theft decreases the efficiency of the electricity network due to power outages, damage to transformers and meters. More generally, NTLs impact the quality of supply and total system revenue (Costa-Campi et al., 2018, de Souza Savian et al., 2021, and Messinis & Hatziargyriou, 2018). While QoS is typically measured in terms of interruption frequency or duration, losses of electricity are instead measured either as the proportion of purchased energy that did not reach the end user, or as the difference between delivered and purchased energy.

T&D losses represent a high cost for the utility and the society and the problem is particularly severe in Africa. According to Adams et al. (2020), $5 billions is lost annually in Sub-Saharan Africa (SSA) due to T&D losses, with South Africa alone contributing $1.5 billion. Yakubu et al. (2018) state that power losses impact the financial health of utilities and impede new investments in power generation, transmission, and distribution. As a result, electricity losses lead to higher costs for the utilities, and higher tariffs for users. Eventually, higher electricity tariffs encourage electricity fraudsters, contributing to poorer QoS (de Souza Savian et al, 2021, Jamil & Ahmad, 2019, and Leite et al., 2020).

The literature has extensively studied the institutional determinants of electricity losses. Sadovskaia et al. (2019) indicate that improved urbanization, privatization, development, and corruption might reduce electricity losses. Mohsin et al. (2021) find that T&D losses are minimized when the governing bodies in the power sector work with independent power producers (IPPs) and private actors. Nagayama (2010) finds that T&D losses decrease with the introduction of IPPs in Asian developing countries, the privatization in Latin America, and the unbundling in developed countries. Sen & Jamasb (2012) find a positive impact of unbundling and the introduction of the independent regulatory authority in India. Balza et al. (2013) show that a one percent increase in cumulative private investment is associated with a reduction of T&D losses by 0.13 percent in Latin America. Smith (2004) finds that T&D losses are highly correlated with each of the governance dimensions defined by Kaufmann et al. (2010). Nepal & Jamasb (2015) show that a combination of strong governance and proper institutions with corruption control can reduce the electricity theft. Our approach differs to previous studies as we consider the institutional determinants as fixed and that no new investments are made. This is captured by constant input and output levels and fixed technologies for the electricity generation processes. Putting this differently, we look for potential electricity loss reductions without modifying the global electricity environment as such modification might be complex in East Africa.

Besides the important efforts put on better understanding the institutional determinants of electricity losses, several performance analyses have been conducted for the utilities (Bongo et al., 2018, Arcos-Vargas et al., 2017, Von Hirschhaussen et al., 2006). In that case, transmission and distribution losses are considered as a source of inefficiency as they represent energy not supplied, which could be billed and generate revenue for the utility. In practice, electricity losses are added to the electricity generation process as an input (Edvardsen & Forsund, 2003, Jamasb & Pollitt, 2003, Ramos-Real et al., 2009, Xie et al., 2017), output (Bongo et al., 2018, Petridis et al., 2019), or by-product. Table 5 (in the appendix) lists the main papers using electricity losses in performance measurement. Our approach differs to previous studies as we do not consider electricity losses as part of the electricity generation processes. We rather investigate minimal electricity losses given the inputs, outputs, and technologies of the electricity generation processes.

The paper is organized as follow. Section 2 presents important facts and figures on electricity losses in East Africa in order to contextualize our empirical investigation. Section 3 gives our empirical strategy. In Section 4, we explain and describe our data and give our results. We conclude in Section 5.

2 Electricity losses in East African countries

The REN21 2016 report on renewable energy and energy efficiency in East African countries (REN21, 2016) estimates that the electricity losses represents 22% of the power supply. This number is relatively high compared to an average of 12% for the Sub-Saharan African and a world average of 8%.

East African countries are seeking to mitigate electricity losses, with as a target a minimum loss rate of 15% at least. Based on the SE4ALL[1] country analysis and other reference documents such as the master plans for electricity generation, transmission and distribution, the national energy policies and/or strategies[2], we detail

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[1] Sustainable Energy for All (SE4ALL) is an independent organization linked to the United Nations that works toward the achievement of the Sustainable development goal 7: access to affordable, reliable, sustainable and modern energy for all. Their website (`https://www.se4all-africa.org`) provide useful information on East African countries.

[2] With the exception of Burundi, whose national energy policy and strategy date back to 2011, all other East African countries have renewed their national policies and/or strategies in the last seven years. This is the case for Tanzania in 2015, Kenya and Rwanda in 2018, and Uganda in 2019. Ethiopia has instead developed a national electrification programme which also dates from 2019. These national policies and strategies outline the main challenges in the energy sector, as well as the main strategic directions for increasing access to electricity and the quality of service. The reports of these national policies and strategies can be downloaded from the websites of the respective ministries in charge of energy and other institutions such as the energy regulator.

the situation of each country in the East African Community.

In Burundi, the 2011 energy sector strategy reports electricity losses of up to 24.4% in 2011, of which about 15% are attributed to technical losses. The socio-political crisis of 1993-2005 damaged the electricity transmission and distribution network. An audit carried out in 2015 shows that, in addition to technical losses, invoiced and unpaid electricity is one of the main causes of NTL. In his study on the electricity sector in Burundi, Nsabimana (2020) shows that only 42% of energy receivables are recovered each year. The SE4ALL study plans to reduce losses to 15% in 2020, and to 10% in 2030. To achieve this objective, the SE4ALL study provides for an action plan including the construction of new hydroelectric power plants, the rehabilitation of the electricity network, the reduction of unpaid bills and the generalization of pre-paid meters.

In Rwanda, loss reduction is planned through the 2018 National Energy Strategic Plan. In 2017, electricity losses accounted for 22%, 17% were attributed to technical losses and to 5% for NTLs. The national energy policy aims to reduce electricity losses to 15% by 2024. It also seeks to improve the reliability of the network by reducing power cuts from 91.7 hours to 14.2 hours. To achieve this, it plans to carry out energy efficiency awareness campaigns, acquire fraud detection equipment, extend the use of prepaid meters, and strengthen the transmission and distribution network.

In Kenya, the 2018 National Energy Policy and the 2016 SE4ALL diagnostic study show that the country looses represent about $17 millions per year due to electricity theft and the under-sizing of the feeders. Challenges to be addressed include vandalism and aging of electricity infrastructure, power outages, and electricity theft. The energy policy plans to reduce electricity losses to less than 15% in 2020, through increased transmission capacity, distribution system automation and smart grid projects.

The poor performance of the electricity sector in Tanzania is seen through the 2015 National Energy Policy, the 2015 SE4ALL Action Programme, and the 2018 Energy and Water Utilities Regulatory Authority (EWURA) Performance Report. High tariffs and poor recovery of receivables are a barrier to attracting $IPPs$, and thus new investments in the network. Tanzania plans to reduce electricity losses to less than 14% from 2018. To achieve this goal, the national energy policy foresees new investments in construction, rehabilitation and expansion of T&D infrastructure, and interconnection with neighboring countries.

Loss reduction in Uganda is planned through the 2019 National Energy Policy, and the 2015 SE4ALL Action Plan. Despite progress in reducing losses, about 600 GWh is lost each year. Uganda aims to reduce losses to less than 15% by 2030, by strengthening the transmission and distribution network, curbing vandalism of transmission infrastructure and attracting $IPPs$ into the transmission sector. It also intends to implement incentive-based regulation for QoS.

Finally, Ethiopia is one of the fastest growing countries in East Africa in terms of electricity generation. However, the National Electrification Program (NEP 2.0) for 2019 reports high commercial losses, 18% out of 23% total losses in 2017. In addition, 10–15% of losses are related to poor billing and collection systems. The 2019 NEP 2.0 aims to reduce electricity losses to 14% by 2037, by ensuring the financial viability of the two utilities, modernizing institutions, and improving the revenue collection system.

All East African Countries have ambitious target to reduce their power losses. However, their strategies involve investments to increase the inputs and the outputs. In the next section, we develop a method to estimate the potential reductions in power losses, maintaining inputs, outputs and technologies constant.

3 Empirical strategy

We consider that we observe N decision making units (DMU), countries in this study, during T time periods. Each DMU uses P inputs, $\mathbf{x}_t \in \mathbb{R}_+^P$, to produce Q outputs, $\mathbf{y}_t \in \mathbb{R}_+^Q$ at time t, and generate electricity losses $l_t \in \mathbb{R}_+$. Our objective is to evaluate the minimal losses that can be achieved given the inputs and the outputs and the technology used for every time period. The electricity losses represent our proxy for the quality performance gaps. We have two inputs (the length of the transmission lines and the purchased electricity) and two outputs (the number of consumers and the energy delivered). These inputs and outputs are very common in the literature (see Table 5 in the Appendix). Losses can occur in that process.

3.1 Estimating minimal electricity losses

While the actual electricity losses are observed, this is not the case for the minimal electricity losses. The particularity of our approach is to compute minimal electricity losses given the electricity generation process. As this process is typically unknown, we adopt a nonparametric approach by reconstructing the process using the data and imposing some regulatory conditions. These conditions are very general and avoid trivial and unrealistic reconstruction. We select the following technology axioms:

A1 (free disposable inputs): *It is always possible to produce less outputs for given input quantities.*

A2 (free disposable outputs): *More inputs never reduce the outputs.*

A3 (convex technology set): *If two input quantities can produce a certain output amount, then any convex combination of these two input quantities can produce the same output amount.*

A4 (variable returns-to-scale): *The technology exhibits variable returns-to-scale.*

A5 (no technological degradation): *The technology possibilities do not reduce over time.*

Moreover, a particularity of our sample is that we have a few number of countries per time period. A well-established procedure in that case is the windows analysis that is widely utilized as an analytic technique to detect efficiency trends in many fields, such as local government, the banking industry (Asmild et al., 2004, Fadzlan& Muhd-Zulkhibri, 2007), energy and the environment (Wang et al., 2013, Sueyoshi et al., 2017), telecom companies (Yang& Chang, 2009), and power plants (Sueyoshi et al., 2013). Roughly speaking, time periods are pooled together.

This technique operates on the principle of moving averages and establishes efficiency measures by treating each DMU in different periods as a separate unit. In practice, we have to select the window's length and we choose 3 years to have enough entities in each windows (18 in our case). Let us define $\mathbf{x}^w \in \mathbb{R}^P_+$ and $\mathbf{y}^w \in \mathbb{R}^Q_+$ as the input-output of the entities in window w.

Given our nonparametric reconstruction of the electricity generation process and the window approach, we end with the following estimator for the minimal losses for a particular DMU operating at $(\mathbf{x}_t, \mathbf{y}_t)$:

$$l^w(\mathbf{x}_t, \mathbf{y}_t) = min_{\lambda^w_{j\tau}, j\in\{1,\dots,N\}, \tau\in w} \left(\begin{array}{c} \sum_{\tau\in w}\sum_{j=1}^{J} \lambda^w_{j\tau} l^w_{j\tau} \mid \mathbf{y}_t \leq \sum_{\tau\in w}\sum_{j=1}^{J} \lambda^w_{j\tau}\mathbf{y}^w_{j\tau}, \\ \mathbf{x}_t \geq \sum_{\tau\in w}\sum_{j=1}^{J} \lambda^w_{j\tau}\mathbf{x}^w_{j\tau}, \\ \sum_{\tau\in w}\sum_{j=1}^{J} \lambda^w_{j\tau} = 1, \\ \lambda^w_{j\tau} \geq 0 \ \forall j, \tau. \end{array} \right). \tag{1}$$

In words, $l^w(\mathbf{x}, \mathbf{y})$ gives us the minimal electricity losses that a particular entity operating at $(\mathbf{x}_t, \mathbf{y}_t)$ can be reached at time t given the inputs-outputs of the other entities and the technology. We emphasize that the estimator fulfills the imposed axioms. Firstly, **A1** and **A2** are translated by the output and input inequalities. Next, **A3** implies that linear combinations of outputs and inputs are included. This is done, in practice, by including weight variables $\lambda_{j\tau}$ for every DMU j and time τ. These weights are directly useful to consider variable returns-to-scale (**A4**). It suffices to impose that these weights sum to unity. Finally, **A5** is captured by the window-specific sums.

Finally, all observations in window w are included when evaluating the minimal losses at time t. This implies that our estimator is window-dependent. Putting this differently, we may have several estimators for the minimal losses at time t if time t is present in several windows. This is the case for all periods except the beginning or ending period. As our main interest is the minimal losses for each time period and entity, we have to aggregate the window-dependent estimators. A simple way to do that is to take the arithmetic average as follows:

$$l(\mathbf{x}_t, \mathbf{y}_t) = \frac{1}{\#w} . \sum_{t \in w} l^w(\mathbf{x}_t, \mathbf{y}_t). \tag{2}$$

$l(\mathbf{x}_t, \mathbf{y}_t)$, contrary to $l^w(\mathbf{x}_t, \mathbf{y}_t)$ is window-independent and is directly useful to conduct the rest of our analysis.[3]

3.2 Measuring quality performance gaps

It is difficult to interpret the estimated minimal losses without relating them to the actual losses. A simple way to do that is to take the ratio or the difference between both. We define the quality performance gap ratio and difference for a specific entity at time t as follows:

$$QPGR_t(l_t, \mathbf{x}_t, \mathbf{y}_t) = \frac{l_t(\mathbf{x}, \mathbf{y})}{l_t}. \tag{3}$$

$$QPGD_t(l_t, \mathbf{x}_t, \mathbf{y}_t) = l_t - l_t(\mathbf{x}, \mathbf{y}). \tag{4}$$

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[3] It is also possible to take the average in each window. This is not interesting for us.

$QPGR_t(l_t, \mathbf{x}_t, \mathbf{y}_t)$ is smaller than unity by construction as the minimal losses cannot exceed the actual one. When this ratio is strictly smaller than one it indicates that it is, in principle, possible to improve the service quality without modifying the inputs, the outputs, and the technology. A value of one indicates that the service quality is at its maximum given the inputs, outputs, and the technology. Reaching a higher service quality would require a change in inputs, outputs, or technology. $QPGD_t(l_t, \mathbf{x}_t, \mathbf{y}_t)$ gives us the amount of potential electricity losses. A value of zero indicates that the maximal service quality has been reached. Finally, we once more emphasize that these two indicators are nonparametric estimators of the unknown counterparts.

4 Data and Results

In this section, we apply our methodology to East African Countries to estimate the minimal losses associated with their production process.

4.1 Data sources

We collect data from six countries: Burundi, Ethiopia, Kenya, Rwanda, Uganda and Tanzania, for a period of 10 years, from 2008 to 2017. Data were collected either physically by visiting the different electricity utilities and their regulators and online through their websites and specific requests.

Table 1: Organization of the electricity sector

Country	Generation	Transmission	Distribution
Burundi	REGIDESO	REGIDESO	REGIDESO
Ethiopia	EEP	EEP	EEU
Kenya	KenGen + REP + IPPs	KPLC, KETRACO	KPLC
Rwanda	REG + IPPs	REG	REG
Tanzania	TANESCO + IPPs	TANESCO	TANESCO
Uganda	IPPs	UETCL	9 Private firms

East African countries have different organisations for the energy sector (Table 1). Uganda, Kenya and Ethiopia have a vertically separated sectors, while the other countries have companies that are still vertically integrated. We use the data provided by the vertically integrated operators or the new created companies, completed by secondary sources, including the regulator. We collected data from Régie de Production et de Distribution d'Eau et d'Electricité (REGIDESO) for Burundi, Rwanda Energy Group (REG) for Rwanda, Tanzania Electricity Supply Company (TANESCO) for Tanzania, Ethiopian Energy Power (EEP) and Ethiopian Energy Utility (EEU) for Ethiopia. For Uganda, the data were provided by the regulator, Electricity Regulatory Authority (ERA). For Kenya, we used the annual reports of Kenya Power Lighting Company Limited (KPLC) from 2008 to 2018. KPLC's annual reports include all aggregated data on electricity generation, transmission and distribution. They include data from other entities, such as Kenya Generating Company Limited (KenGen), IPPs, Regional Electrification Program (REP), and its own data.[4]

4.2 Descriptive statistics

We present in this subsection the main summary statistics. The complete database we construct for this study can be downloaded in the appendix.

4.2.1 Electricity generation process

In Table 2, we present the descriptive statistics for our two inputs (the transmission length[5] and the purchased electricity) and two outputs (the number of consumers and the energy delivered). For each country, we present the average value over the sample period and the change for the considered period.

All countries serve more and more customers over time and the growth is substantial, especially in Rwanda and Kenya that both have a yearly growth rate above 20%. Electricity delivered is also increasing but at a lower rate (except in Ethiopia), implying a lower average consumption per customer. The average annual growth rate for the transmission line is equal to 7.6% with a large disparity between countries with some countries (Burundi) that did not invest at all while others, like Ethiopia, managing to more than double their transmission capacity.

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[4] In Kenya, the financial year starts in July and we have considered that it corresponds to a calendar year to make data comparable.

[5] East African countries have different capacities for their transmission lines and they have the target to increase the minimum capacity to 110 kV. For this study, we select transmission lines with a capacity of 60 kV and above.

Table 2: Descriptive statistics − inputs and outputs

Country	Statistics	Transmission length HV (km)	Electricity Purchased (GWh)	Energy delivered (GWh)	Customers (numbers)
Burundi	average	322.00	247.69	191.11	79 783
	change	0.00 %	4.37 %	3.82 %	11.08 %
Ethiopia	average	9587.21	6789.09	5048.20	1 757 104
	change	8.66 %	14.13 %	13.75 %	6.10 %
Kenya	average	4743.08	8076.73	6644.50	2 736 670
	change	4.01 %	5.55 %	5.13 %	21.26 %
Rwanda	average	744.20	484.86	383.42	382 516
	change	4.85 %	12.60 %	12.12 %	24.15 %
Tanzania	average	5059.21	5626.09	4596.52	1 262 224
	change	2.77 %	5.96 %	5.73 %	13.01 %
Uganda	average	1439.97	2694.19	2031.63	632 657
	change	4.58 %	6.50 %	9.31 %	16.16 %

4.2.2 Actual electricity losses

We compute the electricity losses as the difference between purchased and delivered electricity. Descriptive statistics are provided in Table 3. In average over the period, 21% of the purchased electricity is lost. This represents a loss of power of 18 895 GWh per year. Uganda managed to decrease losses from 34% in 2008 to 17% in 2017 by increasing the energy delivered while maintaining the losses in GWh almost constant. All other countries experience higher losses in 2017 compared to 2008. Burundi had the highest losses in percentage at the end of the period with 29% of the purchased electricity being lost. It should also be noticed that electricity losses have could vary considerably from one year to another.

4.3 Quality performance gaps

Using our estimated minimal electricity losses, we are able to compute our indicators of the quality performance gaps. Given our limited number of data, our results should be interpreted with caution and we concentrate mainly on the average value over the period. Table 4 reports the average value of per country for $QPGR$ and $QPGD$.

The average value of 0.92 for $QPGR$ means that countries can reduce electricity losses by an average of 8% while keeping their inputs, outputs, and technologies

Table 3: Descriptive statistics − electricity losses

Country	Statistics	Electricity losses (GWh)	Electricity losses (%)
Burundi	Average Min-Max Change	56.58 36.43 - 79.13 12.51%	22.68% 15%-29%
Ethiopia	Average Min-Max Change	1740.89 673.27 - 2758.33 27.90%	24.88% 19%-37%
Kenya	Average Min-Max Change	1432.23 1056.30 - 1933.00 7.88%	17.56% 16%-20%
Rwanda	Average Min-Max Change	101.44 53.76 - 149.21 7.88%	20.68% 19%-24%
Tanzania	Average Min-Max Change	1029.58 462.09 - 1479.63 15.05%	18.62% 7%-23%
Uganda	Average Min-Max Change	662.56 587.95 - 752.09 -0.81%	25.56% 17%-35%

constant. This performance gap represents an average saving of 78.82 GWh per year and per country. The potential reductions are limited in Rwanda and Kenya, they are more important in Tanzania and Uganda.

Table 4: Quality performances gaps

Country	*QPGR* (%)	*QPGD* (GWh)	Electricity price ($/MWh)	Potential savings ($)
Burundi	0.95	2.42	117	283 140
Ethiopia	0.92	184.48	47	6 956 000
Kenya	0.98	34.09	231	7 874 790
Rwanda	0.98	1.85	195	360 750
Tanzania	0.85	159.65	166	26 501 900
Uganda	0.86	90.02	193	17 373 860
Average	0.92	78.82		

Next, we use the electricity price data from the World Bank[6] to transform the performance gap, expressed in GWh, into potential savings in dollars. More precisely, we estimate the average savings per country by multiplying the average value of *QPGD* by the 2014 electricity price. The estimated annual savings per country are given the last column of Table 4. Overall, this represents a potential net saving of $60 millions per year in East African. We point out that Tanzania and Uganda have the largest potential saving.

5 Conclusion and policy recommendations

East African countries have a high level of electricity losses and they have as a target a reduction of losses to 15% or below. For that, they develop energy policies to improve infrastructures and billing, i.e. they have investment plans to reduce losses. Reducing electricity losses will have a positive impact not only on the utility, with improved revenue collection and increased profits, but also on customers and countries. For customers, minimizing electricity losses helps to increase the QoS and reduce electricity tariffs. For governments, it allows subsidies originally directed to the electricity sector to be allocated to other priority sectors. Given the importance of energy in improving quality of life, poverty reduction and economic growth, minimizing losses will generate new resources to increase installed capacity, and furthermore access to

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[6] Retrieved from the GovData360 project available at `https://govdata360.worldbank.org`.

electricity. In this way, the different countries will be able to achieve the Sustainable Development Goals.

In this study, we analyze the quality performance gap that is estimated through the minimization of electricity losses. We estimate a non-parametric performance analysis model that minimizes electricity losses given inputs, outputs and technologies. That is, we estimate the potential losses reduction that do not require investments but rather adopting the best practice in the electricity generation process.

The model we develop is fairly simple and does not require data on prices but only data on inputs and outputs. For the inputs, we use a transmission input, the network length and generation input, the energy purchased. For the outputs, we use the energy delivered and the number of clients. Electricity losses are neither inputs nor outputs but a measure of the quality performance gap. They have to be minimized given inputs and outputs.

We provide for each country an estimation of the performance gap. Less performing countries have a 15% performance gap, best performing countries a 2% one. This represents the potential for loss reduction if best practices were adopted. Expressed in dollars, the potential savings for East African countries are important and would result in improved financial health of the utilities, better service quality and reduced costs.

Despite the use of a window analysis, one main limitation of the analysis is the limited number of comparable units. We use data for 6 East African countries covering 10 years. Additional data could be used to improve the results and provide better proxy for the performance gap. This kind of study can also be applied to other sectors facing the same challenges, like the water sector.

CRediT authorship contribution statement RN: Investigation, Data curation BW: Methodology, AG: Funding acquisition, All: Conceptualization, Validation, Formal analysis, Writing - original draft, Writing - review and editing.

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A Electricity losses in the performance literature

Table 5: Electricity losses in performance analysis

Authors	**Outputs**	**Inputs**
Bagdadioglu et al. (1996)	Number of customers, electricity supplied, peak demand, service area	Labor, transformer capacity, network size, general expenses, **electricity losses**
Bongo et al. (2018)	Electricity delivered, number of customers, **electricity losses**	Electricity urchased, network length
Edvardsen et al. (2003)	Electricity delivered, number of customers, network length	**Electricity losses**, OPEX, capital
Forsund & Kittelsen(1998)	Customer density, number of customers, electricity supplied	Labor, **electricity losses**, capital and materials
Jain & Thakur (2010)	Electricity supplied	Installed capacity, auxiliary consumption, **electricity losses**
Jamasb & Pollitt(2003)	Electricity delivered, number of customers, network length	TOTEX, OPEX, network length, **electricity losses**
Meenakumari & Kamaraj (2008)	Number of customers, electricity supplied	Installed capacity, network length, **electricity losses**
Pacudan & Hamdan (2019)	Number of customers, service area, electricity sales	labor, network length, **electricity losses**
Pérez-Reyes &Tovar (2009)	Annual sales, number of customers	labor, **elecricity losses**, network length, number of substations, capital
Petridis et al. (2019)	Energy supply, number of customers, number of city served, interruptions, **energy losses**	Labor, elecricity delivered, number of transformers, network length, transformer capacity
Ramos-Real et al.(2009)	Electricity delivered, number of customers	Labor, **electricity losses**, service area
Tovar et al. (2011)	Electricity delivered, number of customers	Number of employees, network length, **electricity losses**

Vaninsky (2006)	Utilization of net capacity	OPEX, share of revenue, **electricity losses**
Vaninsky(2008)	Fuel utilization	OPEX, **electricity losses**
Von Hirschhausen et al.(2006)	Electricity delivered, number of customers, inverse density index	Labor, network length, peak load, **electricity losses**
Xie et al. (2018)	Number of customers, electricity delivered	Network length above 35 kV, transformer capacity above 35 kV, labor, **electricity losses**
Yunos & Hawdon(1997)	Electricity supplied	Installed capacity, labor, **electricity losses**, public generation capacity factor

B Data

The dataset used for this paper can be downloaded at `link_here`