energies

MDPI

Article

Electricity Sector Reform Performance in Sub-Saharan Africa: A Parametric Distance Function Approach

Adwoa Asantewaa [1,2], Tooraj Jamasb [3] and Manuel Llorca [3,*]

1 World Bank Group, 1818 H Street NW, Washington, DC 20433, USA; aasantewaa@worldbank.org
2 Business School, Durham University, Mill Hill Lane, Durham DH1 3LB, UK
3 Copenhagen School of Energy Infrastructure (CSEI), Department of Economics, Copenhagen Business School, Porcelænshaven 16A, 2000 Frederiksberg, Denmark; tj.eco@cbs.dk
* Correspondence: mll.eco@cbs.dk

Abstract: Electricity sector reforms have transformed the structure and organization of the sector worldwide. While outcomes of reforms in developed and developing countries have been extensively examined, there is limited analysis of the reforms in sub-Saharan Africa (SSA). This paper analyses the performance of electricity sector reforms in 37 SSA countries between 2000 and 2017. We use a stochastic frontier analysis approach to estimate a multi-input multi-output distance function to assess the impact of reform steps and institutional features on indicators of investment and technical efficiency. Results indicate a positive correlation between reforms and installed generation capacity per capita, plant load factor, and technical network losses. The presence of an electricity law, sector regulator, vertical unbundling, and private participation in the management of assets were positively correlated with reform performance. Perceptions of non-violent institutional features such as corruption, regulatory quality and governance effectiveness do not seem to have had a significant effect, but perceptions of political stability, violence, and terrorism influenced reform outcomes. We conclude that a workable reform in SSA involves vertical unbundling with an electricity law, a regulator, and private ownership and management of assets where feasible. However, positive outcomes go hand in hand with higher technical network energy losses which indicates higher investment in the generation segment than in the network segment. Hence, emphasis should be placed on decoupling the energy losses from power generation.

Keywords: electricity sector reform; sub-Saharan Africa; institutions; stochastic frontier analysis; distance function

JEL Classification: H54; O13; L94; P11; Q48

check for updates

Citation: Asantewaa, A.; Jamasb, T.; Llorca, M. Electricity Sector Reform Performance in Sub-Saharan Africa: A Parametric Distance Function Approach. *Energies* **2022**, *15*, 2047. https://doi.org/10.3390/en15062047

Academic Editors: Bai-Chen Xie, Farhad Taghizadeh-Hesary and Karim L. Anaya

Received: 29 September 2021
Accepted: 25 February 2022
Published: 11 March 2022

1. Introduction

During the 1980s, the electricity sectors of sub-Saharan African (SSA) countries were beset with capacity shortages, poor service quality, price-cost margins, high subsidies, high energy losses and low access rates [1–4]. The sector was in dire need of investments, but access to finance was limited due to a global macroeconomic and debt crisis at the time. Several countries in the region (and in Latin America) were highly indebted and could not borrow more without risking solvency or threatening the stability of global financial markets [5]. Thus, the traditional sources of finance for infrastructure projects at the time (i.e., International Development Organizations) indicated that they would only be open to provide further support if countries would reform their sectors to address the systemic issues causing the persistent underperformance [6,7].

These reforms aimed at introducing policies, regulations, and institutions that would unfetter the monopoly of state-owned utilities and provide avenues for private actors to participate in competitive markets [3,4,6]. The rationale was that unbundling of the traditional vertically integrated electricity utility would disentangle the vertical diseconomies in the electricity supply industry (ESI). Then, liberalization of the potentially competitive segments (generation and retail) would facilitate new entrants from the private sector, which would generate and sustain competition to reveal the optimal levels, mix and prices [8–11]. On the other hand, regulation of the networks (i.e., transmission and distribution), and sometimes ownership change would provide high-powered incentives and hard budget constraints. This would internalize the problem of information asymmetry and eradicate the perverse incentives associated with natural monopolies while improving governance and fighting corruption [2,8,12–14]. These efficiency improvements are expected to be passed on to consumers directly through price and quality competition, or indirectly through re-investment in new assets [15].

Although the rationale for reforms was similar across countries, the context was remarkably different. In advanced economies, the electricity industries featured excess generation capacity, expensive technology choices, and inefficient production [16,17]. In these countries, price trends, switching rates in retail competition, and cost per unit of energy delivered were considered essential indicators of reform performance [17]. On the other hand, in developing countries, there was a chronic shortage of capacity and the need for massive investments across the whole electricity supply chain [18,19]. Electricity was unreliable, access rates were low, and utilities were financially unviable. Consequently, reforms in these countries aimed at, amongst other things, increasing the level of investments in the sector, improving the efficiency of existing assets and the operational performance of sector utilities [17].

Due to these differences, there were concerns that the 'standard reform model' (based on the experiences of advanced economies) being prescribed by international development organizations was not a right fit for SSA countries. However, there was an insistence that some elements of the model still retained its relevance in these contexts and thus should not be discarded based on identified limitations. Rather, reformers were encouraged to review and select the options, mechanisms, and pace of reforms most appropriate to their needs and circumstances [6]. This has resulted in the proliferation of a range of reform models across the region, often featuring elements of the 'standard reform model' and remnants of the traditional vertically integrated structures [20,21].

In SSA, reforms were implemented in waves. The earliest waves focused on expanding the generation base, increasing the load factor of generation plants, optimizing labor employment in sector utilities, reducing technical and commercial losses in the networks, closing price-cost margins, and promoting private sector participation in the delivery and management of electricity services. It had no provisions for poverty-related issues and environmental concerns, and thus was criticized to be in the rent-seeking interests of private capital over considerations of social welfare [22]. Subsequently, policymakers deployed specialized vehicles to tackle social issues [23,24]. The idea was that once the immediate challenges of low investments and productive inefficiencies have been effectively addressed, subsequent reform waves would explicitly pursue the establishment of competitive markets to improve the welfare of consumers.

This study assesses the performance of reforms in delivering on its immediate objectives in SSA. We achieves this by modelling the impacts of a set of reform steps on core indicators of investment promotion and technical efficiency, i.e., net installed generation capacity per capita; technical network losses; and plant load factor. We use a stochastic frontier analysis (SFA) approach to estimate a multi-input multi-output distance function using a data sample of 37 SSA countries from 2000 to 2017. This methodology differs from earlier studies, where a single performance indicator is modelled as a function of key reform steps and country-level (and or firm-level) heterogeneities. As noted by [19], cross-country econometric assessments of the impacts of reforms are limited because of model specification challenges and the inadequacy of existing approaches in reflecting the multifaceted nature of the program. This study presents an alternative approach as the use of multi-input multi-output distance functions allows for simultaneous assessment of multiple performance indicators of reforms across countries and over time while accommodating the multiple steps that comprises reforms. This approach also enables the capturing of potential interdependencies and trade-offs common in multi-objective policy interventions that cannot be captured in previous approaches. To our knowledge, this is one of the first panel data studies on ESR performance for SSA as a region. It is also amongst the first analysis of reforms to capture the multifaceted nature of reforms, thus providing a holistic assessment across countries and over time.

The remainder of this paper is organized as follows. Section 2 presents the literature review within the context of theory and empirical evidence. Section 3 defines the model and the econometric approach used in the study. Section 4 describes the data. Section 5 presents the results. Section 6 concludes and offers recommendations for policy.

2. Literature Review

Reforms in SSA involved a set of steps or measures based on a model template [11]. These steps included (i) the enactment of an 'Electricity Law'; (ii) corporatization and commercialization of the core utility; (iii) the establishment of an independent regulatory authority; (iv) the unbundling of the core utility vertically and horizontally; and (v) private participation in the delivery and management of electricity assets [25–28]. In this section, we discuss these reform steps and their theoretical foundations in the order of the preferred sequencing, i.e., legislation, regulation, restructuring, and private participation [28,29]. We subsequently review other key factors affecting reforms including the role of institutions and the starting point of reforms. Finally, we present relevant empirical studies on reform performance in SSA.

2.1. Legislation and Regulation

The theoretical foundations of reforms are grounded in the organizational economics literature. As explained by [30], in a world of positive transaction costs, legal rules matter for efficient outcomes. Consequently, ESRs are typically initiated with a legislative Act that sets out the general framework for restructuring, private sector participation, and the establishment and role of regulatory bodies [11]. The Act signals commitment to implementing reforms and reduces the uncertainty associated with property rights, contract resilience, and conflict resolution procedures [31]. It provides assurances to private investors and reduces the risk of regulatory taking [32]. Regulatory taking is a situation when regulation limits the owners of a private property of economic use of it, even though it does not formally divest them of the title to the property. In SSA, the Act also makes provisions for poverty-related programs such as electrification, subsidy schemes, energy efficiency and conservation, and renewable energy development.

Once the legal basis of reforms is established, reforms pursue the separation of the policymaking and regulatory functions of the sector, which was traditionally mandated to one entity. Policy formulation remains with the State and regulation is assigned to an autonomous regulator (which is established) which is also given oversight over the reform process according to the provisions in the Electricity Law. The importance of this statutory regulator is critical given the extensive empirical evidence of a strong correlation between the effectiveness of the regulatory agency and the progress and performance of reforms [17,33]. Ref. [34] reiterate this in their study of Indian states, concluding that reforms are only as effective as the commitment of the regulator to implement it.

Economic regulation is necessary because the network segments of the ESI (i.e., transmission and distribution) have natural monopoly characteristics, making the market an ineffective mechanism to deliver optimal outcomes [35–37]. Regulation refers to rules, directives or discretionary authority that determine the structure of markets and guide the conduct of economic activities. The rules may be stipulated by a contract or legislation [38,39]. Theory of economic regulation postulates that institutional oversight could remedy this market failure through the imposition of rules backed by penalties (or rewards) to modify the behaviour of actors in the industry [40]. The regulator is charged to balance the interest of all market participants, safeguarding the high sunk costs of investors, and protecting consumers from monopoly exploitation. Public interest theory explains that the relevance of regulation is not only in the context of imperfect competition, unbalanced market operation and missing markets, but in the prevention and correction of undesirable market results [41,42]. This is generally in the form of social regulation as per considerations of justice, paternalistic motives, or ethical principles [43].

2.2. Restructuring–Unbundling, Corporatization, and Commercialization

In the next instance, the ESI is vertically unbundled, i.e., separating the potentially competitive activities (generation and retailing) from the natural monopoly segments (transmission and distribution). It is essential that unbundling takes place with due consideration of the political, social, and economic contexts of the reforming country to ensure that undesirable outcomes that may complicate subsequent adjustments to the process or worsen the welfare of consumers are mitigated [44]. Vertical unbundling often begins with the separation of the distribution business. This is necessary because many of the inefficiencies in the sector originate from distribution activities, and not separating that segment could jeopardize potential gains in other parts of the ESI [7]. Following this, the distribution utility may be horizontally unbundled to provide enough firms for yardstick regulation. This is to ensure that the regulator is supplied with multiple sources of information for effective regulation [44].

Then, the transmission activity is separated, which is critical for promoting private investments in generation as it allows for non-discriminatory third-party access to the grid [22,45,46]. However, this separation disrupts real-time coordination, and thus to coordinate generation with the load, a system operator is established to oversee power scheduling and dispatching. Some reform scholars advocate for ownership unbundling of transmission [47–51]. However, given the institutional limitations of most SSA countries, it is recommended that the grid remains in state ownership [44]. Nonetheless, the regulator should define the rules of grid access which should preferably be a regulated third-party access at this stage. It is important that the grid has adequate capacity to support the reforms during the initial years to prevent network congestion, which could serve as a barrier to new entry and hinder competition [11]. In addition, investments in generation without corresponding investments in networks could result in increased technical losses, service interruptions, and poor quality of service. Following this, the generation segment may be split into several units to remove the dominance of the incumbent and create an adequate number of firms for competition.

Finally, the successor utilities are corporatized. Corporatization refers to transforming state assets and entities into corporations with structure of publicly traded companies. In the electricity sector, this involves the incorporation of the successor utilities as limited liability entities with the government often retaining majority ownership. It may involve delegated public joint stock, and publicly listing companies to introduce corporate and business management techniques. These companies tend to have a board of directors, management, and shareholders. Almost all SSA countries have undertaken this reform step. This corporatization is carried out to instill good commercial practices and prepare for a subsequent redefinition of property rights if desired [26]. This allows for legal protection and third-party enforcement which is absent under state ownership [52].

2.3. Private Participation and Property Rights

The emphasis on private participation during reforms is underscored in property rights theories, which can be secured through the judicial system as well as the regulatory process. Property rights are believed to provide the necessary economic incentive system that shapes resource allocation. This is because private enterprises are driven by profits and may have more professional know-how in management, operating procedures, and use of appropriate technologies [31]. Private entrants are expected to create new production possibilities and efficiency improvements which could be captured and appropriated for the benefit of consumers [53–55]. Furthermore, privatization makes intervening in enterprise operations difficult for governments and politicians, so government manipulation is less likely [31].

The general position is that public ownership is superior to private ownership under a few circumstances [56–59]. However, there have been several instances. Earlier property rights theories were quite optimistic about an evolution toward economic efficiency with private ownership and or participation. However, there are several examples of failures of privatization to deliver economic efficiency gains in the electricity sector [11,60–63]. A notable example in SSA is Nigeria which has been fully privatized since 2006 but significant inefficiencies persist. On the other hand, Norway maintains government ownership and is among the well-functioning electricity systems [44]. Several other factors may account for the disparity between these two countries, but it does indicate that the private sector may not necessarily be the solution in some institutional contexts. With several of such examples globally, the consensus in the reform literature is that privatization is not necessarily a required aspect of reforms [44].

Furthermore, ownership of electricity assets has national security implications due to the pervasive nature of electricity in all aspects of the economy. Consequently, governments in SSA are typically reluctant to transfer the ownership of electricity assets to the private sector permanently and tend to lean towards temporary transfer of property rights. This often involves the transfer of specific economic rights to assets or aspects of it to a private party without changing the ownership of the asset [30,64]. Innovative Public–Private Partnership (PPP) models, typically in the form of Management Service Contracts (MSC), Affermage contracts or concessions, have made such impermanent transfers of property rights possible and common [7] (see the World Bank PPP database for more details on the various forms of public-private partnerships). However, different specifications of property rights have different effects on economic behaviour and outcomes as they provide different levels of incentives [30,43,65,66]. Nonetheless, if privatization is desirable and feasible, it would ideally start with the distribution networks as it signals to potential investors a commitment to instill commercial discipline in the sector.

2.4. The Role of Institutions, System Size and Initial Sector Structure in Reforms

Institutions play an important role in public policy. Ref. [3] refer to institutional factors as the sector and macro-level legal and regulatory frameworks that influence and support the continuity of the reform process. Reforms generally involve politically unattractive requirements, which makes commitment to the process difficult to secure and sustain [7]. Consequently, the sector transformation process and its outcomes at each stage are fragile and susceptible to political economy factors. In many developing countries like those in SSA, reforms take place within institutional settings that are characterized by unstable political systems, interventionist governments, unclear legislation on property rights, limited accountability, lack of judicial credibility and corruption [44,67]. During the reform process, it is therefore imperative that governments demonstrate political and legislative leadership and sustained commitment to regulatory and institutional changes. However, policymakers need to make realistic assumptions in reform formulation to ensure alignment with the institutional attributes of the country [18,68].

The impact of institutional quality on economic performance have emerged in various performance analyses [69–72]. The literature identifies two main approaches to institutional economics, i.e., the incentives approach and the governance approach. In distinguishing between incentives and governance, ref. [68] refer to incentives as the rules related to utility pricing and subsidies among other issues, and governance as how credible commitments are generated. Ref. [34] explain that, in the regulation literature, while earlier emphases had been on incentives [73,74], the new institutional economics is concerned with governance [75,76]. Refs. [77,78] explain that governance is not randomly distributed across countries, but good governance requires time and resources to develop, with wealthier countries more likely to enjoy good governance. Ref. [79] adds that good governance is also a function of a country's political and social history, especially in those countries that inherited a set of institutions from former colonial powers.

In many developing countries, the prevalence of economic corruption and political opportunism is a significant source of inefficiency in the electricity sector, generally at the expense of the poor [7]. These tendencies emanate from high stakes in reform transactions and the plentiful opportunities for rent-seeking [80]. Political opportunism may take the form of electricity underpricing at the expense of the commercial viability of the sector and government fiscal space. In liberalized electricity sectors, the quality of the regulator has been indicated to be a good reflection of the institutional capacity or governance capabilities of the industry and the country in general [34,42,81]. This is particularly important in the SSA context where reforms depart significantly from the standard reform models. However, capture theory asserts that overtime, regulation will come to serve the interests of the branch of the industry it governs [43]. The regulator may tend to avoid conflicts with the regulated company because it is dependent on it for its information while there are career opportunities for the regulators (personified) in the regulated companies [41].

In addition to these institutional considerations, there are other sectoral factors that may affect reform processes and performance. A notable example is the size of the electricity system which can hinder the implementation of reforms [25]. There have been arguments that the benefits of a full reform package may be small in relation to the costs in small electricity systems as the case for unbundling the sector gets weaker as the system becomes smaller [25,28,47,82]. In addition, the issue of hydrology has become particularly important with the prevalence of droughts and other climatic changes that have decreased water discharge and availability in hydropower plants [83]. As at the end of 2018, the International Hydropower Association estimated that Africa had about 36,264 megawatts (MW) of installed hydroelectric generation capacity, representing over 20% of installed generation capacity [84]. Thus, hydrology is an important aspect of SSA electricity systems and their performance [85,86].

2.5. Reform Performance in Sub-Saharan Africa

Ref. [45] identify three main approaches for evaluating ESR performance: econometric methods, efficiency and productivity analysis, and individual and comparative case studies. The study indicates that econometric studies are best suited for well-defined issues and hypotheses, while efficiency and productivity analysis (which can be based on econometric methods) are preferred for measuring the efficiency of transforming inputs into outputs relative to best practice [45]. Case studies, which are typically conducted at macro (country) or micro (household or firm) levels are suitable when in-depth investigation and qualitative analysis are required.

In SSA, the principal push-factor for ESR was the urgency to transfer the investment burden onto the private sector. Thus, the earliest waves of reforms focused on facilitating such investments while improving technical efficiency which has been indicated to be compatible with other economic efficiency objectives [87,88]. Some studies have shown that utilities of countries that reformed their electricity sectors performed better in terms of technical efficiency than those that did not, predicated on the combination and in some cases the sequencing of reform steps [60].

Ref. [89] evaluated the impact of the privatization of the Ivorian vertically integrated electricity utility (defined by a ten-year management contract) on technical efficiency. The study utilized pre-reform and post-reform time series data from 1959–1995 using an SFA approach. The parametric and non-parametric tests performed could not reject the hypothesis of significant technical efficiency improvements after signing the contract, although the performance was irregular over the period. However, the results also indicated that technical efficiency never reached the levels of the 1970s when the company was under close government supervision.

Ref. [90] utilized the data envelopment approach (DEA) to evaluate the changes in total factor productivity (TFP) for a sample of 12 operators in the Southern Africa Power

Pool (SAPP) between 1998 and 2005. The results indicated a slight improvement in TFP in the region, although the study could not establish that the efficiency improvements were due to the reforms. However, the findings suggested that although the companies had not utilized their capital and human assets better, they had adopted better technologies and commercial practices.

A panel data analysis by [91] for 92 countries including eight countries in SSA from 1982 to 2008 found a statistically significant but limited effect of reforms on plant load factor and network losses after controlling for country-specific variables such as GDP.

3. Methodology

A Stochastic Distance Function to Measure Reform Performance

Ordinary least squares (OLS) and some of their variants have traditionally been used in production economics to estimate functions (e.g., production or costs functions) that pass through the mean of the observed values in the sample. In the early 1950s, a persuasive argument was made that although producers may indeed attempt to optimize, not all are successful in doing so. OLS delivered estimates of models in which the 'average' rather than the 'best-practice' behaviour of producers was described. Thus, it provided information about the technology but not on the efficiency of the production process. This mooted discussions on how production functions were estimated, giving rise to the proposal and application of frontier analysis techniques.

Frontier methodologies are based on the theoretical premise that a production frontier (or its dual, the cost frontier) represents an ideal of best practice that an economic agent cannot exceed, and deviations from this represent inefficiencies. Consequently, it theorizes that a producer is 'technically' efficient if, and only if, it is impossible to produce more of any output without producing less of some other output or using more of some inputs [92,93]. Frontier approaches may be parametric in nature, as SFA; nonparametric, such as DEA; or even semi-parametric, such as the stochastic nonparametric envelopment of data (StoNED) proposed by [94].

SFA models originated from the near-simultaneous publications by [95,96]. In these papers, the production frontier is modelled as an equation expressed as $y = f(x, \beta)\exp(v - u)$, where y is an output, x is a vector of inputs, β represents parameters to be estimated, and '$v - u$' represents a convoluted error term. The first part of this error term, v, is a two-sided random disturbance that captures the effects of statistical noise and measurement errors associated with the functional form, while the term u is a one-sided random term that captures technical inefficiency. These error terms are assumed to be identically distributed across observations, distributed independently of each other and uncorrelated with the explanatory variables.

When multiple outputs are produced using multiple inputs, refs. [97,98] distance functions provide a functional characterization of such production technology. Distance functions allow for the description of a production technology without explicitly specifying any behavioral objective [99–101]. Distance functions can be input-oriented or output-oriented. Output (input) distance functions are used when outputs (inputs) are endogenously determined in the model. Output (input) distance functions provide an indication of the maximal (minimal) proportional expansion (contraction) of the output (input) vector given an input (output) vector [101,102].

We propose an output distance function to estimate the efficiency with which SSA countries have translated reform steps and some institutional features into sector-level performance outcomes. Distance functions provide the conceptual underpinning for efficiency and productivity analysis. Many studies present applications to the electricity sector, e.g., [34,103,104]. Moreover, our model can also be interpreted under a 'benefit-of-the-doubt' approach (see, e.g., [105]; or [106]). In that sense, our model serves to identify the outcomes deemed as important by the countries when reforming their electricity sectors (we would like to thank an anonymous referee for pointing this out). If we define a vector of reform steps as $x = (x_1, \ldots, x_K)$ and a vector of reform outcomes as $y = (y_1, \ldots, y_M)$, where m = 1, . . . , M and k = 1, . . . , K represent the number of outcomes/outputs and reform steps/inputs respectively, we can then specify a feasible multi-input multi-output production technology using the outcome set $P(x)$ that can be produced using the vector of reform steps, x, such that $P(x)$ = {y: x can produce y}, and it is assumed to satisfy the set of axioms depicted in [107]. As proposed by [98], such an outcome distance function can be defined as:

$$D_O(x, y) = \min\{\varphi : (y/\varphi) \in P(x)\} \tag{1}$$

where φ represents the minimum scalar by which all the outcomes can be proportionally divided while remaining in the feasible production set. Ref. [107] demonstrate that such an outcome distance function has the following characteristics: (i) it is linearly homogenous in y; (ii) it is non-decreasing in y and non-increasing in x; (iii) it is convex in y and quasi-convex in x; and (iv) if the distance function D_O (x, y) takes a value less than or equal to 1, then y belongs to the feasible production set $P(x)$ such that 0 < TE $\leq$ 1. Consequently, when a firm is operating on the frontier, it has a distance function value equal to unity and consequently a technical efficiency score of 1.

If we use a flexible functional form like the transcendental logarithmic (translog) specification, the model can be expressed as:

$$\begin{aligned} \ln D_{Oi}(x, y) = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mi} + 0.5 \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni} + \sum_{k=1}^{K} \beta_k x_{ki} \\ +0.5 \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} x_{ki} x_{li} + \sum_{k=1}^{K} \sum_{m=1}^{M} \delta_{km} \ln x_{ki} \ln y_{mi}, \quad i = 1, \ldots, N \end{aligned} \tag{2}$$

where α, β and δ are parameters to be estimated, i indicates the ith observation in the sample, and all other variables are defined as before. The frontier surface can then be defined by setting D_O (x, y) = 1, which implies that ln D_O (x, y) = 0. This equation must satisfy the conditions of symmetry and homogeneity of degree +1 in outputs. The symmetry condition is met if $\alpha_{mn} = \alpha_{nm}$ and $\beta_{kl} = \beta_{lk}$, and the homogeneity condition is met if $\sum_{m=1}^{M} \alpha_m = 1$, $\sum_{n=1}^{M} \alpha_n = 0$ and $\sum_{n=1}^{M} \delta_{km} = 0$. Following [108], homogeneity of degree +1 can be imposed by normalizing the output distance function by one of the outputs arbitrarily chosen, e.g., y_M. This transforms Equation (2) into the following expression:

$$\begin{aligned} \ln\left[\frac{D_{Oi}(x,y)}{y_{Mi}}\right] = \alpha_0 + \sum_{m=1}^{M-1} \alpha_m \ln\left(\frac{y_{mi}}{y_{Mi}}\right) + 0.5 \sum_{m=1}^{M-1} \sum_{n=1}^{M-1} \alpha_{mn} \ln\left(\frac{y_{mi}}{y_{Mi}}\right) \ln\left(\frac{y_{ni}}{y_{Mi}}\right) + \sum_{k=1}^{K} \beta_k x_{ki} \\ +0.5 \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} x_{ki} x_{li} + \sum_{k=1}^{K} \sum_{m=1}^{M-1} \delta_{km} x_{ki} \ln\left(\frac{y_{mi}}{y_{Mi}}\right), \quad i = 1, \ldots, N \end{aligned} \tag{3}$$

After rearranging terms, Equation (3) can be rewritten as:

$$-\ln(y_{Mi}) = TL\left(x_i, \frac{y_i}{y_{Mi}}, \alpha, \beta, \delta\right) - \ln D_{Oi}(x, y) \tag{4}$$

where $-\ln D_{Oi}(x, y)$ represents the radial distance from the boundary, i.e., deviations from optimal production levels. We set $-\ln D_{Oi}(x, y)$ equal to u, which represents the inefficiency term, and we add a noise term, v, to capture statistical noise. This transforms Equation (4) into the [109] version of the traditional stochastic frontier model proposed by [95,96]. We assume this error term to be a normally distributed, and u component following a half-normal distribution. In order to estimate the model, we need to make some assumptions about the distribution of the inefficiency term. Ref. [95] assumed a half-normal distribution, while [96] assume an exponential distribution. Other adopted distributions include the truncated normal [110] and the gamma distributions [111–113].

Moreover, we also include some control variables (w) to capture sector and country heterogeneities that may impact the process of transforming the sector reform steps into performance (see Section 4 for more details). We subsequently obtain Equation (5):

$$-\ln(y_{Mi}) = TL\left(x_i, \frac{y_i}{y_{Mi}}, w, \alpha, \beta, \delta, \zeta\right) + v + u \quad (5)$$

where ζ represents additional parameters to be estimated, which are linked to the control variables. In this paper, we are also interested in identifying sources of inefficiency in the process of transforming reform steps into performance. However, the inefficiency term in the [95] model described before has a homoscedastic constant variance, i.e., $u_{it} \sim N^{+}(0,\ \sigma_u^2)$, which does not allow for the study of the determinants of inefficiency. Estimates from such models can yield biased estimates of both frontier coefficients and country-specific inefficiency scores [114]. This issue can be addressed using a heteroscedastic frontier model that allows for the incorporation of variables as inefficiency determinants through the pre-truncation variance of the inefficiency term, u. However, there are alternative ways to introduce inefficiency determinants in SFA [115]. Considering the incorporation of inefficiency determinants, Equation (5) can be rewritten as:

$$-\ln(y_{Mi}) = TL\left(x_i, \frac{y_i}{y_{Mi}}, w, \alpha, \beta, \delta, \zeta\right) + v + u(z, \xi) \quad (6)$$

where z stands for the inefficiency determinants and ξ denotes the parameters to be estimated.

4. Data

We utilize a dataset that comprises of an unbalanced panel of 37 SSA countries from the year 2000 to 2017 (the list of countries included can be found in the appendices). In total, the number of observations is 511. The countries included in our analysis have implemented at least one reform step during the period of observation. Data used in this study were obtained from the United Nations and World Bank databases, as well as online resources of relevant sector institutions in the relevant countries.

We consider three main reform steps as inputs, i.e., the presence of an electricity law, vertical unbundling of the ESI, and the presence of an autonomous sector regulator. The variables considered are dummies that take value 1 in case the reform step (or private participation) has been implemented, and 0 otherwise. Table 1 presents the descriptive statistics of these variables. The details of the implementation of the reform steps are given in Appendix A.

Table 1. Description of reform steps (inputs) and private participation (control variable).

Reform Steps (Inputs)	Description	Descriptive Statistics
Electricity law act	The presence of a law that initiated reforms (initiated sector liberalization).	Max = 1 Min = 0 Mean = 0.87 St. Dev. = 0.33
Vertical unbundling unb	Legal unbundling-separate jurisdictions for generation, transmission and coupled distribution and retail.	Max = 1 Min = 0 Mean = 0.18 St. Dev. = 0.38
Sector regulator reg	The presence of an autonomous sector regulator.	Max = 1 Min = 0 Mean = 0.74 St. Dev. = 0.44
Control Variable		
Private participation pi	Private participation in part or all segments of the ESI in the form of management service contracts, leases/affermage contracts, concessions, and divestments, among others. This includes brownfield PPP arrangements only.	Max = 1 Min = 0 Mean = 0.26 St. Dev. = 0.44

Source: compiled by the authors.

We consider three key performance indicators as outcomes. These include the level of installed generation capacity per capita, the load factor of the generation portfolio, and the level of technical network energy losses. These outputs were specifically chosen to denote the level of investments in the electricity sector and the technical efficiency of the assets in all segments of the ESI, as per the aim of the first wave of reforms. Table 2 provides the descriptive statistics of the outcome variables and Appendix B provides more details of these.

Table 2. Description of performance indicators (outputs).

Performance Indicator (Output)	Description	Descriptive Statistics
Installed generation capacity per capita gencap	Measures the level of investment per capita in the generation segment. It is calculated as (net installed generation capacity in kW/total population). It is measured in kilowatt.	Max = 1.61 Min = 0.01 Mean = 0.12 Std. Dev. = 0.19
Plant load factor *plf*	Measures the efficiency of the generation assets. It is calculated as (total electricity production/(net installed generation capacity × number of hours in the year). It is measured in percentage.	Max = 0.88 Min = 0.05 Mean = 0.41 Std. Dev. = 0.15
Transmission and distribution network energy losseslosses	Measures the efficiency of transmission and distribution assets. It is calculated as the sum of technical network losses divided by total electricity supply (where supply is the sum of domestic production and net imports). We note that several databases measure technical network energy losses as percentage of total production instead of total supply (i.e., production plus net imports). Where there are cross-border power exchanges, this results in overestimation of the actual technical losses. Our variable is measured in percentage and has been transformed in a 'positive' outcome/output to be in the model. Therefore, an increase in this variable, implies reductions of transmission and distribution losses.	Max = 0.58 Min = 0.032 Mean = 0.07 Std. Dev. = 0.16

Data Source: United Nations Database.

Control Variables and Inefficiency Determinants

In order to capture the effects of institutions and sector heterogeneities on reform performance, we included several control variables in the model. We also estimated our model without controls, and alternatively with controls affecting directly, and exclusively, inefficiency. In both cases, the estimated coefficients of reform outcomes kept their sign and significance. However, the estimated coefficients of the reform steps lost their significance. In this sense, we must highlight that electricity sector reforms occur in a complex political economy and institutional environment which can obscure its impacts. Thus, it can be challenging to isolate the impact of reforms without accounting for institutional and sector features such as the effects of various governance attributes. Initial estimates of our model focused exclusively on modelling the reform steps but found most of the variables of interest not to be significant. Further review of the literature influenced our decision to include various sector characteristics, such as the size of hydro generation, the size of the electricity system, and other reform steps and governance indicators. Thus, it is not surprising that model specifications without these considerations do not present meaningful results.

The control variables include installed generation capacity (as a proxy for system size) and the size of hydroelectric capacity to capture the effects of hydrological changes. In addition, three aspects of the World Bank Governance Index (WGI) are included to capture the effects of institutions. These are political stability and absence of violence and terrorism, regulatory quality, and governance effectiveness indicators. Private ownership and participation in the management of the electricity sector is also included as a control variable. The decision to do so instead of including it as an input is because private ownership and management of electricity assets is often implemented to improve the operational and managerial performance of sector utilities (i.e., reduce commercial losses and improve billing and collection, among others) and not to expand the generation base, plant load factor or technical network losses. However, perceptions of the financial and operational performance of the sector influence investment decisions. These perceptions may be shaped by the ownership and management structure of sector utilities.

Finally, we included five determinants of inefficiency. These are the two sector level control variables, i.e., generation capacity and the private ownership and participation in management variables. We also include the corruption indicator of the WGI, as well as the presence of a regulator dummy to explore potential impacts of regulatory risks on reform performance. Table 3 summarizes the control variables and inefficiency determinants.

Table 3. Description of institutional variables and other sectoral characteristics (control variables and inefficiency determinants).

Control Variables and Inefficiency Determinants	Description	Descriptive Statistics
Regulatory quality rq	This is a dimension of the WGI which captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.	Max = 4.30 Min = 1.26 Mean = 2.94 St. Dev = 0.55
Governance effectiveness ge	This is a dimension of the WGI which captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of government commitment to such policies.	Max = 0.73 Min = −1.73 Mean = 0.66 Std. Dev. = 0.52
Political stability and absence of violence ps	This is a dimension of the WGI which captures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism.	Max = 4.72 Min = 1.24 Mean = 3.13 Std. Dev. = 0.76
Control of vorruption cc	This is a dimension of the WGI which captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests. An increase in this variable implies that a country is less corrupt, and a decrease implies that a country is more corrupt.	Max = 1.04 Min = −1.81 Mean = 0.54 Std. Dev. = 0.59
Hydroelectric vapacity hydro	Installed hydroelectric capacity (MW).	Min = 0 Max = 3814 Mean = 522.31 Std. Dev. = 702.67
Net installed generation capacity (MW) gc	This refers to the size of the generation capacity (MW). It serves as an indicator for the size of the electricity sector.	Max = 53,028 Min = 14.3 Mean = 2349 Std. Dev. = 7698

Data Source: World Bank and United Nations Databases. Note: hydro is introduced in the model both as a control variable in the frontier and as an inefficiency determinant.

5. Results and Discussion

Production theory assumes that output-oriented distance functions should satisfy the curvature and monotonicity conditions previously described (for further discussion on the imposition of these constraints, see [101]). As a direct consequence, we expect the coefficients of outcomes/outputs (β) to be positive and that of the reform steps/inputs (α) to be negative for this type of distance function. The parameters of the model are estimated using the maximum likelihood procedure. As we use the variable *gencap* to impose homogeneity, the dependent variable of the model is –log (*gencap*). In order to facilitate the interpretation of the estimated parameters, the output variables have been transformed into deviations to their mean values after taking logarithms. Both the coefficients of outputs and inputs can be respectively interpreted as distance function partial elasticities with respect to outcomes and reform steps at the sample mean. The original variable *losses* represent a 'bad' output/outcome, as an increase in this variable means that the transmission and distribution losses have increased, and hence it does not imply an improvement but a worsening of sector performance. In order to facilitate the comparability of results, we transform this variable into a standard output. Thus, similarly to *plf* and *gencap*, an increase of this variable in the model denotes an improvement in sector performance and we expect the coefficients of these three variables to be positive.

Table 4 presents the parameter estimates of three specifications of the output distance function utilized in this study, i.e., the Cobb-Douglas, a translog without inefficiency determinants and a translog with private participation, the presence of a regulator, the size of the electricity sector, control of corruption, and the level of hydroelectric capacity in the generation mix as inefficiency determinants. We present the results of all the model specifications but only discuss the results of the translog model with inefficiency determinants, since this latter model is the preferred one. We carried out likelihood ratio (LR) tests to compare the three models presented in Table 4. The test value when comparing the Cobb-Douglas and the translog without inefficiency determinants is 157.17 ***, while the values of the test when comparing the translog with inefficiency determinants against the Cobb-Douglas and the translog without inefficiency determinants are respectively 213.86 *** and 56.69 ***. These values confirm that both the Cobb-Douglas and the translog without inefficiency determinants are rejected in favour of the translog with inefficiency determinants, and hence we consider the latter as our preferred model.

As shown in Table 4, the estimated first-order coefficients of the performance indicators, i.e., *gencap* and *plf*, are positive and statistically significant, and that of *losses* is negative and statistically significant. The positive coefficient of *gencap* indicates that reforms are correlated with increased rate of investments in the generation segment of the ESI above the growth in population. This finding is in line with studies such as [116] and [116,117]. Ref. [116] explains that electricity sector investments in SSA increased in the early 2000s, with IPPs and Chinese-funded investments (49% of Chinese investments in the power sector between 2010 to 2020 were in hydropower [118]), accounting for over 13.8 gigawatts of generation capacity in the region at the end of 2016. Note that an increase in the rate of installed generation capacity per capita does not necessarily assure capacity adequacy as rate of increase in demand could be higher than the rate of increase in population due to higher consumption per capita.

The positive and significant coefficient of the *plf* variable indicates a positive correlation between reforms and the load factor of generation portfolios in SSA. This finding can be explained by the increased share of combined and open cycle gas turbines in the generation capacity investments after reforms. These types of power plants are known to have higher firm capacity and being less prone to adverse weather conditions. As at the end of 2017, over 84% of installed power capacity in SSA was from these thermal sources. In addition to these favourable technological features, the majority of the new investments were covered under power purchasing agreements which promotes the maximum utilization of power plants.

Table 4. Parameter estimates.

Variable	Cobb-Douglas		Translog		Translog w. Inefficiency Determinants	
	Coefficient	**Std. Error**	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**
Frontier						
Outputs						
ln gencap	<u>0.88</u>		<u>1.03</u>		<u>0.85</u>	
ln plf	0.51 ***	0.03	0.49 ***	0.08	0.57 ***	0.08
ln losses	−0.39 ***	0.02	−0.52 ***	0.07	−0.42 ***	0.07
Inputs						
act	0.03	0.04	−0.23 ***	0.08	−0.23 ***	0.08
unb	−0.13 ***	0.03	−0.43 **	0.21	−0.47 ***	0.18
reg	−0.01	0.03	−0.32 ***	0.09	−0.37 ***	0.09
Control Variables						
pi	−0.13 ***	0.03	−0.10 ***	0.03	−0.21 ***	0.04
rq	−0.04	0.04	0.08 *	0.04	0.06	0.04
ge	−0.09	0.05	−0.05	0.05	−0.04	0.05
ps	−0.06 ***	0.02	−0.12 ***	0.02	−0.09 ***	0.02
hydro	−0.01 ***	0.01	−0.01 ***	0.01	−0.01 ***	0.01
ln gc	0.01	0.01	−0.04 ***	0.01	−0.01	0.01
Output Interactions						
0.5 (ln *plf*)^2			0.25 ***	0.06	0.21 ***	0.05
0.5 (ln *losses*)^2			0.26 ***	0.04	0.24 ***	0.04
(ln *plf*) · (ln *losses*)			0.29 ***	0.04	0.27 ***	0.04
Input Interactions						
act · unb			0.36 *	0.21	0.36 **	0.17
act · reg			0.26 ***	0.09	0.25 ***	0.08
unb · reg			0.06	0.09	0.08	0.10
Inputs-Outputs Interactions						
(ln *plf*) · act			−0.18 **	0.07	−0.25 ***	0.08
(ln *plf*) · unb			−0.18 **	0.09	−0.14	0.09
(ln *plf*) · reg			0.32 ***	0.05	0.28 ***	0.05
(ln *losses*) · act			−0.09 *	0.06	−0.16 ***	0.06
(ln *losses*) · unb			−0.08	0.07	−0.07	0.08
(ln *losses*) · reg			0.35 ***	0.04	0.29 ***	0.04
intercept	−0.34 ***	0.05	0.02	0.09	0.16 *	0.09
Noise Term						
ln ($\sigma_v{}^2$)	−5.07 ***	0.36	−5.04 ***	0.35	−5.56 ***	0.32
Inefficiency Term (variance)						
intercept	−1.64 ***	0.09	−2.02 ***	0.11	−3.44 ***	0.27
ln gc					−0.45 ***	0.10
pi					0.86 ***	0.22
hydro					0.01 ***	0.01
reg					0.63 ***	0.22
cc					−0.25	0.17

Significance code: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Note: Underlined values are computed through the application of the homogeneity conditions.

The coefficient of losses was, however, found to be negative. This indicates that reforms were negatively correlated with the rate of reduction in technical network losses. This finding is not surprising given the limited investments in network reinforcement and maintenance, largely due to the lack of effective and sustainable business models for private investments in networks. The concept of independent power transmission is being explored, but reservations about the institutional capacity of SSA countries to deliver such business models remain [119]. As a result, electricity network infrastructures in SSA have become old and obsolete. Most countries in SSA are developing countries facing exponential demand growth due to increased economic activity, population growth and access expansion. With the increasing load in the dilapidated networks, the percentage of energy lost in transport often increases if the grid is not well-maintained and reinforced.

With respect to the reform steps, we find that the first-order coefficients of *act*, *unb*, and *reg* are significant at the 1% significance level and with the expected negative sign of the inputs' coefficients in an output distance function. The significance of the coefficient of the *act* variable indicates a positive correlation between the existence of an electricity law which legitimizes reforms and sector performance.

The significance of the coefficient of *reg* also indicates the critical role of an autonomous authority in sector reforms, as an administrator of electricity tariffs, overseer of IPP negotiations and enforcer of third-party access; all of which are important considerations for prospective investors. However, the inefficiency term shows a positive relationship between the presence of an electricity sector regulator and inefficiency, indicating that the presence of a regulator could be a source of inefficiency in reform performance especially in an environment of poor regulation. This finding suggests potential regulatory risks that could be disincentivizing investments in SSA electricity sectors [120].

The significance of the coefficient of *unb* indicates a correlation between vertical unbundling and reform performance. This is a particularly interesting finding given that several SSA countries are contemplating whether to vertically unbundle their electricity sectors, while others such as Zimbabwe are considering reintegrating their sectors.

Of the 37 countries in our sample, seven countries had unbundled their electricity sectors as at the end of 2017, namely, Angola, Nigeria, Ghana, Kenya, Uganda, Zimbabwe, and Lesotho. These countries were also amongst the most extensive reformers in the region, with all having introduced at least two other reform steps. However, of these countries, Zimbabwe and Lesotho were the only unbundled electricity systems that featured in the top ten performers. Interestingly, these countries are members of the Southern African power pool (SAPP), which gives them access to a larger market. This finding suggests that the impacts of unbundling may be amplified when the country has access to a larger market.

We also find that pi, introduced in the model as a control variable, has a negative and significant coefficient, indicating that private ownership and management is positively correlated with reform performance. However, this reform step is double edged as a positive correlation is observed between its presence and inefficiency. However, the story around private ownership and participation in management is a complex one. During the period under observation, fifteen countries had some form of private participation in their electricity sectors at some point in time (see Appendix A). Of these countries, only Nigeria had undertaken full privatization (i.e., sold its generation and distribution assets to private entities), while Uganda and Kenya had their utilities listed on their respective national security exchanges. In addition, Uganda also appointed Umeme as the private distribution concessionaire. Beside these four countries, sustained private participation contracts were concentrated in the francophone African countries, i.e., Côte d'Ivoire, Gabon, Mali, and Cameroon. In the remaining countries, private participation was temporal, usually between two to three years, or were failed privatization attempts. In several instances, cancellations of private management or concession contracts were due to supposed deteriorated performance and allegations of failure of private parties to make the necessary investments as agreed in contracts. For the private parties, the common problem is the realization that the problems in the sector are often worse than had been anticipated. In several cases, data used in contracts have been found to be inaccurate, with baseline performance benchmarks often worse than what was agreed on in contracts. These discrepancies are often observed after contract signature when the private party has access to the books of utilities. In some cases, contracts maybe revised to reflect these changes, but in several others, contracts are abrogated. Thus, the revised assessments of performance indicators during periods of private sector participation (even if brief) can create an impression of deteriorated performance.

In the assessment of the impact of institutions, we found a positive correlation between political stability and absence of violence and terrorism, *ps*, and reform performance. This finding is as expected as electricity sector investments are usually immovable assets, making it particularly critical to consider a safe environment in investment decision-making. Electricity sector assets have also historically been a target of civil unrest, with notable examples including the destruction and looting of the Mount Coffee hydropower station in Liberia and the curtailed development of the Bumbuna hydropower station in Sierra Leone during periods of prolonged conflicts in both countries.

Similarly, the estimated coefficient of the governance effectiveness index (*ge*) is not significant. This indicates that perceptions of the quality of public and civil services, the degree of independence of these institutions from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies are not correlated with reform performance. This is also the case for the regulatory quality (*rq*) dimension of the WGI. The insignificance of the coefficient of this variable indicates that perceptions about the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development is not correlated with better reform performance.

We found the control of corruption (*cc*) variable included as an inefficiency determinant to be insignificant. This finding shows that perceptions about the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests has no relationship with reform performance.

A general impression emerging from these results is that perceptions about non-violent institutional aspects have no correlation with reform performance. This is largely because commercial interests are usually protected in contracts, and thus perceptions of non-violent institutional features may not be a determinant of investment decisions, especially as contracts are usually enforced by international judicial systems.

We found the coefficient of installed generation capacity (as a proxy for size) as insignificant when introduced as a control variable, but significant when introduced as a determinant of inefficiency. These results indicate that while there is no relationship between the size of electricity systems and reform performance, the size of an electricity sector is correlated with higher efficiencies in reform performance. We also found that the size of the installed hydroelectric capacity, hydro, was positively correlated with reforms, but also with higher inefficiency in reform performance.

Reform Performance

Reform performance from 2000 to 2017 has been irregular, with changes in trend coinciding with major global economic events such as the 2008 financial crises and the US shale revolution. As shown in Figure 1, there is a dip in reform trends between 2002 and 2003, which can be explained as a learning curve effect. However, from 2003 to 2009, a slow but steady improvement in performance is observed from an average performance score of 74 to a peak of 78% in 2009. However, performance begins to fall after 2009. This can be explained by the 2008/2009 financial crises during which access to capital became limited, severely constraining investments in electricity infrastructure globally [121]. With investments being a main indicator of performance in this study, it is unsurprising that the adverse effects of the crises can be observed in this performance trend. However, in 2012/2013, the deterioration in performance seemed to have been abated and this change coincides with the US shale revolution in 2012/2013. The increased production of US tight oil and gas through fracking created a surplus of crude oil on the international market which led to a fall in crude oil prices. This bolstered global economic growth (except for oil exporting countries) and ameliorated the effects of the financial crisis.

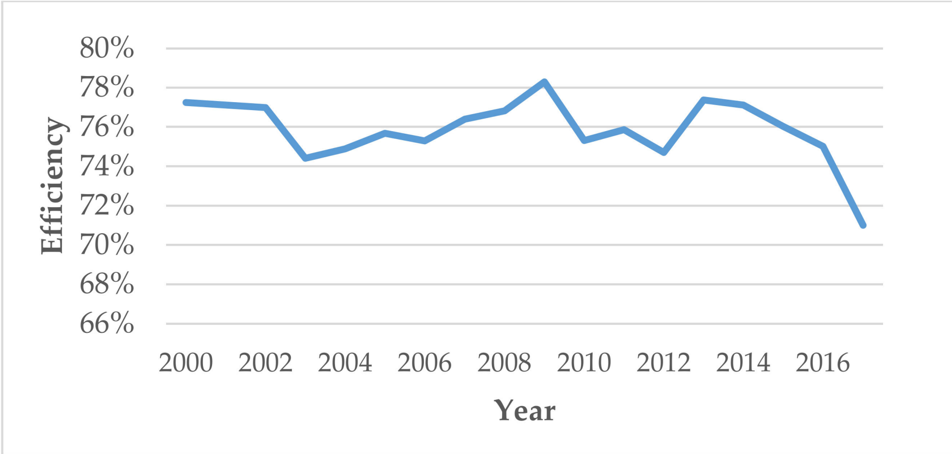

Figure 1. Electricity sector reform performance trend in SSA from 2000 to 2017.

In addition to the average annual performance for all the countries, we have calculated the average performance score for each country from 2000 to 2017 (see Figure 2 and Appendix C). These scores indicate the country-level efficiency of transforming reforms into the observed sector performance outcomes. Figure 2 shows that Gabon emerged as the most efficient reformer with an average score of 93%, followed by Cote d'Ivoire, South Africa, and Senegal in second place, and Zimbabwe in third place. There is no doubt that there are important lessons in the experiences of all countries in the sample, but for the purpose of this exercise, we focus on the top four performing countries mentioned above.

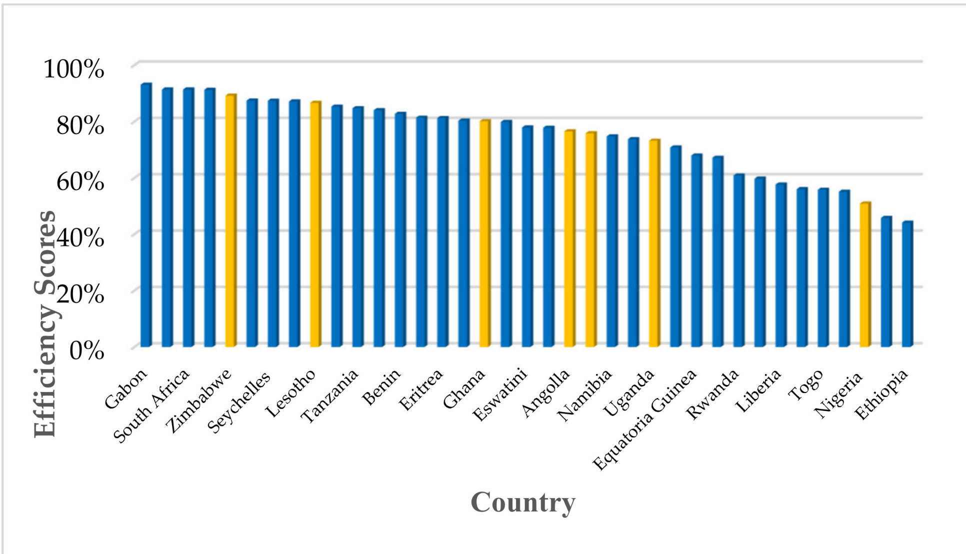

Figure 2. Average efficiency scores of SSA countries (2000–2017). Note: Countries with unbundled electricity systems are presented in yellow.

Gabon is among the earliest reformers in SSA having given its vertically integrated utility out as a concession as early as 1995. The concession aimed at leveraging the private sector to instill commercial discipline and improve the operational performance of Société d'Energie et d'Eau du Gabon (SEEG), the company that holds the monopoly for water and electricity distribution in the country. The selection of the Concessionaire was based on a single bidding criterion, i.e., proposed percentage reduction in tariffs with key performance improvements including service quality, expanding coverage at affordable rates, and ending the fiscal burden of the sector to free up public resources for other sectors of the economy [122]. The Concessionaire also had to invest a minimum of $135 million in rehabilitation (60% in water), but also informally commit to investing another $130 million in the sector over the concession period. The Concession consortium also acquired 51% of SEEG and made an initial public offering (IPO) for the remaining 44% of the company's shares with an exclusive offer of 5% to SEEG employees. While the Concessionaire was responsible for managing the generation infrastructures, investments in new generation capacity remained with the state. Figure 3 shows a gradual decline installed generation capacity per capita over the period under observation, but there are noticeable improvements in plant load factor while changes in technical losses remain negligible.

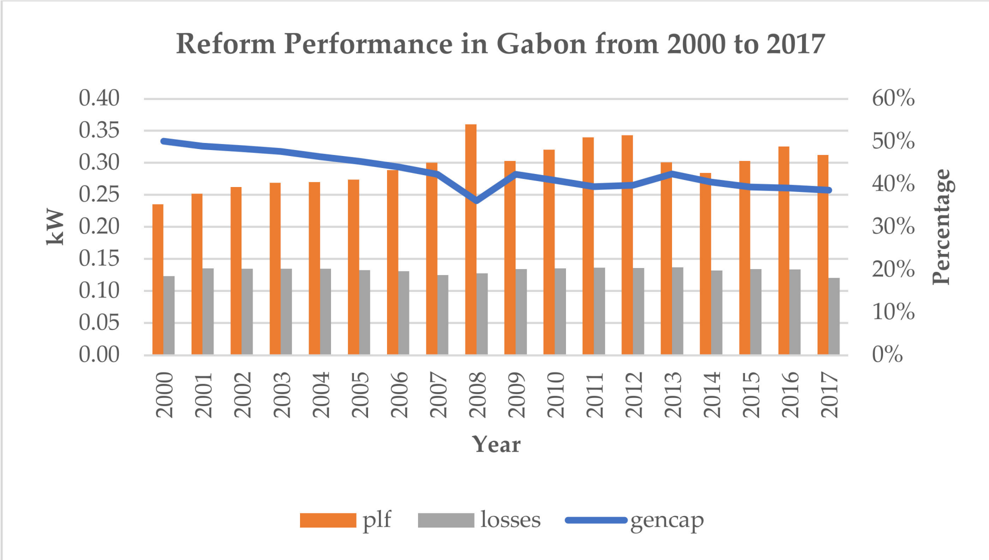

Figure 3. Evolution of plant load factor (in percentage), technical network losses (in percentage) and installed generation capacity per capita (in kilowatt) in Gabon.

However, note that in 2018, SEEG's concession was terminated on allegations of deteriorated quality of service and complaints from consumers. The termination of the contract made international headlines given the way the requisition of assets was done, in a manner described by Veiola (the Concessionaire) as "brute force." It must be noted that Gabon is an upper-middle-income country with abundant power generation resources including fossil fuels and hydropower. Thus, at the earlier stages of reforms, the country had a significant reserve margin in generation which allowed for an efficiency-oriented concession agreement. Until the present, Gabon is yet to host an independent power producer (IPP), and the Government of Gabon remains the main counterpart for pipeline projects instead of the utility, as in many advanced economies in the region.

Figure 4 shows the performance indicators of Côte d'Ivoire. This country hosted the first IPP project in the region in 1994, the 210 MW Compagnie Ivorienne de Production d'Électricité (CIPREL) owned by the French Eranove group. The success of CIPREL stimulated interests in the second IPP, the 330 MW Azito gas-fired plant which came online in 2000 and was the largest IPP project in West Africa at the time. Currently, Côte d'Ivoire is a net exporter of electricity to Benin, Burkina Faso, Ghana, and Togo. In addition, the successful liberalization of the generation segment, the vertically-integrated Compagnie Ivoirienne d'Électricité (CIE), was given out as a concession to Eranove as far back as 1990. CIE was also divested, with Finagestion, a subsidiary of emerging capital partners owning 54% of the total shares, and the State of Côte d'Ivoire owning 15%, private Ivorian investors owning 26%, and the employee pension fund of CIE owning the remaining 5%. Arguably, the involvement of the private sector in generation created the necessary incentives for efficient technology choices and optimal utilization of power plants as can be seen from the trend in load factor.

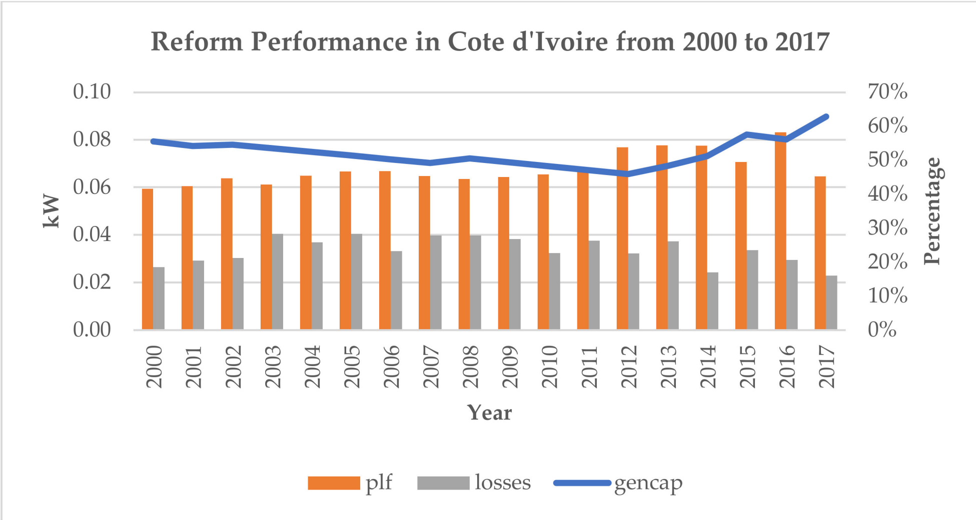

Figure 4. Evolution of plant load factor (in percentage), technical network losses (in percentage) and installed generation capacity per capita (in kilowatt) in Cote d'Ivoire.

Senegal, whose performance indicators are displayed in Figure 5, shares a similar experience with Cote d'Ivoire with respect to its early engagement with IPPs. Senegal commissioned its first IPP, the Gti Dakar, as early as in 2000. The state-owned vertically-integrated utility, SENELEC, owns about half of the generation capacity, with the remaining capacity owned by IPPs. SENELEC remains publicly-owned and managed. However, the government has a unique arrangement with the staff of SENELEC by means of a performance contract since 2012. The agreement includes an incentive scheme of bonuses and sanctions to improve the management and commercial performance of SENELEC and has been reported to have led to improvements in operational performance and the productive efficiency of sector assets.

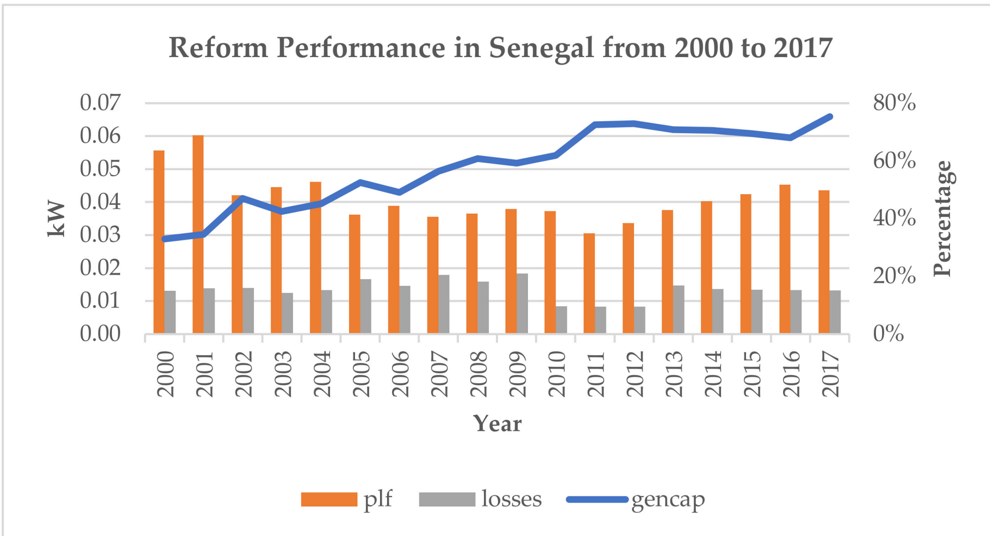

Figure 5. Evolution of plant load factor (in percentage), technical network losses (in percentage), and installed generation capacity per capita (in kilowatt) in Senegal.

What these three countries share is a francophone colonial heritage and corresponding institutional structures that are favourable for regulation by contracts [120]. These institutional assets make engagements with the private sector easier and the liberalization process more sustainable.

South Africa is unsurprisingly in the top performing countries, being home to over 50% of the installed generation capacity in SSA. The structure of the South African electricity sector is especially unique, remaining vertically-integrated despite being the largest electricity system in the region. The fully state-owned utility, Eskom, holds 91% of the country's gross generation capacity, with the remaining held by 137 municipal power companies (1.8%) and IPPs (7.2%). It has 30 operational power stations with a nominal generation capacity of 44,172 MW, comprising coal (85.1%), gas (5.6%), hydro (4.7%), nuclear (4.3%) and wind (0.2%) power plants. Eskom owns, operates, and maintains 95% of the national transmission network and shares the distribution network with 187 licensed municipal distributors. Eskom was converted from a statutory body into a public company, Eskom Holdings Limited, in July 2002.

Figure 6 presents the performance indicators of South Africa. This is the only country of the four top-performers that initiated reforms very late as it relied on public funds for sector investments. This was made possible by its upper-middle-income country status. At the earlier stages of reforms, South Africa was one of the few countries in SSA that had excess generation capacity, but also continues to make investments in new generation capacity. Investments in the generation were also complemented by massive investments in the networks in the forms of grid reinforcements and extension, the result of an ambitious electrification programme by the new post-apartheid government. Thus, South Africa is one of the few countries in SSA that had the means as well as the zeal to invest in electricity sector without private capital. It is, therefore, unsurprising that it has one of the highest plant load factors, highest per capita generation, and lowest technical network losses which never exceeded 10% during the period under observation. Currently, it is the largest exporter of electricity within the SAPP, trading electricity with Botswana, Lesotho, Mozambique, Namibia, Eswatini, Zambia and Zimbabwe. However, over the last few years, there have been concerns about tightening spare capacity which could compromise future trade.

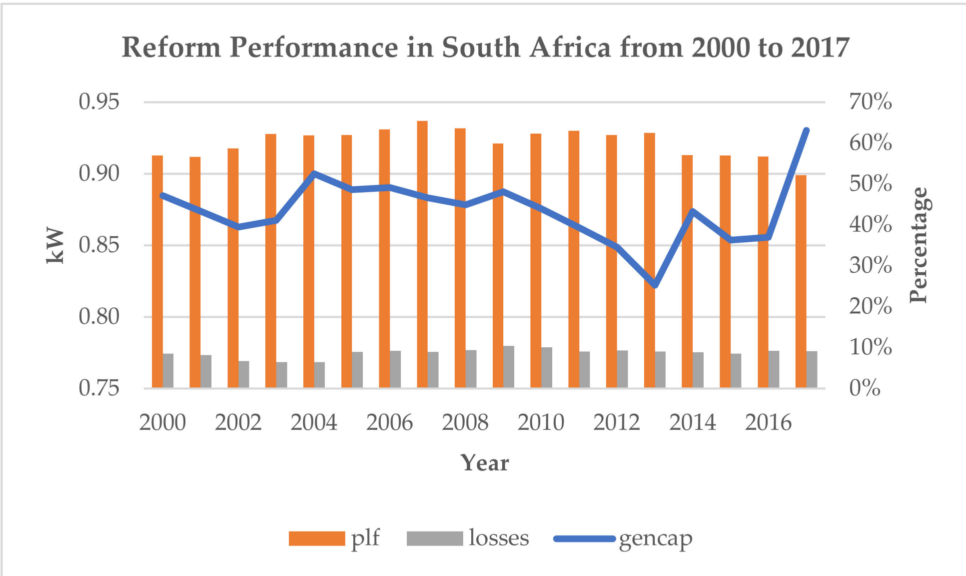

Figure 6. Evolution of plant load factor (in percentage), technical network losses (in percentage) and installed generation capacity per capita (in kilowatt) in South Africa.

6. Conclusions and Policy Implications

In this study, we assessed electricity sector reform performance for a set of 37 SSA countries from 2000–2017. We used a multi-input multi-output distance function to define a best performance frontier comprising three indicators, i.e., net installed generation capacity per capita, plant load factor, and technical network losses. This performance frontier was modelled as a function of some reform steps including the enactment of an electricity law, vertical unbundling of the industry, and the establishment of a sector regulator. Private participation in the ownership and management of electricity assets was included as a control variable. The presence of a sector regulator and private participation were also included as inefficiency determinants.

In order to understand the impact of institutional quality on reform performance, we included four dimensions of the WGI, namely, perceptions of political stability and absence of violence and terrorism, control of corruption, regulatory quality, and government effectiveness as measures of institutional quality. The level of installed hydroelectric capacity in the generation portfolio was also included as a control variable and as a determinant of inefficiency to understand the effects of hydrology on reform performance. Lastly, we included the installed generation capacity (as a proxy for the size of the electricity sector) in the model as a control variable and determinant of inefficiency.

The results show that reforms are positively correlated with installed generation capacity per capita, the rate of increase of plant load factor, and negatively correlated with reductions in technical network losses. We also found that the presence of an electricity law, vertical unbundling of electricity sector, and the presence of an electricity sector regulator were positively correlated with reform performance, as well as private participation introduced as a control variable. However, private participation and the presence of the sector regulator were also sources of inefficiency in the model with inefficiency increasing with the implementation of these reform steps.

We found that perceptions about political stability and absence of terrorism and violence was positively correlated with reform performance. However, perceptions of regulatory quality and governance effectiveness had no bearing with reform performance. Moreover, perceptions of corruption were not a source of inefficiency in the model. The effect of hydrology on reform performance was small but significant both as a control variable and as a determinant of inefficiency. Finally, we found a negative relationship between the size of an electricity sector and inefficiency, indicating that larger electricity systems are more efficient in reforms than smaller ones.

We conclude that the structure of a desirable reform model in SSA for maximum technical efficiency improvements and investment involves a vertically unbundled electricity sector with an independent regulator. This framework should be legally enshrined in an electricity law, with private participation in the operations and management of electricity assets where preferred. However, the positive outcomes of reforms may go hand in hand with an increase of technical network losses. Hence, emphasis should be put on decoupling these losses from generation capacity and plant load factor. Smaller electricity systems should consider partaking in regional electricity markets to neutralize potential inefficiencies during reforms.

Author Contributions: Conceptualization, A.A., T.J. and M.L.; methodology, A.A., T.J. and M.L.; software, A.A., T.J. and M.L.; validation, A.A., T.J. and M.L.; formal analysis, A.A., T.J. and M.L.; investigation, A.A., T.J. and M.L.; resources, A.A., T.J. and M.L.; data curation, A.A.; writing—original draft preparation, A.A., T.J. and M.L.; writing—review and editing, A.A., T.J. and M.L.; visualization, A.A., T.J. and M.L.; supervision, T.J. and M.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: Financial support from the Copenhagen School of Energy Infrastructure (CSEI) is acknowledged. The activities of CSEI are funded jointly by Copenhagen Business School and energy sector partners.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Years in which the countries undertook the different reform steps.

Country	Year Electricity Act Was Enacted	Year of Vertical Unbundling	Year in Which an Autonomous Sector Regulator Was Put in Place	Years in Which There Was Private Participation in the Management and Ownership in the Sector (Exclude IPPs).
Angola	2002	2014	No	2008
Benin	2007	No	No	No
Botswana	2008	No	No	No
Burkina Faso	2007	No	2007	No
Cabo Verde	2006	No	2003	2000–2008
Cameroon	2011	No	2000	2000 until today
DR. Congo	2010	No	No	No
Cote d'Ivoire	2000	No	2000	2000 until today
Equatorial Guinea	2005	No	No	No
Eritrea	2004	No	No	No
Eswatini	2007	No	2007	No
Ethiopia	2000	No	2000	No
Gabon	2005	No	No	1996–2018
The Gambia	2005	No	2000	No
Ghana	2000	2000	2000	No
Guinea	No	No	No	2015–2017
Kenya	2000	2000	2007	2006 until today
Lesotho	2002	2000	No	No
Liberia	2009	No	No	2010 until today
Malawi	2002	No	2002	No
Mali	2000	No	2000	2000 until today
Mauritania	2001	No	2001	No
Mozambique	2000	No	No	No
Namibia	2000	No	2000	No
Nigeria	2005	2006	2006	2006 until today
Rwanda	2011	No	2001	No
Sao Tome and Principe	No	No	2005	2003 to 2006
Senegal	2000	No	2000	No
Seychelles	2012	No	2009	No
Sierra Leone	2011	No	2011	No
South Africa	2006	No	2000	No
Tanzania	2008	No	2000	2002 to 2006
Togo	2000	No	2000	2000–2006
Uganda	2000	2000	2000	2003
Zambia	2000	No	2000	No
Zimbabwe	2003	2003	2003	No

Note: Some reform steps indicated to have been implemented in 2000 were implemented in 2000 or earlier.

Appendix B

Table A2. Installed generation capacity per capita of sub-Saharan African countries.

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Angola			0.03	0.03	0.03	0.04	0.04	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.08	0.09	0.10	0.15
Benin								0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.03
Botswana									0.08	0.08	0.08	0.08	0.08	0.07	0.30	0.29	0.29	0.34
Burkina Faso								0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02
Cabo Verde	0.11	0.12	0.18	0.18	0.18	0.17	0.15	0.16	0.19	0.18	0.21	0.22	0.27	0.28	0.30	0.31	0.32	0.37
Cameroon	0.05	0.05	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.08	0.08	0.08	0.08	0.08
DR Congo											0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
Cote d'Ivoire	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09
Eq. Guinea						0.05	0.05	0.07	0.07	0.07	0.08	0.08	0.34	0.32	0.31	0.30	0.29	0.44
Eritrea					0.06	0.06	0.06	0.06	0.05	0.05	0.04	0.04						
Ethiopia	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.04	0.04
Eswatini								0.13	0.14	0.14	0.14	0.15	0.17	0.16	0.17	0.17	0.17	0.17
Gabon	0.33	0.33	0.32	0.32	0.31	0.30	0.29	0.28	0.24	0.28	0.27	0.26	0.26	0.28	0.27	0.26	0.26	0.26
Gambia	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.06	0.06	0.06	0.06
Ghana	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.14	0.14	0.16
Guinea																0.05	0.05	0.05
Kenya	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05
Lesotho	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Liberia										0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Malawi	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Mali	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
Mauritania		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.06	0.11	0.11	0.12
Mozambique	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.10
Namibia	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.23	0.22	0.22	0.18	0.23	0.22	0.21	0.21	0.21	0.21
Niger																	0.01	0.01
Nigeria						0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07
Rwanda		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Sao Tome and Principe						0.09	0.09	0.09	0.08	0.08	0.08	0.12	0.12	0.12	0.11	0.13	0.13	0.14
Senegal	0.03	0.03	0.04	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.07
Seychelles										0.73	0.71	0.91	0.90	0.95	0.95	0.93	0.93	1.62
Sierra Leone												0.01	0.01	0.01	0.01	0.02	0.02	0.02
South Africa	0.88	0.87	0.86	0.87	0.90	0.89	0.89	0.88	0.88	0.89	0.88	0.86	0.85	0.82	0.87	0.85	0.86	0.93
Tanzania		0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Togo	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Uganda	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Zambia	0.16	0.16	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.14	0.14	0.14	0.14	0.16	0.15	0.17	0.17
Zimbabwe				0.17	0.17	0.17	0.16	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.14	0.14	0.14

Table A3. Plant load factor of electricity systems of sub-Saharan African countries from 2000 to 2017.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Angola			38%	43%	39%	34%	43%	30%	39%	44%	42%	41%	45%	60%	51%	43%	40%	27%
Benin								15%	13%	10%	13%	11%	9%	5%	11%	10%	8%	10%
Botswana									47%	41%	34%	28%	16%	50%	38%	47%	44%	39%
Burkina Faso								27%	27%	31%	25%	21%	22%	31%	33%	33%	32%	36%
Cabo Verde	35%	35%	25%	27%	30%	32%	39%	39%	35%	39%	38%	37%	31%	32%	29%	29%	29%	27%
Cameroon	50%	46%	35%	39%	43%	45%	53%	44%	48%	45%	48%	52%	40%	41%	46%	48%	47%	46%
DR Congo											34%	34%	33%	35%	37%	37%	36%	37%
Cote d'Ivoire	42%	42%	45%	43%	45%	47%	47%	45%	44%	45%	46%	47%	54%	54%	54%	49%	58%	45%
Equatorial Guinea						41%	45%	30%	30%	35%	29%	41%	17%	24%	27%	28%	28%	18%
Eritrea					18%	19%	17%	19%	22%	23%	24%	26%	28%	29%	30%	27%	27%	22%
Ethiopia	22%	21%	11%	12%	11%	13%	14%	16%	18%	20%	26%	30%	36%	42%	46%	50%	34%	37%
Eswatini								38%	31%	38%	41%	46%	39%	37%	34%	30%	22%	25%
Gabon	35%	38%	39%	40%	40%	41%	43%	45%	54%	45%	48%	51%	51%	45%	43%	45%	49%	47%
Gambia	33%	56%	53%	53%	51%	51%	50%	48%	51%	43%	37%	39%	38%	31%	27%	28%	29%	27%
Ghana	68%	65%	54%	42%	37%	45%	56%	41%	43%	42%	45%	46%	47%	49%	49%	34%	37%	35%
Guinea																23%	30%	31%
Kenya	47%	48%	51%	52%	56%	56%	60%	63%	58%	56%	56%	56%	55%	56%	50%	48%	50%	51%
Lesotho	53%	53%	54%	61%	58%	65%	69%	80%	80%	80%	79%	70%	69%	73%	73%	76%	72%	76%
Liberia										26%	22%	21%	21%	21%	21%	21%	20%	19%
Malawi	29%	28%	27%	29%	31%	32%	33%	34%	39%	42%	44%	45%	44%	44%	41%	41%	41%	36%
Mali	78%	42%	43%	37%	37%	35%	37%	34%	36%	24%	25%	24%	22%	20%	21%	23%	25%	23%
Mauritania		41%	42%	38%	39%	37%	41%	42%	47%	45%	42%	43%	47%	39%	39%	25%	24%	19%
Mozambique	42%	56%	60%	52%	56%	63%	70%	73%	71%	79%	76%	77%	69%	67%	74%	88%	85%	71%
Namibia	42%	36%	43%	46%	40%	46%	43%	49%	51%	43%	36%	47%	35%	40%	35%	35%	33%	38%
Niger																	23%	19%
Nigeria						36%	34%	32%	28%	25%	34%	34%	36%	33%	34%	34%	29%	29%
Rwanda		26%	29%	35%	36%	23%	31%	30%	36%	35%	35%	41%	42%	43%	36%	34%	38%	36%
Sao Tome and Principe						33%	34%	36%	38%	42%	46%	30%	34%	34%	37%	34%	36%	34%
Senegal	64%	69%	48%	51%	53%	41%	44%	41%	42%	43%	43%	35%	38%	43%	46%	48%	52%	50%
Seychelles										61%	66%	56%	58%	57%	57%	59%	63%	37%
Sierra Leone												26%	27%	25%	27%	22%	25%	25%
South Africa	57%	57%	59%	62%	62%	62%	63%	65%	64%	60%	62%	63%	62%	62%	57%	57%	57%	52%
Tanzania		74%	80%	51%	37%	45%	41%	50%	50%	54%	54%	53%	58%	61%	64%	54%	65%	64%
Togo	26%	15%	21%	27%	23%	23%	27%	21%	18%	22%	21%	18%	20%	17%	18%	22%	50%	34%
Uganda	67%	68%	74%	66%	71%	48%	36%	43%	44%	50%	52%	49%	46%	47%	46%	44%	45%	47%
Zambia	51%	52%	51%	52%	54%	56%	63%	62%	61%	64%	62%	65%	70%	73%	66%	64%	46%	55%
Zimbabwe				47%	52%	51%	44%	40%	40%	38%	45%	49%	49%	51%	55%	53%	40%	42%

Table A4. Technical network losses of sub-Saharan African countries from 2000 to 2017.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Angola			15%	15%	15%	15%	12%	14%	11%	11%	12%	12%	12%	12%	12%	12%	12%	12%
Benin								16%	16%	21%	19%	19%	19%	20%	20%	20%	21%	21%
Botswana									10%	12%	10%	12%	11%	9%	7%	13%	14%	15%
Burkina Faso								15%	13%	12%	11%	12%	12%	13%	13%	13%	12%	13%
Cabo Verde	15%	23%	17%	19%	19%	18%	22%	26%	28%	26%	25%	25%	27%	26%	26%	26%	27%	27%
Cameroon	22%	26%	23%	24%	19%	17%	13%	10%	10%	10%	11%	19%	24%	27%	28%	21%	21%	21%
DR Congo	18%	20%	21%	28%	26%	28%	23%	28%	28%	27%	23%	26%	22%	26%	17%	23%	21%	16%
Cote d’Ivoire	18%	20%	21%	28%	26%	28%	23%	28%	28%	27%	23%	26%	22%	26%	17%	23%	21%	16%
Equatorial Guinea						10%	10%	10%	10%	11%	10%	10%	10%	10%	11%	11%	11%	11%
Eritrea					18%	17%	15%	16%	17%	13%	13%	13%	13%	13%	13%	13%	13%	13%
Ethiopia	10%	12%	11%	11%	11%	11%	11%	11%	13%	15%	20%	21%	19%	15%	19%	19%	19%	19%
Eswatini								12%	12%	13%	12%	11%	12%	12%	12%	12%	12%	12%
Gabon	18%	20%	20%	20%	20%	20%	20%	19%	19%	20%	20%	20%	20%	21%	20%	20%	20%	18%
Gambia	22%	22%	22%	20%	19%	22%	22%	22%	21%	21%	22%	20%	21%	21%	19%	19%	19%	22%
Ghana	21%	15%	22%	26%	28%	23%	20%	22%	23%	25%	21%	15%	12%	13%	14%	12%	13%	14%
Guinea																12%	10%	10%
Kenya	19%	19%	18%	17%	15%	15%	15%	17%	17%	16%	17%	17%	18%	18%	18%	17%	20%	19%
Lesotho	20%	20%	17%	18%	19%	19%	19%	15%	12%	15%	11%	9%	13%	11%	13%	15%	18%	13%
Liberia										8%	8%	13%	13%	13%	13%	14%	17%	17%
Malawi	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	22%	20%	15%	22%	9%	25%
Mali	10%	10%	10%	10%	10%	10%	9%	10%	10%	5%	5%	5%	5%	5%	5%	5%	5%	6%
Mauritania		4%	3%	3%	9%	9%	9%	18%	16%	17%	18%	16%	15%	17%	17%	16%	16%	17%
Mozambique	20%	21%	22%	16%	16%	15%	18%	19%	19%	20%	19%	18%	17%	18%	17%	30%	17%	15%
Namibia	10%	10%	10%	14%	5%	10%	7%	13%	9%	7%	9%	9%	12%	8%	13%	8%	11%	10%
Niger																	18%	16%
Nigeria						21%	21%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Rwanda	27%	27%	27%	21%	27%	26%	11%	14%	15%	15%	17%	17%	20%	16%	20%	20%	20%	
Sao Tome and Principe						31%	30%	29%	28%	28%	27%	26%	24%	24%	20%	16%	15%	14%
Senegal	15%	16%	16%	14%	15%	19%	17%	21%	18%	21%	10%	10%	10%	17%	16%	15%	15%	15%
Seychelles										9%	10%	10%	10%	9%	9%	7%	7%	6%
Sierra Leone												51%	44%	58%	44%	31%	30%	30%
South Africa	9%	8%	7%	6%	6%	9%	9%	9%	9%	10%	10%	9%	9%	9%	9%	8%	9%	9%
Tanzania		25%	23%	26%	20%	27%	26%	22%	19%	35%	20%	22%	18%	19%	18%	17%	15%	15%
Togo	6%	15%	14%	14%	13%	15%	14%	17%	17%	16%	17%	16%	15%	16%	15%	14%	14%	9%
Uganda	35%	37%	39%	31%	50%	40%	33%	33%	39%	39%	29%	25%	25%	21%	19%	18%	20%	17%
Zambia	4%	4%	4%	4%	4%	6%	7%	13%	22%	20%	19%	24%	8%	10%	17%	12%	15%	10%
Zimbabwe				12%	13%	13%	11%	12%	11%	16%	18%	17%	19%	17%	17%	18%	17%	18%

Appendix C

Table A5. Estimated efficiency scores of SSA countries.

	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Angola		82%	80%	80%	79%	75%	75%	70%	76%	72%	72%	76%	93%	72%	66%	61%	45%
Benin							66%	67%	84%	70%	70%	65%	92%	84%	91%	95%	94%
Botswana								78%	79%	67%	70%	58%	77%	63%	92%	93%	92%
B. Faso							57%	56%	59%	52%	50%	53%	62%	65%	66%	65%	71%
Cabo Verde	76%	74%	51%	54%	58%	81%	86%	86%	97%	96%	96%	92%	92%	91%	86%	89%	85%
Cameroon	80%	63%	67%	68%	69%	79%	66%	73%	68%	74%	81%	75%	80%	90%	84%	83%	84%
DR Congo										39%	43%	37%	38%	74%	64%	60%	59%
C. d'Ivoire	80%	91%	94%	95%	97%	93%	96%	95%	92%	90%	93%	96%	97%	93%	92%	95%	0%
Eq. Guinea					71%	71%	65%	65%	70%	66%	73%	52%	59%	67%	68%	68%	46%
Eritrea				90%	86%	77%	83%	84%	69%	73%	73%						
Ethiopia	42%	28%	30%	28%	31%	32%	34%	38%	43%	53%	56%	59%	59%	64%	70%	44%	45%
Eswatini							80%	72%	83%	84%	93%	84%	81%	78%	69%	57%	62%
Gabon	83%	92%	94%	93%	95%	94%	93%	96%	95%	89%	91%	93%	86%	81%	87%	91%	87%
Gambia	72%	93%	95%	95%	94%	95%	94%	94%	91%	87%	87%	87%	81%	74%	75%	79%	78%
Ghana	96%	92%	91%	88%	87%	90%	83%	88%	91%	88%	79%	76%	74%	76%	61%	66%	64%
Guinea															58%	62%	63%
Kenya	85%	84%	83%	77%	80%	68%	77%	74%	73%	74%	74%	75%	74%	73%	71%	77%	76%
Lesotho	89%	85%	90%	92%	93%	95%	88%	80%	84%	74%	68%	78%	75%	84%	92%	95%	85%
Liberia									54%	43%	56%	56%	57%	57%	60%	65%	64%
Malawi	61%	54%	57%	59%	62%	63%	63%	69%	72%	73%	74%	87%	85%	74%	82%	69%	84%
Mali	80%	58%	54%	54%	54%	54%	54%	55%	37%	39%	39%	41%	36%	38%	40%	44%	43%
Mauritania		77%	70%	75%	71%	76%	92%	95%	95%	95%	95%	96%	92%	90%	72%	71%	64%
Mozam-bique	81%	91%	73%	75%	76%	84%	88%	86%	91%	89%	88%	80%	85%	88%	99%	96%	81%
Namibia	84%	81%	88%	68%	82%	74%	88%	86%	72%	66%	83%	67%	70%	71%	63%	64%	71%
Niger																55%	55%
Nigeria					63%	60%	52%	49%	49%	55%	53%	55%	53%	55%	53%	51%	48%
Rwanda		62%	55%	55%	48%	53%	52%	60%	64%	64%	64%	68%	71%	68%	72%	76%	72%
Sao Tome					83%	88%	88%	91%	95%	97%	78%	81%	81%	83%	73%	74%	69%
Senegal	98%	93%	93%	94%	91%	90%	92%	90%	95%	83%	73%	78%	93%	95%	96%	97%	96%
Seychelles									94%	97%	82%	93%	91%	93%	94%	96%	52%
S. Leone											94%	88%	97%	86%	76%	77%	77%
S. Africa	80%	83%	86%	92%	92%	96%	96%	95%	93%	95%	95%	94%	94%	89%	89%	89%	82%
Tanzania		95%	82%	63%	75%	70%	90%	82%	96%	87%	88%	87%	91%	94%	88%	94%	95%
Togo	42%	45%	52%	47%	53%	53%	58%	54%	56%	59%	54%	57%	55%	53%	57%	87%	68%
Uganda	92%	95%	78%	93%	87%	75%	76%	85%	84%	75%	71%	68%	66%	62%	59%	62%	60%
Zambia	74%	74%	73%	76%	79%	86%	88%	94%	94%	90%	95%	89%	92%	87%	81%	64%	67%
Zimbabwe			86%	91%	93%	80%	77%	78%	85%	94%	94%	95%	94%	96%	96%	85%	90%

References

1. Newbery, D.M. Network capacity auctions: Promise and problems. *Util. Policy* **2003**, *11*, 27–32. [CrossRef]
2. Newbery, D.M. Regulatory Challenges to European Electricity Liberalization. *Swed. Econ. Policy Rev.* **2003**, *9*, 9–44.
3. Jamasb, T.; Nepal, R.; Timislina, R.; Toman, M. Energy Sector Reform, Economic Efficiency and Poverty Reduction, 2014, University of Queensland School of Economics Discussion Papers Series 529. Available online: http://www.uq.edu.au/economics/abstract/529.pdf (accessed on 28 September 2021).
4. Jamasb, T.; Nepal, R.; Timilsina, G.R. A Quarter Century Effort Yet to Come of Age: A Survey of Power Sector Reforms in Developing Countries. *Energy J.* **2017**, *38*, 195–234. [CrossRef]
5. Bradshaw, Y.W.; Huang, J. Intensifying Global Dependency: Foreign debt, Structural Adjustment, and Third World Underdevelopment. *Sociol. Q.* **1991**, *32*, 321–342. [CrossRef]
6. World Bank. The World Bank's Role in the Electric Power Sector: Policies for Effective Institutional, Regulatory, and Financial Reform, 1993. World Bank Report, No. 11676. Available online: http://documents.worldbank.org/curated/en/477961468782140142/The-World-Banks-role-in-the-electric-power-sector-policies-for-effective-institutional-regulatory-and-financial-reform (accessed on 28 September 2021).

7. World Bank. Private Sector Development in Electric Power, World Bank Report. 2003. Available online: http://documents.worldbank.org/curated/en/436591468125976661/016824232_200309276015837/additional/264270UG0PGD.pdf (accessed on 28 September 2021).
8. Joskow, P.L.; Schmalensee, R. *Markets for Power: An Analysis of Electric Utility Deregulation*; MIT Press: Cambridge, MA, USA, 1983.
9. Ennis, H.; Pinto, S. Privatization and Income Distribution in Argentina. 2002. Available online: https://www.researchgate.net/publication/265364411/download (accessed on 28 September 2021).
10. Toba, N. Welfare impacts of electricity generation sector reform in the Philippines. *Energy Policy* **2007**, *35*, 6145–6162. [CrossRef]
11. Jamasb, T.; Mota, R.; Newbery, D.; Pollitt, M. Electricity Sector Reform in Developing Countries: A Survey of Empirical Evidence on Determinants and Performance, 2005. World Bank Policy Research Paper, No. 3549. Available online: http://documents.worldbank.org/curated/en/393231468780575236/Electricity-sector-reform-in-developing-countries-a-survey-of-empirical-evidence-on-determinants-and-performance (accessed on 28 September 2021).
12. Galal, A.; Jones, L.; Tandon, P.; Vogelsang, I. Welfare Consequences of Selling Public Enterprises: An Empirical Analysis. *South. Econ. J.* **1994**, *62*, 1098. [CrossRef]
13. Domah, P.; Pollitt, M.G. The restructuring and privatisation of the electricity distribution and supply businesses in England and Wales: A social cost-benefit analysis. *Fisc. Stud.* **2001**, *22*, 107–146. [CrossRef]
14. Pollitt, M.G. The role of policy in energy transitions: Lessons from the energy liberalisation era. *Energy Policy* **2012**, *50*, 128–137. [CrossRef]
15. Sen, A.; Jamasb, T. Diversity in Unity: An Empirical Analysis of Electricity Deregulation in Indian States. *Energy J.* **2012**, *33*, 83–130. [CrossRef]
16. Sen, A.; Nepal, R.; Jamasb, T. Have Model, Will Reform: Assessing Electricity Reforms in Non-OECD Asian Economies. *Energy J.* **2018**, *39*, 181–209. [CrossRef]
17. Pollitt, M. Evaluating the evidence on electricity reform: Lessons for the South East Europe (SEE) market. *Util. Policy* **2009**, *17*, 13–23. [CrossRef]
18. Bergara, M.E.; Henisz, W.J.; Spiller, P.T. Political Institutions and Electric Utility Investment: A Cross-Nation Analysis. *Calif. Manag. Rev.* **1998**, *40*, 18–35. [CrossRef]
19. Kessides, I.N. The Impacts of Electricity Sector Reforms in Developing Countries. *Electr. J.* **2012**, *25*, 79–88. [CrossRef]
20. Gratwick, K.N.; Eberhard, A. Demise of the standard model for power sector reform and the emergence of hybrid power markets. *Energy Policy* **2008**, *36*, 3948–3960. [CrossRef]
21. Wamukonya, N. Power Sector Reforms in sub-Saharan Africa Some Lessons. *Econ. Political Wkly.* **2005**, *40*, 5302–5308.
22. Joskow, P.L. Electricity Sectors in Transition. *Energy J.* **1998**, *19*, issn0195–issn6574. [CrossRef]
23. Estache, A.; Foster, V.; Wodon, Q. Accounting for Poverty in Infrastructure Reform: Learning from Latin America's Experience, 2002. World Bank Working Paper Report Number 23950. Available online: http://documents.worldbank.org/curated/en/413901468758394547/Accounting-for-poverty-in-infrastructure-reform-learning-from-Latin-Americas-experience (accessed on 28 September 2021).
24. Carvalho, A.; Nepal, R.; Jamasb, T. Economic reforms and human development: Evidence from transition economies. *Appl. Econ.* **2015**, *48*, 1330–1347. [CrossRef]
25. Bacon, R. Privatization and Reform in the Global Electricity Supply Industry. *Annu. Rev. Energy Environ.* **1995**, *20*, 119–143. [CrossRef]
26. Bacon, R. A Scorecard for Energy Reform in Developing Countries. Viewpoint. World Bank, 1999. Available online: https://openknowledge.worldbank.org/handle/10986/11487 (accessed on 28 September 2021).
27. Bacon, R.W.; Besant-Jones, J. Global Electric Power Reform, Privatization and Liberalisation of the Electric Power Industry in Developing Countries. *Annu. Rev. Energy Environ.* **2001**, *26*, 331–359. [CrossRef]
28. Besant-Jones, J. Reforming Power Markets in Developing Countries: What Have We Learned? World Bank Report No. 38017. World Bank. 2006. Available online: http://documents.worldbank.org/curated/en/483161468313819882/pdf/380170REPLACEMENT0Energy19.pdf (accessed on 28 September 2021).
29. Zhang, Y.F.; Parker, D.; Kirkpatrick, C. Electricity Sector Reform in Developing Countries: An Econometric Assessment of the Effects of Privatisation, Competition and Regulation. *J. Regul. Econ.* **2008**, *33*, 159–178. [CrossRef]
30. Coase, R.H. The problem of social cost. *J. Law Econ.* **1960**, *3*, 1–44. [CrossRef]
31. Guasch, J.L. Granting and Renegotiating Infrastructure Concessions: Doing it Right, 2004. World Bank Report. Available online: https://openknowledge.worldbank.org/handle/10986/15024 (accessed on 28 September 2021).
32. Fischer, R.; Serra, P.; Joskow, P.L.; Hogan, W.W. Regulating the Electricity Sector in Latin America. *Economía* **2000**, *1*, 155–218. [CrossRef]
33. Green, R.J.; Trotter, S.D. Electricity Regulation. In *Regulatory Review 2002/2003*; Vass, P., Ed.; Bath, Centre for the Study of Regulated Industries: Bath, UK, 2003; pp. 21–53, reprinted in *The Development of Energy Regulation*; Vass, P., Ed.; pp. 55–87.
34. Ghosh, R.; Kathuria, V. The effect of regulatory governance on efficiency of thermal power generation in India: A stochastic frontier analysis. *Energy Policy* **2016**, *89*, 11–24. [CrossRef]
35. Joskow, P.; Tirole, J. Merchant transmission investment. *J. Ind. Econ.* **2005**, *53*, 233–264. [CrossRef]

36. Arrow, K.J. The Organization of Economic Activity: Issues Pertinent to the Choice of Market Versus Nonmarket Allocation'. In *Public Expenditure and Policy Analysis*; Haveman, R.H., Margolis, J., Eds.; Rand MacNally College Publishing Company: Chicago, IL, USA, 1970; pp. 67–78.
37. Shubik, M. On different methods for allocating resources. *Kyklos* **1970**, *23*, 332–337. [CrossRef]
38. Teplitz-Sembitzky, W. Regulation, Deregulation, or Reregulation-What Is Needed in The LDCs Power Sector? World Bank Working Paper Series 9213. 1990. Available online: http://documents.worldbank.org/curated/en/521881468739783393/Regulation-deregulation-or-reregulation-what-is-needed-in-the-LDCs-power-sector (accessed on 28 September 2021).
39. Joskow, P.L. Regulation and Deregulation after 25 Years: Lessons for Research. *Rev. Ind. Organ.* **2005**, *26*, 169–193. [CrossRef]
40. Posner, R.A. Theories of Economic Regulation. *Bell J. Econ. Manag. Sci.* **1974**, *5*, 335–358. [CrossRef]
41. Den Hertog, J.D. General Theories of Regulation. 1999. Available online: https://www.mtk.ut.ee/sites/default/files/mtk/dokumendid/e35f555bc5922cc21262fabfac7de2fc.pdf (accessed on 28 September 2021).
42. Cubbin, J.; Stern, J. The Impact of Regulatory Governance and Privatization on Electricity Industry Generation Capacity in Developing Economies. *World Bank Econ. Rev.* **2006**, *20*, 115–141. [CrossRef]
43. Kim, J.; Mahoney, J.T. Property rights theory, transaction costs theory, and agency theory: An organizational economics approach to strategic management. *Manag. Decis. Econ.* **2005**, *26*, 223–242. [CrossRef]
44. Jamasb, T. Between the state and market: Electricity sector reform in developing countries. *Util. Policy* **2006**, *14*, 14–30. [CrossRef]
45. Jamasb, T.; Newbery, D.; Pollitt, M. Core Indicators for Determinants and Performance of the Electricity Sector in Developing Countries. World Bank Policy Research Working Paper 3599. 2005. Available online: http://documents.worldbank.org/curated/en/659371468152083306/Core-indicators-for-determinants-and-performance-of-the-electricity-sector-in-developing-countries (accessed on 28 September 2021).
46. Joskow, P.L. Restructuring, Competition and Regulatory Reform in the U.S. Electricity Sector. *J. Econ. Perspect.* **1998**, *11*, 119–138. [CrossRef]
47. Hunt, S. *Making Competition Work in Electricity*; John Wiley & Sons, Inc.: New York, NY, USA, 2002.
48. Joskow, P.L. Markets for Power in the U.S: An Interim Assessment. *Energy J.* **2006**, *27*, 1–36. [CrossRef]
49. Joskow, P.L. Introduction to Electricity Sector Liberalization: Lessons Learned from Cross- Country Studies. MIT School of Economics Study. 2006. Available online: https://economics.mit.edu/files/2093 (accessed on 28 September 2021).
50. Newbery, D.M. Determining the regulatory asset base for utility price regulation. *Util. Policy* **1997**, *6*, 1–8. [CrossRef]
51. Littlechild, S.C. *Evolution of Global Electricity Markets: New Paradigms, New Challenges, New Approaches*; Sioshansi, F.P., Pfaffenberger, W., Eds.; Elsevier Global Energy Policy and Economics Series: Amsterdam, The Netherlands, 2013.
52. Alchian, A.A. Some Economics of Property Rights. *Il Politico* **1965**, *30*, 816–829.
53. Demsetz, H. Some Aspects of Property Rights. *J. Law Econ.* **1966**, *9*, 61–70. [CrossRef]
54. Demsetz, H. Toward a Theory of Property Rights. Towards a Theory of Property Rights. *Am. Econ. Rev.* **1967**, *57*, 347–359.
55. Demsetz, H. *Ownership, Control and the Firm*; Oxford University Press: New York, NY, USA, 1988.
56. Hart, O.; Shleifer, A.; Vishny, R. The Proper Scope of Government: Theory and an Application to Prisons. *Q. J. Econ.* **1997**, *112*, 1127–1161. [CrossRef]
57. Megginson, W.L.; Netter, J.M. From State to Market: A Survey of Empirical Studies on Privatization. *J. Econ. Lit.* **2001**, *39*, 321–389. [CrossRef]
58. North, D.C. *Institutions, Institutional Change, and Economic Performance*; Cambridge University Press: Cambridge, UK, 1990.
59. North, D.C. A Transaction Cost Theory of Politics. *J. Theor. Politics* **1990**, *2*, 355–367. [CrossRef]
60. Zhang, Y.F.; Parker, D.; Kirkpatrick, C. Competition, Regulation and Privatisation of Electricity Generation in Developing Countries: Does the Sequencing of the Reforms Matter? *Q. Rev. Econ. Financ.* **2005**, *45*, 358–379. [CrossRef]
61. Estache, A.; Gomez-Lobo, A.; Leipziger, D. Utilities Privatization and the Poor: Lessons and Evidence from Latin America. *World Dev.* **2001**, *29*, 1179–1198. [CrossRef]
62. Freije, S.; Rivas, L. *Inequality and Welfare Changes: Evidence from Nicaragua. The Distributional Impact of Privatization in Developing Countries*; Chapter, 3, Nellis, J., Birdsall, N., Eds.; Center for Global Development: Washington, DC, USA, 2003; pp. 85–121.
63. McKenzie, D.J.; Mookherjee, D. The Distributive Impact of Privatization in Latin America: Evidence from Four Countries. *Economia* **2003**, *3*, 161–218. [CrossRef]
64. Foss, K.; Foss, N. Assets, Attributes and Ownership. *J. Econ. Bus.* **2001**, *8*, 19–37. [CrossRef]
65. Pejovich, S. *Fundamentals of Economics: A Property Rights Approach*; Fisher Institute: Dallas, NT, USA, 1979.
66. Pejovich, S. Karl Marx, Property Rights School and the Process of Social Change. *Kyklos* **1982**, *35*, 383–397. [CrossRef]
67. Laffont, J.J. *Regulation and Development*; Cambridge University Press: Cambridge, UK, 2005.
68. Levy, B.; Spiller, P.T. The Institutional Foundations of Regulatory Commitment: A Comparative Analysis of Telecommunications Regulation. *J. Law Econ. Organ.* **1994**, *10*, 201–246.
69. Imam, M.I.; Jamasb, T.; Llorca, M. Sector reforms and institutional corruption: Evidence from electricity industry in Sub-Saharan Africa. *Energy Policy* **2019**, *129*, 532–545. [CrossRef]
70. Imam, M.I.; Jamasb, T.; Llorca, M. *Political Economy of Reform and Regulation in the Electricity Sector of Sub-Saharan Africa*; Cambridge Working Papers in Economics CWPE 1949/Electricity Policy Research Group Working Paper EPRG, May 1917; Faculty of Economics, University of Cambridge: Cambridge, UK, 2019.

71. Erdogdu, E. A cross-country analysis of electricity market reforms: Potential contribution of New Institutional Economics. *Energy Econ.* **2013**, *39*, 239–251. [CrossRef]
72. Nepal, R.; Jamasb, T. Reforming the Power Sector in Transition: Do Institutions Matter? *Energy Econ.* **2012**, *34*, 1675–1682. [CrossRef]
73. Loeb, M.; Magat, W.A. A Decentralized Method for Utility Regulation. *J. Law Econ.* **1979**, *22*, 399–404. [CrossRef]
74. Laffont, J.-J.; Tirole, J. *A Theory of Incentives in Procurement and Regulation*; MIT Press: Cambridge, UK, 1993.
75. Tommasi, M. Presidential Address: The Institutional Foundations of Public Policy. *Economia* **2006**, *6*, 1–36.
76. Tommasi, M.; Velasco, A. Where Are We in the Political Economy of Reform? *J. Policy Reform* **1996**, *1*, 187–238. [CrossRef]
77. Kaufmann, A.; Kraay, A.; Zoido-Lobaton, P. Governance Matters. World Bank Policy Research Paper Number WPS2196. 1999. Available online: http://documents.worldbank.org/curated/en/665731468739470954/Governance-matters (accessed on 28 September 2021).
78. Kaufmann, A.; Kraay, K.; Mastruzzi, M. Governance Matters VIII. World BANK Policy Research Paper No. WPS4978. 2009. Available online: http://documents.worldbank.org/curated/en/598851468149673121/Governance-matters-VIII-aggregate-and-individual-governance-indicators-1996--2008 (accessed on 28 September 2021).
79. Mahoney, C. The Power of Institutions. *Eur. Union Politics* **2004**, *5*, 441–466. [CrossRef]
80. Olsson, O. Diamonds are a rebel's best friend. *World Econ.* **2006**, *29*, 1133–1150. [CrossRef]
81. Estache, A.; Wren-Lewis, L. Toward a Theory of Regulation for Developing Countries: Following Jean-Jacques Laffont's Lead. *J. Econ. Lit.* **2009**, *47*, 729–770. [CrossRef]
82. Besant-Jones, J.E.; Harris, C.G.; Stuggins, G.; Townsend, A.F. Operational Guidance for World Bank Staff: Public and Private Roles in the Supply of Electricity Services. World Bank Report, No. 37476. 2004. Available online: http://documents.worldbank.org/curated/en/183841468135585067/Operational-guidance-for-World-Bank-Group-staff-public-and-private-sector-roles-in-the-supply-of-electricity-services (accessed on 28 September 2021).
83. Koch, F.; Reiter, A.; Bach, H. *Effects of Climate Change on Hydropower Generation and Reservoir Management*; Springer: Cham, Switzerland, 2016; pp. 593–599. [CrossRef]
84. International Hydropower Association. 21 May 2020. Available online: https://www.hydropower.org/region-profiles/africa (accessed on 28 September 2021).
85. Cole, M.; Elliott, R.; Stroble, E. Climate Change, Hydro-dependency and the African Dam Boom. *World Dev.* **2014**, *60*, 84–96. [CrossRef]
86. Blimpo, M.; Cosgrove-Davies, M. Electricity Access in SSA: Uptake, Reliability and Complementary Factors for Economic Impact. Africa Development Forum Series Report No. 135194. 2019. Available online: http://documents.worldbank.org/curated/en/837061552325989473/pdf/135194-PUB-PUBLIC-9781464813610.pdf (accessed on 28 September 2021).
87. Wolfram, C.D. Electricity Markets: Should the Rest of the World Adopt the United Kingdom's Reforms? *Regulation* **1999**, *22*, 48–53.
88. Pestieau, P.; Tulkens, H. Assessing and Explaining the Performance of Public Enterprises. *Finanzarchiv* **1993**, *50*, 293–323. [CrossRef]
89. Plane, P. Privatisation, Technical Efficiency and Welfare Consequences: The Case of the Côte d'Ivoire Electricity Company (CIE). *World Dev.* **1999**, *27*, 343–360. [CrossRef]
90. Estache, A.; Tovar, B.; Trujillo, L. How efficient are African electricity companies? Evidence from the Southern African countries. *Energy Policy* **2008**, *36*, 1969–1979. [CrossRef]
91. Erdogdu, E. What Happened to Efficiency in Electricity Industries after Reforms? *Energy Policy* **2011**, *39*, 6551–6560. [CrossRef]
92. Koopman, T. Analysis of production as an efficient combination of activities. In *Activity Analysis of Production and Allowance. Monograph, No. 13*; Koopmans, T.C., Ed.; John Wiley and Sons, Inc.: New York, NY, USA, 1951.
93. Cooper, W.W.; Seiford, L.M.; Tone, K. *Data Envelopment Analysis a Comprehensive Text with Models, Applications, References and DEA-Solver Software*, 2nd ed.; Springer: Cham, Switzerland, 2007.
94. Kuosmanen, T.; Kortelainen, M. Stochastic Non-smooth Envelopment of Data: Semi-parametric Frontier Estimation Subject to Shape Constraints. *J. Product. Anal.* **2012**, *38*, 11–28. [CrossRef]
95. Aigner, D.; Lovell, C.A.K.; Schmidt, P. Formulation and estimation of stochastic frontier production function models. *J. Econom.* **1977**, *6*, 21–37. [CrossRef]
96. Meeusen, W.; van den Broeck, J. Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *Int. Econ. Rev.* **1977**, *18*, 435–444. [CrossRef]
97. Shephard, R.W. *Cost and Production Functions*; Princeton University Press: Princeton, UK, 1953.
98. Shephard, R.W. *Theory of Cost and Production Functions*; Princeton University Press: Princeton, UK, 1970.
99. Lovell, C.A.K. Applying efficiency measurement techniques to the measurement of productivity change. *J. Prod. Anal.* **1996**, *7*, 329–340. [CrossRef]
100. Kumbhakar, S.C.; Lovell, C.A.K. *Stochastic Frontier Analysis*; Cambridge University Press: Cambridge, UK, 2000.
101. Coelli, T.; Prasada Rao, D.S.; O'Donnell, C.J.; Battese, G.E. *An Introduction to Efficiency and Productivity Analysis*, 2nd ed.; Springer: New York, NY, USA, 2005.
102. Kumbhakar, S.C.; Orea, L.; Rodríguez-Álvarez, A.; Tsionas, E.G. Do we estimate an input or an output distance function? An application of the mixture approach to European railways. *J. Prod. Anal.* **2007**, *27*, 87–100. [CrossRef]

103. Estache, A.; Rossi, M.A. Do regulation and ownership drive the efficiency of electricity distribution? Evidence from Latin America. *Econ. Lett.* **2005**, *86*, 253–257. [CrossRef]
104. Perelman, S.; Santin, D. Measuring educational efficiency at student level with parametric stochastic distance functions: An application to Spanish PISA results. *Educ. Econ.* **2008**, *19*, 29–49. [CrossRef]
105. Melyn, W.; Moesen, W. *Towards a Synthetic Indicator of Macroeconomic Performance: Unequal Weighting when Limited Information Is Available*; Public Economics Research Paper 17; CES, KU Leuven: Leuven, Belgium, 1991.
106. Cherchye, L.; Moesen, W.; Rogge, N.; van Puyenbroeck, T. An introduction to 'benefit of the doubt' composite indicators. *Soc. Indic. Res.* **2007**, *82*, 111–145. [CrossRef]
107. Färe, R.; Primont, D. *Multi-Output Production and Duality: Theory and Applications*; Kluwer Academic Publishers: Boston, MA, USA, 1995. [CrossRef]
108. Lovell, C.A.K.; Travers, P.; Richardson, S.; Wood, L. Resources and functioning: A new view of inequality in Australia. In *Chapter in Models and Measurement of Welfare and Inequality*; Eichhorn, W., Ed.; Springer: Berlin/Heidelberg, Germany, 1994; pp. 787–807.
109. Battese, G.E.; Coelli, T.J. Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data. *J. Econom.* **1988**, *38*, 387–399. [CrossRef]
110. Stevenson, R.E. Likelihood functions for generalized stochastic frontier estimation. *J. Econ.* **1980**, *13*, 57–66. [CrossRef]
111. Greene, W.H. Maximum Likelihood Estimation of Economic Frontier Functions. *J. Econom.* **1980**, *13*, 27–56. [CrossRef]
112. Greene, W.H. On the estimation of a flexible frontier production model. *J. Econ.* **1980**, *13*, 101–115. [CrossRef]
113. Greene, W.H. A Gamma-distributed stochastic frontier model. *J. Econ.* **1990**, *46*, 141–163. [CrossRef]
114. Caudill, S.B.; Ford, J.M. Biases in Frontier Estimation Due to Heteroskedasticity. *Econ. Lett.* **1993**, *41*, 17–20. [CrossRef]
115. Llorca, M.; Orea, L.; Pollitt, M.G. Efficiency and environmental factors in the US electricity transmission industry. *Energy Econ.* **2016**, *55*, 234–246. [CrossRef]
116. Eberhard, A.; Gratwick, K.; Morella, E.; Antmann, P. Independent Power Projects in Sub-Saharan Africa: Investment Trends and Policy Lessons. *Energy Policy* **2017**, *108*, 390–424. [CrossRef]
117. Foster, V.; Rana, A. Rethinking Power Sector Reforms in the Developing World. Sustainable Infrastructure Series. World Bank Report. 2020. Available online: https://openknowledge.worldbank.org/handle/10986/32335 (accessed on 28 September 2021).
118. International Energy Agency. Boosting the Power Sector in Sub-Saharan Africa: China's Involvement. IEA Report. 2016. Available online: https://www.oecd.org/publications/boosting-the-power-sector-in-sub-saharan-africa-9789264262706-en.htm (accessed on 28 September 2021).
119. World Bank. Linking Up: Public-Private Partnerships in Power Transmission in Africa, World Bank Working Paper. 2017. Available online: http://hdl.handle.net/10986/27807 (accessed on 28 September 2021).
120. Eberhard, A. Infrastructure Regulation in Developing Countries: An Exploration of Hybrid and Transitional Models. 2006. Available online: https://regulationbodyofknowledge.org/wp-content/uploads/2013/03/Eberhard_Infrastructure_regulation_in_developing_countries.pdf (accessed on 28 September 2021).
121. International Energy Agency–IEA. The Impact of the Financial and Economic Crisis on Global Energy Investment. 2009. Available online: https://iea.blob.core.windows.net/assets/461ac14d-f098-48ce-9ea6-6d1d83160b97/TheImpactoftheFinancialandEconomicCrisisonGlobalEnergyInvestment.pdf (accessed on 28 September 2021).
122. World Bank. Public-Private Partnership Stories. Gabon: Société d'Energie et d'Eau. World Bank Brief. 2010. Available online: https://www.ifc.org/wps/wcm/connect/5e5ae9d4-b56b-48ec-9117-682b5a4e21ae/PPPStories_Gabon_SocietedEnergice.pdf?MOD=AJPERES&CVID=lHI9VQW (accessed on 28 September 2021).