HEC LIÈGE
Management School - Liège Université

UNIVERSITE DU BURUNDI
ECOLE DOCTORALE
P.O. Box : 2700
BUJUMBURA-BURUNDI

Quality of service and access to electricity in Burundi and East Africa, a comparison of sector performance

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René Nsabimana
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Jury :

Axel GAUTIER (Supervisor), HEC Liège, Management School of the University of Liège
Charles KABWIGIRI (Supervisor), the University of Burundi
Didier VAN CAILLIE (President), HEC Liège, Management School of the University of Liège
Augustin Mapapa MBANGALA, Institut Supérieur de Commerce, Kinshasa
Patrick PLANE, CNRS-CERDI, Université Clermont Auvergne
Salomon NSABIMANA, the University of Burundi
Sergio PERELMAN, HEC Liège, Management School of the University of Liège

To Marie Rose, to Rosyrène, to Kenny Marcel

Abstract

Access to reliable, sustainable, modern and affordable energy services for all is one of the goals of the United Nations 2030 Agenda on Sustainable Development (SDG7). Despite the potential for renewable energy resources, more than 600 million people in Sub-Saharan Africa (SSA) remain without energy services. Its demand constitutes only 4% of global demand. Despite the merits of a vertically integrated monopoly, it has been criticized for being inefficient. Thus, a wave of reforms emerged in the 1990s, aiming, among other things, to vertically unbundle the different entities and introduce private sector participation. Burundi is one of the SSA countries for which access to electricity and quality of service are among the lowest in the world.

The thesis examines first the organization and performances of the electricity sector in Burundi. Through a descriptive analysis, it defines the legal and regulatory framework and analyzes performance in terms of access and quality of service. Lack of funding, excessive charges and governance problems at the national water and electricity utility are on the basis for poor performance and the barriers to private sector participation. To improve the quality of service by reducing one MWh of losses due to outages would require additional investments of US$ 223.7 per kVA of transformer installed capacity. Funding for these investments requires incentives for private sector participation, and joint projects within the framework of the East African Power Pool.

Secondly, since the extent to which power sector reforms were implemented varies from country to country, the identification of a required model for performance comparison is essential. Performance is compared using both a generation model and a transmission-distribution model for the case of six East African countries. On average, the performance gap for all countries is 19.6% and 23.5% for the generation and the transmission-distribution models respectively. On the other hand, the results show that countries that have restructured the power sector and attracted private investment tend to be the most technically efficient. Losses of electricity are a common and significant source of inefficiency in all countries. They have a negative impact on both users, utilities and the country. One of the goals of domestic energy policies is to mitigate them. The results show that, on average, it would be possible to reduce electricity losses by 8%, without changing the level of inputs and outputs, as well as the production technology. In this way, minimizing losses could generate enough resources to increase investments and improve the quality of service in the electricity sector.

Finally, this thesis relies on two databases compiled by the author that can be used for academic and managerial purposes. The first database is related to the electricity network in Burundi. It includes data on power outages related to load shedding and the losses they cause. It also includes data on transformers collected through a survey of the entire interconnected network in Burundi. The second database consists of aggregated power sector data from Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. It includes data on inputs and outputs collected through a survey conducted by the author in the various East African utilities.

Résumé

L’accès pour tous aux services d’énergie fiables, durables, modernes et abordable est l’un des objectifs concourant à l’Agenda 2030 des Nations Unies sur le Développement Durable (ODD7). Malgré les ressources potentielles en énergie renouvelables, plus de 600 millions de la population en Afrique Subsaharienne (ASS) reste privé des services d’énergie. Sa demande ne constitue que 4% de la demande mondiale. Malgré les vertus attribuées au monopole verticalement intégré, il a été critiqué d’inefficace. C'est ainsi qu'un courant de réformes est apparu dans les années 1990, avec entre autre objectif étant de séparer verticalement les différentes entités, et d'introduire la participation du secteur privé. Le Burundi fait partie des pays d’ASS l’accès à l’électricité et la qualité de service sont parmi les plus faibles au monde.

La présente thèse examine en premier lieu l’organisation et les performances du secteur d’électricité au Burundi. A travers une analyse descriptive, elle définit le cadre légal et réglementaire et analyse les performances en termes d’accès et de qualité de service. Le manque de financement, l’accroissement des charges et les problèmes de gouvernance de la compagnie nationale d’eau et d’électricité, sont à la base de faibles performance et des barrières à la participation du secteur privé. Pour améliorer la qualité de service, notamment en réduisant 1 MWh de pertes, les résultats montrent qu’il faudrait accroître les investissements à hauteur de 223,7$ par kVA en transformateur. Le financement de ces investissements ne pourrait être acquis qu'en incitant la participation du secteur privé et en privilégiant les projets conjoints dans le cadre du Pool d'Energie d'Afrique de l'Est.

Deuxièmement, l’application des réformes du secteur d’électricité variant d’un pays à un autre, l’identification d’un modèle requis de comparaison de performances s’avère indispensable. Les performances sont comparées en utilisant un modèle génération et un modèle transmission-distribution, pour le cas de six pays d’Afrique de l’Est. En moyenne, l’écart global de performance est de 19.6 et 23.5% respectivement pour les modèles génération et transmission-distribution. D'autre part, les résultats montrent que les pays qui ont restructuré le secteur d'électricité et attiré les investissements privés tendent à être les plus techniquement. Les pertes d'électricité constituent une source d'inefficacité dans tous les pays. Elles ont un impact négatif à la fois sur les utilisateurs, sur les compagnies d’électricité et sur le pays. L’un des objectifs des politiques nationales d’énergie consiste de les minimiser. Les résultats montrent qu'en moyenne, il serait possible de réduire les pertes d'électricité de 8%, sans modifier les niveau d'inputs et d'outputs, de même que la technologie de production. De cette façon, la réduction des pertes pourrait générer suffisamment de ressources pour augmenter les investissements et améliorer la qualité du service dans le secteur de l'électricité.

Enfin, la présente thèse repose sur deux bases de données constituées par l’auteur qui peuvent servir à des fins académiques et managériales. La première base de donnée est relative au réseau d’électricité au Burundi. Elle comprend les données sur les coupures d'électricités liées aux délestages et les pertes qu'elles entraînent. Elle comprend également les données collectées sur les transformateurs à travers une enquête sur tout le réseau interconnecté du Burundi. La deuxième base de données est constituée par des données agrégées du secteur d’électricité du Burundi, d’Ethiopie, du Kenya, du Rwanda, de la Tanzanie et de l’Ouganda. Elle comprend des données sur les inputs et outputs constituée à travers une enquête effectuée par l'auteur dans les différentes compagnies d’électricité d’Afrique de l’Est.

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Introduction

Access to reliable, sustainable, and modern energy services at an affordable cost is one of the goals contributing to the United Nations 2030 Agenda on Sustainable Development Goals (SDG 7). The goal promotes the use of renewable energy technologies. Despite the untapped potential of renewable energy sources, more than 600 million people in sub-Saharan Africa do not have access in the early 2020s to electricity and nearly 2.7 billon people worldwide (Menyeh, 2021). The world energy outlook estimates that demand for electricity grows two-third faster than total final consumption (IEA, 2018), especially due to the high rate of urbanization and the development of the industrial manufacturing sectors (Ali, 2021). Although electricity demand in Sub-Saharan Africa has increased by 50% since the 2000s, it accounts for 4% of world energy demand, and 13% of the world population (Ouedraogo, 2017). In this section, we present the background, objectives, methodology and content of the thesis.

The contextual framework

Access to electricity, a global challenge for developing countries

Electricity is defined as the conversion of electrical energy sources (Gouveia et al., 2015). It is produced from two main sources, namely the non-renewable and the renewable sources. Non-renewable sources include coal, nuclear, oil, among others. There are also renewable energies produced from hydro, wind, solar and biomass (Bongo et al., 2018). Access to electricity contributes to economic development given its economic multiplier effects. Indeed, electricity infrastructure is a long-term investment and an input for the system of production and services. It contributes to the structural transformation of the economy. The low level of electrification hinders the development of modern technologies and the provision of public services such as health, education, transport, communication, etc.

Introduction

Each electricity company's objective is to expand its output, i.e. the number of customers and the electricity consumed, but also to reduce electricity losses. These losses handicap the utility's activity and the general welfare. Electricity losses are considered as undesirable output. They can arise either as a result of faults in the transmission and distribution network, but also from theft. Electricity supply interruption is also one of the reasons for loss, and a cause of poor service quality. Like other goods and services, the electric energy must be delivered to end-users with the high quality of service (QoS).

At present, electricity generation is insufficient to meet the growing demand. The poor installed capacity, the outdate plants, transmission and distribution systems, the poor financial health of the electric utilities, have led many countries to resort to load shedding. Among the reasons for poor QoS, the most commonly cited are the governance structure, the system of subsidies redistribution, the political interference in public electricity services, the monopolistic characteristics of the sector, the absence of competition, as well as illegal connections (Blimpo & Cosgrove-Davies, 2019; Imam et al., 2019; Ullah et al., 2017).

Power outages have a significant impact on quality of life and economic activity. A world survey conducted by the World Bank on the perception of companies on the QoS shows that on average 77.2% of firms have experienced power cuts at a monthly frequency of 9, each lasting on average 5.7 hours. These interruptions resulted in losses of 8.5% for businesses which are forced to spend money to own or share generators. These electricity outages are generally concentrated in Sub-Saharan Africa compared to North Africa (0.8% in Egypt, 0.3% in Djibouti)[1].

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[1] See https://www.enterprisesurveys.org/en/data/exploretopics/infrastructure, visited on March 26, 2022.

African governments have not been able to raise sufficient funds to expand installed capacity and maintain the existing network. They have also been unable to secure their energy needs. So they resort to Official Development Assistance (ODA) and Development Finance Institutions (DFIs) to finance the energy deficit (Eberhard et al., 2017). However, these institutions are also unable to meet investments needs, which implies that other forms of financing, particularly from the private sector, are required (Gregory & Sovacool, 2019). The private sector can play an obvious role in Africa's electricity crisis. The OECD (2007) provides principals for private participation in infrastructure beyond the provision of capital: improving competitiveness and service delivery to consumers, mobilizing technological know-how and managerial skills in support of public interest. In the developed countries, private participation has boosted both access and infrastructure service efficiency. It is within this framework that multilateral financing institutions, particularly the World Bank, have been urging developing countries to reform their electricity sectors.

Pros and cons of vertically integrated monopolies

Network industries have been operated (and continue to be operated in some countries) as vertically integrated public monopolies. These industries are characterized primarily by two main activities, infrastructure and service procurement. In the electricity sector, infrastructure consists of the transmission and distribution network. It is an interconnected network comprising high and medium voltage lines, distribution substations, transformers, poles, etc. On the other hand, the service provision is composed of two main activities, electricity generation and sales. Reasons for the vertically integrated monopoly include reduced transaction costs related to buying and selling with other firms, reduced purchasing costs, correction of market imperfections by internalizing externalities, avoidance of certain regulatory constraints, and increased market power for the monopoly, to name a few. These advantages can be summarized from an economic and technical perspective.

From an economic viewpoint, the advantages of a vertically integrated monopoly include economies of scale. The monopoly is able to reduce its average costs as the marginal output is realized at constant marginal costs. Since infrastructures represent a fixed cost, their intensive use amortizes it over a large number of units of output. Thus, as the service provided increases, the average cost of the network decreases. The technical point of view of a vertically integrated monopoly is the need to reduce the transaction costs of coordinating the interdependent activities of production, transmission, distribution and retail activities. This coordination includes planning for a reliable and inexpensive generation and transmission system, and reducing trading costs. With vertical integration, one company is not dependent to another, avoiding high supply costs for example. By imposing the public monopoly on the electricity sector, the governments ‘objective was to develop this sector, to make it accessible to all at a lower cost, and to ensure equity in access (Fetz & Filippini, 2010; Streel et al., 2011).

However, the vertical public monopoly has been generally criticized as technically inefficient, the industry of electricity in developing countries in particular. Two main reasons justify this inefficiency : a high level of technical and non-technical losses including electricity theft, and inability to connect rural areas and to increase access to electricity (Dertinger & Hirth, 2020). The lack of adequate electricity provision has multifaceted problems to both society and utilities. For the society, the poor QoS and access to electricity implies poor access to basic wellbeing such as health, education, communication, housing, etc. It also impacts income-generating opportunities. On the other sides, the utilities suffer from cost recovery which prevents them getting sufficient resources for investments in new generation capacity, upgrade and expand new infrastructure. As a result, utilities are obliged to increase tariffs and connection charges which accentuate poor access to electricity. This is why, since the 1990s, a movement towards the liberalization of the electricity sector was born.

Electricity sector reform: unbundling, competition, and regulation

One of the reforms consists in unbundling the state-owned vertically electric utility into autonomous units. In this case, infrastructure activities (transmission and distribution) are dissociated from service provision (generation and sales). Three types of unbundling are described in the literature: administrative, legal, and ownership unbundling (Baarsma et al., 2007; Gugler et al., 2017; Streel et al., 2011; Sugimoto, 2021). Baarsma et al. (2007) provides the pros and cons of unbundling. Potential benefits of unbundling include increased competition and efficiency, market simplification, privatization, and supply security. The introduction of competition in the electricity market is therefore another electricity sector reform, which requires the entry of new firms into the market through a general or individual licensing procedure. New entrants have two options, using the existing infrastructure (competition through services) or building their own networks (competition through infrastructures).

Once the vertically integrated monopoly has been unbundled and competitive conditions are in place, and privatization introduced, another required reform is the establishment of a regulatory system. Economic regulation has to protect the public interests reflected in terms of service access, network access and tariffs. Also, the regulator guarantees equal access to infrastructure and customers. Competition in service and infrastructure regulation are therefore linked. In the absence of infrastructures regulation, the owners could capture monopoly profits. Thus the regulator must encourage new entrants to make intensive use of existing infrastructure while planning to build their own. These new entrants, especially in the competitive segments, take the form of private investments or independent power producers.

Different studies investigated the effect of private participation on the efficiency of electricity sector in developing countries. However, there was no consensus about the direction of this relationship. Bagdadioglu et al. (1996) analyzed the effect of ownership on efficiency of 70 distribution utilities in Turkish, while Çelen (2013) evaluated efficiency and productivity of 21 distribution companies in the same country for the period 2002-2009. See & Coelli (2012) analyzed the impact of private ownership on the technical efficiency for in the Malaysian thermal power plants. Findings show that private sector participation positively affects the efficiency of the electricity sector. For the case of Africa, Jamasb et al. (2017) and Bacon (2018) review and detail the scholars that estimated the effect of electricity sector reform on efficiency and productivity. Most of the studies reviewed show a positive impact, such as the private participation. Barabutu & Lee (2018) investigated the effect of ownership separation on the efficiency of the electricity sector in Southern Africa Power Pool (SAPP). They find that the public monopoly negatively affects efficiency, while the private participation would improve performance if a competitive environment in the distribution sector is established. Estache et al. (2008) deplore the non-available and affordable service associated with the public utilities using the case of SAPP. More specifically, the reforms should translate into gains for users in the form of price reductions. However, they do not find any clear correlation between the adoption of reforms and private sector.

Electricity sector reform in Burundi, inadequate private sector participation

Like other Sub-Saharan African countries, Burundi has initiated reforms in the electricity sector. These reforms were initiated by the World Bank in the 1990s through the Structural Adjustment Programs. Since the 1960s, REGIDESO has been a vertically and horizontally integrated state-owned company, under the responsibility of the Ministry of Energy. The horizontal structure results from the public services that have been assigned to REGIDESO, drinking water, electricity supply and, at some times, wastewater sewage. These services could be delivered in the main and secondary urban centers. REGIDESO is involved in all the network activities: production, transmission, distribution and retailing. In 1997, REGIDESO was granted the statute of an industrial and commercial company with autonomous management. It was endowed with a capital stock and well-defined number of shares. It was also assigned to adopt accounting standards.

The reform of the electricity sector in Burundi began with the 2000 Act liberalizing and regulating the provision of drinking water and electrical energy. The Act opens the two utilities to Burundian public and private entities. Although the Act has been passed, no implementing texts have been issued. The Act did not also provide clear guidelines on private participation. A specific law creating a legal framework suitable for investment in the electric power sector and its liberalization has been enacted in 2015. To implement this law, another framework for public-private partnership was also enacted in 2015. However, despite the enactment of the law, REGIDESO still maintains a monopoly on both utilities, and the legislation remained only on paper. The electricity sector, as long as drinking water utilities failed to attract private investments.

The barriers to private sector participation in energy infrastructure are common to many developing countries. The main barriers commonly identified are related to financial factors, regulatory gaps, and capacity building (Muzenda, 2009). At the financial level, energy infrastructure projects require high costs and a long period of time, from the tender to the infrastructure operation: project preparation, environmental investigations, bidding, building, technical assistance, commissioning, etc. The extension of the construction period also entails additional costs. Thus, private investors need to compare the current costs of projects with the expected rate of return, while estimating the risks associated to the projects (Gregory & Sovacool, 2019). Thus, the energy sector may not attract private investors due to low rate of returns and a high level of risk (Pueyo, 2018).

Another barrier is related to financing conditions. The domestic financial market consists of the banking systems, whose interest rates are sufficiently high. Banking institutions favor short-term loans, whereas investments in electric power are long-term projects. In addition, few firms in Africa rarely have access to the bond markets, due to the lack of investment grade ranking. It should also be noted that very few countries in Africa have financial ratings, which should be a guarantee in case of external borrowing. Therefore, they are unable to raise sufficient debt at affordable costs (Eberhard et al., 2016).

Regulatory constraints also hinder private investment in the electricity sector: tariff setting, procurement and recruitment processes, independence of the regulatory authority, etc. In most cases, electricity tariffs are set below the cost of production[2]. The independence of the regulatory authority in some countries is not guaranteed, as the appointment of its members is made by presidential decree or by the Minister in charge of Energy, or proposed by the leading political party. There is thus a risk of political interference in the management of private companies, including the corruption of public officials (Imam et al., 2019; Valasai et al., 2017).

Constraints to private investment may be related to capacity building. In some countries, government officials lack sufficient skills, particularly in negotiating public-private partnerships (PPP). This is the case in particular for the management of international tenders, the negotiation and execution of contracts. Also, the decision making process goes through several instances and slows down the

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[2] In Burundi, for example, it was estimated that the production cost of the thermal power plant was US$0.22 while the average tariff charged to customers by REGIDESO is US$0.20.

execution of contracts. On the other hand, the electricity service is considered by some members of the government as a public good. A large portion of unpaid electricity bills are usually attributable to ministries or other public sector organizations, as is the case in Burundi.

Quality of service dimensions, the case of the electricity sector

In the electricity distribution, the QoS has multiple dimensions. Fumagalli et al. (2007) identifies three dimensions of QoS, the commercial quality, continuity of supply and voltage quality. The commercial quality is estimated before the supply contract, like the time duration before a connection, and after the contract. This later includes meter readings, billing, complaints, etc. While commercial quality, expressed in terms of customer satisfaction, is considered as a non-technical quality, continuity of supply and the voltage quality are considered as highly specific technical characteristics (Cambini, Fumagalli, & Rondi, 2016). The voltage quality is defined as the deviation in period of time or in amplitude, such as increased or decreased voltage. Each deviation reduces the QoS (Arcos-Vargas et al., 2017). Some interruptions are planned whereas others are unplanned. Planned interruptions are due to construction, preventative, routine maintenance and repair. Normally, the consumers must have been given prior information in order to reduce any inconvenience. However, unplanned interruptions refer to forced interruptions due to incidents.

Of these three quality dimensions, the focus of most analyses in the literature is on system reliability, which is defined as the ability of the system to meet customer demand without interruption. Depriving households and businesses of access to electricity for several hours a day is a poor indicator of grid reliability (M. P. Blimpo & Cosgrove-Davies, 2019). Poor grid reliability affects both the electric industries and customers (Saastamoinen & Kuosmanen, 2016; Sultana et al., 2016). For the customer, unreliability of supply results in financial loss, reduced utility, and discontinuance of business. At the electric industry level, interruption of supply increases the energy not supplied, which corresponds to a loss of revenue. It also involves increased operating and maintenance costs to restore service.

The most commonly used indicators for estimating system-level reliability are system interruption frequency index (SAIFI), system interruption duration index (SAIDI), and customer interruption duration index (CAIDI). SAIFI is related to the probability that a customer will experience an interruption. SAIDI measures the average length of time a customer is interrupted, while the CAIDI estimates the average time required to restore service for the average customer per interruption (Ajodhia & Hakvoort, 2005). Other indicators commonly used are average service availability index (ASAI), energy not supplied (ENS)(Yuan et al., 2021), customer minutes lost (CML)(Küfeoglu et al., 2018), momentary average interruption frequency index (MAIFI)(Cambini et al., 2016), etc.

On top of power outages, the transmission and distribution (T&D) of electricity generate power losses, which can be attributed to technical and non-technical factors. Technical losses are the losses that occur within the T&D network due to the cables, overhead lines, transformers and other substation equipment that are used to transfer electricity. Non-technical losses correspond to the electricity consumed but not paid by the consumers, including electricity theft. Electricity losses can be measured in two ways. The first way is to determine the electricity lost due to outages, calculated as the difference between the energy potentially distributed in the case of no power outages and the electricity effectively delivered. The second measure results from the difference between purchased and delivered electricity. It can also be defined as the proportion of purchased electricity that does not reach the consumer. Electricity losses are measured either in gigawatt hours (GWh) and other related measures or as a percentage.

QoS and access to electricity are the foundation of public policy. They are the basis for other policies such as industrialization, transport, education, health, etc. All governments are seeking to mobilize resources to finance investments to increase access to electricity and QoS. To improve the QoS, some solutions are proposed, such as building of new dams, upgrading the electricity network, expanding inspections, detection equipment for electricity fraudsters, increasing the use of prepaid meters, etc. These solutions require modifying the inputs, the outputs or the technology of the electricity generation process.

Objectives of the thesis

Performance can be defined in several ways, and at different levels. It enables to analyze how to achieve an output at the lowest cost. The performance indicator generally adopted is productivity, which could be limited to efficiency or to efficiency and effectiveness. These terms are related to each other. Productivity is generally measured by the ratio of output to inputs. Applied to production possibilities, productivity measures how to increase output at a given level of input. Defined differently, it seeks to determine how to produce the same set of outputs with less input. In this case, productivity is understood as technical efficiency. On the other hand, productivity is equivalent to efficiency and effectiveness. Not only does it seek to determine how to produce an output for a given level of inputs (efficiency), but it also seeks to compare the output with the targets (effectiveness).

The performance comparison can be analyzed at several levels, such as between large groups by determining those that are more productive. One can compare the performance of a company according to well-defined standards and with organizations carrying out similar activities. Within the same organization, one can determine the productivity of each production factor, capital and labor for example. Fried et al. (2008) define the efficiency of a producer by comparing observed values with optimal input and output values. In this case, efficiency is measured by comparing the observed output with the maximum potential output, or the observed input with the minimum potential input. This is how the notion of efficiency, particularly technical efficiency, is analyzed between the observed values and the optimal values. In this respect, we can speak of cost efficiency, revenue efficiency, profit efficiency, depending on the objective to be reached by each operator.

Power outages decrease the performance of a company. At the utility level, they reduce the electricity delivered. In addition, in the event of widespread power outages, customers turn to other sources of energy that are sometimes even more expensive. Power outages also lead to increased operational costs, which are considered as imperfect substitutes for maintenance and capital costs (Coelli et al., 2013). They include labor costs to detect and repair faults, but also the maintenance costs of the equipment.

The aim of this thesis is to assess the electricity sector performance in Burundi, and to draw comparisons within a regional framework, East Africa in particular.

The specific objectives are as follows:

- To describe the organization and performance of Burundi's electricity sector
- To analyze the impact of poor quality of service on the performance of the electricity sector in Burundi
- Compare the performance of the electricity sector in East Africa with respect to quality of service and access to electricity
- To estimate the performance gap and minimum losses of the power sector in East Africa.

Methodology

Production frontier methods are used to determine the frontier, technical efficiency scores and changes in total factor productivity. Entities located on the frontier are labeled as technically efficient, and are best practices against which inefficient ones compare themselves to improve their performance. The production frontier can be estimated using both parametric and non-parametric models. Parametric methods specify a functional form for the production frontier and estimate model parameters and significance tests through econometric techniques (Coelli & Perelman, 1999). Two parametric methods are commonly used, stochastic frontier analysis (SFA) and the deterministic parametric linear programming (PLP) approach.

The SFA approach developed by Aigner et al.(1977) estimates production or cost frontier and generates from the residuals two error terms, a stochastic error term and an inefficient error term . The stochastic error term is due to unexpected events such as climate, lucky, war, etc. One of the limitations of the SFA approach is that it does not allow imposing regularity conditions like monotonicity and curvature constraints required for the production frontier. The PLP approach thus takes into account the monotonicity restrictions. However, it is deterministic, any deviation from the production frontier being linked only to technical inefficiency to correct bias due to shocks.

Parametric approaches not only determine the technical efficiency of each decision-making unit, but also allows to identify "shadow price", i.e. the implicit cost of improving service quality for example. In the electricity sector, the shadow price represents the additional cost in equipment or personnel to reduce unwanted inputs by one unit. Such undesirable units are, for example, electricity losses, interruption duration and frequency, penalties for non-compliance with quality standards, etc.

On the other hand, the estimation of the frontiers can be performed based on a non-parametric deterministic mathematical programming approach, Data Envelopment Analysis (DEA). This approach enables to construct an envelopment frontier in such a way that the different observed values appear on or below the production frontier. First proposed by Farrell (1957), DEA method was implemented by Charnes et al.(1978) who proposed an input-oriented model assuming constant returns to scale. Similarly, Banker et al. (1984) proposed a DEA model for situations with variable returns to scale, assuming that all the entities being compared do not necessarily operate at the optimal scale. Measuring technical efficiency in an input-oriented way raises the question of how to proportionally reduce the quantities of input given the quantities of output. The input-oriented DEA is better adopted as decision-making units (DMU) are subject to incentive regulation such as cost reduction regulation, or price-cap regulation(Cambini et al., 2014; Cambini et al., 2016; Growitsch et al., 2009; Jamasb & Pollitt, 2001; Yu et al., 2007). On the other hand, the output-oriented measure shows how outputs can expand proportionally without modifying input level (Coelli, 1996). Nevertheless, the selection of an input or output orientation model depends on the manager's objective and his ability to control the level of output or inputs.

One of the difficulties encountered in comparing performance is the existence of a limited number of DMUs per time period in the sample. However, it is possible to increase the number of DMUs by treating each DMU at each period as a different unit. Charnes & Cooper (1985) proposed a DEA window method which works on the basis of moving averages. Such DEA window carries the implicit assumption that no technical changes occur during the period analyzed in each window (Wang et al., 2013). DEA window analysis implicitly assumes that there are no technical changes during the period under analysis within each window.

QoS indicator in the electricity sector is of paramount importance in benchmarking studies. QoS indicators are used as bad inputs and perfect substitute of capital and/or operating expenditures to restore the service. Amado et al. (2013) use the DEA model and estimate technical efficiency and total factor productivity change (TFPch). The selected QoS indicators are energy lost due to outages (in KVA), the number of transformers affected by outages, SAIFI and SAIDI. Arcos-Vargas et al. (2017) use the DEA method to compare the performance of 102 small electricity distribution units in Spain, using SAIDI as a QoS variable. Cambini et al. (2014) on the other hand, use the output-based incentives for meeting QoS standards, such as rewards and penalties, as well as SAIDI in the case of the Italian electricity sector. They estimate technical efficiency and TFPch. Giannakis et al. (2005) use the DEA method and two QoS indicators (frequency and duration of interruptions) to estimate the technical efficiency and TFPch of utilities in the United Kingdom. Growitsch et al. (2009) use the DEA method to compare the performance of distribution companies in Europe, using the SAIDI as a quality indicator. Coelli et al. (2013) use parametric and nonparametric methods to compare the technical efficiency and determine the shadow price of quality of 92 distribution companies in France, using SAIFI. These studies focus on a single segment of the electricity sector in Europe continent, that is the distribution sector.

In the African context, very few studies on production frontiers focus on the electricity sector. The available studies are that of Barabutu & Lee (2018), Estache et al. (2008) and Real & Tovar (2020) for the case of utilities belonging to the SAPP, Njeru et al. (2020) for Kenya thermal power plants, and Plane (1999) for the electricity sector in Côte d'Ivoire. These studies investigate the technical efficiency of the different companies using either DEA and/or SFA approach. None of these studies consider service quality as a performance indicator. Estache et al.(2008) and Real & Tovar (2020) deplore the lack of information regarding the electricity sector in African countries, calling on regulators to oblige all regulated utilities to provide data. Different findings show that the reforms have not increased the technical efficiency of the power sector. Unfortunately, none of the studies included Burundi's electricity sector in the performance study. Furthermore, despite integration into the East African Community through infrastructure, no frontier production study was undertaken to compared the electricity sector performance across countries, taking into account the QoS.

Contributions

This thesis contributes both theoretically and empirically using original dataset collected in Burundian districts and East Africa, and address the shortcoming in the literature by comparing the performance of the electricity sector in these countries. Using the PLP approach, we estimate the shadow price of QoS by district. We contribute by using a QoS proxy, the electricity lost due to outages, defined through a dataset on electricity interruptions collected over the period 2014 to 2017.

The second contribution is the performance comparison in a complex electricity sector in East Africa. Focusing benchmarking on a single segment of the sector appears problematic, due to differences regarding the reforms undertaken in each country. We adopted a comparative approach based on two models, a generation model and a transmission-distribution model.

The third contribution is a performance comparison adapted for a limited number of DMUs. We therefore use a window analysis, each DMU being compared to itself over a certain period. On the other hand, electricity losses are considered neither as QoS input or output. Thus, we constitute a new performance comparison model, that is loss minimization, given inputs, outputs and technology.

Another contribution relates to database development of the electricity sector in Burundi and East Africa. Comparing the performance of entities that use the same inputs to produce the same outputs requires data on these variables. The input variables generally used are labor and capital. They can be expressed in numbers or quantities such as the number of workers, installed capacity, number of processors and their installed capacity, etc. They can also be expressed in operational or capital expenditures. See for example Coelli et al. (2013); Growitsch et al. (2009); and Neuberg (1977). Finding the right measurement units for inputs and outputs as well as comparable firms is not always easy.

Through this thesis, we contribute to the literature by setting up two datasets that can serve both academic and managerial purposes. Any benchmarking analysis requires data on both inputs, outputs, and other controllable and non-controllable variables. These data can be obtained from annual reports, sectoral reports, or major international statistics such as the World Development Indicators (WDI). For the electricity sector, the WDI provides indicators such as access to electricity, and consumption per capita form some countries. Availability of data provides guidance to operators in making investment decisions. We thus constituted a unique database, through the visit in the different electricity companies in the different countries. One of the major difficulties is that even within each country, the statistical services do not centralize all the information on the electricity sector. The same is true within each utility where each department has its own data. Also, some indicators are unavailable in some utilities due to the difficulty of constructing them. This is the case, for example, with system reliability indices such as SAIDI and SAIFI. We detail the process of data collection in Burundi districts, and in other East African countries in Appendix A.

Content

Chapter 1 discusses the organization and performance of the electricity sector in Burundi. Part of this chapter was published in MDPI[3]. The electricity sector in Burundi is under the management of a public company, REGIDESO. This company is a horizontally integrated monopoly, handling two public services, drinking water and electricity. It also has a vertically integrated monopoly on the two utilities, as it manages all activities from upstream to downstream. In this chapter, we address the question of why the electricity sector in Burundi does not attract private investment, even though the legal framework allows for it. Descriptive data show that Burundi relies on investments made in the 1980s that do not increase access to electricity. The poor state of the electricity network, the high level of demand compared to supply, under-consumption of electricity, and a block tariff system that does not take into account cost recovery are all factors that handicap the electricity sector in Burundi. The paper is based on the descriptive statistics. We discuss the barriers to the private sector participation as well as the poor performance of the electricity sector in Burundi.

In Chapter 2, we estimate the implicit cost of service quality in the Burundian electricity sector. This chapter was written jointly with Gautier Axel, Perelman Sergio and Nsabimana Salomon. We estimate a translog function using the case of eighteen districts located in five regions all controlled by REGIDESO. We constructed an indicator of poor QoS, the electricity lost due to outages. It was calculated using the average duration of power outages on the interconnected network in Burundi. The electricity losses is therefore the difference between real and potential delivered electricity[4]. Since the districts are not responsible for the

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[3] Nsabimana, R. (2020) Electricity sector organization and performance in Burundi. *Multidisciplinary Digital Publishing Institute Proceedings*, *58*(1), 26.

[4] We detail how we constructed the electricity lost due to outages in Appendix A.

inputs, i.e. the installed capacity of the transformers and the electricity losses, they still control the outputs, i.e. the number of customers and the electricity delivered. Therefore, we define an output-oriented translog function for which estimated the parameter coefficients using the PLP approach. We also derived the shadow price and the implicit cost of QoS.

In chapter 3, we compare the performance of the electricity sector in six East African countries in terms of quality of service. Part of the chapter was published in the East African Journal of Science, Technology and Innovation (EAJSTI)[5]. We address the question of whether private sector participation in the electricity sector improves technical efficiency and total factor productivity. Given the complexity of the electricity sector in East Africa, the comparative analysis is carried out using two models, the generation model and the transmission-distribution model. We use the nonparametric DEA approach to estimate technical efficiency scores The output includes the number of customers and the electricity delivered in GWh. On the other hand, the inputs are taken into account, the installed capacity in MW, the length of the high voltage transmission lines in km, and the electricity losses in GWh. In a second stage, we used Tobit regression to investigate which variables influence the technical efficiency, especially those related to the electricity sector reform.

Chapter 4 was written jointely with Axel Gautier and Barnabé Walheer. Electricity losses are one of the causes of poor quality of service, given their negative impact on users, on electricity companies and on the country. In their national energy policies, East African countries, as well as other countries, have set themselves a loss minimization target. In this chapter, we address the question of at what level

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[5] Nsabimana, R. (2022). Benchmarking of the Electricity Sector in East Africa: An Assessment of Technical Efficiency. *East African Journal of Science, Technology and Innovation, 3*.

should losses be minimized given the production technology, inputs and outputs[6]. The objective is therefore to determine and compare the differences in quality performance in terms of minimizing electricity losses. We used a non-parametric approach to estimate minimum electricity losses by imposing regulatory conditions on the utility generation process. Considering the limited number of comparable DMUs per unit time, we adopt a window analysis procedure. Thus, each DMU is compared over different time periods considering it as a separate unit. We use two inputs, purchased electricity and high voltage transmission lines. On the other hand, the outputs include the number of customers and the electricity delivered. Electricity losses are neither input nor output, but an objective to be achieved in terms of minimization. From the underlined variables, we estimated the performance gap ratios and differences, and the potential saving when losses are minimized. The paper provides other areas for future researches.

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[6] This methodology differs from those used in chapters 2 and 3, where the assessment is based on the regulatory restrictions such as input minimization given the outputs, or output maximization given the inputs. However, both are used as benchmarking methods.

1. Electricity sector organization and performance in Burundi

Abstract

Burundi faces low access to electricity and poor quality of service. The country depends on interconnected networks constructed in the 1980s. In spite of various reforms, REGIDESO remains the vertically and horizontally integrated state-owned company responsible for the production and distribution of electricity, and for the pumping, treating and supplying of drinking water in all urban centres. This paper reviews the organisation, policies and reforms of the electricity sector in Burundi. It assesses its performance on the basis of secondary data obtained from REGIDESO and qualitative data collected through semi-structured interviews. Our results show that, despite the reforms undertaken through the promulgation of the electricity acts in 2000 and 2015, no enforcement measures have been put in place. As a result, electricity access and per capita consumption remain the lowest in East Africa. The electricity sector is also characterised by poor quality of service, due to high power outages, technical and non-technical losses. Among the non-technical losses, unpaid bills, particularly in the public sector, are very high. The study recommends implementing the reform undertaken in 2000 and 2015 by unbundling the water and electricity utilities, and vertically unbundling the electricity sector. Burundi should attract the private sector into assets and competitive activities, and prioritise regional power projects to facilitate interconnection and cross-border electricity trade.

Keywords: Energy policy, Electricity sector reform, access to electricity, quality of service, REGIDESO, Burundi.

Chapter 1. Electricity sector organization and performance in Burundi

1.1.Introduction

Access to reliable, sustainable, and modern energy services at an affordable cost is on the United Nations 2030 Agenda on Sustainable Development Goals (SDG 7). Urbanization and industrialization have increased the demand for electricity two to three times faster than the final consumption(Ali, 2021; IEA, 2018). More specifically, since the 2000s, demand for electricity in Sub-Saharan Africa (SSA) increased by 50%. However, it still accounts for 4% of world energy demand while its population accounts for 13% (Ouedraogo, 2017).

Yet, in developing countries, particularly SSA, QoS and access to electricity are far from being a reality (Carlsson et al. (2020). Power outages and blackouts − ranging daily between 8 and 12 hours in urban areas or even 18 hours in rural ones − characterize certain regions (Valasai et al., 2017). The poor QoS is attributed to technical causes and/or managerial and institutional ones (Blimpo & Cosgrove-Davies, 2019; Imam et al., 2019; Ullah et al., 2017; Valasai et al., 2017).

The electricity network includes activities such as generation, transmission, distribution, metering and sale(Künneke & Fens, 2007). Among these activities, transmission and distribution constitute the infrastructure, while generation, metering and sales are services. Historically, the two main activities have been operating under a vertically integrated public monopoly. Arguments for a vertically integrated monopoly include, among else, economies of scale and reduced transaction costs. By vertically integrating the electricity sector, the government's objective was to make it accessible to all at low cost (Fetz & Filippini, 2010; Streel et al., 2011).

However, in developing as well as in the developed countries, the vertically integrated monopoly has been criticized for not being efficient. In the case of developing countries, the public monopolies have been unable to mobilize sufficient resources and knowledge to expand infrastructures, increase access to electricity, or face to the poor QoS. The electricity sector was also characterized by high technical and non-technical losses, high costs, and high level of subsidies (Bacon, 2018; Imam et al., 2019; Jamasb et al., 2017).

Since the 1990s, a standard model for liberalizing the electricity sector involved many steps, among them power sector restructuration, transparent regulation, and increased private participation in the service provision (Gore et al., 2019; Kapika & Eberhard, 2013). Mobilizing the private investments, especially from independent power producers (IPP) would not only increase infrastructure investments, but also sustain the development of African economies (Baumli & Jamasb, 2020).

Burundi is one of the countries in SSA which is not exempt from electricity sector reforms. Located in the Great Lakes of Africa with a total area of 27,834 km^2, Burundi is endowed with hydropower resources. It has a potential of 1700 MW, 300 MW of which are economically exploitable (Bamber et al., 2014). Domestic hydropower plants account for a capacity of 32 MW**,** and 16.5 MW are imported from the Democratic Republic of Congo (DRC). Access to electricity and QoS are among the lowest in the world. The increase in demand for electricity relative to limited supply has led to load shedding, particularly since the 2000s. The low QoS thus limits the productive capacities of businesses and harms the well-being of consumers. A survey conducted by the World Bank on 157 Burundian firms from August 2014 to February 2015, shows that they observe an average of 6.4 power cuts per month, lasting an average of 4.5 hours each. These power cuts result in losses estimated at 3.4% of sales[7].

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[7] The World Bank conducted a survey in the different countries to analyze the constraints faced by private business. Power outages are part of the infrastructure component. In Burundi, the survey took place from August 2014 to February 2015. The results of the

It should be noted that the problem of power cuts is general for a large part of developing countries. However, service quality levels vary from country to country. Also, the losses incurred by the private sector do not include additional energy costs, idle staff, loss of customers, etc.

Like other countries, Burundi has adopted reforms aimed at horizontally unbundling the drinking water and electricity utilities, and vertically unbundling each of these two utilities. The first Act, enacted in 2000, liberalizes and regulates the drinking water and electricity utilities. The second Act of 2015 reorganizes the electricity sector by separating infrastructures from service provision. Both Acts encourage private sector participation in the different segments. However, the reforms remained on paper, REGIDESO remains the vertically integrated company operating public drinking water and electricity services. The key question is to know the barriers to the reform implementation. In other words, what hinders the private sector's participation in the electricity sector in Burundi?

In this chapter, we contribute by analyzing the electricity sector reform in Burundi and their implementation barriers, through the literature and based on our own surveys. We also describe the status of the electricity sector in Burundi and analyze its performance. We explore policy and strategy documents, as well as the various laws and decrees governing the electricity sector in Burundi. We also base our analysis on primary and secondary data collected in Burundi and other international databases.

In the second section, we analyze the restructuring and participation of the private sector in the electricity sector through a literature review. In the third section, we describe the methodology used. The fourth section analyzes the organization of the

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survey are found through this link downloaded as of 12/26/2021. http://www.enterprisesurveys.org/data/exploreeconomies/2014/burundi#infrastructure electricity sector in Burundi. We analyze the performance of the electricity sector in the fifth section. In the sixth section, we describe the electricity pricing system and compare it to that of East African countries. Finally, we discuss the results in the seventh section and conclude.

1.2.Litterature review

1.2.1. Economics of unbundling in electricity sector

The electricity sector is an interconnected network including generation activities, high voltage transmission lines, distribution substations, transmission and distribution transformers, metering activities, sales, billing and collection, etc. These activities can be divided into two groups: infrastructure and service provision (Streel et al., 2011). Vertically integrating these businesses brings benefits which can be summarized from an economic and technical perspective.

From an economic viewpoint, the main benefits are economies of scale and scope. Economies of scale implies that the monopoly is able to reduce its average costs as the marginal output is realized at constant marginal costs. Electricity infrastructures, such as transmission and distribution represent fixed investments implying fix costs. When they are used intensively, they are amortized over a high output quantity, such as increased customers and the electricity delivered. So as service provided increases, the average costs of the network decreases. On the other hand, economies of scope results from the fact that joint production of two outputs than producing them separately may be cost savings (Carvalho & Marques, 2014; Gugler et al., 2017). Therefore, economies of scope permit to avoid fix costs duplication and better coordinate all activities at all stages. Therefore, customers can benefit from economies of scale and scope through the delivery of affordable and high quality services.

Another reason for vertical integration is technical, that is, the reduced transaction costs. In the electricity sector, these are, for example, the costs of coordinating the various activities of production, transmission, distribution and retail. Coordinating activities include for example planning for a reliable and inexpensive production and transmission system, and reducing trading costs. Especially, when a company uses intermediary markets for example, transaction costs become very high. Therefore, it becomes cost effective when a vertically integrated coordinates all business stages (Fetz & Filippini, 2010).

However, the vertically integrated monopoly, especially in the electricity sector, has been criticized as technical inefficient, especially in the case of developing countries. As noted by Jamasb et al. (2017), it has been characterized by chronic electricity shortages, week institutions, under-capitalization and high system losses. On the other hand, governments were unable to mobilize sufficiently investments for providing access (Dertinger & Hirth, 2020). In the case of SSA countries, macroeconomic conditions including the deterioration of international business climate, fiscal constraints, structural adjustment programmes, which forced governments to reform the electricity sector (Imam et al., 2019).

Streel et al. (2011) describe four economic principles that support the liberalization of network industries, namely vertical unbundling, open access to the network, market competition, and residual regulation. Liberalizing the electricity sector requires, as noted Künneke & Fens (2007), unbundling the infrastructure related service (transmission and distribution) which are subject to natural monopoly, and competitive commercial functions such as production, metering and supply. Thus the vertical separation of the electricity industry requires the unbundling of infrastructure with the provision of services.

Cave (2006), Künneke & Fens (2007) and Sugimoto (2021) distinguish four basic forms of separation that can be classified into economic and legal unbundling, i.e administrative and management unbundling (economic) vs legal and ownership unbundling (legal). Administrative unbundling requires the separation of financial accounts for infrastructures and competitive activities, even though they are operated under a single company. In addition, management unbundling implies dividing staffs into different business units independently from others. On the other hand, in the legal unbundling, one holding company still manages network activities and service provision which are organized separately. Finally, in the ownership unbundling the network operates under separate ownership from production to sales. Individual owners participate in the assets and control the network management. Ownership unbundling stimulates competition and efficiency improvement, simplifies market and the firm structure, increases privatization, and security of supply (Baarsma et al.,2007;Pollitt, 2008).

Once the vertically integrated monopoly has been unbundled and competitive conditions are in place, and privatization introduced, another required reform is the establishment of a regulatory system. Economic regulation has to protect the public interests reflected in terms of service access, network access and tariffs. The purpose of the regulator is to provide a space for market mechanisms, incentives and competition, and to protect the consumer. The regulator guarantees equal access to infrastructure and customers. His rule is to prevent network operators from capturing monopoly rents, to maintain regulation in potentially competitive segments, to make incentive regulation such as cost recovery or productivity improvement, and to match short-term profits with long-term investment requirements (Streel et al., 2011). Thus the regulator must encourage new entrants to make intensive use of existing infrastructure while planning to build their own.

1.2.2. Barriers for private participation in the electricity sector in SSA

One of the arguments for ownership unbundling is to facilitate private sector participation (Baarsma et al., 2007; Pollitt, 2008). Through privatization, ownership and controls are transferred from the public to the private sector. Karekezi & Kimani (2002) identified the most common paths that have been considered by African countries, as requirement for privatization: corporatization, commercialization, contract management, direct sales, and independent power producers (IPPs). The private participation in the electricity sector not only increases infrastructure investments, but also drives renewable energy development (Ahlborg & Hammar, 2014; Baumli & Jamasb, 2020). As noted Balza et al. (2013), most private actors invest much more in generation than transmission and distribution networks, due to sunk investments.

Despite the reforms, there are still barriers to private sector participation in the electricity sector. Such barriers are common to many developing countries. At the financial level, energy infrastructure projects require high costs and a long period of time, from the tender to the infrastructure operation: project preparation, environmental investigations, bidding, building, technical assistance, commissioning, etc. The extension of the construction period also entails additional costs. Thus, private investors need to compare the current costs of projects with the expected return on investment, while estimating the risks associated to the projects (Gregory & Sovacool, 2019; Pueyo, 2018; Williams et al., 2015). Investors need to collect enough revenue to cover operating costs, repay debt and pay back capital providers. Bhattacharya & Kojima (2012) note that the average recovery period for investments in the power sector is 20 years. Another financial barrier is the size of the market in developing countries. Indeed, the financial market comprises a minority of banks constituted in oligopolistic competition (Baumli & Jamasb, 2020). Founding investment projects is done at high interest rates, which negatively affects their profitability. In addition, few companies in Africa rarely have access to the bond markets, due to the lack of investment grade ranking. Therefore, they are unable to raise sufficient debt at affordable rates (Eberhard et al., 2016).

Regulatory constraints also hinder private investment in the electricity sector: tariff setting, procurement and recruitment processes, independence of the regulatory authority, etc. In most cases, electricity tariffs are administered and set below the production costs. The independence of the regulatory authority in some countries is not guaranteed, as the appointment of its members is made by presidential decree or by the Minister in charge of Energy. There is thus a risk of political interference in the management of private companies, including the corruption of public officials (Imam et al., 2019; Valasai et al., 2017). Also, the lack of regulatory independence could lead to low tariffs as a result of political pressure. Tariff regulations are set by balancing promoting affordability to consumers and cost recovery of investments[8].

Constraints to private investment may be related to capacity building. In some countries, government officials lack sufficient skills, particularly in negotiating public-private partnerships (PPP)[9]. This is the case in particular for the management of international tenders, the negotiation and execution of contracts. Also, the decision making process goes through several instances and slows down the execution of contracts. On the other hand, the electricity service is considered by some members of the government as a public good.

1.3.Material and Methods

The assessment of the organization of the electricity sector in Burundi is based on policies, strategies, acts, and decrees. Most documents visited are, among else the

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[8] In Burundi, for example, it was estimated that the production cost of the thermal power plant was US$0.22 while the average tariff charged to customers by REGIDESO is US$0.20. In their study, Ahlborg & Hammar (2014) show that in Tanzania, electricity current tariffs represent on average half of the production costs.

[9] PPP is defined as long contract between public and private sector. Some goals are assigned to the PPP such as financing, designing, implementing, and commissioning infrastructure (Tamošaitienne et al., 2021)

vision Burundi 2025, the Poverty Reduction Strategic Framework (CSLP II), the energy policy letter, the energy sector strategy in Burundi and the National Development Plan (NDP 2018-2027). We also analyzed the different decrees and Acts, such as the Acts of 2000 and 2015 which liberalizes and reorganizes the electricity sector, as well as the implementing decrees.

We assess the performance of electricity sector in Burundi descriptive method. we focus mainly on access to electricity, the quality of service, and the tariff structure. The electricity access is investigated through installed capacity, the transmission and distribution system, and the trend in customers and their consumption.

To estimate the quality of electricity distribution, we use two common indicators, the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). The two indicators are defined as follows(Coelli et al., 2013):

$SAIDI = \frac{\sum_i^n D_i N_i}{\sum_i^n N_i}$ where D_i is the interruption duration for region i, N_i is the number of customers served in each region. It's commonly used to estimate the reliability of electric power utility.

$SAIFI = \frac{\sum_i^n f_i N_i}{\sum_i^n N_i}$ where f_i stands for the number of interruptions per region.

To estimate the SAIFI and the SAIDI, we collected all data related to interruptions on the interconnected network provided by the National Dispatching, which records power interruptions as they occur. Due to the high number of interruptions, we focused on data from 2014 to 2017 on a daily basis. We estimated the frequency and duration of interruption 13 distribution substations localized in five main regions, namely Bujumbura, West, South, North, and East[10]. Other data were obtained from the World Development Indicators of the World Bank (2019).

1.4.Electricity sector organization in Burundi

In this section, we present the electricity sector history. We also describe the electricity policy and the electricity acts of 2000 and 2015.

1.4.1. Electricity sector history in Burundi

1.4.1.1. Status of the electricity sector until the end of 1990

The electricity sector in Burundi has not been sufficiently documented. There are few scientific studies describing its organization. The few available studies are reports carried out by institutions such as (The World Bank, 1985, 1992). Until the end of 1983, Burundi accounted for an installed capacity of 19.8 MW, of which 11.7 MW was hydro and 8.1 MW was diesel. The first run-of-river hydroelectric dam at Mugere with an installed capacity of 8 MW was financed and built by the Chinese government and commissioned in 1982. Prior to this date, electricity was provided from a diesel generator with an installed capacity of 5.5 MW belonging to REGIDESO. However, its available capacity has been steadily decreasing due to aging. The rest of the national production was provided by an isolated network owned by both the private sector and the "Direction de l'Hydraulique et des Energies Rurales "(DHER).

Before the commission of the Mugere dam, Bujumbura, the capital of Burundi was supplied with imported electricity from Ruzizi I commissioned in 1958 to supply electricity to the interconnected system of Congo and Ruanda-Urundi[11]. This plant

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[10] We detail the power outage data collection process in Appendix A.

[11] At the end of the first World War, Burundi and Rwanda were annexed to Congo Belge, under the Belgian colonization. These two territories named Ruanda-Urundi remained

was built by the "Société Belge des Forces Hydroélectriques" of Eastern Congo, and is owned by the "Société Nationale d'Electricité du Congo" (SNEL). According to the World Bank (1985), this company was committed to supplying 33 GWh per year to Burundi without interruption and at no cost until 2005, and to sell to REGIDESO the demand exceeding this capacity. Thus, with the Ruzizi I imports and the construction of Mugere, Burundi has reduced its dependence on thermal energy whose generators were becoming increasingly old. With the construction of Mugere, more than 50% of Bujumbura's urban population would have access to electricity. At the end of 1989, REGIDESO had an installed capacity of 30.6MW supplying 117.3 GWh (The World Bank, 1992).

The electricity transmission network supplying Bujumbura consisted of a 115 km line of 70 kV owned by SNEL, and 25 km of 35 kV from Mugere hydropower plant. At the end of 1983, the transmission and distribution network covered 423.3 km, of which 396.1 km belonged to REGIDESO, and 27.2 km to DHER. Electricity distribution in Bujumbura was provided by a distribution network of 6.6 kV underground cables, while other provinces were supplied by 10 kV overhead lines[12]. At that time, REGIDESO The number of customers was estimated at 13,799 in 1989, including 154 in medium voltage. Consumption per household was estimated at 2,300 kWh par year (The World Bank, 1992). The losses were estimated at 2,5% of purchased electricity. With the extension of the distribution network to the lower income districts of Bujumbura, losses have increased to

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under Belgian mandate until their independence in 1962. The Ruzizi I power station was built to supply electricity in equal parts to the three territories under Belgian colonization.

[12] The 6.6 kV distribution network was installed in the 1960s, as a result of imports from Ruzizi I. This network has not been upgraded and is responsible for frequent power outages in downtown Bujumbura. According to The World Bank (1992), it was already estimated that the 6.6 kV distribution line in the cities of Bujumbura and Gitega had already reached its limits since the 1990’s.

between 12% and 15%, including unbilled and illegal connections(The World Bank, 1985).

1.4.1.2. Role of bilateral and multilateral aid and loans in founding the electricity generation

Much of the power generation and transmission infrastructures date from the 1980s and have benefited from bilateral and multilateral partner funding. Since 1983, the government of Burundi engaged Lahmeyer International of Frankfur, Germany, to carry out hydroelectric potential resources, funded by European Development, Funds (FED). The international consultant identified 41 potential power sources, with an output of 285 MWh, able to generate 1,130 GWh per year. The first 5-year electric investment plan covered the period 1985-1989 (The World Bank, 1985). This plan was articulated around 4 strategic axes: the reduction of dependence on imports, the development of the Rwegura hydroelectric dam, the development of the Ruzizi II dam jointly with Rwanda and DRC (the former Zaire), the construction of a 30 kV line to supply certain towns in Bubanza and Cibitoke, as well as the extension of the distribution network to six low-income districts in Bujumbura.

Funding for this plan required a combination of consumer, government, and lender participation. Consumer participation was limited to connection charges, while that of Government and lenders covered both feasibility studies and construction projects. The main lenders were: The World Bank through the International Development Association (IDA), the Belgian government, the Caisse d'Epargne et de Crédit de France, GIZ and kFw of the Federal Republic of Germany and the FED. The Government’s contribution was estimated at less than 4% of the total financing, the rest being by multilateral loan.

The World Bank (1992) shows that, despite the investment plan, few investments have been allocated to the electricity sector. More specifically, while the 1983-1987 economic and social development provided for 11% investments in the energy sector, that of 1988-1992 plan reduced them to 3%. Unfortunately, only 1.5% of Burundians had access to electricity in 1989, 80% of each concentrated in Bujumbura city. Also, electricity network losses exceeded 15%. The electricity sector was also characterized by power outages on both medium and low voltage grid.

1.4.2. Governance of the electricity sector in Burundi

The statutes governing REGIDESO as a public company in Burundi date from 1968. It was assigned the mission of producing and distributing drinking water and electricity in the main and secondary towns. From that date, REGIDESO's statutes were modified five times in 1978, 1979, 1986, 1989 and 1997. The main changes were related to missions and governance structures. In 1978 for example, REGIDESO was given a third mission for carrying out urban sanitation works, including the evacuation of wastewater and rainwater. An autonomous department responsible for this activity was created in REGIDESO, which became a new public company in 1983, the "Régie des Services des Techniques Municipaux" (SETEMU).

With regard to governance, REGIDESO was managed since 1968 by a Board of Directors composed of 11 members. The 1986 decree reduced this board to eight members, six of whom represent the State and two the consumers. In 1989, REGIDESO was granted the status of a commercial and industrial company. It was given legal personality and organic autonomy. As such, REGIDESO could carry out itself, or under its control, studies and works necessary for carrying out its tasks.

That period corresponds to the commissioning of the last hydroelectric plant, Nyemanga hydropower with an installed capacity of 2.8 MW. The State withdrawal from the electricity sector did not enable increasing the installed electricity capacity. The 1989 decree brought the composition back to eleven, including height government representative. The rest of the directors were composed of two representatives of large and small consumers, and one staff representative. The Director General, as well as the directors of the departments, were appointed by decree.

Finally, the 1997 decree harmonized REGIDESO's statutes with the code for private and public companies. It was given a share capital of BIF 1.442 billion divided into 14,420 shares. The composition of the Board of Directors has been reduced to nine members, five of whom representing the State, two representing large and small consumers, one representing the staff, and the last one designated for his particular skills and experience. However, the decree does not specify the skills that the other members of the board must have. The six directors representing the State generally come from the civil service and represent the various ministries. The latter would be incapable of arbitrating conflicts resulting, for example, from the non-payment of bills by the public sector. As long as they do not represent their own interests or those of their shareholders. As a result, there could arise a possible principal-agent conflict, and problems of free riding. Since the general manager is also a member of the board of directors, he could bribe the other directors to set aside the general interest and maximize their own payoffs.

The general manager, the directors of the departments, the members of the board of directors, all are appointed by decree and depend hierarchically on the Minister of Energy. In this case, there is a risk of political interference making the electricity sector inefficient. Nellis (2005) provides inefficiency problems resulting from the Board of Directors in State-Owned utilities, such as excess personnel recruitment. The high production costs in REGIDESO may be attributed to operating expenses due to high number of employees. For example, The World Bank (1985) estimates operating cost ratio of over 80% in the 1983, while The World Bank (1992) reports that in 1989, REGIDESO consisted of 872 permanent staff and 1100 temporary employees, where one employee serves only 27 customers.

The other difficulty in the electricity sector is the frequent turnover of managers. From 2004 to 2020, REGIDESO had seven general managers, bringing their mandate to an average of two years each, even though they are appointed for a renewable period of four years. As noted Eberhard et al. (2018), the high frequency of turnover in leadership may be the cause of poor performance by impeding robust decision-making. It may also be the basis for corruption in the electricity sector (Imam et al., 2019).

1.4.3. Electricity legislation in Burundi

Like other SSA countries, the electricity sector in Burundi has been characterized by inefficiency, such as poor access to electricity and the poor quality of service. Also, it has been unable to increase investments in energy infrastructures. Since the 1960s, REGIDESO has been a vertically and horizontally integrated state-owned company, operating two public utilities, water and electricity. It has been also assigned, at some times, wastewater sewage. REGIDESO was and still remains responsible for network activities (transmission and distribution), and service provision (production, metering, sales). It executes this mission in the main and secondary urban centers.

The decree of 1997 grants to REGIDESO the statute of an industrial and commercial company with autonomous management. It was endowed with a capital stock and well-defined number of shares. It was also assigned to adopt accounting standards. The decree constitutes the beginning of privatization process, through the adoption of corporatization (Karekezi & Kimani, 2002). However, the decree does not differentiate shares allocated to drinking water service and those allocate to electric utility.

The reform of the electricity sector in Burundi began with the 2000 Act liberalizing and regulating the provision of drinking water and electrical energy. The Act opens the two utilities to Burundian public and private legal entities. Although the Act has been passed, no implementing texts have been issued. Nor does it define the distribution of assets and personnel in the two utilities.

As a result, REGIDESO continued to suffer from a poor financial health, much criticized by the Parliament, civil society and consumer associations. The Profit and Loss Statement shows a decrease in value added in 2016 and 2017, -43% and -68% respectively. In addition, personnel costs absorb a significant portion of the value added: 83% in 2013 and 2014, 91% in 2016 and 285% in 2017. Thus, the government keeps subsidizing REGIDESO. Such subsidies represent 54%, 77.3% and 132% of the value added in 2013, 2016 and 2017 respectively.

Since the promulgation of the 2000 Act, no institutional plan has been developed for its implementation. It was not until 2013 that an organizational audit of REGIDESO was conducted, the report of which was published in August 2013 by the Bureau d'Etude Mazard of Senegal. The diagnosis shows the following weak points that characterize REGIDESO: political interference, lack of coordination of water and electricity services, poor governance, inadequate organization, inadequate accounting, personnel administration that is not human resources management, inadequate business management, a non-optimal supply system, dysfunctional technical management, to name a few.

Based on these dysfunctions, GIZ, through its Water and Sanitation Sector Program (PROSECEAU), conducted an advisory assistance through a strategic study on REGIDESO's governance, the report of which was released in March 2014. The study shows the pros and cons of horizontal separation of REGIDESO into two entities, and risks associated for this separation. The study also identifies the cost of the separation.

Even if the study finds that restructuring is the most financially viable solution, the idea of horizontal unbundling is not to be dismissed. The study presents the main issues to be considered before separation: personnel, assets and liabilities sharing, and customer management. Regardless the separation process, the study proposes two forms of restructuring, financial restructuring and reorganization of REGIDESO. The first measure aims at the adoption of international accounting standards to give a true and fair view of the financial and patrimonial situation. The second aims at implementing the management measures proposed in the organizational audit.

In 2015, the Government of Burundi expressed its willingness to legally separate the electricity sector by enacting Low N°1/13 of April 23, 2015. The law liberalizes the electricity sector without losing the State's control over the sector. It provides for a legal unbundling of production, transport, distribution and sale of electricity. Production is subject to a concession or PPP contract. However, independent power producers can generate in off-grid systems, with the option of selling the surplus to the main transmission and distribution system operator. For the transmission and distribution network, the Act proposes a management contract by a public or private company, in the form of a concession for a period not exceeding 25 years.

Therefore, the Act aims to create a legal framework for new investments in the electricity sector. The Act also created also a regulation and control agency, with the mission to protect interests for both consumers and investors, to control the execution of the delegation contract by the main and/or the independent operator and to issue the certificate of conformity.

In order to attract the private investments, a second Act was also promulgated in 2015, related to the public-private partnership (PPP) contract. The PPP contract may be applied to whole or part to the design, financing, construction or transformation, operation, management, upkeep or maintenance of works, equipment or intangible assets necessary for the provision of public service and other services contributing to the exercise. In the next section, we analyze the performance of the electricity sector.

1.5.Performance of electricity sector in Burundi

In this section, we analyze the performance of the electricity sector in Burundi. We focus our analysis on access to electricity, the quality of service and the structure of electricity tariffs.

1.5.1. Status of electricity network

1.5.1.1. Electricity generation

Burundi is endowed with high potential in renewable energy such as hydro, solar, wind and geothermal, and non-renewable energy such as peat. The REGIDESO maintains and operates eight hydroelectric plants for a capacity of approximately 33 MW. Two of these plants (Rwegura with 18 MW and Mugere with 8 MW) represent 81% of total installed capacity. Except for the Rwegura hydroelectric plant, other power stations are qualified for “run-of-river” and can entirely use their installed capacity, which reduces in the dry seasons. With its reservoir of 17 million m^3, the Rwegura hydroelectric can be used with a guaranteed power of 8 MW for about eight hours a day (The World Bank, 1992). Since 1995, a thermal plant for a capacity 5.5 MW has been installed to further diversify the electricity supply and reduce the electricity deficit. This thermal plant has been rarely used due to its high operational cost. Another 5 MW thermal plant has been operating with the subsidies of the World Bank and the European Union.

Since 2013, the REGIDESO contracted a lease contract with the Interpetrol company to supply 10 MW of thermal plant. This company has been granted an exemption from all taxes and other fiscal levies on imports, on equipment, lubricants, spare parts and fuel imported, for a period of 24 months starting from April 1, 2015[13]. After a long period of electricity shortage, the REGIDESO negotiated a second contract with Interpetrol for a capacity of 30 MW in 2017. The country imports 16.5 MW from the hydroelectric plants of Ruzizi I and Ruzizi II from DRC. Actually, the total interconnected power plants operated by the REGIDESO includes a total installed capacity of around 80 MW comprising 41% for domestic hydroelectric plants, 38% for thermal plants, and 21% for imports. Table 1 shows the current status of electric power in Burundi.

Table 1-1. Interconnected electricity and off-grid networks

Hydro Power plants	Location	Owner	year	Installed Capacity (MW)
Interconnected network				
Rwegura	Gitenge	REGIDESO	1986	18
Mugere	Mugere	REGIDESO	1982	8
Ruvyironza	Ruvyironza	REGIDESO	1980/1984	1.5
Nyemanga	Siguvyaye	REGIDESO	1988	2.8
Gikonge	Mubarazi	REGIDESO	1982	1
Kayenzi	Kavuruga	REGIDESO	1984	0.8
Marangara	Ndurumu	REGIDESO	1986	0.28
Buhiga	Ndurumu	REGIDESO	1984	0.47
Nyamyotsi		REGIDESO		0.3
Total Hydro				**33.15**
Diesel Power Plant				
5MW	Bujumbura	REGIDESO		5
5,5 MW	Bujumbura	REGIDESO	1996	5.5
Location	Bujumbura	Interpetrol	2016-2017	20
Total Diesel power plants				**30.5**
Total REGIDESO (I)				**63.65**

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[13] Ministerial Order N ° 540/649 Of May 5, 2015 Relating to Total Exemptions on the Importation of Equipment and Consumables Granted to the Interpetrol / Energyst Group, Independent Energy Producer.

Hydro Power plants	Location	Owner	year	Installed Capacity (MW)
Imports				
Ruzizi II	Rusizi		1989	13
Ruzizi I	Rusizi		1958	3.5
Total imports (II)				**16.5**
INTERCONNECTED NETWORK (I+II)				**80.15**
OFF-GRID NETWORK				
Kigwena	Nzibwe	ABER	1984	0.062
Butezi	Sanzu	ABER	1990	0.25
Ryarusera	Kagogo	ABER	1984	0.32
Nyabikere	Nyabisi	ABER	1990	0.212
Murore	Rusumo	ABER	1987	0.024
Kayongozi	Kayongozi	ABER	2011	0.5
Total ABER				**1.368**
Mugera	Ruvyironza	Private	1962	0.03
Kiremba	Buyangwe	Private	1981	0.064
Masango	Kitenge	Private	1979	0.025
Musongati	Nyamabuye	Private	1981	0.006
Mutumba	Kirasa	Private	1983	0.045
Mpinga	Mukanda	Private	1983	0.016
Teza	Nyabigondo	Private	1971	0.36
Kiganda	Mucece	Private	1984	0.044
Gisozi	Kayokwe	Private	1983	0.015
Burasira	Ruvubu	Private	1961	0.025
Total Private	-		-	**0.63**
Total OFF-GRID				**1.998**
TOTAL INSTALLED CAPACITY				**82.148**

Source: REGIDESO

Off-grid electricity includes six small hydro plants operated by ABER, for a total capacity of 1.38 MW. Other small plants including hydro, diesel generators, bagasse, and solar panels are operated by a range of private and public actors in the areas not covered by the interconnected network, or to serve as backup due to shortages in the electricity supply (Bamber et al., 2014). Even not accounted in the national production, solar panels are increasingly used as a source of power for households and firms connected to the main grid or located far away from the interconnected grid. Solar power has become an alternative way to cope with the low quality of electricity supply. Under the support of European Union and the Belgian cooperation through ENABEL, a series of off-grid projects have been developed, including photovoltaic (PV) electrification of 30 schools and 20 clinics, and 30 health centers (The World Bank, 2019).

In order to increase access to electricity and meet increasing demand, a series of power generation have been planned, under government and development partner support. Most of donors includes multilateral and bilateral partners, such as the World Bank (WB), European Union (EU), European Investment Bank (EIB), the Government of China, Exim Bank of India and some PPP projects. The Government of Burundi has also signed a memorandum of understanding to import electricity from Ethiopia (The World Bank, 2019). A total installed capacity of 400 MW is planned to be commissioned by 2024 as shown in table 2.

Table 1-2. Power projects and financing

Plant	Fuel	Installed Capacity (MW)	Financing	Year
Mpanda	Hydro	10.4	Burundian Government	2021
Kabu 16	Hydro	20	Exim Bank of India	2021
Jiji-Mulembwe	Hydro	49	WB, AfDB, EU, EIB	2024
Kagu 006	Hydro	8	PPP Swedenergy	2023
Solar projects	Solar	7.5	PPP Gigawatt Global	2019
Peat Power Project	Peat	15	PPP with BUCECO	2020
Ruzibazi	Hydro	15	Chinese Government	2022
Rusumo Falls	Hydro	26.6	World Bank, AfDB	2021
Ruzizi III	Hydro	49	WB, AfDB, EU, EIB	2024
Imports from Ethiopia	Hydro	200	Burundian Government	2020
Total		**400.5**		

Source : The World Bank (2019)

It should be noted that a large part of the planned and ongoing hydroelectric projects appears already in the Master Plan prepared by Electricité de France International (EDFI) in 1988. The execution of this master plan should bring to an installed capacity of 316.2 MW and producing 1218 GWh per year. The master plan anticipated additional economic benefits. In addition to large-scale electrification, the hydroelectric plant and the development of rivers in western Burundi would allow for irrigation of the Imbo plains. It also provided joint projects with other countries, such as Rusumo falls with Rwanda, Tanzania, and Uganda, and Ruzizi III and Ruzizi IV with Rwanda and ex-Zaire.

1.5.1.2. Electricity transmission and distribution

The transmission network carries electric power from the electric generator to the distribution substations. All Burundi provinces are interconnected with the transmission line voltages of 110 kV, 70 kV, 35 kV, and 30kV. Two transmission lines of 110 kV link Ruzizi II hydroelectric plant and Rwegura hydroelectric plant to Bujumbura (RN1) and Gitega substations for a total length of 210 km. A 70 kV transmission line links Ruzizi I hydroelectric plant to Bujumbura for a distance of 112 km and belongs to SNEL. A 35 kV line of 15 km links the Mugere hydroelectric plant to Bujumbura (Ozone substation). Other regions are interconnected by the 30 kV network for a total distance of 1127.27 km in 2017, which serves also as distribution network in certain areas.

The non-rehabilitation of these lines is among the most causes of service interruption in these cities. According to Bamber et al. (2014), the use of outdated transmission technologies is one of most causes of technical losses estimated at 24% of total supply in 2012. A higher voltage transmission network might be created to reduce technical losses. The World Bank (2019) recommends also to replace small section conductors and not to use them in future new lines.

A program of cross-border interconnection facility with the EAPP has been launched to exchange electric power between the national grids. In order to interconnect with the EAPP, Burundi plans to develop three lines of 220 kV, to link to Rusumo Falls to Burundi (161 km), Rwanda (143 km) and Ruzizi III in DRC (78 km). These transmission lines are among the Nile Equatorial Lakes Subsidiary Action Plan (NELSAP) projects aiming to eradicate the poverty and promote economic growth by increasing access to electricity in the Nile Equatorial Lakes (NEL) region. Burundi plans also to develop 110 kV linking the hydroelectric plants under construction to Bujumbura, such as Jiji-Mulembwe, Ruzibazi and Kabu 16.

The distribution network comprises medium voltage (MV) lines of 6.6 kV, 10 kV and 15 kV and LV lines 220/380 V. The 6.6 kV MV is especially underground and located in Bujumbura and Gitega cities, for a total distance of 150 km. These lines were built in the 1960s and were already declared outdated since 1990, which required replacement (The World Bank, 1992). Table 1-3 shows the number of km of high voltage (HV) transmission lines and medium-low voltage (MV-LV) distribution lines per 1000 customers and per 10000 inhabitants.

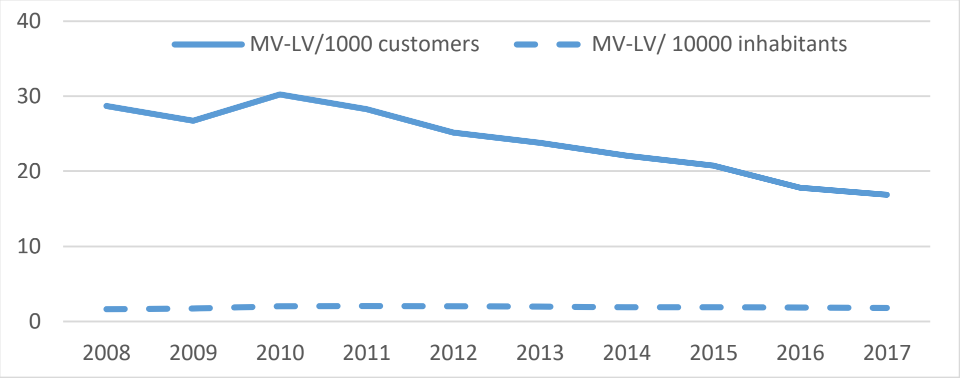
Table 1-3. Evolution of high voltage and medium-low voltage lines in km

Year	HV / 1000 customers	MV-LV/1000 customers	HV/10000 inhabitants	MV-LV/ 10000 inhabitants
2008	6.71	28.68	0.39	1.67
2009	5.85	26.72	0.38	1.73
2010	5.38	30.24	0.37	2.06
2011	4.84	28.27	0.36	2.08
2012	4.25	25.16	0.35	2.05
2013	4.02	23.80	0.34	1.99
2014	3.72	22.07	0.33	1.93
2015	3.40	20.76	0.32	1.93
2016	2.90	17.82	0.31	1.88
2017	2.75	16.87	0.30	1.82

Source: Compiled by the author based on REGIDESO and WDI data

Table 1-3 shows that the length of HV lines and MV-LV lines does not increase with customers and population. Figure 1-1 shows the evolution of medium and low voltage lines per 1000 customers and per 10000 inhabitants.

Figure 1-1. Evolution of MV-LV per 1000 customers and per 10000 inhabitants



Source: the author

Figure 1-1 shows that the evolution of MV-LV lines per 1000 customers tends to decrease, while the evolution per 10000 inhabitants is almost flat. This shows that the distribution network does not grow as the customers increase. Thus, connecting more customers without increasing the distribution network could be the cause of overloads leading to power outages and therefore poor service quality.

1.5.2. Access to electricity in Burundi

Burundi remains one of the least countries in the world with poor access to electricity. Statistics from the World Development Indicator (WDI) show that more than 90% of the Burundian population does not access to electricity in 2017. Access to electricity benefits much more urban areas (61.8%) than rural ones (2%). Despite its position in the Great Lakes in East Africa and its electricity potential, figure 1-4 shows that Burundi is the least compared to East African countries and other country groups.

Table 1-4. Comparison of access to electricity (%) in East Africa

Country	Year		Change per year
	2010	2017	
Burundi	5.30	9.30	0.50
Ethiopia	33.16	44.30	1.39
Kenya	19.20	63.81	5.58
Rwanda	9.70	34.10	3.05
Tanzania	14.80	32.81	2.25
Uganda	12.10	22.00	1.24
South Sudan	1.50	25.38	2.99
South Africa	82.90	84.40	0.19
Mauritius	100.00	98.03	-0.25
Sub-Saharan Africa	33.56	44.57	1.38

Source: Compiled by the author based on WDI data

The electricity access rate is increasing by 0.50% per year and remains below 10% in Burundi. Compared to other East African countries, the access rate is increasing by 5.58% per year in Kenya and 3.05% in Rwanda. While Burundi's electricity access rate in 2010 is higher than South Sudan's, the latter is performing remarkably well with a growth rate of almost 3% per year. Furthermore, countries like Mauritius and South Africa are models in terms of universal access to electricity.

According to Blimpo & Cosgrove-Davies (2019), low access to electricity could be attributed to the affordability gap and structural challenges. They show that pure demand-related accounts for two-fifths of access gap, which comprises high connection charges, irregular income for households, dispersion from the electrical grid, and lack of minimum building standard. Among the structural causes, the authors cite low regulated tariffs not sufficient for cost-recovery. In such a manner, the electric utility faces poor financial position. Access to electricity can also be achieved through diversification of energy sources and per capita consumption. Table 1-5 shows that, in addition to imports, Burundi relies on two main sources, hydroelectric and thermal power plants.

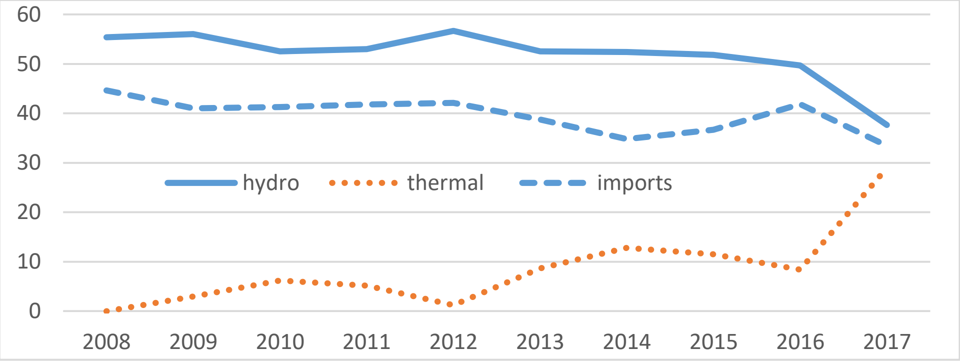
Table 1-5. Electricity purchased by fuel source and consumption per capita in Burundi

Year	Purchased by fuel source (%)			Trend in %			Consumption per capita (kWh)
	hydro	thermal	imports	hydro	Thermal	imports	
2008	55.38	0.00	44.62	-2.18	-	28.06	19.52
2009	56.01	2.97	41.01	3.96	-	-5.52	19.87
2010	52.57	6.18	41.25	9.12	141.62	16.92	21.65
2011	53.00	5.18	41.81	4.15	-13.38	4.73	22.05
2012	56.70	1.17	42.14	6.32	-77.62	0.16	20.06
2013	52.55	8.67	38.78	-0.31	699.09	-1.02	24.79
2014	52.44	12.76	34.80	-1.60	45.18	-11.52	26.49
2015	51.85	11.48	36.67	-5.80	-14.33	0.40	20.62
2016	49.71	8.41	41.88	9.81	-16.07	30.79	19.61
2017	37.63	28.95	33.42	-32.57	206.57	-28.93	17.15

Source: Compiled by the author on the basis of REGIDESO data

In Figure 1-2, we compare purchased electricity by source.

Figure 1-2. Share of purchased electricity per fuel source in Burundi



Source: the author

The share of imported electricity is close to that of hydroelectricity. In addition, as of 2017, the share of thermal energy approximates that of imported electricity and domestic sources. Dependence on imports and thermal energy represents a vulnerability for Burundi. The lack of foreign exchange and fuel shortages could still lead to many power outages. On the other hand, dependence on hydroelectricity makes the country vulnerable, particularly in the event of drought. It would be necessary to exploit other renewable sources such as solar energy.

Consumption per capita remains also very low in Burundi. Blimpo and Cosgrove-Davies (2019) show that in 2014, average consumption per capita in SSA is 483 kWh. It is an amount needed to power a 50-watt lightbulb continuously a year. In Burundi, consumption per capita remains around 20 kWh per year and is one of the lowest value in East Africa and the world. In 2017, it represents 17 kWh for Burundi, 50 kWh in Rwanda, 68 kWh in Uganda, 81 kWh in Ethiopia, 116 kWh in

Tanzania, and 168 kWh in Kenya[14]. Table 1-4 shows that Kenya has the highest level of consumption per capita, followed by Tanzania. Statistics of the World Development indicators estimate the per capita consumption in SSA for 486 kWh in 2017. There is a long way for Burundi to reach this average. Figure 4 compares the electricity consumption per capita in East Africa.

1.5.3. Electricity quality of service in Burundi

Access to electricity requires also the reliability of supply. Poor QoS is among the most challenges for many developing countries, where customers spend several hours a day without access to electricity (Blimpo & Cosgrove-Davies, 2019; Hunt.et al., 2018; Tait, 2017). The main causes of electricity interruptions include among else the generation capacity constraints, under-investments in new infrastructures, lack of fund to maintain existing network, etc. Countries which are dependent to hydroelectric power face to the climate change conditions. Hydroelectric power in Burundi is vulnerable to drought, especially in the dry seasons. The level of water in the big basin of Rwegura reduced dramatically the last years, which reduced the electricity produced. During the two last decades, the country news long periods of electricity shortage. Electricity load shedding has been operated in the cities, especially in Bujumbura with the large customers. Table 1-6 shows average frequency and duration of electricity interruptions in the five regions belonging to REGIDESO, from 2014 to 2017.

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[14] We calculated the consumption per capita using data on the electricity sector in the different countries and the total population obtained from the WDI.

Table 1-6. Interruption frequency and duration per year

Region	Interruption frequency				Interruption duration (hour)			
	2014	2015	2016	2017	2014	2015	2016	2017
Bujumbura	770	656	408	1018	162	120	80	149
East	334	607	478	710	63	125	90	99
North	147	325	266	753	29	51	45	108
South	840	802	567	1172	159	142	110	164
West	235	375	261	881	54	70	45	132

Source: Compiled from a database on load shedding set up by the author

Frequency and duration of interruptions vary from one region to another. We estimated them using data collected from the interconnected network, especially in five main regions. The findings show that two regions were particularly affected by the power cuts, the South region with two distribution substations, and Bujumbura with five distribution substations. On average, the highest duration of outages is observed in 2017 in the South with 1,172 hours, the equivalent of 49 working days per year. In Bujumbura, the average duration reached 1,018 hours, equivalent to 42 working days without electricity. In order to estimate the system reliability of supply, we measured two indicators, SAIFI and SAIDI. Table 1-7 shows the evolution of the reliability indices, where SAIDI is represented in hours.

Table 1-7. Liability indices from 2014 to 2017

Year	SAIDI(hour)	SAIFI
2014	612	127
2015	595	109
2016	391	74
2017	962	140

Source: Author calculations

SAIDI and SAIFI are the highest in 2017 and the lowest in 2016. In 2017, each customer experienced 962 hours of interruption on average, which corresponds to 40 days per year without electricity, versus 16 days in 2016. Causes of poor reliability of supply include the lack of maintenance and investments needed to provide reliable service. Especially, the high costs of the REGIDESO hampered its financial situation and the regulated tariffs were fixed below cost-recovery.

1.5.4. Electricity losses

Two types of electricity losses are distinguished, technical, and non-technical losses. The technical losses are due to the dissipation of electric energy through the transmission and distribution, such as poor equipment level, unbalanced loading, and heating insulation materials between conductors (Jawad & Ayyash, 2020; Viegas et al., 2017). The non-technical losses are associated with the connections to the network, the system of metering, billing, or fraudulent behavior (Cambini et al., 2014; Fumagalli et al., 2007; Jawad & Ayyash, 2020; Smith, 2004; Viegas et al., 2017). The electricity losses in Burundi range between 20% and 30%.

One of the causes of non-technical losses is the unpaid bills which became unrecoverable. Especially, debt from the public sector and from the residential is higher than that of general commerce and industries[15]. A parliamentary inquiry carried out in 2012 shows that the accumulation of unpaid bills results from the slowness in collection. Table 1-8 shows the distribution of unpaid bills between the different customer categories and over electricity sales.

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[15] The government debt includes those of ministries, public schools, military camps, and municipalities, personalized state administrations, and diplomatic missions. Debt for residential includes households and religious missions.

Table 1-8. Trends in unpaid water and electricity sales by customer category and in terms of electricity sales

Year	Unpaid water and electricity bills by customer category (%)			Unpaid bills over electricity sales (%)			
	public	business	residential	public	business	residential	Total
2008	48.7	17.9	33.4	47.9	17.6	32.8	98.2
2009	49.7	16.9	33.4	51.4	17.5	34.6	103.4
2010	52.1	12.1	35.8	48.3	11.2	33.2	92.7
2011	45.4	17.0	37.6	44.3	16.6	36.7	97.6
2012	44.3	15.1	40.6	45.7	15.6	41.8	103.1
2013	29.2	21.1	49.7	27.1	19.6	46.1	92.8
2014	42.8	17.3	40.0	58.7	23.7	54.9	137.3
2015	42.5	18.0	39.5	82.1	34.7	76.4	193.2
2016	43.7	17.9	38.4	78.2	32.0	68.6	178.7
2017	44.1	20.3	35.6	80.1	36.9	64.6	181.6
Mean	44.3	17.3	38.4	56.4	22.5	49.0	127.9

Source: Compiled by the author on the basis of REGIDESO data

Unpaid bills for water and electricity exceed electricity sales. The high unpaid bills are associated with the bad financial position of the REGIDESO, which lack funds to rehabilitate the existing electricity network and to invest in the new generation, transmission, and distribution of electricity.

The high cumulated unpaid bills conduct to the higher debt of the REGIDESO, especially for its suppliers such as Interpetrol, SNEL and SINELAC, a situation qualified of circular debt in Pakistan (Kessides, 2013; Mirza et al., 2021; Zameer & Wang, 2018). The circular debt occurs when the government delays in releasing subsidies on time or its failure to pay the differential costs to power generation, which affects the performance of the entire value chain and prevents profits to the electricity utility.

In order to pay for the electricity purchased and sustain the financial health of the REGIDESO, the government increased the electricity tariffs. The next subsection analyzes the tariff structure in Burundi and compares it with other Eastern Africa countries.

1.5.5. Electricity pricing system

In general, the literature distinguishes three type of electricity tariff structure : Increasing Block Tariffs (IBT), Decreasing Block Tariffs (DBT) and Linear Block Tariff(LBT) (Briceño-Garmendia & Shkaratan, 2011; Pacudan & Hamdan, 2019). In the IBT, the unit price per kWh follows an increasing step-function linked to sequentially defined blocks. It is the opposite for the DBT which is generally applied in the general commerce where the prices reduce when high quantities are purchased. In the linear tariff, the is no discrimination in the tariffs. The price is the same for each kWh consumed.

In Burundi, electricity tariffs have been always administered. Before the creation of the regulatory authority, the government set the tariffs without taking network costs into account. The tariff set up in 2011-2012 aimed at improving REGIDESO's financial health. However, the electricity supply didn’t increase. Another tariff increase occurred in September 2017. It was estimated on the basis of new investments in power plants and the operating costs of the REGIDESO. Thus, the tariff was increased to 20 cents per kWh. Before the increase of 2017, it was estimated that the tariff structure was below the marginal costs, which hampered cost recovering and enhanced the bad financial health of the public company.

The electricity tariff has almost doubled for all end users. According to interviews with some consumers, the tariff increase did not take into account the population purchasing power, resulting in under-consumption. In response to the tariff increase, some consumers who are able combine electrical energy for electrical appliances with solar energy for lighting or heating. The under-consumption of electricity is associated with the lack of foreign exchange that the country suffers. Much of the industry business is idle due to the lack of imported raw materials[16].

The IBT-based tariff structure also disadvantages large consumers. The more electricity is consumed, the higher the tariff paid and the higher the costs. Electricity is one of the costs that every company has to bear. One of the large industrialists interviewed said that the new tariff structure tripled his electricity costs from BIF 50 million to BIF 150 million per month. The hoteliers interviewed revealed that under the current tariff structure, electricity costs consume one third of turnover. They propose to change the tariff structure based on DBT.

We also compare the tariff structure applied in the East African Community (EAC) for two end-users, the LV household, and the large industrial tariff. For households, except Uganda which applies a linear tariff, other countries apply an IBT. Given the block differential and the fixed charges in each country, we consider an average consumption of 225 kWh per month for households and determine the average price per kWh. For large industries, fixed charges are applied per month according to the subscribed power, in addition to the price per kWh. Due to the lack of information on the level of power subscribed, we only compared the price per kWh. Since the tariffs are expressed in the local currencies, and taking into account the fluctuation of the exchange rate, the average tariffs were converted in US dollars 2010 exchange rate[17]. The structure of tariffs in the EAC is replied the figure 10.

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[16] Burundi has long suffered from a lack of foreign exchange, with limited exports compared to imports. Much of the foreign exchange was provided through budget support, which has dried up since 2015. Statistics from the Bank of the Republic of Burundi (BRB) show a net external reserve stock that is negative. In response to the shortage of foreign reserves, a policy of rationing has been implemented, favoring imports of pharmaceuticals, chemical fertilizers and petroleum products.

[17] The exchanges rates are obtained from the World Development Indicators. Electricity tariffs are obtained from the Electricity Regulatory Authority in Uganda, Rwanda Utility Regulatory Authority in Rwanda, Kenya Power Lighting Company in Kenya and Tanzania Electricity Supply Company in Tanzania.

Table 1-9. East African countries' electricity tariffs in 2020 (US$, 2010)

Country	Household	Large industries
Burundi	0.27	0.26
Kenya	0.20	0.13
Rwanda	0.40	0.18
Tanzania	0.19	0.11
Uganda	0.35	0.14

Source: Compiled by the author based on country data

It’s shown that Rwanda and Uganda charge higher tariffs for LV consumers than large industries. In Burundi, the tariffs for LV and MV consumers are a bit the same. Tanzania charges the lowest tariff to the two customers, compared to other countries. A study carried out in the EAC shows that households account for the largest share of national electricity consumption in Burundi and Rwanda. It also shows that residential customers account for 5% of consumption and less than 30% in Uganda and Kenya (REN21, 2016).

1.6.Discussion and policy implications

From the previous sections, it is clear that the electricity sector in Burundi is facing poor performance. Indeed, access to electricity remains one of the lowest in the world. In addition, the electricity sector has been characterized by significant power outages, particularly load shedding. Also, the financial health of REGIDESO, a horizontally and vertically integrated company, leaves much to be desired. The poor performance of the electricity sector could be attributed to technical, economic and governance causes.

The electricity sector in Burundi is characterized by a lack of supply while demand is increasing. Indeed, the supply of electricity is based on hydroelectric power plants built in the 1980s, whose available capacity is steadily decreasing. The age of the power plants thus affects their capacity. In addition, the electricity supply is vulnerable to climate change, especially due to long dry seasons. These long dry seasons, not only affect electricity production, but also cause major famine and food crisis (Aghakouchak, 2015).

The level of Lake Rwegura, the largest hydroelectric plant in Burundi, is constantly decreasing. The study on energy problems and choices carried out in 1992 had already shown that the existing installed capacity could cover the demand until 1995 (The World Bank, 1992). In addition, the transmission and distribution network is aging, especially the urban network of Bujumbura which is responsible for a large part of the power interruption. It should be noted that the existing facilities in the 1990s were intended to supply the city of Bujumbura with little districts and the other towns of the provinces. In the meantime, the city of Bujumbura, as well as other cities have grown, which has pushed up the electricity demand. The increase in connection reduced the QoS through voltage fluctuations, resulting in losses for users.

A large part of the population along the electricity network is not connected, which often leads to illegal connection. For example, a large part of households surrounding the city of Bujumbura have illegal connections, which is often the cause of fatal accidents. The lack of connection stems to some extent from the scattered settlement structure in rural areas. As noted Williams et al. (2015), low density and highly dispersed settlement patterns increase distribution infrastructure costs per customer comparatively to more densely populated areas. The low level of connection can also be linked to the low purchasing power of the population. Blimpo & Cosgrove-Davies (2019) report the connection of an additional customer leads to increased losses for the utility[18]. Moreover, as stated Golumbeanu &

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[18] During our visit in some regions, we discovered some localities where REGIDESO has installed transformers that connect only one customer. This becomes very expensive since the individual consumption is limited whereas the cost of a transformer is exorbitant. To this, we must add the cost of transmission and distribution networks.

Barnes (2013), connection charges in SSA are the highest in the World. As a result, high electricity charges may discourage low-income households to afford monthly bills.

The electricity is also suffering from a lack of funding. Existing electricity infrastructures in Burundi have been constructed on the basis of external funding, both in the form of concessional loans and grants. However, the poor financial health of the power company, exacerbated by high operating charges, has resulted in failure to repay debts, which has led to insolvency. As a result, not being able to improve the financial situation of the electricity company makes it difficult, if not impossible, to contract external debt. Moreover, since Burundi does not have any financial rating, borrowing at relatively high interest rates limits its ability to repay. It should also be noted that the domestic debt of the state is becoming increasingly excessive, which limits the private sector's financing.

Even though laws on liberalization and privatization have been enacted, it remains that the trend is towards nationalization of public enterprises, which often leads to governance problems. The adoption of reforms is slow and faces internal political conditions and resistance. Such problems include political instability, internal conflicts, and the instability of leaders. Gore et al. (2019) show that poor access to other financial support, domestic political conditions, and political resistance affect the timing, pace, and extent of reforms. In Burundi, resistance to the reform implementation is manifested through the weak willingness to disengage in state-owned utilities.

One of the virtues of maintaining a vertically integrated monopoly is the reduction of transaction costs, particularly in contract negotiations. This is possible if there is a strong institutional context. However, in the case in weak institutional settings, the electricity sector may be vulnerable to corruption. This is possible notably in large projects such as the construction of large hydroelectric dams, government intervention, monopolistic characteristics of the sector, lack of competition, and substantial revenues from the sale of electricity (Imam et al., 2019). A series of hydroelectric dam projects die before completion. This is the case of the Mpanda and Kabu 16 hydroelectric projects which should be commissioned in 2021 as seen in table 1-2.

Also, poor governance in the negotiation of contracts lengthens project execution times. This is the case for the solar and peat PPP contracts that should be available from 2019. REGIDESO negotiated a contract for supplying diesel power of 30 MW, with an independent power producer. With this contract, REGIDESO must pay for the service provided even if the installed capacity has not been entirely consumed[19]. Contract negotiation problems are at the root of the increased costs for REGIDESO, potentially leading to insolvency with its debtors. Also, the increase in unpaid electricity bills by various customers, coupled with the increase in costs related to the thermal energy contract, has led to a circular debt, as REGIDESO is no longer able to meet its debts to its debtors. The existence of circular debt can also be a barrier to private investment. The contract negotiation problem can also be the reason for the length of the infrastructure construction work, from the preparation of the bidding documents to the execution of the contract. Muzenda (2009) proposes that tenders should be advertised, while limiting restricted tenders, to ensure transparency.

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[19] It should be noted that the negotiated installed capacity exceeds the available capacity of REGIDESO, which has made it possible to increase the electricity supply. The same independent producer has a monopoly on fuel imports. The risk is that if the government maintains the tariffs at a level that does not allow for cost recovery, the producer could threaten to break the contract, thus leading to poor quality of service and access to electricity. Also, it could exercise its monopoly power by making fuel scarce in order to negotiate a price increase, which would lead to higher prices throughout the country and a reduction in the standard of living of the population.

To improve the performance of the electricity sector, it is important that the government horizontally separate the two utilities of drinking water and electricity. The government could initially subsidize the water utility to make it profitable and attractive to the private sector. For the power sector, the government could accelerate the ongoing construction of hydroelectric plants. It could then implement competition in both infrastructure and service provision to attract investment in the power sector.

It should implement favorable investment climates, clear policy and regulatory frameworks, and local availability of cost-competitive fuels (Eberhard et al., 2017, Eberhard & Gratwick, 2011). Burundi should also prioritize regional generation, transmission and cross-border trade projects to improve service quality and access to electricity. Burundi should also work to increase the quality of service, particularly by reducing power outages. The proposed approaches are outlined in Chapter 2.

2. The cost of quality of service improvement in electricity distribution in Burundi: a parametric shadow price approach[20].

Abstract

The quality of service (QoS) in the sector is of paramount importance to the industry, to customers and to the regulator. It is measured by the duration and frequency of electricity interruptions and their consequences. Improving the QoS in the electricity sector cannot be achieved without costs. In this paper, we estimate the cost of preventing losses due to electricity interruption at REGIDESO, a vertically and horizontally integrated company in Burundi. We use a parametric output distance function approach, assuming that the utility's objective is to increase the number of customers and the amount of electricity delivered. Electricity losses enter the production process as inputs, imperfect substitutes for capital. We identify the sources of inefficiency and the trade-off between poor QoS and capital investments. To estimate the translog output distance function, we make use of Parametric Linear Programming approaches. The results show that customers are the main drivers of costs. The shadow price of QoS is estimated at US$223.70 and is higher in Bujumbura than other regions.

Keywords: Quality of service, Output distance function, shadow price, REGIDESO.

2.1. Introduction

Like other goods and services, electrical energy must be delivered with a high quality of service (QoS). One aspect to which every electricity distributor must pay attention is the system's reliability, that is the ability of the system to meet customer

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[20] Joint with Axel Gautier, Sergio Perelman and Salomon Nsabimana

demand without interruption (Ajodhia & Hakvoort, 2005; Coelli et al., 2013; Fumagalli et al., 2007). System reliability is usually estimated by measuring the average power outage experienced by each customer in terms of frequency and duration. Poor grid reliability often leads to electricity losses, with a negative effect on the utility, consumers and the country (Zhou et al., 2014).

Electricity losses are often defined both in terms of the proportion of purchased energy that does not reach the end user, or by the difference between delivered energy and purchased energy. However, electricity losses can also result from outages, i.e. the amount of electricity not delivered during the outage time. Estimated on an annual basis, the electricity not delivered due to outages can be obtained by the difference between the energy potentially delivered in the absence of outages, and the electricity delivered. It is this measure of electricity loss that is used in this study.

Power losses due to outages are considered as undesirable outputs that every utility seeks to avoid due to the associated costs. For the utility, they represent the additional capital expenses to avoid outages such as constructing new power plants, upgrading the transmission and distribution network, installing specific equipment for outage detection, etc. It also includes the additional operational expenses incurred to maintain the good QoS: purchase of various equipment and supplies, additional manpower, financial charges, penalties paid for not meeting service quality standards, etc. For customers, power losses are the losses incurred as a result of voltage variation or power cuts, which also result in additional expenses for lighting, cooking or connecting electrical appliances. The variation in power voltage often leads to house fires, equipment deterioration, while the electricity company cannot repair the damage. These losses are measured by estimating the willingness to pay (WTP) to avoid power cuts. Finally, for the society or country, costs represent the total subsidies allocated to the electricity sector to mitigate power cuts, which would have been allocated to other priority sectors.

The cost of QoS can be estimated through the shadow price, defined as the marginal rate of transformation between good and bad outputs, or the marginal rate of technical substitution between good and bad inputs (Färe et al., 1993; O'Donnell & Coelli, 2005). The derivation of shadow price from undesirable output or input requires information on the market price of the desirable output or input. More specifically, the observed price of desirable output (input) reflects its shadow price, while the absolute shadow price of undesirable outputs reflects the opportunity costs. In the literature, the shadow price has been estimated in various areas, such as energy (Coelli et al., 2013; Färe et al., 1993; Küfeoglu et al., 2018; Mirza et al., 2021; Yuan et al., 2021; Zhou et al., 2014), water (Brea-Solis et al., 2017; Maziotis et al., 2020; Molinos-senante et al., 2021), railways (O'Donnell & Coelli, 2005), airways (Coelli et al., 1999), public sector (Grosskopf et al., 1995), and banking (Fukuyama & Weber, 2008). In these studies, the shadow price represents either the compensation or penalty resulting from poor QoS, or additional investment costs to improve the QoS.

To estimate the shadow price of QoS, a flexible translog multi-output multi-input technology is computed using either stochastic frontier Analysis (SFA) or parametric linear programming (PLP) which are both parametric approaches. The SFA approach distinguishes two types of random errors, a noise error and an inefficiency term. The random noise term picks up whatever the model cannot explain such as uncontrollable or unobservable factors. On the other hand, the inefficiency term which captures firm's inefficiency such as managerial inefficiency (Llorca et al., 2016). In the SFA approach, environmental variables can be considered in two ways, either by entering the production function as additional inputs, or in a second stage as drivers of technical efficiency. On the other hand, the PLP technique selects the values of parameters by specifying a parametric functional form for the production technology using linear programming. It is used to estimate the production frontier by minimizing the total value of distance functions over the sample. It is insensitive to the effects of unobservable variables, but imposes monotonicity restrictions at all points of the production function (Coelli et al., 2013; Coelli & Perelman, 1999).

In this paper, we estimate the shadow price of QoS in Burundi electricity sector, using an output distance function. In fact, REGIDESO is a vertically integrated utility in charge of generation, transmission and distribution of electricity (and water) in Burundi. The company serves 19 districts within five regions and we managed to obtain detailed information on the electricity distribution activity at the district level[21]. An important policy objective is to increase the distribution of electricity in Burundi, especially the number of connected households and firms and the amount of electricity delivered. We have detailed information on these outputs (customers and electricity delivered) at the district level. The rationale for using the output distance function derives from the fact that REGIDESO seeks to maximize its output (at the district level) given the available input.

To compare the different districts, we need information on the distribution activity at the district level i.e. the input used in each district by REGIDESO. Finding appropriate data on the electricity distribution is a concern as the company is integrated both vertically and horizontally (water + electricity) and the distribution activity is not organized independently at the district level. Information on both labor and generation at the district level is therefore not available.

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[21] In this study, we use the data of 18 districts, those of the 19th district being not available for one variable.

In our approach, we use a capital input: the transformers capacity at the district level (in kVA) which are an important part of the distribution network. A higher transformer capacity allows the company to increase the outputs at the district level. We use a second input, electricity losses due to outages at the district level. We detail hereafter how we construct this variable.

One of the reasons for electricity losses is the lack of capital or the poor quality of capital of the distribution network, and a higher quantity/quality of capital decreases electricity losses. Electricity losses are an imperfect substitute to capital as power outages could also have been caused by other factors, for instance the lack of generation capacity. Our main interest is to measure the substitutability between capital and electricity losses, and to compute the shadow price of capital, i.e. the capital cost of increasing QoS.

The current study contributes to a threefold objective. First, we compare the technical efficiency of REGIDESO across its 19 districts located in 5 regions of Burundi, from 2014 to 2017. To do so, we make use of a parametric output distance function, by considering environmental and region-specific effects. Secondary, we compute the shadow price of QoS, identify the trade-off between QoS and capital by estimating the marginal rate of technical substitution between capital and electricity losses. Finally, the study is based on a dataset compiled by the authors through their own surveys[22] and those provided by the electricity company.

This paper is organized as follows. In the second section, we describe the electricity distribution in Burundi. In the third section, we present how to measure the shadow price through the output distance function. We derive the input elasticities and the

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[22] Since we have no database on transformers in Burundi, we conducted a survey in September and October 2020 to establish their inventory and location. In this study, we consider the transformers as fixed capital.

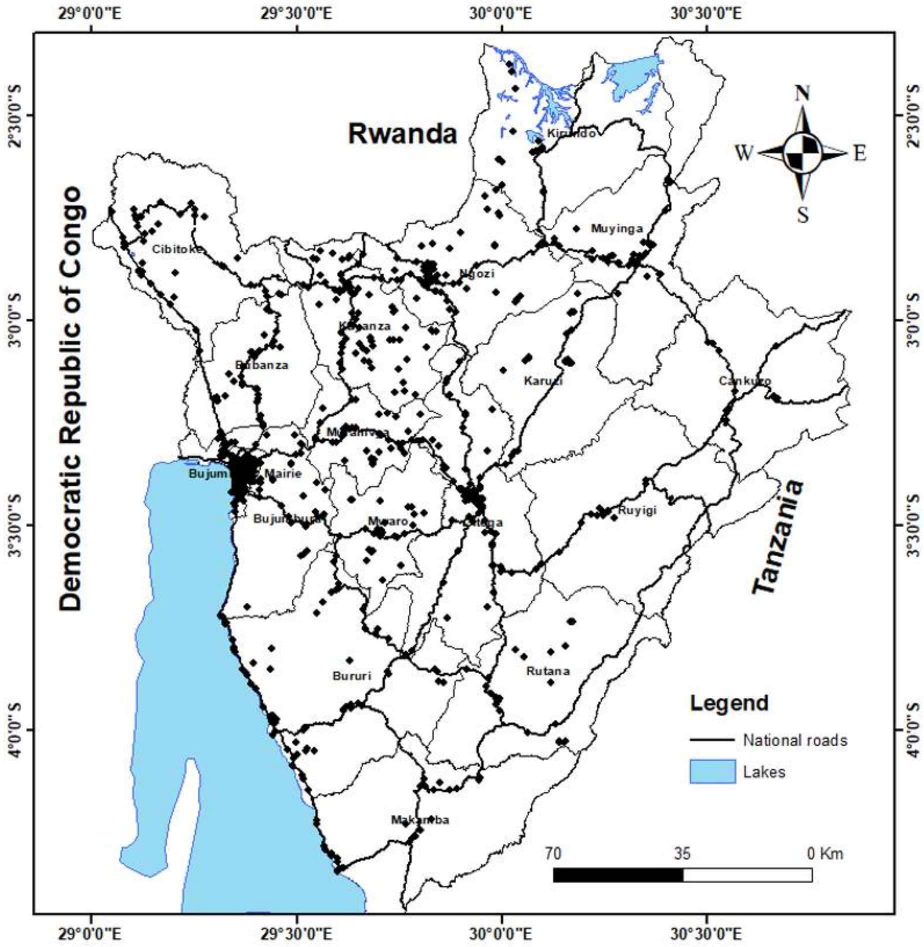
shadow price of QoS in the fourth section and present data in the fifth section. The results are presented and discussed in the sixth section. Finally, we conclude.

2.2.Electricity distribution network and quality of service in Burundi

The electricity sector in Burundi is vertically integrated, under the management of a state-owned utility, the REGIDESO. The grid system is made of interconnected network formed by height generating plants, 14 distribution substations, five regions and 18 districts. From the various distribution substations, electricity is disseminated to consumers through distribution feeders, which are either underground or overhead. The underground lines were built in the cities of Bujumbura and Gitega in the 1960s and are outdated. Due to the lack of investment for maintenance and repair, the underground network is subject to power cuts that can last for several days, resulting in poor QoS, especially in downtown Bujumbura.

The electricity transmission and distribution network in Burundi, as well as the commercial system, is managed across 5 regions comprising 19 districts. It includes both the interconnected network and the off-grid network formerly managed by the Agence Burundaise d'Electrification Rurale (ABER). The capacity of transformers differs according to the number of customers, the type of customer and the area served. In Burundi, the distribution network transformers have an installed capacity that varies between 25 and 630 kVA. Figure 1 shows the distribution of transformers across the 19 districts.

Figure 2-1. Transformer distributions in Burundi



Source: The authors based on the survey data

These transformers are located on the main national roads and in the main urban centres. The Bujumbura region concentrates more than half of the transformers, followed by districts such as Gitega, Ngozi and Kayanza. In addition, some localities have only one transformer serving one or a minority of customers.

Since the 1990s, Burundi has experienced a large deficit in electricity supply due to high demand over available generation capacity[23]. Since the 2010s, a load shedding program has been undertaken, particularly at peak hours. Some distribution feeders have experienced long planned load shedding ranging from 1 to 12 hours per day, and sometimes a whole day, as evidenced by the 2014-2015 World Bank survey.

REGIDESO records huge electricity losses, especially accumulated unpaid electricity bills which exceed sales, as seen in chapter 1. The low collection of unpaid bills, combined with technical losses, hinders any investment project by REGIDESO to provide more electricity and connect the largest number of customers. As Blimpo & Cosgrove-Davies (2019) stated, electricity outages constitute the main cost of doing business in Sub Saharan Africa and constraints industries and services expansion. More specifically, electricity outages have a negative impact on firm productivity and competitiveness, and reduce public finance through low tax collection.

2.3.Material and methods

A distance function approach specifying the production technology of a multi-output multi-input firm was been first proposed by Shephard (1970). Output distance shows the maximal expansion in output vector keeping the input vector unchanged. In this section, we present the output distance function and its properties and derive the shadow price through the SFA and PLP approaches.

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[23] The electrification program undertaken since 2007 has increased the number of customers, which more than doubled between 2008 and 2017. However, no additional generation plants have been commissioned so far.

2.3.1. The output distance function

In a multi-output multi-input production technology, let consider a firm $i\epsilon(1,2,\dots,N)$ using a set of inputs vector $X=(x_1,\dots,x_K)\,\epsilon\mathcal{R}_+^K$ to produce a set outputs vector $Y=(y_1,\dots,y_M)\epsilon\mathcal{R}_+^M$ at time $t\epsilon(1,2,\dots,T)$. A production technology in the case of multi-output multi-input function is defined as:

$$P(x)=\{(\,y\,\epsilon R_+^M : x\ can\ produce\ y\} \qquad (1)$$

The production technology satisfies the proprieties discussed by Färe & Primont (1995). From the production technology, Shephard (1970) defined the output distance function on the output set $P(x)$ as:

$$D^o(x,y)=min\{\,\rho : \left({}^{y}/_{\rho}\right)\epsilon P(x)\} \qquad (2)$$

For each point (x,y), we seek the lowest value of the scalar ρ so that $(x,y/\rho)$ remains within the feasible production possibilities bounded by the frontier, known as technical efficiency score.

$D^o(x,y)$ is non-decreasing, positively linearly homogeneous and convex in y, and decreasing in x. If y is an element of the feasible production set $P(x)$, $D^o(x,y)\leq 1$. If y belongs to the isoquant $P(x)$, $D^o(x,y)=1$ and the firm is efficient. The output distance function provides information on how to proportionally expand the output vector without modifying the input vector.

2.3.2. Translog output distance function

In this section, we define the output distance function in the case of multi-input multi-output production technology, in which a firm uses $K*1$ input vector

$x(x_1, x_2, \dots, x_k)'$ to produce $MX1$ output vector $y(y_1, y_2, \dots, y_m)'$. The translog distance function over M outputs and K inputs for firm i can be written as follows:

$$lnD_i^o = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mi} + 0.5 \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni} +$$

$$\sum_{k=1}^{K} \beta_k ln\, x_{ki} + 0.5 \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \ln x_{ki} \ln x_{li} + \sum_{k=1}^{K} \sum_{m=1}^{M} \delta_{km} \ln x_{ki} \ln y_{mi} + \sum_{j=1}^{J} \theta_j z_{ji},$$

$$i = 1,2,..,N \qquad (3)$$

Where $\alpha, \beta, \delta\ and\ \theta$ are the unknown parameters to be estimated, and lnD_i^o the translog distance function. $\ln y_{mi}\ and\ ln\, x_{ki}$ are expressed into logarithm in deviation from their sample means. z_{ij} for $j = (1, \dots, J)$are exogenous environmental variables that can affect the production technology for the i^{th}firm of the sample.

We assume that the output distance function respects the restrictions for homogeneity of degree +1 in the outputs:

$\sum_{m=1}^{M} \alpha_m = 1,$

$\sum_{n=1}^{M} \alpha_{mn} = 0,$

$\sum_{m=1}^{M} \delta_{km} = 0,\ k = 1,2, \dots, K,$ (4)

those of symmetry

$\alpha_{mn} = \alpha_{nm},\ m, n = 1,2, \dots, M;$

$\delta_{km} = \delta_{mk}, k, l = 1,2, \dots, K,$ (5)

and the monotonicity conditions which imply that the elasticities with respect to outputs and inputs satisfy respectively non decreasing and non-increasing restrictions:

$max\ \sum_{i=1}^{N} lnD_i^o$

s.t $lnD_i^o \leq 0, i = 1,2,\dots,N$ and $D_i^o \leq 1$,

$e_{ki} = \frac{\partial lnD_i^o}{\partial lnx_{ki}} = \beta_k + \sum_{l=1}^{K} \beta_{kl} \ln x_{li} + \sum_{m=1}^{M} \delta_{km} \ln y_{mi} \leq 0, i = 1,2,\dots,N, k = 1,\dots,K$

$e_{mi} = \frac{\partial lnD_i^o}{\partial lny_{mi}} = \alpha_m + \sum_{n=1}^{M} \alpha_{mn} \ln y_{ni} + \sum_{k=1}^{K} \delta_{km} \ln x_{ki} \geq 0, i = 1,2,\dots,N, m = 1,\dots,M$ (6)

Where e_{ki} and e_{mi} are the partial elasticities with respect to inputs and outputs respectively. We note that PLP determines at least one point such that $D_i^o = 1$, which represents the frontier.

2.3.3. *Shadow prices*

The partial derivative of the output distance function with respect to the k^{th} input is used to define its shadow price. It reflects the slope of the isoquant, i.e, the marginal rate of technical substitution (MRTS) between two inputs. The shadow price is defined as the ratio of the partial derivatives. It is obtained as follows:

$$\frac{w_{ki}^*}{w_{li}^*} = \frac{\partial D_i^o/\partial x_{ki}}{\partial D_i^o/\partial x_{li}} = \frac{e_{ki}}{e_{li}}\frac{x_{li}}{x_{ki}} \quad (7)$$

$$\frac{w_{mi}^*}{w_{ni}^*} = \frac{\partial D_i^o/\partial y_{mi}}{\partial D_i^o/\partial y_{ni}} = \frac{e_{mi}}{e_{ni}}\frac{y_{ni}}{y_{mi}} \quad (8)$$

Where w^*_{ki} and w^*_{li} are shadow prices with respect k^{th} and l^{th} inputs, w^*_{mi} and w^*_{ni} are the shadow price with respect to m^{th} and n^{th} outputs. In this study, we are interested by the shadow price with respect to inputs, that is the MRTS between capital and poor QoS.

2.4.Data collection

Data has been collected through 19 districts that belong to REGIDESO, and for 4 years from 2014 to 2017, based on the availability of data, particularly those related to power cuts. Data on processor capacity was collected through a survey conducted by the authors between September and October 2020. Transformers are considered as fixed capital as they do not change over time. Data on the power outages are missing for one district during the four years[24], and for two districts during one year. As data is cross-sectional, we omitted the missing values. Therefore, we consider data for 18 districts for four years, with 70 observations.

2.4.1. The output variables

Two outputs are commonly used in comparing the performance of the electricity sector: the electricity delivered and the number of customers. Electricity delivered, measured in MWh, is the amount of electricity consumed and invoiced that reaches the end-user. It excludes technical and non-technical losses. Even if the electricity is delivered, part of the invoices remains unpaid, as part of non-technical losses. In Burundi, much of the electricity consumed remains unpaid, particularly that for the public sector. Since the beginning of the 2010s, REGIDESO has generalized the use of prepaid meters, especially in the main urban centers, in order to maximize revenue collection. However, the tariff structure does not stimulate high

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[24] The power cuts concerning the Jenda-Mwaro-Tora distribution station were not listed by the national dispatching center because the station was out of service during the study period.

consumption[25]. REGIDESO also complains about under-consumption of electricity, which distorts expectations in terms of delivered electricity.

The second output is the number of customers. REGIDESO distinguishes 11 types of customer categories that can be grouped into residential and non-residential customers. The residential category includes households and small and medium-sized firms. Non-residential category includes industries and higher businesses, the public sector, diplomatic and religious missions, etc. In this study, customers are identified through the number of electricity meters which are either pre- or post-paid[26].

2.4.2. Input variables

Two input variables were chosen, transformer capacity representing capital, and the amount of electricity losses due to outages, a proxy for QoS. The transformers considered are those of the distribution system with capacities varying from 25 to 630 kilovolt amperes (kVA). We have omitted transformers located at power plants and distribution stations whose installed capacity generally exceeds 1000 kVA.

The second input is the electricity lost due to power outages. We collected daily information on load shedding listed by feeder and by distribution station. We

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[25] The electricity billing system in Burundi discriminates according to the quantity consumed and the category of customers. A social tariff is set for consumption of up to 50 kWh. Beyond this amount, the electricity tariff increases as the consumption blocks increase. It should be noted that household tariffs differ from those of the industrial sector and the public sector.

[26] The tariff system distinguishes between low and medium voltage customers. Low voltage customers include household, commerce and industry, and administration. Medium voltage customers depend on the type of contract: medium voltage with subscribed power, with subscribed power and peak, without subscribed power or peak. The available data relate to sales in BIF and not in quantity and by district. The data available by customer group relates to sales in BIF and not in quantity, the latter being listed by district. This is why the customer variable relates to districts and not to categories.

established the average interruptions duration and frequency per substation, and extrapolated them to the districts according to the level of closeness[27]. It should be noted that a district is sometimes associated with one or more distribution stations. The calculation of the average does not therefore accurately reflect the reality of each district. It should be noted that some districts have two or three distribution points. We therefore estimate the losses by averaging the outages from the corresponding distribution stations. We have defined the electricity not served due to outages as the difference between potential consumption if available 24 hours a day and the electricity actually delivered through the following formula:

$$Electricity\ Loss_{it} = \frac{Electricity\ delivered * Interruption\ duration}{365 * 24} \qquad (9)$$

2.4.3. Environmental factors

Three variables are considered for environmental factors, customer density, industry proportion and monetary poverty. Customer density ($Dens$) was calculated on the basis of the ratio between the number of customers provided by REGIDESO, and the area covered by the network. The latter was estimated by the authors, based on the geographical position of transformers. Assumed that all surrounding households are connected to electricity, and using Google Earth Pro,

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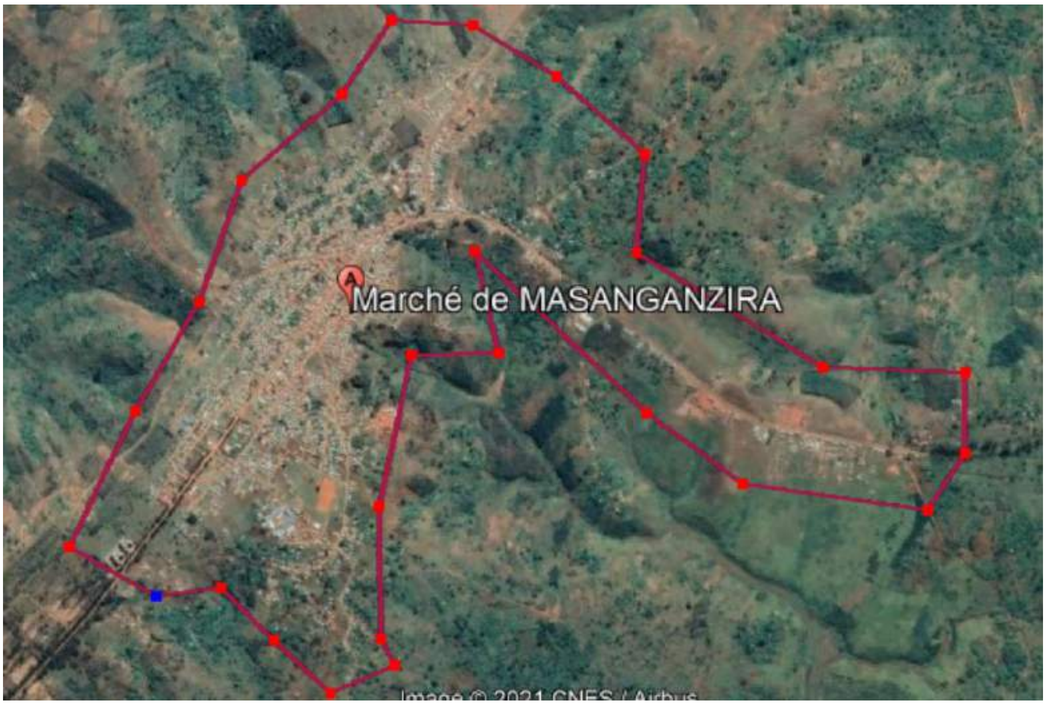
[27] Electricity losses due to outages are those corresponding to load shedding that took place between 2014 and 2017, each lasting at least 30 minutes. We have omitted planned outages due to works or other failures with generally short durations. Load shedding was recorded on a daily basis at distribution stations through reports compiled at the national dispatching centre. At REGIDESO, while the distribution substations are administered by the electricity department, the districts are under the commercial department. Power outages are reported at the distribution station level, while customers and delivered electricity fall under the commercial department. To estimate the electricity due to outages, we took into account the closeness of the distribution substations to the districts. Thus, the estimated losses differ from the technical and non-technical ones, which result from the difference between purchased and delivered electricity.

we determined the area in km^2. Each district's total area is the sum of the sub-areas covered by the transformers. Figure 2 shows an example of area calculation.

Figure 2-2. Determination of the area



Source: The authors using google maps.

Monetary poverty (Pov) reflects the ability to connect to the grid and to consume electrical energy. The lower the monetary poverty rate, the higher the demand for electricity connection and consumption. On the other hand, high monetary poverty could be associated with non-technical losses such as theft. Data on monetary poverty comes from the report of the modular survey on the household living conditions carried out in 2013/2014 by the Institut des Statistiques et Etudes Economiques au Burundi (May 2015). The determination of the monetary poverty rate took into consideration the annual expenditure per adult equivalent. We assume that monetary poverty remains the same throughout the study period.

The third environmental variable is the proportion of industrial sector. Industrialization is generally conditioned by connection to electricity. The presence of an industry is materialized by all transformers with a capacity equal or higher than 300 kVA. Industrialization generally corresponds to a high level of electricity consumption. In times of energy deficit, we assume that the presence of an industry increases electricity cuts and therefore the poor quality of service. If there are industrial zones, REGIDESO could concentrate electricity distribution there in the event of a shortage, to the detriment of the residential sector. A large part of these transformers is located in Marie de Bujumbura. In other distribution centers, these industries represent, for example, water pumping stations, tea factories, cement factories, etc. The industrialization rate of each district is defined by the ratio between the total installed capacity of transformers and their number. Table 2-1 summarizes data.

Table 2-1. Summary of data

Variable	**Unit**	**Mean**	**Std. Dev.**	**Min**	**Max**
		Outputs			
Customer (y_1)	Numbers	5698.19	14867.58	539.00	79036.0
Electricity delivered (y_2)	MWh	10992.44	33007.94	120.84	160974.8
		Inputs			
Transformers (x_1)	Kva	10556.99	18229.77	1360.0	81785.00
Electricity losses (x_2)	MWh	750.20	2471.92	0.09	13125.17
		Environmental variables			
Monetary Poverty (Pov)	Percent	0.58	0.15	0.17	0.80
Industry proportion (Ind)	≥300 kVA	0.26	0.19	0.00	0.66
Customer density ($Dens$)	number per km^2	10.69	7.50	1.24	38.37

Source: Compiled by the authors from REGIDESO and survey data

Table 2-1 shows the existence of a large disproportion of variables by district. This is particularly noticeable for the input and output variables. With regard to the environmental variables, there is also a large variation between the districts. The monetary poverty rate is close to 100% in some regions, which makes the average exceed 50%. This determines the low capacity to face the costs of connection and payment of electricity consumed. Low industrialization also may determine under-consumption of electricity. The average proportion of transformers with a capacity greater than or equal to 300 kVA is below 30%. This shows that a large part of customers is the residential sector, with low consumption. Furthermore, the customer density is low in almost all districts, the highest being 38 customers per kilometer square. Table 2-2 shows the correlation between input and output variables.

Table 2-2. Correlation of inputs and outputs

	Customer	Electricity delivered	Transformer capacity	Electricity losses
Customer	1			
Electricity delivered	0.98	1		
Transformer capacity	0.97	0.98	1	
Electricity losses	0.95	0.96	0.94	1

Source: Compiled by the authors

There is a high correlation between the input and output variables. A poor household is unable to afford neither the costs of electricity connection, nor the high tariffs of electric energy. A transformer can be installed in any area and still lack customers, due to poverty. Alternatively, the high poverty rate could be associated with electricity theft. The level of industrialization is also correlated with inputs and outputs. Industries require transformers with high installed capacity, taking into account the potential for electricity consumption. Table 2-3 shows the shares of output and inputs by region in 2017.

Table 2-3. Output and input shares in the different regions (%)[28]

Region	Outputs		Inputs	
	Customers	Electricity delivered	Transformer capacity	Electricity losses
Bujumbura	67.23	75.59	43.33	60.19
East	8.14	5.81	14.29	7.62
North	11.71	7.19	18.83	9.76
South	5.73	2.51	8.08	6.73
West	7.20	8.90	15.47	15.70

Source: Compiled by the authors

The Bujumbura region has more than 50% output and input. More precisely, it has 67.23% of customers and consumes 75,59% of electricity on average per year. In

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[28] The last line shows the total number of customers, the electricity delivered in MWh, the total transformer capacity in kVA, and the average electricity losses due to outages in MWh.

other words, the Bujumbura region is the most served in terms of electricity. It is the region that contains a large part of the industrial sector which consumes high electric energy quantity. As a result, it is the region that suffers a large proportion of electricity losses. On the other hand, the southern region is the least connected. In table 2-4, we report the partial productivities by region.

Table 2-4. Partial productivity per region

Region	Customer per 100 kVA	Electricity delivered per 100 Kva	Customer per MWh of losses
Bujumbura	80	176	7
East	38	43	1055
North	36	43	570
South	29	55	23
West	46	46	13
Mean	40	54	440

Source: Compiled by the author

Overall, a 100 kVA transformer connects 40 customers, while 440 customers share one MWh of electricity losses. However, there are disparities between regions. There is a high productivity of transformers for Bujumbura compared to other regions. A 100 kVA transformer connects 80 customers on average. The consumption per transformer in this region is 176 MWh, or 1.76 MWh per kVA. As a result, Bujumbura region experiences a high frequency of electricity overloads compared to the other regions, so that one MWh of losses is shared by 7 customers, compared to 1055 in the Eastern region.

2.5.Empirical Results

In this section, we present the results according to two models with and without environmental variables (z). We first present the coefficients of the translog variables estimated with the PLP approach. We then present the technical efficiency and the input and output elasticities.

2.5.1. Output distance function parameters

We estimate the output distance function using PLP approach. The underlined coefficients were obtained by application of the homogeneity of degree +1 in outputs and symmetry restrictions, the electricity delivered (y_1) chosen as the reference variable. Since the input and output variables are log-normalized with respect to their means, the first-order input and output coefficients can be interpreted as relative output distance function elasticities. The translog output distance function is non-decreasing in output and non-increasing in input, that is $\frac{\partial lnD_i^o}{\partial lnx_{ki}} \leq 0 \; and \; \frac{\partial lnD_i^o}{\partial lny_{mi}} \geq 0$

As a result, the input elasticities are negative, while those of output satisfy restrictions of homogeneity of degree +1 and are positive. Table 2-5 shows the computed parameters of the output distance function.

Table 2-5. Output distance function estimation

Parameters	Variables	Without z	With z
α_0	Intercept	-0.61	-0.43
Output interactions			
α_1	ln(y1)	0.703	0.687
α_2	ln(y2)	0.297	0.313
α_{11}	ln(y1)ln(y1)	0.000	0.025
α_{22}	ln(y2)ln(y2)	0.000	0.025
α_{12}	ln(y1)ln(y2)	0.000	-0.025
Inputs interactions			
β_1	ln(x1)	-0.865	-1.025
β_2	ln(x2)	-0.080	-0.100
β_{11}	ln(x1)ln(x1)	-0.414	-0.376
β_{22}	ln(x2)ln(x2)	-0.040	-0.052
β_{12}	ln(x1)ln(x2)	0.046	0.059
inputs-outputs crossing			
δ_{11}	ln(x1)ln(y1)	-0.078	-0.060
δ_{12}	ln(x1)ln(y2)	0.078	0.060
δ_{21}	ln(x2)ln(y1)	-0.017	-0.025
δ_{22}	ln(x2)ln(y2)	0.017	0.025
Environmental variables			
σ_1	Poverty (z1)		-0.028
σ_2	Industry (z2)		-0.532
σ_3	Customer-density (z3)		0.009

Source: compiled by the authors

The first order coefficients respect the monotonicity conditions, namely a positive sign for the output parameter coefficients, and a negative sign for the input ones. Moreover, the coefficients respect the restrictions on homogeneity of degree +1 in output and those on symmetry. Concerning the coefficients related to the outputs, those assigned to the customers are the highest. A large part of REGIDESO's activities are customer-related: connection to electricity, maintenance of the low-voltage network, installation of meters, management of complaints, invoicing and collection, etc. There is also a high weight of investments in transformers compared to electricity losses, which have a non-negligible value. The sum of the first-order coefficients for inputs in absolute values is less than one in the model without z (0.945) and greater than one in the model with z (1.125). The sum reflects the existence of returns to scale, which are decreasing in the model without z and increasing in the model with z. Thus, considering the model without z, any 10% increase in all inputs leads to a less proportional increase in output, i.e. 9.45%. However, in the model with z, any 10% increase in inputs leads to a greater than proportional increase in output, i. e. 11.25%. We can thus rely on the model with environmental variables, which estimates the output distance function well. Taking into account the weight of transformer investments in the coefficients, it is clear that their expansion would allow for a higher than proportional increase in the number of customers and the electricity delivered.

The coefficient on income poverty is negative. This is understandable since, despite the availability of the transmission and distribution network in some areas, very few customers are connected to it. Blimpo & Cosgrove-Davies (2019) note that connecting an additional customer in SSA generates more costs than revenues. Gaur & Gupta (2016) and Jawad & Ayyash (2020) stated that income poverty is one of the reasons for electricity theft. Connecting the poor to electricity requires government subsidies which would be directed towards reducing the cost of connection, and social tariffs for poor households.

The coefficient for the industrialization share is also negative. Indeed, industrialization increases the demand for electricity, while supply is insufficient. The higher demand over supply results in overloads, which cause power outages, and increase the electricity losses. Finally, the coefficient associated to customer density is positive. The higher the customer density, the lower the investment in the transmission and distribution network, and the higher the productivity.

2.5.2. Analysis of the technical efficiency scores

We represent in table 2-6 the technical efficiency scores obtained from the two models, under PLP approach.

Table 2-6. Technical efficiency scores

Region		Without z	with z
All	Mean	0.690	0.793
Year	2014	0.713	0.798
	2015	0.713	0.810
	2016	0.635	0.760
	2017	0.692	0.799
Regions	Bujumbura	0.744	0.934
	East	0.755	0.869
	North	0.650	0.796
	South	0.644	0.711
	West	0.709	0.754

Source: Compiled by the authors from the results

The average technical efficiency scores show that increasing the variables in the model improves performance. In fact, the technical efficiency scores increase from 69.2% to 79.9% when the model is switched from one without environmental variables to one with environmental variables, representing an increase of 10.3%. Thus, the performance gap which is 31% in the model without z decreases to 20.7% in the model with z. This is consistent with the findings of Giannakis et al. (2005) who report that efficiency scores increase with the number of variables. However, the performance gap in the two models remains very high based on the classification done by Barabutu & Lee (2018), Mbangala & Perelman (1997) and Xie et al. (2018). This shows that the electricity sector in Burundi remains inefficient. This inefficiency is evident throughout all years and regions, except the year of 2015 and Bujumbura region in the model with z.

The natural monopoly theory provides advantages in terms of economy of scale and scope. The REGIDESO is the only company that generates and operates the electricity transmission and distribution network. Moreover, it has no competition on the customers and can therefore carry out any supply related strategy. As Growitsch et al. (2009) stated, the technical efficiency scores contradict the assumption of economies of scale and scope.

2.5.3. Output distance function elasticities

The comparison of output and input elasticities provides information on cost drivers and returns to scale. Table 2-7 provides input et output elasticities. With respect to output elasticities, we find that customers are the most important cost drivers in the Burundian electricity sector. At the aggregate level, the elasticity for the customer variable (e_y1) is 0.703 and 0.687 in the models without z and with z. In these two models, any 10% increase in the number of customers requires a proportional increase of 7.03 and 6.87% respectively in all inputs. However, the elasticity of the variable electricity delivered (e_y2) is 0.297 and 0.313. Any 10% increase in this output requires a proportional increase in all inputs of 2.97 and 3.13%. These results are consistent with those of Coelli et al.(2013). Indeed, a large part of the electricity sector's activities are associated with customers such as new connections, billing, receiving calls and complaints, etc. Moreover, Blimpo et al. (2018) argue that connecting a new customer in SSA loses revenue when tariffs are regulated and set at a level that does not cover costs. Golumbeanu & Barnes (2013) detail the costs associated with connecting new customers, which are the basis of poor access to electricity in SSA.

Table 2-7. Input and output elasticities

Region	Year	Elasticities Without Z					Elasticities With Z				
		e_x1	e_x2	Scale elasticity	e_y1	e_y2	e_x1	e_x2	Scale elasticity	e_y1	e_y2
Mean	Mean	-0.860	-0.080	0.945	0.703	0.297	-1.025	-0.100	1.125	0.687	0.313
	2014	-0.890	-0.089	0.982	0.702	0.298	-1.046	-0.112	1.158	0.694	0.306
	2015	-0.860	-0.082	0.948	0.702	0.298	-1.025	-0.103	1.127	0.685	0.315
	2016	-0.830	-0.090	0.918	0.699	0.301	-0.987	-0.113	1.100	0.675	0.325
	2017	-0.870	-0.061	0.929	0.709	0.291	-1.037	-0.074	1.112	0.691	0.309
Bujumbura	Mean	-0.020	-0.015	0.033	0.995	0.005	-0.336	-0.02	0.35	0.986	0.014
East		-1.020	-0.080	1.095	0.658	0.342	-1.152	-0.100	1.252	0.641	0.359
North		-0.760	-0.138	0.895	0.686	0.314	-0.904	-0.174	1.077	0.654	0.346
South		-1.070	-0.030	1.105	0.675	0.325	-1.228	-0.035	1.263	0.666	0.334
West		-0.850	-0.074	0.945	0.727	0.273	-1.016	-0.094	1.110	0.724	0.276

Source: Compiled by the authors

For a proper interpretation of the input elasticities, their sum, which at the same time represents the scale economies, is multiplied by -1, as done in Coelli & Perelman (1999). We are particularly interested in the elasticities of the model with z. In this model, the sum of the input elasticities is on average greater than 1 in all years. Thus the production function admits increasing returns to scale. Comparing the elasticities at the regional level, there are increasing returns to scale, with the exception of Bujumbura, where the returns are decreasing. Increasing inputs, particularly investments in transformers, which have a high weight in inputs, in the East, North, South and West regions would increase both the number of customers and the electricity delivered, which implies an increase in access to electricity. Moreover, the Bujumbura region seems to have reached an optimum, with decreasing returns to scale. This is not surprising given the size of the electricity sector compared to other regions. Bujumbura controls more than 60 percent of the customers, of the electricity delivered, and of the investments in transformers.

2.5.4. Marginal cost of quality of service

The marginal cost of quality of service is the additional investment cost of reducing electricity losses by one MWh. This marginal cost is determined from input elasticities and the cost per MWh of electricity losses. Knowing the relative elasticities of the inputs, we need to gather information on the cost of the electricity losses. Given the difficulty of estimating the cost of electricity losses, we can instead estimate the Marginal Rate of Technical Substitution, which is equal to the ratio of the costs of inputs, such as capital and electricity losses. Coelli et al (2013) assumed a cost of electricity losses equal to US$1. This marginal cost of QoS is close to what is found in this study. Table 2-8 shows the shadow quality ratio.

Table 2-8. Shadow price ratio of Quality of Service (Electricity losses vs transformer capacity)

	Years/regions	Without z	with z
ALL	Mean	0.77	0.98
Years	2014	0.83	1.01
	2015	0.64	0.81
	2016	0.49	0.64
	2017	1.27	1.64
Regions	Bujumbura	0.16	15.49
	East	0.40	0.37
	North	0.09	0.12
	South	1.64	1.69
	West	0.34	0.47

Source: Authors

On average, the shadow price ratios are higher in the model with z (US$ 0.98) than the model without z (US$ 0.77). Considering their evolution along years, the shadow price ratios, which are high in 2014 (US$ 0.83 in the model without z and US$ 1.01 in the model with z) reduce until 2016 where they get the minimal values. However, the shadow price ratios increase and become maximal in 2017 and in the two models. The shadow price ratios are derived from the partial derivatives and reflect the slope of the isoquant.

At the regional level, a higher shadow price ratio is observed in the southern region (1.64) in the model without z, while that of Bujumbura becomes excessive in the model with z. The Northern region displays the lowest shadow price ratio. Bujumbura, with the largest number of customers, is therefore the one that suffers the most from power cuts. This region requires significant investments to reduce the electricity losses due to outages. In fact, this electricity networks, particularly the underground distribution network is outdated. Bujumbura's underground network largely supplies the urban centre, which contains the most industrial and commercial activities. Any increase in electricity consumption, particularly during service hours, triggers power outages. Companies established in the city center are obliged to own a generator, given the lack of electricity supply throughout the day. Small and medium-sized enterprises that are unable to acquire a generator are forced to stop their activities while waiting for the restoration of electricity. Not upgrading this network is a burden both for REGIDESO, the customers and the country.

When a power outage occurs, it takes a relatively long time before locating the origin of the outage, which mobilizes excessive operational costs related to additional employees. Even if the origin of the power outage is localized, the spare parts are sometimes of lower quality, which implies that the solution does not last a long time.

In addition, while the number of customers was estimated at around ten thousand at the end of the 1980s, it constantly increased and reached around 80,000 in 2017. However, the installed capacity only increased in 2017 with the rental of a generator. The increase in the number of customers and electricity needs given the same level of installed leads to high electricity losses due to outages.

In a recent feasibility study carried out by REGIDESO with a view to the electrification of 28 towns in the communes and the reinforcement of the 30 kV networks, it was found that the cost of a gross kWh would be BIF 396.78, which corresponds to an amount of BIF 396,780 per MWh. Considering an exchange rate of one US dollar against BIF 1808.27 in 2018, the cost of one MWh would come to US$218.22, which is the average cost of 1MWh of electricity losses. The increase in electricity losses therefore increases costs for the electricity company and limits its profitability. As a result, renewing investments would become very difficult. It is therefore important for REGIDESO to increase investments and upgrade the Bujumbura distribution network. In addition, as Fenrick & Getachew (2012) and Saastamoinen & Kuosmanen (2016) pointed out, underground cabling may decrease the level of interruption. On the other hand, Coelli et al. (2013) state that the number of outages should be lower in the big cities where the feeders are mostly short and underground. Therefore, the question that arises is to know how investments costs are required to reduce the electricity losses due to outages.

Multiplying this cost of 1 MWh lost by the shadow price ratio, we obtain the shadow price of investments in transformer capacity which is shown in table 2-9.

Table 2-9. Shadow price of quality of service

	Years/regions	Without z	with z
All	Mean	176.07	223.70
Years	2014	180.51	220.22
	2015	140.44	176.72
	2016	106.84	138.99
	2017	276.51	358.86
Regions	Bujumbura	34.28	3380.54
	East	86.39	81.79
	North	19.95	27.07
	South	357.89	367.88
	West	74.46	102.18

Source: compiled by the authors

The shadow price necessary to reduce 1 MWh of electricity losses due to outages is on average US$176.07 for the model without z and US$ 223.70 for the model with z. As we have seen in the shadow price ratios, the shadow price decreases from 2014 to 2016 and increases considerably in 2017, which shows that the cost is not equitably restored between the years. In 2017, the shadow price reached US$276.51 and US$358.86 in models without and with z.

By comparing the shadow price between the regions, it would be high costly to reduce losses and therefore power outages in the southern region and in the two models, compared to the northern, eastern and western regions, as well as to Bujumbura in the model without z. Considering the environmental variables, the additional costs of investments in transformers to reduce 1 MWH become exorbitant, standing at US$3380.54, compared to US$81.79 and US$27.07 in the northern and eastern regions region respectively. The shadow price of Bujumbura deviates significantly from the mean in the model with z.

The low investments required in the northern and eastern regions are justified on the one hand by the fact that the transmission and distribution network in these regions is recent. A large part of these networks was installed in the 2000s. On the other hand, the number of customers is relatively low in these regions, so that load shedding does not affect them. The low electricity consumption does not lead to overloading in peak hours, which justifies the low cost of investments. However, the low density of customers in these regions results in low investment productivity. The transmission and distribution network crosses long distances without customers, which increases technical losses.

The high investment costs represent the cost that would serve as compensation for the losses suffered by consumers during power outages. In countries where the regulator has provided quality incentives by setting up quality standards, the additional investment costs would thus correspond to the penalties that would be imposed on the electric utility, as suggested Cambini et al. (2014, 2016), Coelli et al. (2013), and Growitsch et al. (2010). For the 118,588 customers in 2017 and an average loss of 0.11 MWh, this compensation would have been valued at US$ 44.1 million. This amount corresponds to the additional capital expenditure that REGIDESO would have had to bear to increase the QoS. In this case, it should compare the penalties with the additional investment costs and decide either to maintain the good QoS or to maintain the status quo and accept the losses, which results in a double trade-off for REGIDESO.

By investing, REGIDESO will reduce electricity losses, which will enable it to increase output, such as the number of customers and the electricity delivered. However, investing in electrical infrastructure requires exorbitant resources, as Bongo et al. (2018) point this out. Innovative financing is therefore necessary, in particular through the private sector participation. This can be involved both in infrastructure through ownership participation. The private sector could also be involved in areas subject to competition such as generation and sales. This, of course, amounts to removing barriers to the private sector, in particular by vertically unbundling the electricity sector and setting up an independent regulator. Political interference in public companies in general and in the electricity sector should decrease.

On the other hand, REGIDESO could maintain the status quo. In this case, the losses linked to the electricity outages become increasingly high, which increases their negative impact. REGIDESO will not be able to generate enough revenue and its financial situation will go from bad to worse. Electrical energy being an input for other sectors, the poor access and QoS leads to the loss of general well-being and affects the economic growth of the country. Burundi therefore has an interest in increasing investments to improve the QoS.

2.6.Conclusion

In a vertically integrated and unregulated electricity sector, customers are unable to claim their rights in terms of QoS. Poor QoS of electricity takes the form of outages, which can vary in both frequency and duration. Its impact can be seen both from the perspective of the electricity company, the customers, and the society. Preventing power outages requires not only investments in network expansion, but also upgrading the existing the transmission and distribution network. There is therefore a trade-off between investment expenditure in the electricity sector on the one hand, and maintaining the status quo and accepting electricity losses on the other. In a system where there are incentives for QoS, maintaining the poor QoS means accepting penalties.

In this paper, we estimated the shadow price of QoS, which is defined as the implicit cost of electricity losses for the period is 2014-2017. These shadow prices were calculated for 19 districts located in five regions all belonging to REGIDESO, a vertically and horizontally integrated company that produces and distributes drinking water and electricity in Burundi. We estimated a parametric output distance function model, using the electricity losses together with the transformer capacity as inputs, and the number of customers and the electricity delivered as outputs. From the production technology, we derived the shadow price ratio of inputs. More specifically, we determine the implicit cost of electricity losses, with the aim of increasing the quality of service.

The results show that customers are the main cost consumers. On the other hand, the electricity sector in Burundi admits decreasing returns to scale in the model without environmental variables, and increasing returns to scale when environmental variables are taken into account. However, Bujumbura displays high decreasing returns to scale. Technical efficiency scores are generally below 80%, indicating that the electricity sector in Burundi is inefficient. However, the benchmarking discussed in this chapter is within districts belonging to the same electricity company. Obtaining data on several utilities will improve the benchmarking of the electricity sector. This comparison is the subject of chapters three and four.

Moreover, the implicit cost of the QoS is on average US$ 176.07 and US$ 223.70 per kVA respectively in the models without or with environmental variables. This implicit cost increases for the southern region in the model without environmental variables (US$357.89) and becomes exorbitant for the Bujumbura region in the model with environmental variables (US$ 3380.54). The implicit cost of QoS corresponds to penalties that should be imposed on the electricity company for not complying with quality standards. The establishment of quality incentives thus requires the existence of an independent regulator.

The results are of interest to customers, the utility, and the regulator. For customers, the implicit costs of power outages are an opportunity cost of using generators or other means to cope with outages. For the utility, blackouts are a loss of efficiency, due to low investment in the electricity sector, which could be the result of either low electricity tariffs or non-payment of bills. From the regulator's perspective, the shadow price is the penalty that REGIDESO should pay for not complying with QoS standards.

Having been unable to mobilize sufficient resources to increase investments in the electricity sector, Burundi should resort to other forms of innovative financing. It should implement the reforms undertaken in 2000 and 2015, by vertically separating the electricity sector and attracting private investment. In addition, the involvement of the State in the management of public utilities should be limited to regulation and an independent regulator should be available.

One of the main limitations of this study is access to data and the presence of comparable DMUs. The study compares districts and regions belonging to the same utility. This study could be extended to autonomous utilities. It could also be applied to comparable sectors such as water pumping stations and network companies such as telecommunications. The comparison of power sector performance would be interesting if it was done in a regional framework. In Chapter 3, we use a non-parametric method and benchmark the performance of Burundi's electricity sector against that of East African countries.

3. Benchmarking of the Electricity Sector in East Africa, an Assessment of Technical Efficiency

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 a tobit regression model to investigate the effect of environmental variables on the technical efficiency scores. On average, the East African power sector exhibits performance gaps of 19.6% for the generation model, and 23.5% for the transmission-distribution model. the Mann-Whitney test shows that there is no statistically significant difference between inefficiency in the two models. On the other hand, findings show that private sector participation in the electricity sector, as well as GDP per capita positively influence the technical efficiency scores. Therefore, countries that have attracted the private sector

into the generation and/or distribution sectors have improved their technical efficiency compared to others with state-owned utilities.

Keywords: *Electricity Sector Reform, Quality of service, Data Envelopment Analysis, Performance gap, East Africa*

3.1.Introduction

Since the 1990s, developing countries have engaged in the process of electricity sector reform, driven, namely by the sector’s low 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, and power supply quality (Dertinger & Hirth, 2020; Mohsin et al., 2021). Initiated by multilateral lenders like the World Bank and other international trade partners, the electricity sector reform unfolded in several steps: the enactment of an “Electricity Law”, corporatization and commercialization of the core utility, the unbundling of the state-owned utilities vertically and horizontally, the introduction of competition principles, the private participation in the management of electricity assets, the introduction of an independent regulatory authority (Asantewaa et al., 2022; Bacon, 2018; Dertinger & Hirth, 2020).

Despite the electricity sector reforms, over 860 million people over the world do not have access to electricity (Kizilcec et al., 2021), with more than 600 million living in Sub-Saharan Africa (Adams et al., 2016; Opiyo, 2020). Insufficiency of power generation, priority to dispatch electricity to urban and peri-urban areas with highly productive use leave more than 80% of the rural population without electricity access. More specifically, those who are connected suffer from frequent blackouts.

East African countries have also followed the stream of electricity sector reforms. However, their implementation was not successful in all countries. Kenya has unbundled the generation sector from that of transmission and distribution. Uganda created three different entities, while Ethiopia separated the distribution sector from that of generation and transmission. Other countries like Burundi, Rwanda and Tanzania maintained the vertically (and horizontally) integrated electricity sector. However, Rwanda has initiated a management contract system by entrusting the electricity sector to a holding company. In this study, we seek to answer the following question: Did power sector reform improve performance in East Africa?

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 that converts inputs to outputs to evaluate the performance of similar organizations or entities 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 scores, defined as ratios of weighted outputs to weighted inputs.

Various goals are assigned to the DEA models such as finding the technical efficiency 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).

DEA approach was used to benchmark the different sub-systems of the electricity sector, such as power generation (Jaraitė & Di Maria, 2012; Njeru et al., 2020; See & Coelli, 2012), transmission (da Silva et al., 2019; Llorca et al., 2016) and distribution (Barabutu & Lee, 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) have considered 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 & Lee (2018), Estache et al. (2008), Njeru et al. (2020), Plane (1999) and Real & Tovar (2020).

We contribute to filling this gap by benchmarking the performance of the electricity sector in East Africa. Given the complexity of the power sector, we aggregate the data at the country level. Instead of comparing the performance of individual firms, we focus on the industry. The analysis is carried out through generation model and transmission-distribution model. Finally, the study is based on our compilation of a detailed dataset concerning six countries for a ten-year period from 2008 to 2017.

In Section 2, we briefly present the literature on the DEA method. We describe the electricity sector in East Africa in Section 3. In Section 4, we present the methodology and describe the data. The results are presented and discussed in Section 5, and finally, we conclude.

3.2.Literature review

DEA is a widely benchmarking method used to evaluate the productive efficiency of different organizations or entities known as Decision Making Units (DMUs). It is a non-parametric method that uses piecewise linear programming to estimate the most efficient or best-practice frontier from a set of DMUs (Giannakis et al., 2005). It has been used to compare the performance in different aspects of electricity utility such as generation, transmission, and distribution. DEA approach compares inefficient DMUs to actual efficient ones, without specification of cost or production function.

Two common DEA models are used: the CCR and BCC models. The two models are attributed to their founders as Charnes, Cooper, & Rhodes (1978) for the first, and Banker, Charnes, & Cooper (1984) for the second. The CCR model determines the overall efficiency assuming Constant Returns to Scale (CRS). It considers that the outputs increase in the same proportions as the inputs. For this, inefficient units are those that deviate from this scale. The BCC model is an extension of the CCR model for Variable Returns to Scale (VRS). It considers that all DMUs do not necessarily operate at their optimum. Returns to scale can indeed be decreasing (DRS) or increasing (IRS).

DEA models are either input-oriented or output-oriented. In the DEA output-oriented model, a DMU has to maximize outputs given the level of inputs. However, input-oriented models minimize input factors required given the level of outputs. Most studies comparing the performance in electricity distribution units use the DEA input-oriented, due to fact that they are subject to incentive regulation such as cost efficiency, lower prices, and reduced electricity losses (Jamasb, 2006; Jamasb & Pollitt, 2003; Yu et al., 2007). In developing countries, energy policy aims to increase access to electricity, and the quality of service. Therefore, the objective of the electricity sector is to expand service better than cost minimization (Mbuvi et al., 2012), implying the use of DEA output-oriented.

The majority of the studies benchmarking the electricity sector performance have been conducted in European countries (Amado et al., 2013; Arcos-Vargas et al., 2017; Cambini et al., 2014; Coelli et al., 2013; Giannakis et al., 2005; Gouveia et al., 2015; Petridis et al., 2019; Von Hirschhausen et al., 2006), North and Latin American countries (da Silva et al., 2019; Llorca et al., 2016; Ramos-real et al., 2009; Xavier et al., 2015), and Asia (Bobde & Tanaka, 2018, 2020; Xie et al., 2018). Little research has been conducted in SSA (Barabutu & Lee, 2018; Estache et al., 2008; Njeru et al., 2020; Plane, 1999; Real & Tovar, 2020). Among few studies conducted in the case of SSA, Plane (1999) focuses on the electricity sector in Côte d'Ivoire and assesses the impact of private management on technical efficiency improvement. On the other hand, Barabutu & Lee (2018), Estache et al. (2008), and Real & Tovar (2020) benchmarked the vertically integrated utilities in the Southern Africa Power Pool. In the case of East Africa, Njeru et al. (2020) compared the performance of 27 thermal electricity generation in Kenya, without extending the study to the hall generation companies. However, no extended study was conducted on the electricity sector in East Africa. On the other hand, none of them did not take into account the reforms undertaken such as unbundling.

A common characteristic of the different studies is the use of two output variables, the number of customers and the electricity distributed (Arcos-Vargas et al., 2017; Cambini et al., 2014; Giannakis et al., 2005; Pacudan & Guzman, 2002; Petridis et al., 2019; Ramos-real et al., 2009; Xavier et al., 2015; Xie et al., 2018). The most inputs used are either monetary or non-monetary ones. Monetary inputs include total expenditures, operating expenditures (Cambini et al., 2014; T. J. Coelli et al., 2013; Giannakis et al., 2005), maintenance and outage repairing costs (Gouveia et al., 2015), etc. Non-monetary inputs include labor force, number and/or capacity of transformers, service area, installed capacity, etc. The transmission line length is either used as input (Bongo et al., 2018; Jamasb & Pollitt, 2001; Pacudan & Guzman, 2002; Petridis et al., 2019; Von Hirschhausen et al., 2006; Xavier et al., 2015; Xie et al., 2018) or output (Amado et al., 2013; Giannakis et al., 2005; Gouveia et al., 2015).

The choice of input and output variables in the performance comparison of the electricity sector depends on the objective of the evaluator. An input variable in one sector can be considered as an output in another. This is the case, for example, for electricity transmission lines which are intermediate outputs when comparing the performance of electricity generation companies. However, in the case of electricity transmission companies, these lines become inputs, because of the costs they entail.

The electricity losses are treated as an indicator of poor quality of service, and undesirable output. Lu & Lo (2007) replied by Ebrahimnejad & Tavana (2014) proposed three alternatives to deal with undesirable outputs in the DEA model: (1) simply ignore the undesirable output, (2) consider them as output and adjust the distance measurement to restrict their expansion and, (3) treat the undesirable output as input. Some authors used the electricity losses as input (Amado et al., 2013; Coelli et al., 2013; Jamasb & Pollitt, 2003; Pacudan & Guzman, 2002; Ramos-real et al., 2009; Von Hirschhausen et al., 2006; Xie et al., 2018), others used them as output (Arcos-Vargas et al., 2017; Petridis et al., 2019).

One of the main issues of the DEA approach is the choice of inputs and outputs in the electricity sector. Estache et al. (2008) address issues related to the quality and volume of data, which reduces the possibility for the regulator to coordinate the changing tariffs with the evolution of the efficiency performance. Çelen (2013), Coelli et al.(2013), and Xie et al. (2018) address the small sample size of entities, and the international comparability problems. In the case of the electricity industry in developing countries such as Sub-Saharan Africa, Real & Tovar (2020) deplore the non-availability of a full and detailed database to perform efficiency analysis. Mardani et al. (2017) address the complex structure of the regional electricity sector and the difficulties relating to the benchmarking studies. Alizadeh et al. (2020) address this gap using a network DEA model integrating interactions between the sub-systems, which measures the performance of the entire electricity sector. However, the model lacks of adequate data which are available only for three years.

Other studies focus on the contribution of electricity sector reforms to performance, including vertical unbundling and private sector participation. Bobde & Tanaka (2020) focused their analysis of the vertical unbundling based on DEA, and statistically tested the returns-to-scale hypothesis using the case of India. They find that the vertically integration of generation and distribution sectors separated with the transmission model has a significant positive impact on the technical efficiency. On the other hand, studies have analyzed the impact of reforms on the technical efficiency of the electricity sector.

For instance, Bacon (2018), Bagdadioglu et al.(1996), Barabutu & Lee (2018), Çelen (2013) and Jamasb et al. (2017) conclude that private participation would improve performance if there was a competitive environment.

3.3.State of the electricity sector in East Africa and data

East African Countries engaged in a process of electricity sector reform. Starting with the energy enactment, Kenya was the first country that reformed the electricity sector in 1997. It was followed by Uganda in 1999, Burundi in 2000 and 2015, Rwanda in 1999, Tanzania in 2008, and Ethiopia in 2013. One of the reforms consists to unbundle the vertically integrated state monopolies. The unbundling model chosen differs from one country to another. Suppose that G stands for generation, T for transmission, and D for distribution, table 1 shows the restructuration process and the status of the electricity sector in the six countries.

Table 3-1.Macroeconomic indicators and electricity sector reform in East Africa

Description	**Burundi**	**Rwanda**	**Tanzania**	**Kenya**	**Uganda**	**Ethiopia**
Land Area (*10,000 km^2)	2.57	2.47	88.58	56.91	19.98	100.00
Population (10^6 in 2017)	10.83	11.98	54.66	50.22	41.16	106.40
Population density (km sq)	421.61	106.40	88.24	485.65	61.71	205.28
GDP per capita (PPP constant 2010US$)	670.8	1724.5	2961.5	1888.8	2809.1	1768.2
Electricity Act	2000/2015	1999	2008	1997	1999	2013
Restructuration	G-GTD	G-GTD	G-GTD	G-T-TD	G-T-D	GT-D
Generation	REGIDESO	REG, IPPs	TANESCO, IPPs	KenGen, IPPs, REP	IPPs	EEP
Transmission	REGIDESO	REG	TANESCO	KPLC, KETRACO	UETCL	EEP
Distribution	REGIDESO	REG	TANESCO	KPLC	9 private firms	EEU

Source: Compiled by the author

Note: REG: Rwanda Energy Group, TANESCO: Tanzania Electricity Supply Company, KenGen: Kenya Electric Generation Company, KPLC: Kenya Power Lighting Company, KETRACO: Kenya Transmission Company, UETCL: Uganda Electricity Transmission Company Limited, REP: Regional Electrification Program, EEP: Ethiopian Electric Power, EEU: Ethiopian Electric Utility

In Table 3-1, population, land area, and GDP per capita statistics are obtained through the World Development Indicators (WDI) of the World Bank. The rest of the data comes from our own investigation. Four models of power sector restructuring in East Africa can be distinguished, namely G-GTD, G-T-TD, G-T-D, and GT-D.

In the G-GTD model, a vertically integrated company is responsible for generation, transmission and distribution (GDT). In addition, one or more IPPs operate in the generation sector (G) and the electricity produced is purchased by the vertically integrated company. This model is operating in Burundi, Rwanda and Tanzania. In Rwanda, 58 IPPs were licensed for power generation in 2017 and supplied 48.64% of the installed capacity. In Burundi, Interpetrol is the only IPPs operating with a gas-fired plant.

Each of the three remaining countries has its own model. In Kenya, the generation sector is run by a public company and independent producers (G). Their output is purchased by KPLC, which handles transmission and distribution (TD). There is another company responsible for the development of new transmission projects (T). Model adopted in Kenya is therefore G-T-TD. Ethiopia has separated its power sector into two companies, one for generation and transmission, and another for distribution. Here the model is GT-D. In Uganda, on the other hand, all three sectors have been vertically separated. Several operators are involved in both generation and distribution, while transmission is handled by a single operator. Its model is G-T-D.

The different countries differ according to their total installed capacity across the different electricity sources. Table 3-2 shows the installed capacity by fuel source, and the proportion of renewable (RE) and non-renewable energy (Non-RE) sources.

Table 3-2. East African installed capacity balance in 2017 (MW)

Source	Burundi	Ethiopia	Kenya	Rwanda	Tanzania	Uganda
Hydro	50	3816	826	85	568	929
Thermal	30	87	553	74	70	136
Natural Gas	-	-	-	-	727	-
Gas methane	-	-	-	29	-	-
Geothermal	-	331	652	-	-	-
Cogeneration	-	-	28	-	-	96
Wind	-	-	26	-	-	-
Solar	-	-	1	9	-	50
TOTAL	84	4234	2086	197	1365	1211
RE share	58	98	73	48	42	89
Non-RE share	42	2	27	52	58	11

Source: the author

East African countries have diversified their power generation sources, but at different levels. Kenya is the first country to exploit several sources of electricity, while Burundi relies solely on hydroelectric and thermal power. The use of solar energy is still underdeveloped in the latter country. Electricity resources are both renewable and non-renewable. Ethiopia and Uganda are the countries with the highest rate of renewable energy. In Tanzania and Rwanda, non-renewable energy dominates, particularly natural gas and methane gas.

In Table 3-3, we compare the status of installed capacity, transmission lines, purchased power, and number of customers for the 2017 fiscal year. We express these quantities on a per capita and/or per km^2 basis.

Table 3-3. Electricity generation, transmission and distribution (2017)

Country	Installed capacity (kW per 10000 habitants)	Purchased (kWh per habitant)	Transmission (m per habitant)	Customer per km^2	Consumption (kWh per habitant)
Burundi	74.1	24.0	0.03	4.6	17.2
Ethiopia	454.1	104.2	0.13	2.2	80.7
Kenya	468.1	203.2	0.12	10.9	164.7
Rwanda	172.8	62.2	0.09	29.1	49.7
Tanzania	269.7	124.4	0.11	2.4	115.9
Uganda	286.4	82.4	0.04	5.9	68.1

Source: Compiled by the author

Kenya and Ethiopia have the highest installed capacity per 10,000 inhabitants. However, the electricity purchased per capita in Ethiopia is decreasing, as a significant share is exported to neighboring countries. Investment in electricity is limited in Burundi both in terms of installed capacity and transmission lines. Similarly, per capita consumption is the lowest. Customer density, as measured by the ratio of customers to land area, is lowest in Tanzania and Ethiopia. Rwanda and Kenya, on the other hand, have relatively high density, resulting in high access to electricity.

3.4.Material and methods

3.4.1. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a widely non-parametric benchmarking technology developed by Charnes et al. (1978) and used to evaluate the productive efficiency of different organizations or entities known as Decision Making Units (DMUs). It uses piecewise linear programming to estimate the most efficient or best-practice frontier from a set of DMUs (Giannakis et al., 2005). The difference with the parametric methods is that there is no functional form specification for the production function in the DEA method.

Two common DEA models are used, the CCR model developed by Charnes et al. (1978) which determines the overall efficiency assuming Constant Return to Scale (CRS), and the and the BCC model developed by Banker et al. (1984)[29] which was extended to the Variable Return to Scale (VRS). The BCC model determines in which scale are operating the different DMUs, such as increasing, decreasing or constant return to scale(Bongo et al., 2018). DEA technique provides information about peers, which is useful for managerial purpose. It respects the assumptions developed by Färe & 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 & 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 variable returns to scale (VRS) seeks to minimize the inputs and still remain within the feasible production set. It is defined as follows:

$$\max_{\theta,\lambda} \theta \quad \text{s.t} -y_i + Y\lambda \geq 0; \theta x_i - X\lambda \geq 0\ ; N1'\lambda = 1\ ; \lambda \geq 0 \qquad (1)$$

Where $N1$ is a $Nx1$ vector of 1s, λ is an $Nx1$ vector of weights, θ the distance function. It shows how much to proportionally contract the input vector without changing the

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[29] The CCR and BCC methods refer to the names of their authors, namely: Charnes, Cooper, & Rhodes (1978) for CCR method, and Banker, Charnes, &Cooper (1984).

output vector. It is comprised between 0 and 1. θ_i is viewed as the proportional reduction in inputs by the i^{th} firm, without changing outputs.

3.4.2. Second-stage DEA model : Tobit regression

Another aspect of efficiency is to identify which environmental factors explain the technical efficiency scores of the different DMUs. A Tobit regression parametric model first proposed by Tobin (1958) is used to determine which factor may explain the technical efficiency scores, as some parts of inefficiency may be attributed to unfavorable environment (Çelen, 2013). The observed efficiency score obtained from the DEA are defined in terms of environmental variables (z_{it}), as follows:

$\theta_{it}^{*} = z'_{it}\beta + \varepsilon_{it}$ with $\varepsilon_{it} \approx N(0, \sigma^2)$

Where z_{it} is an $(rx1)$ vector of environmental variables, and β is an $(rx1)$ vector of parameters to be estimated. We note that the estimated coefficients of parameters in Tobit regression are interpreted like the Ordinary Least square (OLS) regression coefficients. The only difference is that the linear effect lies in the censored latent variable and not the observed outcome (Çelen, 2013). The observed efficiency score (θ_{it}) can be defined as censored below 0 and above 1:

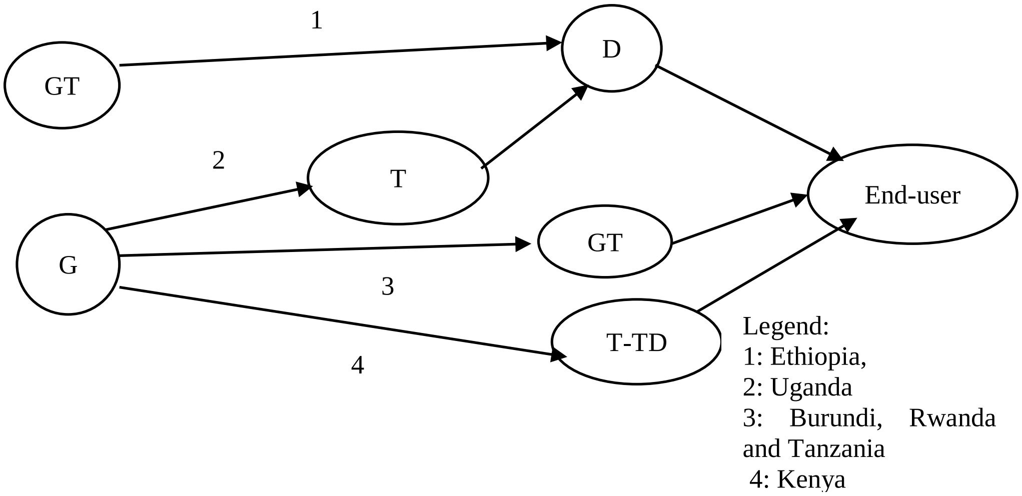
$$\theta_{it} = \begin{cases} \theta_{it}^{*}, if\ 0 < \theta_{it}^{*} < 1 \\ 0\ \ for\ other\ values\ of\ \theta_{it}^{*} \end{cases}$$

3.4.3. Choice of models and output and input variables.

The DEA model consists of comparing the performance of DMU, using the same inputs to produce the same outputs. The aim is to choose which variables fits for all models.

Based on the data in Table 3-1, we can represent the power sector in East Africa as shown in Figure 3-1.

Figure 3-1. Structure of the electricity sector in East Africa.



Source: Author

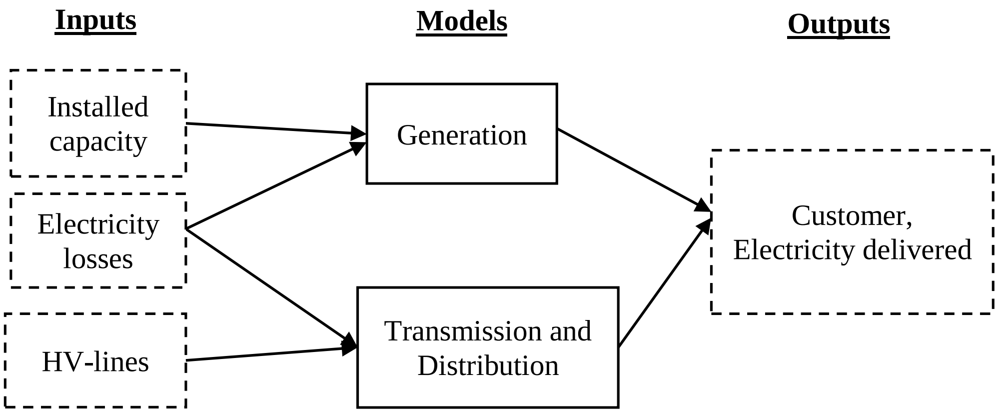
The installed capacity constitutes a common input for G, GT, and GTD. In this case, the purchased electricity would be an intermediate output, as would the electricity transmission lines. The noticeable problem is linked to the objective of each country, such as exporting the electricity generated. For example, Ethiopia exports 7-11% of the electricity generated to Sudan, Kenya, and Djibouti. With its new hydroelectric dam construction projects, it has already concluded PPA to export 400 MW to Kenya, with an ambitious plan to export to large markets such as Egypt and South Africa (Lavers et al., 2021). Thus, the installed capacity is shared with other trade partners. The same is true of Kenya, which exports to Tanzania and Uganda. On the other hand, Burundi and Rwanda import a large part of the electricity from the Democratic Republic of Congo.

However, whether or not exporting, the costs of the power plants are the responsibility of the country. Thus, the installed capacity is retained as input.

In T-TD, the electricity company either purchases electricity locally or imports it. In this a case, the purchased power may be treated as input. According to Gilsdorf (1995), purchased power constitutes a simple transfer from the generation utility to consumers. From Real & Tovar (2020) point of view, the purchased electricity does not affect technical, maintenance, or other costs of electricity. This is why we do not use the electricity purchased as input. In the case of the distribution model (D), we take into account a company whose business is to operate, maintain and extend the distribution networks such as transformers, distribution substations, distribution lines, etc. It also sells and installs meters, distributes electricity, maintains customer relationships. However, the transmission lines are an input for both the T-TD and D models.

Labor is a common input to all models. However, we did not get the data for this variable. In addition, the number of customers and the electricity delivered are common outputs. Our objective is therefore to choose unifying models, which take into account the specificities of all countries. Even if the purchased electricity is excluded from the composition of the inputs, it is not entirely delivered to the end-users, because of electricity losses. These losses of electricity, especially non-technical losses entail enormous costs (Jamil & Ahmad,2019) and have multifaceted consequences for the electricity company, society, and the country (de Souza Savian et al., 2021). Therefore, the electricity losses are considered as inputs. Figure 3-2 shows the models required for the benchmarking process.

Figure 3-2. Benchmarking models and input-output variables



Source: Author

We adopt a comparison of the electricity sector in East Africa using the G and TD models. Model G assumes a company that generates and delivers electric energy directly to customers regardless of its form. Installed capacity constitutes the capital input. On the other hand, the principal input for TD is the high voltage (HV) transmission line length. The electricity losses are common input for G and TD. They are considered as imperfect substitutes of labor costs to reduce technical losses such as tracking down the perpetrators of electricity thefts, enforcing collection of unpaid electricity bills (Jamil & Ahmad, 2019), and investments. Electricity losses also capture the QoS in the distribution systems (Edvardsen & Førsund, 2003). The installed capacity is expressed in MW. High-voltage transmission lines have a capacity of 66 kV or more. Losses and electricity delivered are expressed in GWh. Customers are expressed in thousands. They include both the residential and industrial sectors. Table 3-4 summarizes the different variables by country. The changes in the last column show the average annual growth rates.

Table 3-4 Summary of inputs- outputs variables per country

Country	Mean	Std. Dev.	Min	Max	Average growth (%)
Output 1-Electricity delivered (GWh)					
Burundi	191	19	162	226	2.2
Ethiopia	5048	2021	2825	8586	13.9
Kenya	6951	1068	5322	8272	5.1
Rwanda	383	126	225	596	11.9
Tanzania	4235	814	2725	5310	5.2
Uganda	2032	517	1278	2803	9.2
	Output 2-Customers (thousands)				
Burundi	8	2	5	12	10.7
Ethiopia	176	35	140	244	6.7
Kenya	274	168	106	618	21.8
Rwanda	38	21	11	72	23.6
Tanzania	126	49	74	211	12.4
Uganda	63	30	30	118	16.5
	Input 1- Installed capacity (MW)				
Burundi	59	8	54.85	80	4.8
Ethiopia	3713	1.172	783	4832	39.5
Kenya	1785	421	1268	2351	7.3
Rwanda	113	48	68	207	13.9
Tanzania	1234	187	964	1474	4.9
Uganda	777	223	385	1179	14.5
	Input 2-Transmission lines (Km)				
Burundi	322	0	322	322	0.0
Ethiopia	5629	1888	3085	8772	12.9
Kenya	4743	628	4040	58560	4.3
Rwanda	450	125	371	745	8.6
Tanzania	5076	451	4816	5896	2.4
Uganda	1440	227	1178	1627	4.1

Country	Mean	Std. Dev.	Min	Max	Average growth (%)
	Input3- Electricity losses (GWh)				
Burundi	57	15	36	79	10.3
Ethiopia	1741	892	673	2902	26.2
Kenya	1426	338	1057	1932	7.1
Rwanda	101	37	54	149	13.7
Tanzania	1391	191	1028	1664	8.0
Uganda	663	53	588	752	-1.1

Source: Compiled by the author

Burundi has low investment in installed capacity (4.8%) and high voltage transmission lines (0.0%). Conversely, the number of customers has grown beyond the generation capacity (10.7%). As a result, the growth rate of electricity losses approaches that of customers (10.3%). Ethiopia has significantly increased its investment in generation capacity (39.5%). However, it has failed to increase the number of customers (6.7%) along with the rate of investment. Moreover, the increase in losses is twice the amount of electricity delivered (26.2 vs 13.9%). Kenya and Rwanda are the market leaders in expanding the number of customers (21.8 vs 23.6%). In both countries, electricity losses are growing at the same rate as installed capacity (7.5 and 7.3% for Kenya, 13.7 and 13.9% for Rwanda), and they exceed that of electricity delivered (5.1% for Kenya, 11.9% for Rwanda). Finally, in Uganda, the rate of customer growth slightly exceeds that of installed capacity (16.5 vs 14.5%). It controls electricity losses given their negative growth rate.

Table 3-5 illustrates the correlation between the input and output variables. Transmission lines are strongly correlated with losses and delivered electricity. Although there is a correlation between installed capacity and the number of customers, it is not strong. The same is true for the correlation of customers with transmission lines and electricity losses.

Table 3-5. Inputs outputs correlation

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

Source: the author

3.5.Results and discussion

In this section, we present the results from the input-oriented BCC-DEA method. Since TE scores at VRS overestimate performance (Giannakis et al., 2005), we focus on CRS TE scores. We also analyze the nature of returns to scale. Note that the CRS TE scores obtained according to the CCR and BCC-DEA method are the same. The results are obtained using the DEAP version 2.1 developed by Coelli (1996).

3.5.1. Electricity sector performance gap

We present the results for both the generation and transmission-distribution models. In table 3-6, we present the technical inefficiency of the power sector by country and year. We also represent the average technical efficiency over a 5-year period.

Table 3-6. Technical inefficiency

Model	Year	Burundi	Ethiopia	Kenya	Rwanda	Tanzania	Uganda	Mean
Generation model	2008	29.2	11.4	0.0	15.7	17.6	22.8	16.1
	2009	20.0	33.7	0.0	11.1	13.2	43.7	20.3
	2010	19.0	23.2	0.8	7.2	9.4	38.1	16.3
	2011	12.2	30.8	1.1	0.0	18.4	36.5	16.5
	2012	20.0	69.6	6.9	0.0	18.1	45.5	26.7
	2013	19.2	67.6	11.2	0.0	18.0	40.6	26.1
	2014	0.0	23.0	6.7	8.7	13.0	32.6	14.0
	2015	27.4	62.1	12.2	0.0	8.7	25.3	22.6
	2016	16.9	41.1	13.3	8.6	15.8	25.3	20.2
	2017	42.9	39.7	7.0	0.0	0.0	14.8	17.4
	2008-2012	20.1	33.7	1.8	6.8	15.3	37.3	19.2
	2013-2017	21.3	46.7	10.1	3.5	11.1	27.7	20.1
	2008-2017	20.7	40.2	5.9	5.1	13.2	32.5	19.6
Transmission-distribution model	2008	37.6	22.1	4.2	22.6	55.7	37.0	29.9
	2009	20.2	33.7	2.1	22.8	42.5	30.8	25.4
	2010	34.3	23.2	0.0	14.6	44.1	19.3	22.6
	2011	22.6	30.8	0.0	9.5	27.5	14.1	17.4
	2012	39.5	66.2	4.7	1.9	42.1	27.0	30.2
	2013	33.6	64.2	13.2	22.6	31.0	24.6	31.5
	2014	0.0	21.9	7.4	6.4	29.8	18.0	13.9
	2015	49.6	58.5	0.7	3.2	20.9	11.1	24.0
	2016	44.9	38.0	5.6	8.3	36.2	7.4	23.4
	2017	45.0	36.6	0.0	0.0	17.3	0.0	16.5
	2008-2012	30.8	35.2	2.2	14.3	42.4	25.6	25.1
	2013-2017	34.6	43.8	5.4	8.1	27.0	12.2	21.9
	2008-2017	32.7	39.5	3.8	11.2	34.7	18.9	23.5

Source: the author

Considering the generation model, we find that the technical inefficiency of the electricity sector in Kenya and Rwanda is relatively more efficient compared to the other countries. Their respective technical inefficiencies are 5.9 and 5.1 percent. These countries are characterized by a high rate of customer growth. On the other hand, the electricity sector is technically more inefficient in Burundi, Uganda, and Ethiopia, accounting for 20.7, 32.5, and 40.2 percent respectively. Kenya performs better in the first 5 years, while Rwanda performs better in the last 5 years. For Burundi, Uganda, and Ethiopia, their electricity sectors are inefficient for all 10 years. However, for the latter country, technical inefficiency decreases from 45.5% in 2012 to 14.8% in 2017, representing a performance improvement of about 20%. For Ethiopia, performance is worse in the last 5 years compared to the first 5 years, with technical inefficiency increasing from 33.7% to 46.7%. For Tanzania, technical inefficiency falls between the two groups of countries. Its technical inefficiency is between 10% and 20%. Overall, the power sector in East Africa is technically inefficient at 19.6%, this average being related to the technical inefficiency weight of Ethiopia and Uganda.

In moving from the generation model to the transmission-distribution model, a significant degradation in technical efficiency is observed for Burundi and Tanzania, while Uganda instead increases its technical efficiency. Uganda has significantly minimized its electricity losses, while Burundi has not upgraded its high voltage transmission system since 1990. Since then, long-distance power transmission has been provided by 30 kV medium-voltage lines, which are also used in the distribution network. For Ethiopia, the technical inefficiency is similar in both models. This country has significantly increased the installed electricity capacity. However, customer growth remains low, while average electricity losses are very high, at 26.2% per year. Par contre, le Kenya et le Burundi gardent des scores d'efficacité relativement très élevés, leur inefficacité technique étant de 3.8% et 11.2% respectivement. Overall, according to the transmission-distribution model, the electricity sector is technically inefficient by 23.5%, which means a degradation in performance compared to generation model. However, this statement is not statistically verified.

To test whether there is a significant difference between the technical inefficiencies under the two models, we used a non-parametric hypothesis test known as the Wilcoxon rank-sum (Mann-Whitney) test. This test examines the null hypotheses regarding whether there is no significant statistical difference between any two groups, such as between the generation model and the transmission-distribution model in this study. The alternative hypothesis shows a significant statistical difference in technical inefficiencies between the two models. Bagdadioglu et al. (1996) show that the test generates a z-value for large sample sizes ($n >$10), and the level of significance can be determined using the tables of the standardized normal distribution. Atris (2020) provides the formula for determining the critical value z. If the estimated probability value ($p -$value) is less or equal to 0.05, we reject the null hypothesis and accept the alternative hypothesis. Otherwise, we accept the null hypothesis.

The results of the Mann-Whitney test show that the $z -$value is 1.345 and the $p -$value is 0.1786, greater than 0.05. We do not reject the null hypothesis (H0). As a result, there is no statistically significant difference in technical inefficiency between the two models. It should be recalled that the two models differ in the use of inputs under the two generation technologies, namely installed capacity in the generation model, and high voltage transmission lines in the transmission-distribution model. However, both models have in common the outputs and the electricity losses that represent a bad input. Thus, switching from one model to the other does not significantly decrease the inefficiency of the power sector in the countries considered and depending on the generation technology selected in this study.

To interpret the technical efficiency scores obtained from DEA, we refer to similar studies that divide these scores into classes and assign an efficiency level to each class. We can mention among others Barabutu & Lee (2018), Ervural et al. (2018) and Mbangala & Perelman (1997). Thus, we qualify as moderate efficient the DMUs whose technical inefficiency is less or equal to 10%, marginal efficiency for those whose technical inefficiency is between 10 and 20 %. Finally, DMUs with technical inefficiency scores above 20% are qualified as totally inefficient. Thus, in the sense of the generation model, the power sector is moderately efficient in Kenya and Rwanda, marginally efficient in Tanzania, and totally inefficient in Burundi, Uganda and Ethiopia. In the transmission-distribution model, only Kenya is moderately efficient. Rwanda and Uganda are marginally efficient, while Burundi, Ethiopia, and Tanzania are completely inefficient.

3.5.2. 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 inputs and economic outputs (Wang & Feng, 2015). 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 & 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.

In this study, the specific inefficiency can be attributed largely to electricity losses, but also to installed capacity and transmission lines. Losses are an undesirable input that must be minimized, its excess being harmful. Inefficiency related to installed capacity and high voltage transmission lines relates to their underuse. There is also inefficiency specific to the outputs. It shows that given the same inputs, it is possible to increase the output. In other words, a good use of inputs leads to an optimal output. Input and output inefficiencies are known as input and output slacks. Input slack indicates the need to further reduce the corresponding inputs, while output slacks imply any additional output that can be produced by the efficient level of production. Bagdadioglu et al., (1996) show how to measure the quantities of input slacks and output slacks as follows:

$$x_{io}^{*} = \theta_o x_{io} - s_i^{-}, i = 1, \dots, m$$

$$y_{ro}^{*} = y_{ro} + s_r^{+}, r = 1, \dots, s$$

The quantity of inputs to be reduced is obtained by the difference between the value of the actual quantities and the target value of inputs ($x_{io} - x_{io}^{*}$). On the other hand, the quantity of output to be increased is obtained by the difference between the target values and the observed values of output ($y_{ro}^{*} - y_{ro}$).

The reduction of input or the increase of output thus allows the inefficient entity to get closer to the efficiency frontier. From the input targets obtained from DEAP version 2.1, we derive averages for each country over a 5-year and 10-year period. Table 3-7 shows the input slacks as percentages of the observed values, which are the same in the two models.

Table 3-7. Proportion of input slacks by country

Year	Installed capacity	Transmission lines	Electricity losses
Burundi			
2008-2012	0.0	0.0	20.3
2013-2017	7.3	0.0	14.0
2008-2017	3.63	0.0	17.2
Ethiopia			
2008-2012	60.2	63.0	27.8
2013-2017	49.4	48.2	33.0
2008-2017	54.8	55.6	30.4
Kenya			
2008-2012	0.9	1.7	1.7
2013-2017	2.7	2.9	4.3
2008-2017	1.8	2.3	3.0
Rwanda			
2008-2012	3.9	27.6	13.3
2013-2017	2.9	3.4	3.4
2008-2017	3.4	15.5	8.4
Tanzania			
2008-2012	15.2	43.9	41.9
2013-2017	10.8	29.4	26.6
2008-2017	13.0	36.7	34.2
Uganda			
2008-2012	36.7	18.4	52.0
2013-2017	32.0	10.7	17.4
2008-2017	34.3	14.5	34.7
All			
2008-2012	19.3	26.3	26.0
2013-2017	17.5	15.8	16.4
2008-2017	18.4	21.0	21.2

Source: Compiled by the author

From Table 3-7, it can be seen that Ethiopia has a very high proportion of slacks in installed capacity. This shows that the underutilized installed capacity averages 54.8%, or 60.2% during the period 2008-2012. The same is true for the underutilization of transmission lines, which has an overall average of 55.6% or 63% for the period 2008-2012. Its input inefficiency is also reflected in electricity losses whose average is 30.4%. Other countries with high input slacks are Uganda in terms of installed capacity (34.3%) and electricity losses (34.7%) and Tanzania in terms of transmission lines (36.7%) and losses (34.2%). Burundi also has a loss reduction problem. It would be able to reduce them by 17.2%. Kenya is the only country with a relatively lower level of slacks, while Rwanda has an underutilization of transmission lines. Thus, all countries should take steps to optimize the use of power sector resources to increase access to electricity and quality of service.

Interpretation of the different slacks appears to be somewhat difficult without disaggregated data at the output level, including the category of consumers and their electricity consumption. Where the industrial sector is developed, electricity consumption is higher than in the residential sector, which has a large number of customers. For example, REN21 (2016) shows that industrial sector consumption is higher in Kenya, Tanzania, and Uganda than in Burundi and Rwanda[30]. Ethiopia has also increased industrial sector consumption. On the other hand, aggregating the data at the country level could thus penalize one or another company as inefficient when it is doing well. However, incentive mechanisms can be created in each country to make the power sector more technically efficient. This would mean, for example, assigning each company targets to achieve in terms of access to electricity and QoS. For example,

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[30] According to REN21 (2016) the electricity delivered to households accounts for 5% in Tanzania, while commercial and industrial sector represents 70% of the electricity consumed in Uganda and Kenya. The poor level of industrialization can be one of the main causes of inefficiency. Therefore, conducting the energy policy must be coupled with other policies, such as industrialization.

the regulator could provide rewards for companies that meet the target, and penalize those that are inefficient. It is also important to analyze the impact of private sector participation on technical efficiency.

3.5.3. Have reforms in the electricity sector improved technical efficiency?

To find out the factors that determine technical efficiency, we conduct a second stage study by estimating a Tobit regression model. In this model, the technical efficiency scores obtained from the generation model and from the transmission-distribution model are considered as dependent variables.

To analyze the importance of the reforms on the performance of the electricity sector, we rely on two independent variables, vertical unbundling and private sector participation. They are dummy variables that take into account the year of reform implementation, to which we assign the value 1, and 0 if no reforms are implemented. We also consider two other indicators commonly used in the second stage. GDP per capita is expressed in hundreds of constant dollars in 2015, obtained from the World Development Indicators (WDI). Customer density is obtained by the ratio of the number of customers per square km of land area, the latter being also obtained from WDI.

We anticipate a positive relationship between the implementation of reforms and the performance of the power sector. On the other hand, the increase in GDP per capita not only increases the inputs, but also the outputs through the increase in customers and electricity consumption. Finally, a high customer density implies a high access rate to electricity, which has a positive impact on performance. Table 3-8 shows the estimated values of the parameters of the independent variables with the Tobit regression.

Table 3-8. Determinants of technical efficiency scores

VARIABLES	Parameter	Generation model	Transmission Distribution model
Constant	β_0	0.474***	0.299***
		(0.0563)	(0.0512)
Private participation	β_1	0.213***	0.182***
		(0.0628)	(0.0564)
Unbundling	β_2	-0.322***	-0.0103
		(0.0510)	(0.0458)
GDP per capita	β_3	0.0309***	0.0325***
		(0.00935)	(0.00855)
Customer density	β_4	0.00526	0.00105
		(0.00350)	(0.00313)
Observations		60	60

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The coefficient on the parameter associated with private sector participation is positive and statistically significant at the 1% level in all models. In contrast, the coefficient on the parameter associated with vertical separation has a negative sign, which is contrary to our hypothesis. A positive sign is also associated with GDP per capita and customer density. However, it is not statistically significant for the latter factor. Thus we can conclude that the attraction of the private sector has a positive impact on the performance of the electricity sector, as does the increase in GDP per capita. On the other hand, the vertical separation does not show an expected sign, which may result from the choice of other variables.

Private participation, in whatever form, could contribute to increased technical efficiency. This is also consistent with the results of Bagdadioglu et al. (1996), Barabutu & Lee (2018), Çelen (2013), and See & 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), public intervention in the electricity sector often leads to political interference, which results in higher electricity losses, such as electricity theft.

On the other hand, Eberhard et al. (2018) show that the vertically integrated and state-owned electricity sectors is associated with poor governance. These institutions are characterized by a high level of bureaucracy, which hampers the decision-making process. Bagdadioglu et al. (1996) proposes to accelerate the privatization programme. Attracting the private investors could improve access to electricity and the quality of service, as the state-owned utilities are sufficiently inefficient to cover the countries. Barabutu & Lee (2018) propose implementing programmes such PPP in the case of the electricity sector in Southern Africa.

Even if vertical unbundling does not have the expected effect, other studies prove the contrary. Nagayama (2010) finds, for example, that vertical unbundling has increased installed capacity per capita in developing Asia and developed countries, while reducing transmission and distribution losses in developed countries. Asantewaa et al., (2022) find that vertical unbundling in SSA improves power sector performance. Their findings suggest that unbundling would be of interest when the country has access to a large market. In addition, they find that private sector participation in management or ownership positively affects performance. Mullarkey et al. (2015) also find that power sector restructuring improves power sector performance.

3.6.Conclusion

The first two chapters analyzed the performance of the electricity sector in Burundi. However, an international comparison of power sector performance with other countries is necessary. In this chapter, we estimate the technical efficiency of the power sector in East African countries. We use panel data from utilities in six countries from 2008 to 2017. Given the complexity of the utilities arising from the diversity in the reform implementation, we base our performance comparison on a generation model and a transmission-distribution model. We test the convergence of the technical efficiency scores obtained from the two models using the non-parametric Mann-Whitney test. The technical efficiency scores are obtained using a non-parametric DEA linear programming model, using the DEAP version 2.1 solver developed by Coelli 1996. This model also determines the relative inefficiencies of inputs and outputs, which are reflected in terms of the underuse of inputs and the expected output that could be achieved using the available inputs. We are particularly interested in input inefficiencies, given the input-oriented DEA model. In the second stage, we analyze the impact of environmental factors, those related to power sector reform and other macroeconomic variables, on technical efficiency.

The results show that, overall, the power sector is 19.6 percent inefficient in the generation model and 23.5 percent inefficient in the transmission-distribution model. These results show that the power sector in East Africa is globally inefficient, given the high performance gaps. However, the degree of technical inefficiency varies from country to country.

Kenya and Rwanda are moderately efficient, with significant annual customer growth rates compared to other countries. On the other hand, Burundi and Ethiopia are technically inefficient in both models. For Ethiopia, its inefficiency is more based on the underutilization of investments in installed capacity and transmission lines, which could have served increasing electricity access and consumption.

For Burundi, technical inefficiency is based on excessive electricity losses that threaten the financial health of REGIDESO. These losses deprive the utility of generating sufficient revenues not only for recovering costs, but also to increase investments to improve both service quality and access to electricity. To reduce electricity losses, investments should be made in electricity fraud detection equipment and prepaid meters should be generalized to all consumers to minimize unpaid bills, especially for public sector.

It should be noted that the poor QoS also has an impact on water supply, as much of the water is pumped by electricity. As REGIDESO is a horizontally and vertically integrated public company, inefficiency in electricity distribution negatively affects its financial health, but also the welfare of users. Investing in installed capacity, transmission and distribution lines and their regular maintenance becomes problematic. Burundi could implement the 2000 law on the horizontal separation of the drinking water and electricity sectors and outsource their management to independent operators, while strengthening the capacity of the regulatory authority.

Encouraging private sector participation in the electricity sector would improve sector performance. Countries have the responsibility to put in place measures to remove barriers to the private sector, particularly those related to financing and regulatory quality. Private sector participation can be both in competitive services such as generation and sales, as well as in infrastructures. At the generation level, private investment should be directed towards untapped sources of electricity in the region, such as nuclear, solar, wind, and geothermal.

Finally, all six countries are members of the East African Power Pool. One of its objectives is electricity interconnection and trade. Joint investments should be made to facilitate the mobilization of resources for the construction of power plants and transmission lines. Harmonization of the transmission system will increase system reliability and access to electricity. The main limitations of this study are related to low data coverage. If data were available, the study could be extended to all member countries of the East African Power Pool, using other benchmarking approaches such as stochastic frontier analysis. We have just seen in this chapter that losses are an important slack in the countries under analysis, and a source of inefficiency. It would be important to analyze how to minimize them, which is the purpose of Chapter 4.

Chapter 3. Benchmarking the electricity sector in East Africa

4. Quality performance gaps and minimal electricity losses in East Africa[31]

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 (e.g. higher transmission capacity), the outputs (e.g. improved billing system), 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 of the electricity generation process constant. Minimal losses are then compared to actual losses to construct quality performance indicators. Using a detailed and tailored database for six East African countries over a 10-year period, we show that electricity losses could be reduced by 8% without requiring new investments, representing approximately $60 million per year.

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

4.1. 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

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[31] Joint with Axel Gautier and Barnabé Walheer

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 million 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; 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 billion 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; 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 on T&D losses 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 utilities taking into account electricity losses. 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.

In practice, electricity losses are added to the electricity generation process often as an undesirable output input (Bongo et al., 2018; Petridis et al., 2019) or as an input (Bagdadioglu et al., 1996; Edvardsen & Førsund, 2003; Jain & Thakur, 2012; Jamasb

& Pollitt, 2003; Meenakumari & Kamaraj, 2008; Pacudan & Hamdan, 2019; Pérez-Reyes & Tovar, 2009; Ramos-real et al., 2009; Tovar et al., 2011; Vaninsky, 2006; Vaninsky, 2008; Von Hirschhausen et al., 2006; Xie et al., 2018; Yunos & Hawdon, 1997). Table 5 lists the main papers using electricity losses in performance measurement and details the inputs and outputs used in the analysis.

Table 4-1. 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 purchased, 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**

Authors	Outputs	Inputs
Pérez-Reyes &Tovar (2009)	Annual sales, number of customers	labor, **electricity losses**, network length, number of sub-stations, capital
Petridis et al. (2019)	Energy supply, number of customers, number of city served, interruptions, **energy losses**	Labor, electricity 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**, generation capacity factor

Source: compiled by the authors

Our approach differs to previous studies as we do not consider electricity losses as part of the electricity generation processes but as a measure of the performance gap

(Walheer & He, 2020). 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 describes our empirical strategy and how we estimate quality performance gaps. In Section 4, we present and describe our data and give our main results. We conclude and provide policy recommendations in Section 5.

4.2. 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 represent 22% of the power supply. This number is relatively high compared to an average of 12% forthe Sub-Saharan African and a world average of 8%.

Reducing losses is therefore a key challenge for East African countries. They are seeking to mitigate electricity losses, with as a target a minimum loss rate of 15% at least. Based on the SE4ALL[32] country analysis and other reference documents such as the master plans for electricity generation, transmission and distribution, the national energy policies and/or strategies, we detail the situation of each country in

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[32] Sustainable Energy for All (SE4ALL) is an independent organization linked to the United Nations that works to achieve Sustainable Development Goal 7: access to affordable, reliable, sustainable and modern energy for all. Its website (https://www.se4all-africa.org) provides useful information on East African countries.

the East African Community[33].

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. It was shown in Chapter 1 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 prepaid 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,

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[33] 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.

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 losses represent about $17 million 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.

4.3. Empirical strategy

We consider that we observe N countries during T time periods. The electricity generation process of each country at time t consists of two inputs (captured by $\boldsymbol{x_t}$): the length of the transmission lines and the purchased electricity[34], and two outputs (captured by $\boldsymbol{y_t}$): the number of consumers and the energy delivered. These inputs and outputs are very common in the literature (see Table 4-1). Also, electricity losses, denoted by l_t, occur at every period t.

Our objective is to evaluate the minimal losses that can be achieved given the inputs

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[34] We do not use as an input the generation capacity or the electricity produced in a given country. The reason is that there are a lot of imports/exports between countries. For that reason, the electricity purchased better reflects the electricity generation process of a country.

and the outputs and the technology used for every time period. The electricity losses represent our proxy for the quality performance gaps.

4.3.1. 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 the banking industry (Asmild et al., 2004; Fadzlan & Muhd-zulkhibri, 2007), the energy and the environment (Sueyoshi et al., 2017; Wang et al., 2013), the telecoms (H. Yang & Chang, 2009), and power plants (Sueyoshi et al., 2013).

This technique operates on the principle of moving averages and establishes efficiency measures by treating each country 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 $\mathbf{x}^{w}$ and $\mathbf{y}^{w} \in \mathrm{R}$ 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 country operating at ($\mathbf{x}_t$, $\mathbf{y}_t$):

$$l^{t}(x_t, y_t) = min\lambda^{\omega}_{j\mathrm{T}, j\epsilon\{1,\ldots,N\},\mathrm{T}\epsilon\omega} \left(\begin{array}{c} \sum_{\mathrm{T}\epsilon\omega} \sum_{j=1}^{J} \lambda^{\omega}_{j\mathrm{T}}\, l^{\omega}_{j\mathrm{T}} | y_t \leq \sum_{\mathrm{T}\epsilon\omega} \sum_{j=1}^{J} \lambda^{\omega}_{j\mathrm{T}}\, y^{\omega}_{j\mathrm{T}}\,, \\ x_t \geq \sum_{\mathrm{T}\epsilon\omega} \sum_{j=1}^{J} \lambda^{\omega}_{j\mathrm{T}}\, x^{\omega}_{j\mathrm{T}}, \\ \sum_{\mathrm{T}\epsilon\omega} \sum_{j=1}^{J} \lambda^{\omega}_{j\mathrm{T}} = 1, \\ \lambda^{\omega}_{j\mathrm{T}} \geq 0 \forall j, \mathrm{T} \end{array} \right) \quad (1)$$

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 reach 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 $\lambda^{\omega}_{j\mathrm{T}}$ for every country j, window ω and time T. These weights are directly useful to consider variable returns-to-scale (**A4**). It suffices to impose these weights sum to unity. Finally, **A5** is captured by the window-specific sums.

Finally, all observations in window ɯ 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 and ending periods. As our main interest is the minimal losses for each time period and country, we have to aggregate the window-dependent estimators. A simple way to do is to take the arithmetic average as follows:

$$l(x_t, y_t) = \frac{1}{\neq \text{ɯ}} . \sum_{t\epsilon \text{ɯ}} l^{\text{ɯ}}\,(x_t, y_t) \qquad (2)$$

$l(x_t, y_t)$, contrary to $l^{\text{ɯ}}(x_t, y_t)$ is window-independent and is directly useful to conduct the rest of our analysis.[35]

4.3.2. 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:

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[35] It is also possible to take the average in each window. This is not interesting for us. Note also that this aggregation scheme, while simple, is theoretically correct (see e.g. Walheer, 2018).

$$QPGR_t(l_t, x_t, y_t) = \frac{l_t(x,y)}{l_t} \tag{3}$$

$$QPGD_t(l_t, x_t, y_t) = l_t - l_t(x, y) \tag{4}$$

$QPGR_t(l_t, x_t, y_t)$ 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. $QPGD_t(l_t, x_t, y_t)$ gives us the amount of potential electricity losses in GWh. A value of zero indicates that the maximal service quality has been reached. Finally, we once moreemphasize that these two indicators are nonparametric estimators of the unknown counterparts.

4.4. Data and Results

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

4.4.1. Data sources

We collect data from six countries: Burundi, Ethiopia, Kenya, Rwanda, Ugandaand 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. East African countries have different organizations for the energy sector (Table 4-2).

Table 4-2. 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 + UEGCL	UETCL	9 Private Firms

Source: compiled by the authors

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.[5]

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.

4.4.2.1. Electricity generation process

In Table 4-3, we present the descriptive statistics for our two inputs (the transmission length[36] 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.

Table 4-3. 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 %

Source: Compiled by the authors

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[36] 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.

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.

4.4.2.2. Actual electricity losses

We compute the electricity losses as the difference between purchased and delivered electricity. Electricity losses are reported in absolute value (GWh) and in percentage of the purchased electricity. Descriptive statistics are provided in Table 4-4. In average over the period, 21% of the purchased electricity is lost. This represents a loss of power of 18 895 GWh per year. There is only one country, Uganda, that manages to decrease significantly the electricity losses, from 34% in 2008 to 17% in 2017. Uganda increased the energy delivered and maintain the power losses in GWh almost constant. All other countries experience higher losses in 2017 compared to 2008. Burundi and Ethiopia had increasing losses in both absolute value and in percentage of the electricity delivered. Burundi had the highest losses in percentage at the end of the period with 29% of the purchased electricity being lost. Kenya, Rwanda and Tanzania had increasing losses in GWh but they remain constant in percentage. It should also be noticed that electricity losses have could vary considerably from one year to another.

Table 4-4. 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%

Source: compiled by the authors

4.4.3. 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 4-5 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 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 4-5. Quality performance 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[37] 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 million per year in East African. We point out that Tanzania and Uganda have the largest potential saving.

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

4.5. Conclusion

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

We collected data on actual electricity losses in East Africa and we show that the countries are far from reaching these goals. With the exception of Uganda, electricity losses are increasing everywhere in absolute value (GWh) and in some countries also in percentage of the electricity delivered. The objective of this study is to provide a measure of the performance gap. In this study, 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. From that, we can identify a quality performance gap corresponding to the losses that could be avoided if a country adopts the best practices.

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 a generation input, the energy purchased. For the outputs, we use the energy delivered and the number of clients. These inputs and outputs are standard in the literature. Electricity losses are neither inputs nor outputs but a measure of the quality performance gap. Losses have to be minimized given inputs, outputs and the technology.

We provide for each country an estimation of the performance gap. Less performing countries have an average 15% performance gap, best performing countries a 2% one, compared to best practices in the region. This represents the potential for loss reduction if best practices were adopted, that we estimate to be equal to 8% in average. Expressed in dollars, the potential savings for East African countriesare important; Tanzania has the highest potential savings that we estimate at $ 26 million. Improved performance would result in better financial health for the utilities, better service quality and reduced costs. Ultimately this could benefit to consumers and provide affordable energy for more.

We use data for 6 East African countries and the sample period covers 10 years. Despite the use of a window analysis, one main limitation of the analysis is the limited number of comparable units. The sample used for the analysis remains limited. Furthermore, electricity produced and delivered depend on demand and production conditions that could be affected by different shocks. Our parametric model cannot easily take these shocks into consideration. For all these reasons, we are cautious when we interpret the result and we are focusing mainly on the country average performance over the period. However, we manage to provide reasonable estimations for the performance gap and to show that there are substantial possibilities to decrease losses by adopting best practices.

Additional data could be used to improve the results and provide better proxy for the countries performance. Our objective is to continue to work on this topic and to collect further data for research.

One of the main contribution of this paper is to develop a methodology to estimate quality performance gaps. This kind of study can be replicated in other sectors facing the same challenges. This is for instance the case of the water sector where a substantial fraction of the pumped water is not delivered to consumers. As for electricity, there is a performance gap and our methodology could be used to assess this gap in different regions or countries.

Conclusions, policy implications and direction for future researches

The conclusion is centered around three points. In the first section, we summarize the main findings across the chapters. In the second section, we propose policy measures to incentivize the private sector and how to transform the reforms for greater efficiency. Finally, we address guidelines for further research.

Summary of the thesis

In the first chapter, we investigate the organization and performance of the electricity sector in Burundi. We find that Burundi has shown a willingness to reform its electricity sector by putting in place a legal and regulatory framework. Indeed, the 2000 law unbundles horizontally and vertically the drinking water and electricity utilities. It aims to attract the private participation in each sector. However, this law has not been implemented, as REGIDESO remains the sole operator for the two utilities characterized by poor performance.

Access to electricity remains one of the lowest in the world. Electricity generation depends on investment in installed capacity made in the 1990s. Despite a potential of 1,700 MW of which 300 MW is economically exploitable, installed capacity, including imports, is just over 80 MW. Demand for electric energy increased with urbanization while supply remains insufficient. As a result, Burundi implemented a load shedding program, resulting in a poor QoS. In addition, electricity losses are excessive, including unpaid electricity bills, particularly from the public sector.

Conclusion, policy implications and direction for future researches

Burundi has resorted to a system of increasing tariffs, the aim being to improve the financial health of the electric utility. The pricing system available is increasing block tariff, which has led to under-consumption. The low level of electricity consumption, tariff administration that does not allow for cost recovery, and non-payment of bills, mainly by the public sector, could be barriers to private sector participation. The study proposes to implement power sector reforms and reduce barriers to private sector participation.

In the second chapter, we propose measures to improve the QoS in the electricity sector in Burundi. This chapter is based on an original database that we have compiled ourselves from the power outages and from a survey on transformer capacity at the district level. These districts are managed in five regions all belonging to REGIDESO. We estimated a translog distance function using parametric linear programming (PLP) model.

We compare the results following a model without environmental variables and a model with environmental variables (z). The results show that customers are the highest cost consumer, while transformers represent a large weight in the inputs and in both models. The overall performance gap is 31% in the model without z and 20.6% in the model with z, showing that the electricity sector is inefficient. We also find that the shadow price of investments in transformers required to reduce 1 MWh of electricity losses due to outages is US$179.07 and US$223.70 per kVA for the model with z and the model without z, respectively. These investments are excessively expensive and it would be impossible for REGIDESO to cover them, given its fragile financial health. In this case, the trade-off appears to be: accept investment and reduce power cuts and the electricity not served as a result of the interruptions, maintain the status quo and accept the losses. Burundi should separate the public drinking water sector from the electricity sector by entrusting them to two different institutions. Separation of ownership in each sector through private sector participation in both management and infrastructure, as well as reducing political interference in management, could lead to improved performance, including ensuring access to electricity and quality of service in both sectors.

In this chapter, QoS in the electricity sector is defined by electricity not served due to outages, which are obtained by the difference between the electricity potentially delivered without outages and the electricity that has been consumed. This formula has shortcomings because it assumes that all power plants are operating at maximum capacity and that customers do not change their consumption during the year. For this reason, in Chapters 3 and 4, we used an alternative measure of electricity loss as an indicator of poor QoS, calculated as the difference between purchased and delivered electricity.

In Chapter 3, we analyze Burundi's electricity sector from an international perspective by comparing its performance with that of East African countries. Although these countries share the same climatic conditions, they differ from the electricity sector reform perspective. Some countries have implemented power sector reforms and have attracted the private sector, either in generation and distribution or through the asset ownership. Given the complexity of the power sector, we compared the performance under a generation model and a transmission-distribution model. We used a non-parametric method, DEA input-oriented. We tested the equivalence of the results from two model using the Mann-Whitney test. We also used the Tobit regression to investigate the factors determining the technical efficiency, especially those related to electricity sector reform. We used data for 6 countries and ten-periods comprising two outputs and three inputs.

The results show that the East African power sector is overall technically inefficient, the performance gap being 19.6 and 23.5 percent respectively in the generation model and transmission-distribution model. For Burundi, the performance gap is 20.7 percent in the generation model, and 32.7 percent in the transmission-distribution model. These performance gaps are similar to those found in Chapter 2 and confirm the inefficiency of the electricity sector in Burundi. The Mann-Whitney test shows that there is no statistically significant difference between the technical efficiency scores obtained in the two models. On the other hand, we find that electricity losses are the main cause of inefficiency in the electricity sector in all countries. Analyzing the factors that determine technical efficiency, we find that private sector participation and GDP per capita increase the performance of the power sector. Therefore, improving private sector participation in power generation and distribution, as well as in asset management or ownership, could increase power sector performance.

Chapter 4 is devoted to the study of quality performance gaps and minimal electricity losses in East Africa. Electricity losses are one aspect of QoS. Policies to reduce electricity losses require changes in inputs, such as increasing installed capacity or upgrading transmission and distribution networks, and outputs, such as improving the billing and collection system. In this chapter, a new angle of estimating electricity loss minimization has been considered. We determined and compared the minimum losses to the actual losses by estimating a non-parametric method without changing the inputs, outputs and technology. We used data from six countries over a ten-year period. Purchased electricity and high voltage transmission lines are used as inputs, while customers and delivered electricity are outputs. Electricity losses are neither an input nor an output, but a variable that must be minimized given the inputs, outputs, and technology. This allowed us to identify performance gaps by country.

The results show that the performance gap represents an average saving of 78.82 GWh per year and per country. The potential reduction of electricity losses depends from one country to another. The quality performance gap ratio is for example equal to 5%, while the quality performance gap difference is 2.42 GWh representing a potential saving of US$ 283,140. In the second chapter, we saw that the shadow price for the model with environmental variable was equal to US$ 223.70 per kVA, such as US$ 223,700 for a transformer capacity of 100 kVA. Reducing power losses would save money that can be used to purchase an additional transformer of 100 kVA. However, taking into account the willingness of individual countries to reduce their electricity losses, the estimated quality performance gaps allow each country to set an annual target for loss minimization.

Policy implications

From the analysis across the four chapters, it appears that the electricity sector in Burundi remains technically inefficient. This is apparent both in the first two chapters, where the electricity sector in Burundi is studied alone, and in the last two chapters when it is compared to other East African countries. It would therefore be interesting to take steps to make the electricity sector in Burundi efficient. This would mean not only implementing power sector reforms, but also removing barriers to private sector participation.

Moving forward with the power sector restructuring process

The comparison of power sector performance in East Africa shows differences in terms of power sector reform implementation. Some countries have restructured their sectors and promoted private sector participation, while others retain a vertically (and horizontally) integrated monopoly. However, the latter has been criticized for being inefficient: inability to connect most of the population, particularly those in rural areas, high levels of technical and non-technical losses, frequent power outages, and insufficient supply to meet demand. Furthermore, while the virtues of vertically integrated monopolies include reduced transaction costs and increased economies of scale, it has been noted that public monopolies are characterized by very high costs, which limits their profitability.

Many developing countries have established a legal framework for the restructuring process. Jamasb (2006) describes how the restructuring process is carried out, aiming in particular to separate competitive activities (electricity generation and supply) from the natural monopoly segments (transmission and distribution) as a first step. Indeed, the inefficiency of the electricity sector is much more evident in the electricity distribution. In developing countries, inefficiency is generally based on regulated tariffs set at a level that does not allow for cost recovery, unpaid bills, technical and non-technical losses, and the inability to reduce power outages.

These technical and non-technical losses deprive the utilities of revenue, which contributes to their poor financial health. To this end, Jamasb (2006) proposes the introduction of competition in the distribution segment by creating a number of distribution companies in both the interconnected and off-grid systems. In the Eastern African context, this model is working in Uganda, where Umeme Limited has been awarded a 20-year concession contract over the distribution sector previously operated by Uganda Electricity Bord, together with a range of other utilities operating mainly in off-grid settings (Mawejje et al., 2013).

Restructuring also aims to separate the generation and transmission sectors. In this case, competition can be organized in the generation sector by creating several units, and organizing a wholesale electricity market based on a single seller at marginal cost. At the generation level, IPPs can generate electricity at their own risk, or by establishing power purchase agreements (PPAs) with existing generation companies. Uganda and Kenya are two countries that have successfully attracted IPPs (Eberhard et al., 2017; Kapika & Eberhard, 2013; Meyer et al., 2018). These IPPs have contributed significantly to investments in power generation and function under PPP contracts that take various forms: build-own- operate (BOO), build- own -transfer (BOT), design-build-finance-operate-transfer (DBFOT), or design-build-own-operate-maintain-transfer (DBFOOMT) (Eberhard & Gratwick, 2011; Mouraviev & Kakabadse, 2016). According to Asantewaa et al. (2022), competition in the generation market helps to limit the dominance of the incumbent and facilitates competition in the wholesale market. Joskow (2003) shows that private sector participation in generation can mobilize sufficient resources for the construction of new plants.

Unbundling of the electricity sector can take three forms: administrative, legal, and capital separation. By analyzing the pros and cons of the three forms, Baarsma et al., (2007) show that administrative unbundling is the least effective. It consists of separating the accounts of the infrastructure activities on the one hand, and of the activities subject to competition on the other, while remaining under the vertically integrated management of the company. This form has been adopted, for example, in

Tanzania, where generation, transmission, and distribution departments are managed separately and headed by senior managers. Capital separation should be the most interesting, but achieving it is a big challenge. Indeed, it is sometimes difficult to determine the market value of assets. And when this separation is achieved, the assets are often sold at lower prices, leading to speculation by politicians who want to acquire these assets, and a loss for the utility. This is why the legal separation of the competitive and infrastructure activities into different entities is the most advantageous, which is a prerequisite for privatization. Countries such as Uganda, Kenya, and Ethiopia adopted the legal unbundling, while Rwanda adopted a management contract with a holding company.

Overcoming barriers to electricity sector reform

In the 1980s and 1990s, SSA countries encountered difficulties in financing their power sector investments, and subsidies, initially intended to support the rural poor, only benefited the urban population. Macroeconomic conditions justify the inefficiency of the power sector in SSA, such as the deteriorating business climate, government budget constraints, structural adjustment programs (Imam et al., 2019; Jamasb, 2006). Public monopolies have been criticized for inefficiency: long power outages, weak institutions, undercapitalization, poor equipment maintenance, high technical and non-technical losses, inability to provide electricity to the poor population (Jamasb et al., 2017). The electricity sector reforms aimed at improving efficiency in terms of quality of service, access to electricity, reducing discrepancies between price and costs through cost-reflective tariffs (Kessides, 2013; Newbery, 2002).

Under the impetus of major donors such as the World Bank, the various countries of SSA, Burundi in particular, have put in place legislations aimed at reforming the electricity sector, which have remained only on paper. Their implementation, however, varies from country to country. Eberhard et al. (2016) show that only five SSA countries had vertically separated their power sector, established a regulatory agency, and attracted private sector investment, compared to nine countries that had not initiated reforms. A large proportion of countries still had a vertically integrated power sector, even if they had established a regulatory agency or attracted private sector investment.

The electricity sector reforms implementation has encountered a series of obstacles, from political circles, opposition parties, workers' unions, civil society associations (Cheng et al., 2020; Dornan, 2014). The resistance to reform was justified by concerns about high electricity tariffs, job losses, unreliable service, concentration of services in profitable areas, and lack of incentives for private access for the poor. According to Gore et al. (2019), politicians and other policymakers have used their power to delay the implementation process, slow down the adoption of reforms, or pick and choose the reforms that benefit them. According to Dornan (2014), resistance to reforms comes from the general public who fear rising tariffs, and from interest groups such as labor unions who fear job loss or wage cuts resulting from structural adjustment policies. The inefficiency of the electricity sector prior to reform, including an accumulation of unpaid electricity bills.

One of the barriers to reform in the electricity sector is the deficiency in revenue collection, mainly from the public sector, including ministries, government agencies, and state-owned enterprises (Nellis, 2005). We discussed this in Chapter 1, where the accumulation of unpaid bills exceeds REGIDESO's sales, with over 40 percent of the debt originating from the public sector. The poor revenue collection increase

REGIDESO's debts to banks and other suppliers, which conducts to circular debt. As a result, very few private investors would be interested in buying the assets of this public enterprise. The poor revenue collection may be related to the poor governance of state-owned utilities. Nellis (2005) shows that the Board of Directors of state-owned utilities, as well as the heads of departments, are appointed by presidential decree. They are usually chosen from civil servants who represent the ministries, without technical or business experience.

In Burundi, the decree establishing REGIDESO stipulates that among the nine members of the board of directors, only one director is chosen for his particular skills and experience. The decree is silent on the profile of the remaining directors. Also, the decree appoints the Minister of Energy as the supervisor of the electric company, who can terminate any decision of the board of directors that he deems contrary to the public interest. As long as the directors do not represent the interests of the shareholders or their own interests, it would be difficult to claim the debts of their Ministries. Nellis (2005) realizes that the appointment of managers of public enterprises, as well as the members of the board of directors, are often chosen for their political party affiliation and not for their technical skills. Thus, the public enterprise is a source of funds and employment for the party members or their families, which inflates the firm's expenses. Improving the financial health of these enterprises requires managerial and personal skills to address the political barriers to good governance.

Ensuring the independence of the regulatory authority

Another reform in the electricity sector is the establishment of an independent regulatory authority. The objective of the regulatory agency is to facilitate competition, ensure non-discriminatory access to the grid, and provide incentives for improved performance, including a cost-recovery tariff and an improved revenue collection. The absence of an independent regulatory authority is a barrier to the successful reorganization of the electricity sector. The regulatory authority guarantees the interests of both consumers and investors. It sets up performance incentive mechanisms, such as the minimization of electricity losses, reduction of costs, improvement of the quality of supply, thus contributing to the improvement of consumers' welfare. Eberhard et al. (2017) and Eberhard & Gratwick (2011) state that the establishment of an independent, transparent, and equitable regulatory authority contributes to credible decisions on market access, tariffs, and revenues that encourage investment. According to Stern (1997), effective utility regulatory institutions are ones that provide transparency and predictability which are achieved by making regulatory agencies accountable.

According to Bacon (2018), regulation makes sense after unbundling and entry of some private sector into the electricity sector. The rule of the independent regulator is to control the power market of private participants by insuring some efficiency gains are passed to consumers. As Imam et al. (2019) confirm through their findings, the creation of an independent regulator improves the performance of the electricity sector, notably by increasing social welfare.

Jamasb (2006) and Jamasb & Pollitt (2003, 2007) discuss the different forms of incentives on which regulation is based. Incentive regulation contributes to cost efficiency, lower prices, reduced electricity losses, and improved revenue collection. The traditional regulation incentive was based on internal rate of return regulation, which is based on return on investment. Other incentive regulation have been implemented such as output-based regulation (Cambini et al., 2014, 2016; Coelli et al., 2013), and price cap or revenue cap regulation aiming at cost reduction (Jamasb, 2006;

Jamasb & Pollitt, 2007; Joskow, 2014). The regulatory model applied in Uganda and Kenya is cost-reflective tariffs, which has been successful in attracting new investment in electricity generation and distribution (Meyer et al., 2018; Pueyo, 2018).

To identify which utilities meet their cost minimization targets, the regulator must choose appropriate benchmarks and techniques, those derived from best practices in particular. Frontier-based benchmarking methods are the most commonly used. These methods identify or estimate the effective performance frontier from the best practices in an industry or sample of firms. Commonly used frontier-based benchmarking methods are DEA, SFA, and Corrected Ordinary Least Square (Growitsch et al., 2009; Jamasb & Pollitt, 2001). According to Joskow (2014), using competitive or "yardstick regulation" constitutes one way in which regulators can effectively reduce their information disadvantage in the price- setting process.

Removing barriers to private sector attraction

Studies have shown that attracting the private sector contributes to improved power sector performance, such as technical efficiency, access to electricity, and quality of service (Imam et al., 2019). This is consistent with findings in Chapters 3 and 4. Therefore, attracting the private sector is necessary to not only increase installed electricity capacity, but also improve both access and quality of service. However, barriers to private sector participation need to be reduced, including financing, regulatory barriers, and capacity building.

The electricity sector requires high levels of investment. This can be acquired either locally through bank financing or internationally through capital markets. Investments in the power sector are for long-term and the payback period is relatively long.

Financing this type of project therefore requires high guarantees, which are particularly difficult to put in place, especially in developing country environments where banks favor short-term loans at high interest rates. This guarantee can only come from the ability of consumers to adopt electrification and pay for electricity.

Thus, the electrification policy should not be conceived on its own, but should be accompanied by other policies such as urbanization and villagization, industrialization, and the development of services that enable the increased demand for electricity consumption (Yang & Yang, 2018). By financing the construction of power plants, it is necessary to ensure the consumption of the electricity generated, which means increasing consumer income.

Electrification projects are also perceived by lenders and capital providers as very risky especially in developing countries (Williams et al., 2015). The main risks to overcome mentioned by these authors include grid impediment, unregulated competition, loss of operating subsidies, changes in regulated tariffs, and other sources of policy and regulatory uncertainty. To mitigate these risks, it requires the establishment of a sound policy and regulatory environment.

Private sector participation in the electricity sector requires the vertical unbundling of the state-owned utility. The introduction of a regulatory agency thus allows for balancing the interests of both consumers and investors through a tariff that is cost-recovery for investors and affordable for consumers. To achieve this goal, the regulatory agency must ensure that costs, technical and non-technical losses, are reduced by providing incentives for performance. Technological upgrades would reduce technical and non-technical losses, such as pre-paid meters for reduced unpaid bills, and smart grids for improved utility service quality through reduced power outages. On the other hand, when the regulator is not independent, there is political interference aimed at setting tariffs below cost. Improving governance in the power sector could also help attract the private sector, particularly through reducing corruption, as suggested Imam et al. (2019).

Directions for Future Research

This study has focused on the performance of the electricity sector in Burundi and East Africa. However, it has not addressed all aspects of performance. In-depth studies could be conducted to analyze why the power sector remains inefficient. In the following, we propose alternative pathways for power sector research.

Exploring how to increase access to electricity in Burundi

This thesis analyzes access to electricity using REGIDESO administrative data. Although the electricity data shows that access to electricity is low in Burundi, it did not take into account rural electrification, particularly by analyzing private initiative through solar solutions. Development programs are often involved in rural electrification, particularly health facilities, schools, and other infrastructure that do not have access to the interconnected grid. Studies could therefore focus on rural electrification by analyzing the adoption of new renewable energies such as solar photovoltaic panels.

Analyze the impact of the electricity pricing system on access or consumption.

In Chapter 1, we saw that the electricity pricing system differs from one country to another. In particular, it was shown that the increasing block tariff system discourages large consumers. In addition, even if the government provides subsidies by zero-rating lower consumption, it is found that the subsidies benefit the richer people much more than the poor. It would be necessary to study which pricing system would be favorable for both the electricity companies and the consumers. As East African countries have established regulatory agencies for the electricity sector, it would be important to compare the independence of these agencies and their performance in setting tariffs. This study requires in-depth surveys of the agencies, the regulated structures, and the consumers of the services. The study could also be carried out on the demand side by studying, for example, the price elasticity of electricity demand.

Analyze poor service quality and its impact on performance

The quality of service that is the subject of this thesis has been analyzed from the supply side, i.e. the utility. Electricity losses were considered as an indicator of poor service quality, and were calculated in two ways, losses related to power outages and losses resulting from the difference between purchased and delivered electricity. There are other indicators of poor system reliability that can be used for performance comparison. An in-depth benchmarking study taking into account these grid reliability indicators could be conducted within the framework of the East African Power Pool countries.

As the various countries have established regulatory agency entities for the energy sectors and are grouped together in an association, they should harmonize their data collection practices to facilitate benchmarking studies. While we have used the DEA method in this thesis, other benchmarking methods such as the SFA method could be explored to analyze whether performance trends are the same. Benchmarking studies could be conducted separately across the different segments of the electricity sector such as generation, transmission, and distribution. Other studies could be conducted on other network industries such as drinking water, sanitation, telecommunications, air or rail transport, etc.

Analyze the willingness-to-pay for QoS improvement

It would also be important to analyze service quality from the demand side, through willingness to pay. Indeed, poor service quality is a burden and a threat to consumers. The magnitude of the menace is not uniform for the residential and industrial sectors. Similarly, the magnitude could differ within the same group of consumers, distinguishing for example between grouped and single households, small and medium-sized enterprises versus large enterprises. The estimation of willingness to pay can be an instrument that the regulator could use in setting tariffs. Also, it can be one of the indicators to improve investments in the increase of the installed capacity.

Analyzing performance through the EFQM excellence model

The study we conducted concerns the estimation of performance in the context of the sector. However, it has been noted, as we have seen in chapters 1 and 2, that REGIDESO is characterized by poor financial health. As a result, it is unable to achieve its objectives in terms of increasing access to electricity and quality of service. It would therefore be interesting to analyze performance within each utility. This would involve analyzing the system's management quality and the interactions between the different actors. The EFQM excellence model, developed by the European Foundation for Quality Management, could be used as a method of assessing the effects of quality management. The consideration of this model should take into account the characteristics of products, services or types of business, and assign performance scores.

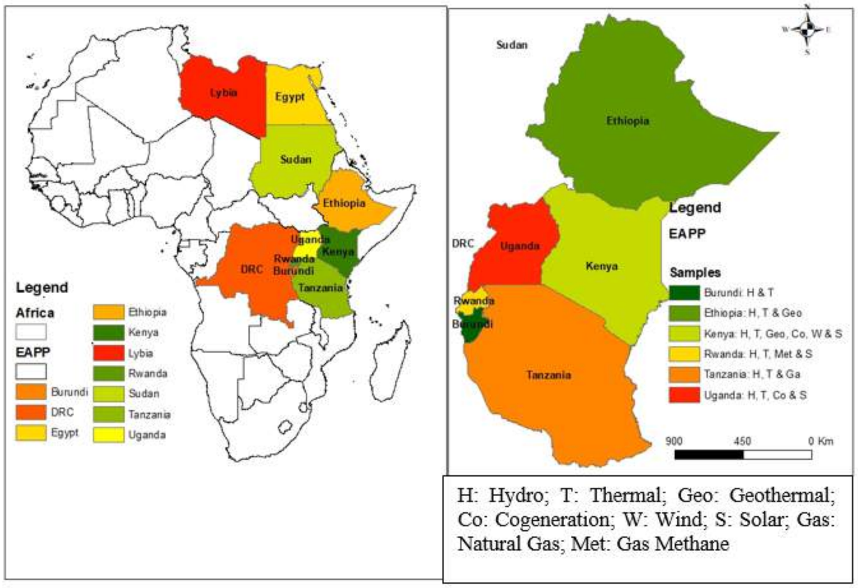
Appendix: Data collection

Data on the electricity sector is of paramount importance. The presence of statistical data assists in decision making for both the public and private sectors. When multi-unit data are available, they facilitate performance comparisons. In the case of our study, we describe the data collection process in the countries concerned. The case study involves six countries. The choice of these countries as case studies is threefold:

(1) These countries are members of the East African Power Pool (EAPP). They share the same climatic conditions. Except for Ethiopia, the other five countries belong to the East African Community. Mobility in these countries does not require a visa application, which made it easy for me to travel to these countries.

(2) Knowing the performance of the power sector in these countries facilitates integration in terms of infrastructure. Since one of the missions of the EAPP is to trade energy through the interconnection of different countries, the study could be used by policy makers to determine what investments should be made to facilitate cross-border trade in electricity. Specifically, countries with electricity surpluses could feed it into the grid and export it to deficit countries. Figure A1 shows the EAPP member countries and the case study.

Figure A-1. EAPP member-countries and the case study



H: Hydro; T: Thermal; Geo: Geothermal; Co: Cogeneration; W: Wind; S: Solar; Gas: Natural Gas; Met: Gas Methane

(3) Benchmarking studies require the availability of comparable data across multiple decision making units. Our objective was to identify the comparable entities, through the available data. We compile data from two databases, one on power outages and transformers in Burundi, and the other on input and output data for the six countries. We thus present the two databases.

A. Data collection in Burundi

In Burundi, some data are available through the yearbook of sectoral statistics published by the "Institut des Statistiques et Etudes Economiques du Burundi" (ISTEEBU) since 2016. Other data were provided by REGIDESO through the production, commercial, and account departments. In cases where there are differences between these two data sources, we rely on the data provided by the electricity company.

For the unpublished data, we have made an inventory ourselves, either through the daily data of the national dispatching center or through our own survey. The data on power outages, including load shedding, are those that occurred between 2014 and 2017. We obtained them by consulting the available duty reports at the central national dispatching center, which records by distribution station all power outages and their causes. As these are multiple, we were interested in load shedding outages that lasted 30 minutes or more[38]. We also conducted an overview of the transformers on the national grid through a survey conducted in September-October 2020 throughout the country.

A.1. Collecting data on power outages

REGIDESO does not publish data on power outages. To identify them, we consulted the daily reports of the central national dispatching office. It coordinates 14 distribution stations, equipped with transformers that lower the voltage for distribution and raise it

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[38] The most frequent outages are related to causes such as the general tripping of a circuit breaker on the main hydroelectric plants, voltage disturbance, troubleshooting work on one or another line, screening work in the hydroelectric plants, tree cutting on the electrical network, etc. These outages are generally planned and of short duration.

for transmission. The Bujumbura region has five distribution stations: RN 1, SNEL, SNEL, POSTE SUD, POSTE NORD. The Western region includes the substations Cibitoke, Bubanza, and Ijenda-Mwaro-Tora. The other posts are: Kayanza and Ngozi, Musasa in the Northern region, Gitega in the Center, Taba and Rumonge in the Southern region.

Each distribution substation has a number of feeders attached to it, and users of the same feeder share the same power line. When a power outage occurs, all users are affected by the outage. Thus, to collect data on outages, we compiled a single table per feeder and per distribution station by listing the date, time of outage and time of restoration, with the difference giving the duration of the outage. Since no day could go by without a power outage, we hired three agents to enter the data, according to the format of the following table:

Table A-1. Coding of electricity outage

Date	Cutoff time	Return time	Cutoff duration	Cibitoke	Ngozi	Poste Nord
				Rugombo	Burengo	SODECO
03-01-16	22:29	01:58	03:29	1		
04-01-16	02:40	06:02	03:22			
04-01-16	22:07	01:19	03:12		1	
04-01-16	22:05	23:18	01:13			1
04-01-16	22:06	06:30	08:24			
04-01-16	22:13	22:32	00:19			

Source: Compiled from REGIDESO data

The data were recorded in time slots corresponding to two different days. To calculate the duration of power outages, we used the following formula:

$$Cutoff\ duration = \text{"24:00"} - cutoff\ time + Return\ time.$$

Sometimes the agents on duty in the distribution stations forgot to record the cut-off time or the handover time, which distorted the calculation of the cut-off time. We omitted these values from the calculation of the duration of the cuts. These values do not intervene in the calculation of the duration and the average frequency of the power cuts. After listing all power outages over a period from January 2014 to December 2017, we determined the average duration and frequency in each region[39], as reported by tables A-2 and A-3.

Table A-2. Average interruption duration in hour per region and per year

Region	Years			
	2014	2015	2016	2017
Bujumbura	770	656	408	1018
East	334	607	478	710
North	147	325	266	753
South	840	802	567	1172
West	235	375	261	881

Source: Compiled by the author from REGIDESO data

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[39] The determination of averages could suffer from some inconsistencies due to generalization to one or another distribution station. For example, we assume that the cuts in Gitega are also for Muramvya, those in Makamba for Bururi, and those in Muyinga for Karusi, taking into account the departure in question.

Table A-3. Average interruption frequency per region and per year

Region	Years			
	2014	2015	2016	2017
Bujumbura	162	120	80	149
East	63	125	90	99
North	29	51	45	108
South	159	142	110	164
West	54	70	45	132

Source: Compiled by the author from REGIDESO data

In this thesis, we focus on two reliability indicators, namely SAIFI and SAIDI. Since the frequency and duration of outages are taken as an average, we assume that all customers in a district or region are affected. For simplicity, we calculate the reliability indicators at the region level, taking into account the number of customers according to the following formulas:

$SAIDI = \frac{\sum_i^n D_i N_i}{\sum_i^n N_i}$ where D_i is the interruption duration for region i, N_i is the number of customers served in each region. It’s commonly used to estimate the reliability of electric power utility.

$SAIFI = \frac{\sum_i^n f_i N_i}{\sum_i^n N_i}$ where f_i stands for the number of interruptions per region.

Table A-4 shows the number of clients by region

Table A-4. Number of customers per region and per year

Region	**Year**			
	2014	**2015**	**2016**	**2017**
Bujumbura	55257	59239	66697	79036
East	7400	8710	10873	8906
North	10852	12484	16395	13464
South	5478	6464	7194	6731
West	7480	7728	9709	9139
Total	86467	94625	110868	117276

Source: REGIDESO

From Tables A-2, A-3 and A-4, we derive the system reliability indicators found in Table A-5.

Table A-5. SAIDI and SAIFI in Burundi per year

Liability indices	Year			
	2014	2015	2016	2017
SAIDI(hour)	612	595	391	962
SAIFI (frequency)	127	109	74	140

Source: Compiled from REGIDESO data

A.2. Data on transformers, customer density and electricity losses due to outages.

A.2.1. Transformer number and capacity

Given the unavailability of statistics on transformers, an important component of the electricity distribution network infrastructure, we conducted a physical inventory of transformers throughout Burundi in collaboration with REGIDESO officials. Since we did not have a reliable database of transformers, we collaborated with regional and district officials[40]. After the inventory of the processors and their capacities, we proceeded to locate them through GPS coordinates.

For the transformers located in the provincial capitals and along the main national roads, we recorded the coordinates of each transformer using GPS. For transformers far from the main urban centers, we located them using Google Earth Pro. Knowing the location of each transformer, the technicians at the distribution centers helped us locate them and provided us with the longitude and latitude coordinates[41]. Table A-6 shows the distribution of transformers by district.

Table A-6. Number and installed capacity of distribution transformer by district in 2020

District	Transformer number	Installed capacity (kVA)	Share (%)
Bubanza	23	2370	1.3
Bujumbura	234	72835	38.9
Bururi	44	4830	2.6
Cankuzo	14	1360	0.7
Cibitoki	44	11405	6.1
Gitega	93	20767	11.1
Jenda-Mwaro-Tora	56	7640	4.1
Karusi	18	2750	1.5
Kayanza	69	10795	5.8
Kirundo	29	3430	1.8
Makamba	19	2120	1.1

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[40] It should be noted that at REGIDESO, the districts and the distribution substations are different entities from an administrative point of view. In fact, the former are managed by the electricity operation service, while the latter belongs to the generation service which is responsible for generation and transmission.

[41] It should be noted that we were only interested in transformers in the distribution network. Thus, we have omitted transformers located in distribution substations and in hydroelectric power plants, which are part of the electricity generation and have a higher installed capacity.

District	Transformer number	Installed capacity (kVA)	Share (%)
Muramvya	45	6920	3.7
Muyinga	37	5700	3.0
Muzinda	51	8500	4.5
Ngozi	86	12860	6.9
Nyanzalac	14	1995	1.1
Rumonge	52	6300	3.4
Rutana	26	2370	1.3
Ruyigi	18	2175	1.2
Total	972	187122	100.0

Source: Survey, 2020

A.2.2. Customer density

From the location of the transformers, we determined the density of customers. For this, referring to satellite photos produced on Google Earth Pro, we determined the area covered by the network. If a transformer is installed in a location, it is assumed that all inhabitants in the vicinity are connected to electricity or likely to be[42]. From the location of a transformer and using google maps, we measured the area covered by the network. A limitation of this study is that the area does not accurately reflect the field data. The determination of the area took into account the following indications:

- Locate the transformer
- Delineate the settlements around the section on which the transformer is located
- Estimate the area covered by the network

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[42] In Tanzania, we were told that in order to determine the electricity access rate, it is assumed that all customers within 1km of a transmission line are connected to electricity. However, this is not the case for Burundi, where a transmission line crosses a large area without any electricity connection.

- For each district, the area is defined by the sum of the individual areas.

Table A-7 shows the network area and customer density per district in Burundi

Table A-7. Customer density per district

District	Area (km2)	Share (%)	Customer density (mean-customer per km2)
Bubanza	5.94	1.5	34.16
Bujumbura	96.45	23.6	6.99
Bururi	11.39	2.8	13.97
Cankuzo	6.51	1.6	14.50
Cibitoki	31.69	7.7	2.32
Gitega	42.86	10.5	4.00
Jenda-Mwaro-Tora	13.82	3.4	5.62
Karusi	7.98	2.0	15.59
Kayanza	14.31	3.5	17.14
Kirundo	9.43	2.3	13.49
Makamba	14.43	3.5	7.75
Muramvya	9.44	2.3	19.54
Muyinga	16.06	3.9	8.21
Muzinda	30.51	7.5	2.42
Ngozi	29.58	7.2	5.83
Nyanzalac	7.07	1.7	13.38
Rumonge	40.72	10.0	1.43
Rutana	11.62	2.8	4.77
Ruyigi	9.38	2.3	11.15
Total	409.19	100.0	10.65

Source: Survey, 2020

A.2.3. Determination of electricity losses due outages

Quality of service in the electricity sector is measured through several indicators. The most commonly used are the frequency and duration of power cuts, network reliability indicators such as SAIDI, SAIFI, CAIDI, MAIFI, etc. For our study, REGIDESO has experienced many power outages. Since the comparison is made at the district level, the districts are not directly responsible for the outages. They suffer from them because either the installed electricity capacity is low, or REGIDESO has not been able to maintain or renew its electricity network. Not being responsible for the power cuts, the districts nevertheless suffer the consequences. This is electricity that could have been consumed and generated revenue. This is what we call outage power.

The electricity lost due to outages was determined based on the following data:

- The average duration of outages in each district
- The electricity delivered in each district

The electricity potentially delivered in the case of normal electricity consumption without outages. This assumes that there are no interruptions during 24 hours and throughout the year. The electricity losses due to outages are thus calculated according to the following formula:

$$Electricity\ Losses_{it} = \frac{Electricity\ delivered * Interruption\ duration}{365 * 24}$$

Table A-8 shows the electricity losses by district and by year calculated using the below formula[43].

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[43] We did not find any power outage data for the Jenda-Mwaro-Tora district, whose substation was down during the period covered. The same is true for the Bubanza and Muzinda districts in 2016, for which data is unavailable.

Table A-8. Electricity losses due to outages in MWh per district and per year

District	Years				Mean
	2014	2015	2016	2017	
Bubanza	13.87	14.12	-	89.28	29.57
Bujumbura	13125.17	8796.91	6589.45	13020.12	10382.91
Bururi	335.97	93.81	85.85	266.72	195.59
Cankuzo	0.93	3.20	0.51	1.30	1.49
Cibitoke	267.29	309.12	332.68	868.63	444.43
Gitega	282.53	829.59	1095.32	282.18	622.41
Karuzi	1.83	0.09	0.22	0.96	0.78
Kayanza	162.64	206.51	258.33	540.84	292.08
Kirundo	14.58	68.51	66.85	175.62	81.39
Makamba	102.27	124.89	63.51	88.36	94.76
Muramvya	97.46	212.53	426.10	180.44	229.13
Muyinga	5.49	2.00	0.40	2.13	2.51
Muzinda	53.16	50.14	-	220.61	81.23
Ngozi	49.21	254.63	218.60	336.03	214.62
Nyanza-Lac	70.57	102.39	67.59	48.85	72.35
Rumonge	591.47	282.03	272.70	178.27	331.12
Rutana	254.60	93.34	7.01	298.96	163.48
Ruyigi	46.65	71.94	38.01	76.93	58.38
Annual mean	814.56	606.15	501.38	877.75	699.96

Source: Compiled by the authors

B. Data collection in other East African countries

In addition to the data collected in Burundi, we visited Uganda, Kenya, Ethiopia and Tanzania. The objective was to compare the performance of the electricity sector in East Africa. This visit was carried out from 23 June to 22 July 2019. For Rwanda, we consulted energy policy and strategy documents, data available on the website of the regulator (RURA) and the holding company (REG Ltd), as well as secondary data available through various studies. We describe the data collection process in each country.

B.1. Data collection in Uganda

In Uganda, we were hosted at the Electricity Regulation Authority, in the economic regulation department. Uganda is a country that has successfully liberalised the electricity sector. In Uganda, electricity is generated by 41 private companies. All these companies generate and sell electricity to a state-owned transmission monopoly company, Uganda Electricity Transmission Corporation Limited (UETCL). This company is responsible for transmission and selling electricity wholesale to distribution companies, the largest of which being Umeme Limited. It should be noted that in Uganda, competition in the electricity sector is at two levels, namely on services and on infrastructure. The generating companies compete on both infrastructure and services. On the other hand, there is competition at the level of electricity distribution, with ERA in charge of regulation. In this country, the regulator centralizes all data on the electricity sector and publishes them on its website www.era.or .

In the following, we detail the data on electricity generation, transmission and distribution used in our study. This website contains information on electricity generation, transmission and distribution, annual reports, licenses and permits, tariffs, consumer rights and obligations, etc. The following tables summarize all the information collected in this country.

Table B-1. Uganda electricity generation plants

Generator	Operator	Technology	Installed capacity
Large Hydros			
Bujagali Hydro Power Plant	Bujagali Electricity Company Limited (BEL)	Hydro	250.0
Nalubaale and Kiira HPPs	Eskom (U) Limited	Hydro	380.0
Isimba HPP	Uganda Electricity Generation Company Limited	Hydro	183.0
Mini-Hydros			
Mpanga	Africa Energy Management System.	Hydro	18.00
Bugoye(Mobuku II)	Bugoye Hydro Limited	Hydro	13.00
Kabalega (Buseruka)	Hydromax Limited	Hydro	9.00
Ishasha	Eco-Power Limited	Hydro	6.60
Mobuku 1	Tibet Hima Mining Co Ltd[2]	Hydro	5.00
Mobuku III	Kasese Cobalt Company Limited	Hydro	9.90
Muvumbe	Muvumbe Hydro (U) Ltd	Hydro	6.50
Siiti 1	Elgon Hydro Siti (PVT) Limited	Hydro	5.00
Rwimi	Rwimi EP Company Limited	Hydro	5.54
Nyamwamba	Africa EMS Nyamwamba Limited	Hydro	9.20
Lubilia	Lubilia Kawembe Hydro Ltd	Hydro	5.40
Nkusi	Hydromax (Nkusi) Ltd	Hydro	9.60

Appendix B: Data collection in other East African countries

Generator	Operator	Technology	Installed capacity
Mahoma	Mahoma Uganda Limited	Hydro	2.70
Hydromax Nkusi (Waki)	Hydromax Nkusi Ltd	Hydro	4.80
Sindila (Butama)	Butama Hydro-Electricity Company Ltd	Hydro	5.25
Thermals			
Namanve	Jacobsen (U) Limited	Thermal	50.0
Electromaxx	Electro-Maxx (U) Limited	Thermal	86.0
Co-generation/ Bagasse			
Kakira	Kakira Sugar Limited	Co-generation	51.1
Kinyara	Kinyara Sugar Works Limited	Co-generation	14.5
SAIL	Sugar & Allied Uganda Ltd	Co-generation	11.9
SCOUL	SCOUL	Co-generation	9.5
Mayuge	Mayuge Sugar Ltd	Co-generation	9.2
Solar PV			
Access Solar	Access Uganda Solar Ltd	Solar PV	10.0
Tororo Solar North	Tororo Solar North Ltd	Solar PV	10.0
Kabulasoke Solar	MSS Xsabo Power Limited	Solar PV	20.0
Mayuge Solar	Emerging Power U Ltd	Solar PV	10.0
Off-grids			
Nyagak	West-Nile Rural Electricity Company	Hydro	3.5
WENRECO	West-Nile Rural Electricity Company	Thermal	1.6
Kalangala	Kalangala Infrastructure Services	Hybrid	1.6
Kisiizi Hospital Power	Kisiizi Hospital Power	Hydro	0.4

Generator	Operator	Technology	Installed capacity
Absolute-Kitobo	Absolute Energy Africa Limited (AEAL)	Solar	0.23
Bwindi	Bwindi Community Micro Hydro Power Ltd	Small Hydro	0.06
Pamoja-Tiribogo	Pamoja Energy Ltd	Biomass	0.03
Pamoja-Ssekanyonyi	Pamoja Energy Ltd	Biomass	0.01
Swam		Small Hydro	0.04
Total			**1182.20**

Source: Electricity Regulatory Authority, 2019

The operating distribution companies are: Umeme Uganda Limited, Uganda Electricity Distribution Company Limited, Pader Abim Community Multipupose Electric Cooperative Society Limited, Bundibugyo Energy Co-Operative Society, Kilembe Investment Limited, Kyegegewa Rural Electricity Cooperative Society.

B.2. Data collection in Kenya

In Kenya, the data used is from the annual reports published on the KPLC Ltd website (https://www.kplc.co.ke/category/view/39/annual-reports). These reports summarize all the information of the electricity sector from generation to distribution. The reports used are from 2008 to 2018. In this country, electricity generation is provided by Kenya Generation company limited (KenGen), Rural Electrification Programme (REP), Independent Power Producers (IPPs), emergency power producers. Transmission and distribution are handled by Kenya Power Lighting Company (KPLC Ltd), while Kenya Transmission Company (KETRACO) handles the development of new transmission infrastructure.

Table B-2. Electricity generation in Kenya in 2018

Generator	Installed Capacity (MW)	Technology
Kenya Generating company (KenGen)		
Tana	20	Hydro
Kamburu	94.2	Hydro
Gitaru	225	Hydro
Kindaruma	72	Hydro
Masinga	40	Hydro
Kiambere	168	Hydro
Turkwel	106	Hydro
Sondu Miriu	60	Hydro
Sangóro	21	Hydro
Small Hydros	11.7	Hydro
Kipevu I Diesel	73.5	Thermal
Kipevu III Diesel	120	Thermal
Embakasi Gas Turbine	30	Thermal
Muhoroni Gas Turbine	30	Thermal
Garissa & Lamu	-	Thermal
Garissa Temporary Plant (Aggreko)		Thermal
Olkaria I	45	Geothermal
Olkaria II	105	Geothermal
Eburru Hill	2.4	Geothermal
OW37. OW 37 kwg 12. OW 37 kwg 13 and OW 39 Olkaria Mobile Wellheads2	15	Geothermal
OW43 Olkaria Mobile Wellheads	12.8	Geothermal
OW905.OW914 .OW915 and OW 919 Olkaria Mobile Wellheads3	52.8	Geothermal
Olkaria IV	140	Geothermal
Olkaria I 4 & 5	140	Geothermal
Ngong	25.5	Wind
KenGen Total	**1610**	
Rural Electrification Programme (Off-grid)		

Generator	**Installed Capacity (MW)**	**Technology**
Thermal	30.4	Thermal
Solar	0.69	Solar
Wind	0.55	Wind
Total Offgrid	**31.6**	
Independent Power Producers (IPPs)		
Iberafrica I&II	108.5	Thermal
Tsavo	74	Thermal
Thika Power	87	Thermal
Biojule Kenya Limited	2	Thermal
Mumias – Cogeneration	26	Thermal
OrPower 4 -Geothermal I.II&III	121	Geothermal
OrPower 4 -Geothermal (the 4th plant)	29	Geothermal
Rabai Power	90	Thermal
Imenti Tea Factory (Feed-in Plant)	0.3	Thermal
Gikira small hydro	0.514	Hydro
Triumph Diesel	83	Thermal
Gulf Power	80.32	Thermal
Regen-Terem	5	Thermal
Gura	2	Thermal
Chania	0.5	Thermal
Strathmore	0.25	Thermal
IPP Total	**709**	
SYSTEM TOTAL	**2351**	

Source: KPLC annual report, 2017-2018.

B.3. Data collection in Ethiopia

In Ethiopia, we collected data from two companies, Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). In the former, we collected data on installed capacity, electricity generated, imported and exported. EEP is involved in the generation and transmission of electricity. EEU, on the other hand, deals with distribution. EEU supplied the data on electricity distribution

Table B-3. Electricity generation in Ethiopia in 2018

Power Plant	**Capacity (MW)**	**Commissioning date**	**Technology**
Koka	43.2	1960/61	Hydro
Awash II	32.0	1966/67	Hydro
Awash III	32.0	1971/72	Hydro
Finchaa	134	1973 & 2001	Hydro
Melka Wakena	153	1988	Hydro
Tis Abay I & II	84	1964/65 & 2000/01	Hydro
Gilgel Gibe-I	184	2003/04	Hydro
Tekeze	300	2009/10	Hydro
Gilgel Gibe-II	420	2009/10	Hydro
Tana Beles	460	2009/10	Hydro
Fincha Amertinesh	97	2011/12	Hydro
Gibe-III	1870	2016	Hydro
Total	**3809**		
Ahsegoda Wind Farm	120	2011/12	Wind
Adama I Wind Farm	51	2011/12	Geothermal
Adama II Wind Farm	153	2015/16	Geothermal
Aluto Langano Geothermal	7.3	1998/99	Geothermal
Total	**331.3**		
Dire Dawa	40	2003/04	Wind

Power Plant	Capacity (MW)	Commissioning date	Technology
Awash 7 kilo	36	2003/04	Standbye diesel
Kaliti	12	2003/04	Standbye diesel
Total	88		Standbye diesel

Source: Ethiopian Electric Power, 2019

B.4. Data collection in Tanzania

In Tanzania, all data collection must be authorized by the Commission on Science and Technology (COSTECH). Thus, we first went to this commission to receive permission to contact the authorities of TANESCO, the vertically integrated electricity company. We visited three departments managed by senior managers: Generation, transmission, distribution. In addition to the data found in this company, we also visited the regulatory authority for energy and water companies (EWURA). We present the generation sector as it stands at the end of 2018.

Table B-4. Electricity generation in Tanzania in 2018

Name	Installed capacity (MW)	Name
Hydro		
Kidatu	204.00	Hydro
Kihansi	180.00	Hydro
Mtera	80.00	Hydro
New Pangani	68.00	Hydro
Hale	21.00	Hydro
Uwemba	0.84	Hydro
Nyumba ya Mungu	8.00	Hydro
Total Hydro	**561.84**	
Thermal Gas &Diesel		

Appendix B: Data collection in other East African countries

Name	**Installed capacity (MW)**	**Name**
Kinyerezi I	150.00	Thermal
Kinyerezi II	240.00	Thermal
Ubungo I Gas Plant	102.00	Natural gas
Ubungo II Gas Plant	129.00	Natural gas
Tegeta Gas Plant	45.00	Natural gas
Somanga Gas Plant	7.50	Natural gas
Mtwara Gas Plant	18.00	Natural gas
Zuzu Dodoma Diesel Plant	7.40	Thermal
Nyakato Plant	63.00	Thermal
Ngara	2.50	Thermal
Biharamulo	4.14	Thermal
Total thermal and gas	**768.54**	
OFF-GRID		
Bukoba	2.56	Thermal
Inyonga	0.48	Thermal
Kasulu	2.50	Thermal
Kibondo	2.50	Thermal
Kigoma	11.81	Thermal
Liwale	0.85	Thermal
Loliondo	5.00	Thermal
Ludewa	1.27	Thermal
Madaba	0.48	Thermal
Mafia	2.18	Thermal
Mbiga	2.00	Thermal
Mpanda	4.30	Thermal
Namtumbo	0.34	Thermal
Songea	8.31	Thermal
Sumbawanga	5.00	Thermal
Tunduru	2.95	Thermal
Total off-grid	**52.52**	
System Total	**1382.90**	

Source: TANESCO

B.5. Data collection in Rwanda

Data on the Rwandan electricity sector comes from different sources. Some of them are available on the website of the Rwanda Utility Regulatory Authority www.rura.rw and REG www.reg.rw. We completed the missing data by exploiting the National Energy Policy and Strategy of 2011 and 2018 (Republic of Rwanda, 2011, 2018). For non-available data, we completed them by exploiting studies such as Bimenyimana et al. (2018); Uwisengeyimana et al. (2016) and Meera et al.(2016). Table A-13 shows the distribution of generation capacity in Rwanda.

Table B-5. Electricity generation in Rwanda

Plant Name	Installed Capacity (MW)	Owner	Year	Technology
Keya	2.2	Adre Hydro &Energicotel	2011	Hydro
Nyamyotsi I	0.1	Adre Hydro &Energicotel	2011	Hydro
Nyamyotsi II	0.1	Adre Hydro &Energicotel	2011	Hydro
Nkora	0.68	Adre Hydro &Energicotel	2011	Hydro
Cyimbili	0.3	Adre Hydro &Energicotel	2011	Hydro
Musarara	0.45	Amahoro Energy	2013	Hydro
Agatobwe	0.2	Carera-Ederer	2010	Hydro
Mazimeru	0.5	Carera-Ederer	2012	Hydro
Kivuwatt Phase I	26.4	Contour Global	2016	Methane
GigaWatt	8.5	Gigawatt Global	2013	Solar
Ntaruka	11.25	GoR	1959	Hydro
Mukungwa I	12	GoR	1982	Hydro
Nyabarongo I	28	GoR	2014	Hydro
Nyabahanga I	0.2	GoR	2012	Hydro

Appendix B: Data collection in other East African countries

Plant Name	Installed Capacity (MW)	Owner	Year	Technology
Nshili I	0.4	GoR	2012	Hydro
Ruzizi II	12	GoR	1984	Hydro
Jabana 1	7.8	GoR	2004	Diesel
Jabana 2	21	GoR	2009	HFO-Diesel
Gishoma	15	GoR	2016	Peat
Jali	0.25	Mainz Stadwerke /Local Agency	2007	Solar
Rukarara I	9.5	Ngali Energy	2010	Hydro
Nyamata Solar	0.03	NMEC Nyamata	2009	Solar
Gaseke	0.582	Novel Energy	2017	Hydro
Biomass (Rice Husk)	0.07	Novel Energy	2016	Biomass
Gisenyi	1.2	Prime Energy	1957	Hydro
Gashashi	0.2	Prime Energy	2013	Hydro
Mukungwa II	2.5	Prime Energy	2013	Hydro
Rukarara II	2.2	Prime Energy	2013	Hydro
Murunda	0.1	Repro	2010	Hydro
Mutobo	0.2	Repro	2009	Hydro
Janja	0.2	RGE Energy UK ltd	2012	Hydro
Nyirabuhombo hombo	0.5	RGE Energy UK ltd	2013	Hydro
Gihira	1.8	RMT	1984	Hydro
Rugezi	2.6	RMT	2011	Hydro
Giciye I	4	RMT	2013	Hydro
Giciye II	4	RMT	2016	Hydro
Rwaza Muko	2.6	Rwaza HydroPower Ltd	2018	Hydro
So Energy	30	So Energy&SP	2017	Diesel
Total	**209. 61**			

Source: National Institute of Statistics of Rwanda, 2017

C. Data used for performance comparison

The data used for the performance comparison in East African countries are for Chapters 3 and 4. They include inputs, outputs, and environmental variables. The inputs used are installed capacity, purchased electricity, high-voltage transmission lines, and electricity losses obtained by the difference between purchased and delivered electricity. Two outputs are used in both chapters, the number of customers and electricity delivered, which represent access to electricity. Losses represent poor quality of service. These input and output variables were collected through visits to the various utilities or through internet searches.

We also used environmental variables to estimate their impact on the performance of the electricity sector. These are GDP per capita in constant US dollars in 2015 and customer density obtained by the ratio between the number of customers and the area of each country. GDP per capita and area were obtained from the World Development Indicators. Two power sector reform indicators were also used, namely private sector participation in generation and/or distribution, and vertical unbundling. Both of these indicators are dummy variables that take the values 1 in the year in which they are observed, and 0 otherwise. Tableau A-14 shows the different variables by country and by year.

Appendix C. Data used for performance comparison in East Africa

Table C-1. Inputs, outputs, and environmental variables

Country	Year	I 1	I 2	I 3	I 4	O 1	O 2	Private	Unbundling	GDP	density
Burundi	2008	0.5	3.2	2.1	0.5	1.6	4.8	0	0	3.1	3.2
	2009	0.5	3.2	2.0	0.4	1.7	5.5	0	0	3.1	3.3
	2010	0.5	3.2	2.4	0.5	1.9	6.0	0	0	3.1	3.4
	2011	0.5	3.2	2.5	0.5	2.0	6.7	0	0	3.2	3.5
	2012	0.5	3.2	2.5	0.6	1.9	7.6	0	0	3.2	3.6
	2013	0.6	3.2	2.6	0.6	2.1	8.0	0	0	3.2	3.7
	2014	0.6	3.2	2.7	0.4	2.3	8.7	0	0	3.3	3.8
	2015	0.6	3.2	2.6	0.7	1.8	9.5	0	0	3.1	4.0
	2016	0.6	3.2	2.9	0.8	2.1	11.1	1	0	2.9	4.1
	2017	0.8	3.2	2.6	0.7	1.9	11.9	0	0	2.9	4.2
Ethiopia	2008	7.8	63.2	35.0	6.7	28.3	140.1	0	0	3.9	0.8
	2009	32.4	64.2	36.8	8.1	28.7	145.7	0	0	4.1	0.9
	2010	32.4	68.2	39.3	7.5	31.9	141.3	0	0	4.5	0.9
	2011	34.7	84.8	49.4	10.0	39.4	145.2	0	0	4.9	0.9
	2012	39.6	101.0	62.8	23.3	39.5	169.3	0	0	5.2	0.9
	2013	42.4	103.9	81.5	29.0	52.5	181.4	0	1	5.6	1.0
	2014	43.9	108.6	79.1	14.7	64.4	194.5	0	1	6.0	1.0
	2015	43.9	108.6	87.2	27.6	59.6	177.9	0	1	6.4	1.0

Appendix C. Data used for performance comparison in East Africa

Country	Year	I 1	I 2	I 3	I 4	O 1	O 2	Private	Unbundling	GDP	density
	2016	45.9	120.2	96.9	22.2	74.7	218.2	1	1	6.8	1.0
	2017	48.3	136.0	110.8	25.0	85.9	243.6	1	1	7.3	1.1
Kenya	2008	12.7	40.4	63.8	10.6	53.2	106.0	1	1	12.6	0.7
	2009	13.1	40.9	64.9	10.6	54.3	126.7	1	1	12.6	0.7
	2010	14.1	42.0	66.9	10.7	56.2	146.4	1	1	13.3	0.7
	2011	15.3	43.3	73.0	11.8	61.2	175.3	1	1	13.6	0.8
	2012	16.9	44.3	76.7	13.3	63.7	203.9	1	1	13.8	0.8
	2013	17.7	48.6	80.9	15.1	64.9	233.1	1	1	14.0	0.8
	2014	18.9	49.7	88.4	16.0	72.4	276.8	1	1	14.3	0.8
	2015	23.0	51.3	92.8	16.3	76.6	361.2	1	1	14.6	0.8
	2016	23.3	55.2	98.2	19.1	79.1	489.0	1	1	14.9	0.9
	2017	23.5	58.6	102.1	19.3	82.7	618.2	1	1	15.1	0.9
Rwanda	2008	0.7	6.6	2.8	0.5	2.3	11.0	1	0	5.5	3.9
	2009	0.7	6.6	3.1	0.6	2.5	14.2	1	0	5.7	4.0
	2010	0.8	6.6	3.5	0.7	2.9	18.8	1	0	6.0	4.1
	2011	0.8	6.6	4.2	0.8	3.4	26.6	1	0	6.3	4.2
	2012	0.8	6.6	3.8	0.7	3.0	33.9	1	0	6.7	4.3
	2013	1.0	6.8	5.2	1.3	4.0	40.6	1	0	6.8	4.4
	2014	1.3	6.8	5.7	1.3	4.4	49.3	1	0	7.1	4.5

Appendix C. Data used for performance comparison in East Africa

Country	Year	I 1	I 2	I 3	I 4	O 1	O 2	Private	Unbundling	GDP	density
	2015	1.3	8.2	6.0	1.3	4.7	56.2	1	0	7.5	4.6
	2016	1.8	9.4	6.8	1.4	5.4	60.2	1	0	7.8	4.7
	2017	2.1	10.5	7.5	1.5	6.0	71.8	1	0	7.9	4.9
Tanzania	2008	9.6	47.7	43.0	15.8	34.2	73.9	1	0	7.6	0.5
	2009	10.1	47.7	46.7	12.5	37.6	79.7	1	0	7.8	0.5
	2010	10.3	47.7	51.8	14.2	40.0	86.0	1	0	8.1	0.5
	2011	11.5	47.7	50.3	10.3	39.8	92.9	1	0	8.4	0.5
	2012	12.6	48.2	55.4	15.6	44.4	102.4	1	0	8.6	0.5
	2013	13.2	48.3	57.3	12.9	46.5	116.6	1	0	8.9	0.5
	2014	13.2	48.3	60.3	13.8	49.5	140.7	1	0	9.2	0.6
	2015	13.2	52.3	62.0	12.5	51.2	164.5	1	0	9.5	0.6
	2016	14.7	59.0	67.9	16.6	53.1	195.1	1	0	9.8	0.6
	2017	14.7	59.0	68.0	14.9	63.4	210.6	1	0	10.2	0.6
Uganda	2008	3.9	11.8	19.4	6.7	12.8	30.1	1	1	7.3	1.5
	2009	5.8	11.8	21.6	7.5	14.0	32.0	1	1	7.5	1.6
	2010	6.2	11.8	23.3	7.0	16.4	38.6	1	1	7.7	1.6
	2011	6.4	11.8	24.1	6.6	17.4	46.7	1	1	8.1	1.7
	2012	8.7	15.5	26.5	7.0	19.5	50.3	1	1	8.2	1.7
	2013	8.6	16.3	28.2	7.1	21.1	62.0	1	1	8.2	1.8

Appendix C. Data used for performance comparison in East Africa

Country	Year	I 1	I 2	I 3	I 4	O 1	O 2	Private	Unbundling	GDP	density
	2014	8.6	16.3	29.3	6.3	23.0	70.1	1	1	8.3	1.8
	2015	8.6	16.3	31.0	6.1	24.9	86.3	1	1	8.5	1.9
	2016	9.2	16.3	32.1	6.1	26.0	98.6	1	1	8.6	2.0
	2017	11.8	16.3	33.9	5.9	28.0	117.8	1	1	8.5	2.1

Source: Compiled by the authors from data collected in East Africa

Note: I1 and I2 are the installed capacity and the high voltage transmission lines expressed in 100 MW and 100 km respectively, I3 and I4 are the electricity purchased and electricity losses expressed in 100 GWh. O1 is the electricity delivered in 100 GWh, and O2 is the customer number in 10000 persons. Private represents private participation, unbundling is related to vertical unbundling. GDP represents GDP per capita in US$100 constant 2015, while density replaces customer density in 100 persons per km square.

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