Master's Dissertation in Engineering

Measuring the Performance of the DR Congo's Electric Power Company (SNEL)

콩고 민주공화국의 전력 회사(SNEL)의 성능 계측

2014년 02월

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Abstract

Measuring the Performance of the DR Congo's Electric Power Company (SNEL)

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This masters' thesis sought to measure the performance of the DR Congo's electric power company (SNEL) by comparing it with other state electric power companies in SAPP (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe) from 2004 to 2013.

In our research, we used the Data Envelopment Analysis (DEA) method, especially the Charnes, Cooper, and Rhodes (CCR) model, to find the technical efficient score of each company. Then we decomposed the change into the Technical Efficiency Change, Technological Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practice in the electricity market (SAPP). After that, we estimated the Malmquist Index to follow the performance progress of each company. Finally, we used the OLS model in the second stage to assess the environmental factors that affected the efficiency of the companies.

The results revealed that SNEL was inefficient and its performance did not progress during the period of our analysis. Even though the important constant of our model (regulatory authority) was statistically insignificant, factors such as human resources, competition in electricity distribution, electricity net exports and the urban population were statistically significant and contributed positively to the companies' efficiency. However, other factors, such as income per capita, competition in electricity generation and vertical integration were also statistically significant, but affected negatively the companies' efficiency. Finally, policy implications were suggested to enhance SNEL's performance trend.

Keywords: DR Congo, SNEL, SAPP, DEA, CCR model, Malmquist Index

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Abbreviations

BPC	Botswana Power Company
DR Congo	Democratic Republic of Congo
EDM	Electricidade de Mocambique
ESCOM	Electricity Supply Corporation of Malawi
ESKOM	Eskom Holdings, South Africa
ENE	Empresa Nacional de Electricidade
NamPower	Namibian National Utility
LEC	Lesotho Electricity Corporation
OECD	Organization for Economic Co-operation and Development
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SNEL	Societe Nationale d'Electricite
SEB	Swaziland Electricity Board
TANESCO	Tanzania Electricity Supply Company Ltd
ZESA	Zimbabwe Electricity Supply Authority

Chapter 1. Introduction

1.1 Background

The focus on the measurement of the performance of state-owned electric power companies has received considerable attention from scholars and practitioners in energy policy literature. Both practitioners and scholars are increasingly looking for ways to amend and improve the performance of electric power companies mainly to maximize their profit (Vasylenko, 2008 and Hwang & Lee, 2012). One of the key areas in corporate strategy is ensuring that the performance measurement provides an orientation for the firm. As a result, many analytical tools are being developed to assess the performance of state electric power companies, to define the appropriate policies for changing the firms' management methods. According to Kellen (2002) and Harvard Business School[1] (2007), organizations measure the performance for several purposes: improvement, planning and forecasting, competition, reward, and regulatory and standard compliance.

On the performance of state electric power companies, the World Bank (1995) and Megginson and Netter (2001) have found that in most developing countries, state electric power companies are inefficient and perform more poorly than private electric power companies. This was the case in India when Meenakumari and Kamaraj measured in 2008 the relative efficiency of 29 state electric power companies and found 22 of them inefficient. Babalola (1999) measured the performance of the National Electric Power of Nigeria

[1] Harvard ManageMotor (2007). Performance Measurement. http://www.vital.co.kr/demo/hmm10/performance_measurement/why_measure_business_performance.html, accessed October 4, 2013.

(NEPD) and assumed factors that influenced the company's performance. However, he found the company's performance disappointing. Mohd-Yunos and Hawdon (1996) also measured the performance of the National Electricity Board of Malaysia and concluded that the company was performing poorly.

On the other hand, Pombo and Taborda (2004) measured the performance of 12 state electric power companies in Colombia before and after their 1994 regulatory reform and found an improvement in their power distribution and profitability rate in their post-reform years. Estache, Tovarc, and Trujillod (2008) assessed the performance change of sample Sub-Saharian African government electric power companies since their main reform took place in the late 1990s and noticed an improvement in the performance of those companies.

In the case of the Democratic Republic of Congo (DR Congo), "La Societe National D' Electricite" (SNEL), similar to any other state electric power company, had sought to measure its performance. The company is under the trusteeship of the Ministry of Energy, which seeks to ensure effective administrative, supervisory, regulatory, and technical control of the energy business in the DR Congo and of the company. However, since the establishment of SNEL in 1970, it has continuously evolved into an industry monopoly. According to the Ministry of Energy (2011), SNEL owns 58 hydropower plants and 52 thermal power plants, 38 high-voltage posts, and a 6,500Km network in the country.

1.2 Problem Statement

The problem of the sector is principally that there is no empirical documentation of performance assessments in the energy sector in the DR

Congo for both research and industrial management. Even though there had been several attempts by the Ministry of Energy to encourage SNEL to improve its performance (ME[2], 2011), there is no empirical information on the performance measurement of SNEL. Therefore, since SNEL is mandated to and aims to ensure efficiency in power supply and profit maximization, it is critical for its management to be empirically informed about how well it is performing in the Southern African Power Pool (SAPP). In fact, one of the problems of the energy sector in the DR Congo is that even though SNEL is vertically integrated and evolving as a monopoly with a commercial and technical mission, it seems to be failing in achieving its mission because of some endogenous and exogenous factors that may be a permanent panacea for its performance. Among the endogenous factors is the company's poor corporate governance, which is manifested by its low level of efficiency, lack of investments, lack of transparency and accountability, deterioration of power infrastructure (due to aging and lack of proper and sustainable maintenance), etc. Among the exogenous factors are the volatile overall macroeconomic conditions, institutional and legal changes, absolute interference of politics with the company management, vertical integration, electricity net imports, and size of the country (Bongos, 2011). All these factors are seen to be affecting SNEL's performance and its achievement of its goal from the perspective of commercialization and profit maximization.

1.3 Research Questions

To test the aforementioned hypothesis, this study seeks to answer the following specific research questions.

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[2]Ministere de l'Energy de la RD Congo (2010). La Problematique du Secteur de l'Energie en Republique Democratique du Congo. Kinshasa- RDC.

- How efficient is SNEL compared to other state-owned companies in the Southern African Power Pool (SAPP)?

- How has SNEL evolved dynamically through the years with respect to efficiency and productivity?

- What are the environmental factors that affect the efficiency of SNEL?

- What possible policies can be prescribed to enhance SNEL's efficiency and productivity?

To answer these questions, we used the CCR model to calculate the technical efficiency score of each company (to answer the first Research Question). Then we decomposed the change into Technical Efficiency Change, Technological Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practice in the SAPP market (to answer the second Research Question). After that, we used the OLS model to assess the environmental factors that are affecting the efficiency of the companies (to answer the third Research Question). From the technical efficiency score results, we determined the best-practice companies, which serve as benchmarks for SNEL. Finally, from all the results, policy implications were prescribed to enhance the performance of SNEL (to answer the third Research Question).

1.4 Hypothesis

To achieve the aforementioned objective, the main hypothesis of this study is that SNEL, as a state-owned company operating in a developing country, is inefficient (World Bank, 1995 and Megginson & Netter, 2001), similar to other state-owned companies in the SAPP (ENE of Angola, BPC of Botswana, LEC of Lesotho, ESCOM of Malawi, EDM of Mozambique, NamPower of Namibia, ESKOM of South Africa, SEB of Swaziland, TANESCO of Tanzania, ZESCO of Zambia, and ZESA of Zimbabwe).

1.5 Purpose and Objectives of the Study

With respect to the identified research problem, the main purpose of this study is to measure the performance of the DR Congo's electric power company (SNEL) and to prescribe some policies to enhance the company's efficiency.

Since our analysis covers the period span from 2004 to 2013, the objectives of this study are:

- To examine the efficiency of SNEL compared to other state electric power companies in the SAPP market;
- To examine the SNEL dynamic progress;
- To determine the environmental factors that affect SNEL;
- To describe some policies to improve SNEL's efficiency and productivity.

1.6 Significance of the Study

The study is very significant, in many ways, to SNEL managers, policymakers, and the government of the DR Congo. To the SNEL management, the study findings will provide a reliable scientific measure, and perspective for describing and evaluating the level, of the company's efficiency. It will also serve as an invaluable source of information and benchmarks for SNEL to improve its efficiency level. This will provide empirical support for the SNEL management's strategic decisions in several critical operating areas (generation-transmission-distribution). For the DR Congo policymakers and government, with the current liberalization of the country's electricity sector, the findings and results of this study will provide invaluable insights and a more reliable guide to monitoring and evaluating the impact of operations within and outside SNEL, as well as the general progress of SNEL.

1.7 Delimitation of the Study

This study is delimited to the performance of 12 state electric power companies (ENE of Angola, BPC of Botswana, SNEL of DR Congo, LEC of Lesotho, ESCOM of Malawi, EDM of Mozambique, NamPower of Namibia, ESKOM of South Africa, SEB of Swaziland, TANESCO of Tanzania, ZESCO of Zambia, and ZESA of Zimbabwe) in the SAPP and covers the period of 2004-2013. It excludes private electric power companies operating in the Southern African Region.

1.8 Structure of the Thesis

The study is organized into six chapters. Chapter 1 gives the Introduction, Background, Problem Statement, Research Questions, Hypothesis, Purpose and Objectives, Significance, and Delimitation of the Study, and the Structure of the Thesis.

Chapter 2 provides an Overview of the Electricity Industry: Electricity Supply Industry, Southern African Power Pool and the Electricity Sector in the DR Congo.

Chapter 3 reviews relevant literature on the Productivity and Efficiency of State-owned Companies and Electric Power Companies.

Chapter 4 introduces the following research methodologies: the CCR

Model, BCC Model, Additive Model, Multiplicative Model, and Malmquist Index.

Chapter 5 presents the study Data, CCR Model and Malmquist Index Results, Environmental Factors Analysis, and Benchmark Analysis.

Finally, Chapter 6 presents the Policy Implications and Conclusion (including the Limitations of the Study).

Chapter 2. Electricity Industry Overview

2.1 Electricity Supply Industry

The electricity supply industry can be functionally divided into generation, transmission, distribution, and supply (Massey, 1997). The functions are differentiated technologically and economically, and regulatory reform has tended to proceed at this level of disaggregation.

Generation is the production of electricity. It involves the transformation of another form of energy into electrical energy. Electricity production may use oil, natural gas, coal, nuclear power, hydropower (falling water), renewable fuels, wind turbines, and photovoltaic technologies. The different generating technologies are differentiated according to their cost structures. The main cost components of electricity generation are (delivered) fuel prices, capital costs, and operating and maintenance costs. The costs are also influenced by the performance of the generating technology (capacity factor, thermal efficiency, and operating life).[3] According to JKNU,[4] nuclear generation has high capital costs due in part to long construction lead times (interest charges) and decommissioning costs (costs of retiring a plant at the end of its design life). The high fixed costs are also due to public opposition to nuclear technology and waste disposal. On the other hand, nuclear technology has low fuel and operating costs (variable costs); and these costs remain relatively constant over the lifetime of a nuclear plant. Hydro generation costs depend largely on the geography and climate. The hydro generation variable

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[3]According to the International Energy Agency (1994), the capacity factor is the utilization of capacity. Thermal efficiency is the ability to generate electricity output per unit of fuel input. The operating life is the scheduled lifetime of a plant.

[4]JKNU: John Kwoka Northeastern University.

costs are low. The costs of coal, oil, and natural-gas-fired generation consist mainly of input fuel prices, so the variable costs of fossil-fuel generation are higher than those of nuclear generation.[5] However, fossil-fuel generation tends to have lower fixed costs than nuclear generation, particularly in the case of gas-fired plants, which have very short construction lead times.

Transmission and distribution comprise the “wires” functions. Transmission is the high-voltage transport of electricity. However, transmission is not merely transportation, but it also involves the management of dispersed generators in a grid to maintain a suitable voltage and frequency and to prevent system breakdown. Transmission is a natural monopoly because competition in transmission would result in duplication of the existing network (duplication of high-voltage AC networks and competing grid coordinators would increase transmission costs). Regulation of transmission typically involves rate-of-return regulation of prices, which, in the classic study of Averch and Johnson (1962), has been shown to lead to over-investment in capital and, consequently, failure to minimize costs.

Distribution is the low-voltage transport of electricity. Similar to transmission, it is generally considered a natural monopoly; competition would similarly entail duplication of the existing set of “wires.” Unlike transmission, there are no benefits to its integration with generation.

Finally, supply of electricity is the sale of electricity to end-users. This includes metering, billing, and marketing, and may be wholesale or retail. Supply is not considered a natural monopoly, nor are there significant advantages to its integration with other functions. Each of these different functions of the electricity supply industry contributes to the costs of

[5] Oil prices are perceived as volatile and risky, and coal prices may increase with environmental restrictions on coal.

providing electricity to final users.

Furthermore, the economic and technological features of the electricity supply industry have stimulated the evolution of its regulation, ownership, and market structure. Since transmission and distribution are natural monopolies, the industry as a whole is deemed a natural monopoly, which suggests that an efficient regulatory framework would be a legal monopoly. On the other hand, a monopoly also leads to deadweight losses when a profit-maximizing monopolist charges prices that exceed the marginal cost. Historically, this has led governments to adopt one of two approaches to the electricity sector: a publicly owned integrated monopoly, or privately owned regulated firms. Many countries (e.g., Ireland, France, Greece, and Italy) consolidated and nationalized their electricity supply industries into state-owned, legal monopolies under the assumption that a state-owned enterprise does not maximize profit, so public ownership should lead to greater consumer welfare. A variant of this approach is regional, legal monopolies, where public enterprise and monopoly occur at the regional level (e.g., Germany). In the case of private but regulated monopolies, firms are presumed to maximize profits, so regulation is used to reduce deleterious impacts on consumer welfare. Regulators of privately owned monopolies concentrate on pricing, often using rate-of-return regulation. The United States and Japan provide examples of investor-owned but regulated regional monopolies. Even in the case of the United States, however, regional governments retain a marked ownership and operative role in segments of the industry. Regardless of whether electric utilities are public or private, or centralized or regional, in most countries, vertical unbundling has only recently begun.

Additionally, technological preferences have influenced ownership and market structure. Certain generation technologies such as hydropower have frequently resulted in state ownership; the state often had the property rights and financial resources needed for large-scale hydroelectric projects. Other shifts in preferences have changed the minimum efficient scale of production. For example, in the aftermath of oil shocks, preferences shifted toward large-scale nuclear projects; whereas with the advent of the Combined Cycle Gas Turbine (CCGT), preferences have shifted toward small-scale CCGT plants. Larger-scale technologies with high fixed costs often lead to state financing, whereas smaller-scale technologies leave more room for private ownership.

2.2 Southern African Power Pool

According to Musaba (2005), the Southern African Power Pool (SAPP) was created in August 1995 at the Southern African Development Community (SADC) summit held in Johannesburg, South Africa. The SADC government members signed an Inter-governmental Memorandum of Understanding for the formation of an electricity power pool in the region under the name of the Southern African Power Pool (SAPP). SAPP is now an association of 12 member countries (Angola, Botswana, DR Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe) represented by their respective state electric power companies (Table 2-1) and organized by SADC.

SADC aims to promote regional integration, and has mandated SAPP to promote electricity trading among SADC members states so that they can all share the available energy resources in the region. SAPP is governed by four agreements: the *Inter-governmental Memorandum of Understanding*, which enabled the establishment of SAPP; the *Inter-utility Memorandum of Understanding*, which established the SAPP basic management and operating

Table 2-1. Electricity Sector in Selected Sub-Saharan Africa Countries

Country	Operator in Distribution	Competition in Generation	Private Role in Distribution	Sector Regulator	Vertical Integration	Main Electricity Source
Angola	Empresa Distribuicao Electricidade (EDEL)	Yes (2003)	No	No	No D–EDEL G and T–ENE	T
Botwana	BPC	No	No	No	Yes	T+I
DR Congo	SNEL	No	No	No	Yes	H
Lesotho	LEC	Yes	Yes	yes	Yes	H+I
Malawi	ESCOM	No	Yes Management contract (SA's TSI) (2001)	yes	Yes	H
Mozambique	EDM	Yes	Yes Management contract and small contracts	Yes Advisor (2000), Regulator (2004)	Yes but 2 more firms in G No horizontal and vertical unbundling	H+I
Namibie	4 Regional Electricity Distributors (2002)	Yes	Yes	Yes (2000)	No	H+I
South Africa	ESKOM	Yes	No	Yes (1995)	Yes But many small D firms	T
Swaziland	SEB	Yes	No	Yes (2002)	Yes	H+I
Tanzania	TANESCO	Yes	Yes Management contract (NetGroup) (2002)	No	Yes	H
Zambia	CAPC+ZESCO	Yes	Yes	Yes (1999–2000)	Yes But 2 big firm	H
Zimbabwe	CAPC+ZESA	Yes	No	No	Yes But 2 firms	H+I

Note: Tr= Transmission, G= Generation, D= Distribution, H= Hydro, T= Thermal, I= Iimport.

Source: Estache et al., 2008

principles; the *Agreement Between Operating Members*, which established the specific rules of operation and pricing; and the *Operating Guidelines*, which provide standards and operating guidelines (Musaba, 2005). The SAPP annual report (2009) argues that the current generation mix in SAPP is 74.3% coal, 20.1% hydro, 4% nuclear, and 1.6% diesel and gas. Coal is predominantly generated in the south (South Africa, Botswana, and Zimbabwe), and hydropower, in the Zambezi Basin (Zambia, Zimbabwe, Mozambique, and Malawi) in the north, the DR Congo, and Cunene (Angola and Namibia). The nuclear power station is in the Western Cape (South Africa), which is far from the coal-fired power plants in the northern and eastern provinces. Most of the diesel power plants are for small isolated rural networks. Coal -fired plants make up the bulk of the 42,000 MW of installed capacity of South Africa's state electric power company (ESKOM). South Africa accounts for more than 80% of the total generation in SAPP, and thus, coal accounts for three-quarters of the total SAPP generation. Outside South Africa, the dominant energy resource is hydropower. The DR Congo has more than 400 TWh/year of economically exploitable hydropower. Further south, the Zambezi, Cunene, and Kwanza river basins have another 100 TWh/year potential.

Even though the region is still dominated by coal generation, SAPP is expecting to meet the future growth in electricity demand in South Africa by developing environmentally clean hydropower in the northern part of the market (Northern SAPP). According to SNEL (2010), the prime target for hydro development is a unique site on the Congo River, called “Inga”. Inga has 40,000 MW of hydro potential in a setting where virtually no civil engineering works would be required and where the environmental impact would be minimal. At present, only 1,775 MW has been installed in the Inga site. There are also significant sites on the Zambezi River, as shown in Table 2-2.

Table 2-2. Significant Hydropower Sites on Congo and Zambezi Rivers

River Basin	Site	Potential (MW)	Installed Capacity (MW)
Congo	Inga	40,000	1,775
Zambezi	Batoka Gorge	1,600	
(Zambia/Zimbabwe)	Devil's Gorge	1,240	
	Kariba	2,130	1,470
	Mupata	1,200	
	Kafue Gorge	1,740	990
	Itezhi tezhi	120	
Zambezi (Mozambique)	Cahora Bassa	3,275	2,075
	Mepanda Uncua	1,780	
	Lupata	654	
	Boroma	444	
Total		54,183	6,977

Source: Southern African Power Pool, 2010

The SADC region is connected by two different power transmission networks: the North Zone and the South Zone. The northern transmission network includes SNEL (DR Congo), ZESCO (Zambia), and ZESA (Zimbabwe). The southern network comprises Eskom (South Africa), BPC (Botswana), and NamPower (Namibia) (SAPP, 2012). The positive impact of these transmission networks in the SADC countries is that it enables member countries to purchase electricity and to sell it to the public: A number of countries in SADC are not yet interconnected, such as Tanzania, Malawi, and Angola (SAPP, 2012). However, SAPP has established some projects to link such countries in the market.

Trade in electricity services is already widespread in the region, and mostly occurs between South Africa and Mozambique. Most of the countries in the region are totally dependent on imports.[6] Due to the regional nature of SAPP, exports have been favored over domestic demand due to the assured enormous revenues from exports.[7] For instance, Zambia and DR Congo derive enormous revenues from selling hydropower to South Africa. Nevertheless, despite the development of operating guidelines for the SAPP DAM,[8] very little progress has been made on that front largely due to the limited excess capacity with which to trade in the competitive market.[9]

Where electricity generation is not enough to meet domestic needs, countries need to purchase power from their neighbors within the region and elsewhere. In this regard, the region is too dependent on South Africa's electric power company (ESKOM) for electricity provision (since South Africa is the main exporter and importer, accounting for approximately 80% of the total electricity trade in the region). Yet ESKOM is currently running out of excess capacity, as domestic demand is outstripping supply. Hence, as the demand for power in South Africa increases, the likelihood of regional deficits also expands. This chronic shortage is expected to continue. The net effect is that in the foreseeable future, the entire region will need a considerable increase in generation capacity to meet the growth in demand. While South Africa will probably remain the key market for such power, regional countries will also need to address the much increased local demand and attract new investors.

[6] Namibia, Botswana, and Swaziland are totally dependent on South Africa for their energy needs.
[7] Source: Uprety, K. (2002), p. 383.
[8] Day Ahead Market.
[9] Chanakira, M., SADC Regional Economic Integration in the Energy Industry. Accessed October 26, 2013 from www.dounia-risri.com/IMG/pdf/Dounia4_pp64-78.pdf.

2.3 Electricity Sector in the DR Congo

According to the SNEL annual report (SNEL, 2010), the DR Congo gained independence on 30 June 1960, the electricity sector had been the responsibility of the state company "Regie de Distribution des Eaux" (REGIDESO), along with six other private utility companies, namely, Cometrick, Forces de I'Est, Forces du Bas Congo, Societe Generale Congolaise des Forces Hydroelectrique (SOGEFOR), Societe Generale Africaine d'Electricite (SOGELEC), and COGELIN. The electricity sector in the DR Congo is managed by SNEL, established by Presidential Decree No. 73/033 on 16 May 1970. In the same context, the SNEL annual report (2000) states that the government approved SNEL's construction of the first phase of its Inga 1 hydropower project. Before the establishment of SNEL, the government proclaimed Presidential Decree No. 67-391 on 23 September 1967 for the establishment of a financial control and technical committee for the construction of the hydroelectric power station of Inga I. This committee was replaced by SNEL and became the national electricity company of the DR Congo in 1970.

With the commissioning of the first phase of Inga I in 1972, SNEL became responsible for the generation, transmission, and distribution of electricity across the country. It also assumed the responsibility of REGIDESO, which today holds the responsibility for water distribution in the DR Congo (a state-owned company). Besides REGIDESO, the government nationalized six private companies, which distributed electricity around the country. At that time, the government began a process of absorbing private utilities around the country into SNEL. This process ended in July 1974, when SNEL had achieved a monopoly on the generation, transmission, and distribution of electricity within the country (SNEL, 2000).

The SNEL annual report (2000) argues that on 5 May 1978, the former President of the DR Congo, Joseph Mobutu SeSe SeKo, signed Presidential Decree No. 78/196 approving the status of SNEL. Since then, SNEL has operated as a state company under the legal framework of the Public Enterprise Act. Its four key purposes are (Esseqqat, 2011):

- To promote electrification in rural areas;
- To reduce the gap in the energy supply in provinces;
- To increase the electrification rate all over the country; and
- To promote electricity exports.

Since 2010, SNEL has been transformed into a Limited Company with Limited Liability (LLC). It includes a General Assembly and Shareholders (the state is currently the sole shareholder).

The company is currently under the control of the Ministry of Energy and the Ministry of Public Enterprises. Below is the summary of their functions:

- The Ministry of Energy is the government institution that ensures effective administrative, supervisory, regulatory, and technical control of the energy business in the DR Congo and the company. Its main mission is to:

  - design, propose, and implement the policy adopted by the government in the areas of electricity generation, transmission, distribution, and supply;

  - grant and, if necessary, remove the licensing operators acts within its jurisdiction (upon the recommendation of the regulatory authority); and

- ensure compliance with legislation and regulations;

- The Ministry of Public Enterprises is the government institution that ensures financial control of the company.

Under the trusteeship of SNEL, we have “La Direction de l’Electrification Rurale” (DER). Its mission is to identify and develop electrification projects in rural areas.

Besides SNEL, the following organizations comprise the institutional framework.

- REGIDESO is the public water utility.

- CNE, or “La Comission Nationale d’Energie” (the R&D body in the energy sector), specifically its Department of Electricity and Renewable Energy, is an advisory body under the supervision of the Ministry of Energy that collects, processes, and analyzes the energy database to establish balance and energy indicators that will facilitate the implementation of coherent and efficient energy strategies by the political authorities.

- SGE, or “le Secrétariat Général de l’Energie,” is the administrative mother entity in the energy sector in the DR Congo. It establishes mandatory policies and is responsible for enforcing the terms of the sector. Each of its divisions grants building permits for small hydro projects and amenities. Finally, it also has the power to control and sanction operators. It plays the role of facilitator and intermediary between private developers of renewable energy projects and the public sector.

- CATE**,** or “La Cellule d’Appui Technique à l’Energie,” is attached to the Office of the Ministry of Energy. Its main mission is to provide institutional support to the Ministry of Energy and ensure capacity building in the government and in energy companies in the public sector. In particular, it performs the following tasks that are relevant to the audience, design, implementation, and monitoring of projects and investments in the sector of energy programs:

  - analysis and coordination of the presentation of investment projects and programs of different donors;

  - mnitoring and definition of sectoral strategies in the medium and long terms;

  - ctribution to technical and financial arrangements for water and electricity projects;

  - rpresentation of the overall responsibility for, and coordination of, sectoral projects or investment programs with bilateral and multilateral donors on infrastructure and other projects under the Ministry of Energy.

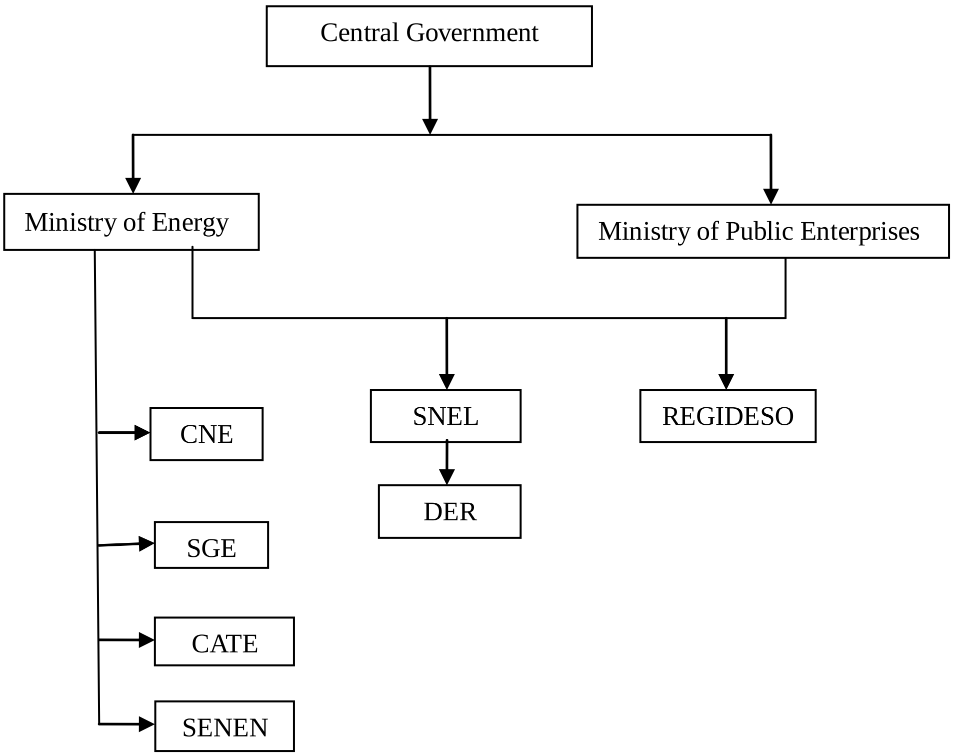
- SENEN, or **“**Le Service National des Energies Nouvelles,” under the trusteeship of the Ministry of Rural Development, also collaborates with the Ministry of Energy to promote renewable energy in rural areas.

Finally, in compliance with the new policy of the electricity sector in the DR Congo, which has yet to be approved, the following three new agencies will be created.

- L’Autorité de Régulation Nationale du secteur de l’Electricité- will be responsible for regulating the electricity sector and protecting the interests of consumers and operators at the national and provincial levels.

- L’Agence d’Electrification Nationale (AGENA) will be responsible for the promotion of private-sector participation in electrification projects in rural areas.

- L’Agence pour le Fonds National Electrification (FONEL) will be responsible for regulating procedures for awarding subsidies and loans to private operators.



Source: Esseqqat, 2011

Since the establishment of the sector, the energy policies of the DR Congo in general and of the electrical system in particular have been characterized by a strongly centralized focus of national magnitude and a strong sense of commitment from the State. This philosophy had initial moderate success, but has completely collapsed throughout the years. The results reflect an almost imminent failure, and the present situation seems completely irreversible unless there is a change in the energy policy of the country.

The rate of electrification (Table 2-3) of the DR Congo is still among the lowest in Africa. The use of even the least sophisticated energy models, such as WASP [10] or MAED, [11] seems impossible, taking into account the disintegration of the electrical system, despite the country's resource potential.

According to Kasemuana (2009), the Energy Policy of the DR Congo's energy sector is based on the following objectives.

- To alleviate poverty and illiteracy;
- To develop an 'extrovert' economy with projects that integrate rural areas and economically viable regions (and where the energy component of the project involves the design of micro or mini electricity power plants with capacities not exceeding 20 MW);

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[10]The "Wien Automatic System Planning" Package model permits the user to find an optimal expansion plan for a power generation system over a long period and within the constraints defined by the planner, which IAEA maintains. So far, four versions of WASP have been created, which have been distributed to several hundred users.

[11]The "Model for the Analysis of Energy Demand" evaluates future energy demand based on medium- to long-term scenarios of socioeconomic, technological, and demographic development. Energy demand is disaggregated into a large number of end-use categories that correspond to different goods and services. The influences of social, economic, and technological driving factors from a given scenario are estimated. These are combined to give an overall picture of future energy demand growth.

Table 2-3. General Operations in the SAPP (2013)

Country	State Company	Installed Capacity MW	Net Electricity Imports Gwh	Net Electricity Exports Gwh	Generation Sent Out Gwh	Electrification Rate %
Angola	ENE	1,793	49	0	5,613	40.2
Botswana	BPC	252	3017	0	372	45.4
DR Congo	SNEL	2,442	562	69	7,021	
Lesotho	LEC	72	49	7.4	486	15.2
Malawi	ESCOM	287	0	19.1	1,809	8.7
Mozambique	EDM	227	89	330	390	15.0
Namibia	NamPower	393	1591	36	1,305	48.8
South Africa	ESKOM	44,170	413	4089	237,430	75.8
Swaziland	SEB	70.6	773	0	288.1	-
Tanzania	TANESCO	1,380	2192	0	3,034	14.8
Zambia	ZESCO	1,870	164	65.6	11,381	18.5
Zimbabwe	ZESA	2,045	1076	701	6,951	36.9

Sources: Southern African Power Pool and the World Bank (2013)

- To implement major industrial projects that demand large amounts of electricity;
- To construct hydroelectric plants at numerous sites throughout the country (Initially, the focus will be on isolated grids, which will later be interconnected.).

Moreover, with the restructuring plan of the government, the objectives of the new policy can now be summarized as follows (SNEL, 2010).

- To promote competition and distribution in the power sector;
- To develop other sources of power;

- To cover progressively the electricity needs of the country (households, rural communities, etc.).

On the generation side, according to the SNEL annual report (2010), the DR Congo has several hydropower and thermal stations across the country, even though a number of these do not produce at full capacity. There are other stations that require refurbishment.

A negative aspect is that most of the hydropower plants do not contribute to the electrification of rural areas in the DR Congo. Therefore, many rural households do not have access to electricity. The benefit of having access to electricity is that it could contribute to the socioeconomic development of the country. Similarly, the establishment of Inga II in 1982 was also portrayed as essentially an economic development project for the country, providing energy infrastructure to the mining sector in Katanga Province, as well as to energy-intensive industries in Kinshasa and other provinces.

Currently, most hydropower and thermal power plants are not being operated due to aging and technical problems. Other electricity plants are being decommissioned. This means the operation period of the power plant has reached 25 years. The establishment of SNEL in the DR Congo is closely linked to the development policies adopted by the country, since SNEL decided to implement a development policy that included skills development for its staff.[12] It was argued that the application of the policy would have improved electrification and offered far wider access throughout the country (SNEL, 2010).

With respect to exports (Table 2-3 also shows the electricity exported in

[12] Initially, most senior staff were foreigners, specifically from Belgium and France. The government changed the situation in 1989 by allowing Congolese citizens to manage SNEL (SNEL, 2000).

SAPP in 2012), the DR Congo is interconnected to the following countries:

- Congo-Brazaville via the Western Network;
- Rwanda and Burundi via the Eastern Network;
- Zambia, Zimbabwe, and South Africa via the Southern Networks (This is in accordance with the SAPP Market.).

Besides these interconnected lines, the DR Congo also supplies power to the following isolated centers in neighboring countries:

- Nocqui (Angola), to which medium-voltage energy is supplied from the network of Matadi (DR Congo);
- Mobayi Mbongo (Central African Republic), to which energy is supplied from central Mobayi (DR Congo);
- Cyangugu Kamembe (Rwanda) and Bujumbura (Burundi), to which energy is supplied from central Ruzizi1 (DR Congo).

As for imports (Table 2-3 shows the electricity imported in SAPP in 2012), the DR Congo imports electricity from neighboring countries and supplies it to its isolated border centers that are far from its existing networks. This is the case with Mokambo, Sakania, and Kasenga, all located in Katanga province, the energy of which comes from Zambia.

Chapter 3. Literature Review

3.1 Performance and Efficiency of State-owned Companies

It has long been the conviction that public enterprises or government-administered organizations are more concerned with social, political, and all but the economic outcomes of business activities. In Africa, especially in the DR Congo, most managers of government-related companies are appointed by the government and often do not have real business knowhow and skills. Moreover, their investment and business decisions may be mainly politically rather than commercially motivated. The inefficiency of such companies is due also to their investment relationship with the government and their management systems. What makes matters worse is that these managers are generally too risk-averse and have no incentives to venture into risky but potentially economically rewarding projects.

It is argued by many that the inefficiency of companies is due in part to their ownership. Boycko et al. (1996) stated that politicians cause state-owned companies to employ excess labor. Furthermore, as Krueger argued (1990), state-owned companies may be pressured to hire politically connected people rather than left alone to tap the market for professionals, or pressured to pursue goals other than profit maximization (Ramamutri, 1987). Jones (1991) argued, however, that corporatizations can manage state-owned enterprises with clear goals, around which government policies must be formulated. A related reason usually put forward as a possible explanation for the inefficient and negative performance of state-owned companies is the government's rigid and bureaucratic supervision of these institutions (based on form, not substance) (Chang & Singh, 1997). Additionally, there are almost no incentives for managers to pursue efficiency and profitability for their institutions. Easy access to low-cost, guaranteed, or recommended government financing may weaken managers' drive towards efficient utilization of resources and reduce threats of job loss, job stagnancy, or even bankruptcy. However, state–owned enterprises in some countries performed poorly even after reforms were introduced (Christensen, 1998).

Moreover, it may be argued that the principal-agent relationship of the type shown in the study of Fama (1980) and Fama and Jensen (1983) is not as strict or as profit-oriented as in privately-owned companies. The objective in public or state-owned companies is not to pursue profit maximization, but to ensure that rules and regulations are adhered to and followed even at the expense of profitability. Vickers and Yarrow (1991) argued that privatization could improve the performance of publicly-owned organizations, solve agency problems, and improve efficiency.

These lines of arguments found some support in empirical studies in this area. For example, Ahuja and Majumdar (1998) used Data Envelopment Analysis (DEA) to examine the performance of 68 Indian state-owned enterprises in the manufacturing sector from 1987 to 1991. The study found that state-owned enterprises were performing more poorly than their privately-owned counterparts. Similarly, Dewenter and Malatesta (2001) used various net- income-based measures and multivariate regressions to process a large data set so as to measure the profitability of state-owned companies and private companies that are included in Fortune magazine's Global 500 for 1975, 1985, and 1995. Their results indicate that state-owned companies are significantly less profitable than privately-owned firms. Evidence of the inferior performance of state-owned companies can be seen in the array of studies that had been initially conducted to examine the effect of privatization on corporate performance. For example, a recent study of Farinos et al. (2007) found significant operating performance improvement in Spanish state-owned enterprises that were privatized through public share issue offerings from 1990 to 2001.

On the other hand, the poor performance of state-owned companies has also found comparable empirical support in literature. Some authors contend that state-owned companies are not always inherently less efficient than private corporations. Private firms may, at times, be less efficient than state-owned firms. Among the cited reasons for the possible inefficiency of private enterprises is the inadequacy of their corporate governance. Even bureaucracy may be a common factor in these situations (Chang and Singh, 1997). Further arguments in defense of state-owned companies are based on the concentrated government ownership of such companies. For example, Dewenter and Malatesta (1997) argued that the government, as a blockholder in state-owned companies, is in a better position to closely monitor the managers of state-owned companies than dispersed owners in private companies.

Some studies tried to conceptually examine ownership structures outside the dual public-private ownership context. A study of McGuiness et al. (2005) using regression analysis considered two forms of ownership structure of Chinese-listed companies. The study mainly examined the effects of state and foreign ownership on the performance of the listed Chinese companies. It also examined state-owned enterprises with substantial foreign ownership. It found a negative association between the free-float size and the corporate performance. The study also found that despite a sizable foreign ownership state, such stakes are not significantly associated with corporate performance.

Some argue that government ownership is an important signal to the market because it gives a company credibility and assures investors and markets, contractors, and suppliers of the government's readiness to insure transactions with them. A study of Bourdman and Vining (1989) used the OLS model to examine samples of three ownership-based categories of companies: state-owned, privately-owned, and mixed-owned. The study found that partial privatization, with the government retaining some equity ownership, was a viable and better strategy for a government that plans to move away from state ownership. A study of Ang and Ding (2006) compared the financial and market performance of state-owned companies and private companies in Singapore and found that the state-owned companies have better corporate governance and higher valuations than the private companies. Omran (2004) also showed that Egyptian privatized firms do not exhibit significant improvement in performance, unlike state-linked companies. Similar results, but for different reasons, were shown by studies in highly developed economies such as that of Bozec (2003) in Canada and Kole and Mulherin (1997) in the United States. The U.S. study found that in that country, companies in which the government owned an interest (between 35-100%) performed almost as well as private-sector firms in the same industry. The results are attributed to the existence of a monitoring mechanism in the government-owned companies that is similar to that in private-sector firms.

A recent and more comprehensive study was conducted by Micco et al. (2007), which examined a large sample of commercial banks in 179 countries from 1995 to 2002. The objective of the study was to examine the relationship between bank ownership and performance and to test if there is a political factor effect. State-owned banks operating in developing countries tend to have lower profitability, lower margins, and higher overhead costs than their privately-owned counterparts. This relationship was weaker in the case of industrial countries.

In the case of the state-owned companies in the DR Congo, Aka (2004) argued that in the 1970s, the state-owned companies outperformed the private companies and contributed over 60% to the country's GDP. However, because of the different crises that the country faced in the last decades, the state-owned companies appeared inefficient and less productive (Tshibangu, 2009).

According to Tshibangu (2009), these multiple and various forms of political and economic instability have pushed the Congolese government to consider the establishment of new intervention structures to reverse the trend. One of the structures engendered by the State with the support of partners is: "le Comité de Pilotage de la Reforme des Entreprises Publiques" (COPIREP), which is the steering committee for the reform of public enterprises and is responsible for implementing the policy on the reform of public enterprises especially in sectors considered profitable for the State: mining, energy, transport, telecommunications, and finance. The reform of state-owned companies in the DR Congo was finally implemented in 2008. This plan for progressive government disengagement changed the status of nearly 50 parastatal companies, with 20 transformed into commercial companies; five, into other public institutions; and five, into public services companies. Four were dissolved or liquidated.[13] Among the transformed companies were GECAMINES, OKIMO, REGIDESO, SNEL, COHYDRO, SNCC, ONATRA, LAC, OCPT and SONAS.

This process is not privatization but a measure that should ultimately lead

[13]Source: Ministere du Portefeuille de la RDC. http://www.ministèreduportefeuille.org, accessed October 15, 2013.

to progressive disengagement of the government from state-owned enterprises. The main objective of the laws passed by Parliament is to improve the productivity and competitiveness of companies under the Ministry of Public Enterprises.

Tshibangu (2009) argued that after the one-year legal timeframe for the transformation of public enterprises as stipulated in the decree of 24 April 2009, no public company that was transformed into a commercial company was able to produce a detailed financial situation report. COPIREP, which drives the process on behalf of the government, has sounded the alarm by requesting that a technical note be sent to the Prime Minister in early April. Thus, COPIREP has requested an extension period for the release of the reform process, which is blocked for the moment by the difficulty of improving the financial situation of the transformed enterprises.

3.2 Performance and Efficiency of Electric Power Companies

From the international perspective, there is a growing volume of literature on studies of the efficiency of electric power companies. The more popular research topics are the development of efficiency rankings and comparisons of company performance. On this point, we highlight herein the scope of the empirical literature that exists in our field of research.

Andrikopoulos and Vlachou (1995) examined the structure and productivity growth in the Greek Public Power Corporation (GPPC) over the period of 1970-1989. Their study entailed estimating a translog cost function to investigate the implication of public ownership on technology and the price of capital vis-a-vis economies of scale.

Instead of demonstrating the impact of ownership, what they succeeded in showing is that economies of scale with respect to capacity contribute significantly to the rate of growth in the total factor productivity. They inferred that policies that are bound to decrease significantly the scale of operation of the GPPC would reduce the company's productivity performance. Based on their findings, they concluded that a GPPC, although publicly owned and operated, was relatively efficient and exhibited, over a wide range of outputs, economies of scale that contributed the most to the rate of growth in the total factor productivity.

Bagdadioglu et al. (1996), in a study of efficiency and ownership in electricity distribution in Turkey, used a non-parametric model to estimate technical and scale efficiency so as to establish a benchmark measure for the relative performance of publicly operated organizations and their private counterparts. The primary goal of their study was to assess the impact and effect of privatization on the reform program of the Turkish electricity industry.

Although their results showed better technical and allocative efficiency scores for privately operated distribution organizations, they indicated that such did not necessarily imply the success of private ownership in electricity distribution, more so as they also observed technically efficient and scale-efficient publicly owned distribution organizations and the fact that government was selective in the utilities it privatized first.

Thus, they stressed caution in interpreting such results as confirming that privatization results in higher efficiency, as some public utilities were among the efficient subsets. They argued that it is difficult to disentangle the direction of causality. Examining the factors and sources of inefficiency extended the scope of their analysis further. Market characteristics were invoked as explanatory variables. Their general conclusion, given sample size limitations, is that scale inefficiency contributed significantly to overall inefficiency.

In a study of Golany et al. (1994), they used DEA to measure and evaluate the operating efficiency of electricity plants under the auspices of the Israeli Electric Corporation (lEC). They posited that given the capital intensity of IEC, marginal improvements in the performance of the electricity industry may result in significant monetary benefits in terms of investment expenditures.

Furthermore, the use of the non-parametric approach is strengthened by the multiple nature of the electricity industry. The adoption of the analytical approach was justified on the grounds that *ex ante* assumption of efficiency in production cannot be taken for granted given the pervasive government involvement and the heavy-handed approach to the regulation of the electricity industry, what with the geopolitical sensitivity of Israel.

The significance of the aforementioned study is undermined by the failure to posit theoretical hypotheses as the bases of the performance. As the geopolitical sensitivity of the industry might be a necessary condition for government involvement, it is not enough to justify public provision or poor performance.

Mohd-Yunos and Hawdon (1997) assessed the efficiency and productivity of the Malaysian Electricity Board (NEB). Their study focused on efficiency as premised on the notion of economic rectitude in electricity production, or, in other words, how to establish an efficient way to operate and manage the electricity utility in Malaysia. The underlying argument is that the public ownership aspect of the electricity industry of developing countries has adversely affected the cost and effectiveness of their electricity policy. This is the same rationale behind the World Bank's advocacy of reduction of state involvement and promotion of privatization.

The empirical findings of Mohd-Yunos and Hawdon showed that the Malaysian Electricity Board (NEB) ranked 18th among 27 countries with respect to technical efficiency. Using the Malmquist productivity index, they also decomposed productivity into its constituents. They found that the productivity growth due to technological shift is not accompanied by the catching-up effect in productivity movement.

Mohd-Yunos and Hawdon estimated that the NEB could reduce costs by over 40 percent of 1987 prices. They showed that the DEA method has the capacity to indicate the feasible benefits from continued improvement in the technical efficiency of electricity production. A key conclusion of their study is that a change in ownership does not in itself lead to improvement in efficiency performance. A similar finding of the study of Bagdadioglu et al. (1996) showed that some publicly owned firms performed as well as privately owned firms among sample firms in developing countries.

Fare[14] et al. (1985), in a study of electricity utilities in Illinois, relaxed their restrictive assumption of the structure of production technology and developed non-parametric mathematical programming models capable of decomposing and evaluating the various components of technical efficiency.

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[14]The study of Fare et al. (1990) was conducted in the same spirit as that of Fare (1985) but investigated the productivity growth of utilities in Illinois between 1975 and 1981 using the Malmquist index approach. They decomposed productivity growth into parts -- one that accounted for efficiency changes, and another that accounted for shifts in the production frontier. They found the rates of productivity growth stable over the period, but they observed deterioration due to technological regression between 1976 and 1977.

They specified one output, the electricity generated (Kwh), and three inputs, labor (the average number of employees), fuel (Btu), and generating capacity (MW). In addition to the data on physical inputs and outputs, additional data on boiler turbine generator units, output prices, first year of commercial operation, regulatory region, and earned rate of return were used to explain the pattern of the calculated efficiencies.

They evaluated the following efficiency measures: technical efficiency, congestion, scale efficiency, and overall efficiency. Their results showed that scale inefficiency (95.6 %) is more pervasive than congestion. They inferred that this was the main contributor to the disparity they found between the overall efficiency (90.2 %) and the pure technical efficiency (97.7 %). As to the scale efficiency, only three plants were operating at their optimal scale. The larger plants operated with increasing returns to scale, but the smaller plants were in the decreasing-returns-to-scale region of the production frontier.

Pollitt (1995) examined the ownership and performance hypothesis from the various aspects of electricity services using both parametric and non-parametric techniques on a cross-country sample. Consistent with the battery of evidence for the ownership and performance debate, his results showed that there are no significant differences between the two distinct ownership types.

A more important aspect of Pollitt's study is the realization that the two techniques, the parametric and non-parametric techniques, for measuring efficiency yield similar results. To further the efficiency evaluation, using the censored regression approach, the Tobit model, Pollitt regressed the efficiency measures against some explanatory variables. The load factor emerged as a major determinant of efficiency.[15]

[15]This is not surprising given that the load factor measures the success of capital

Pollitt (1996) examined the relative efficiencies of 78 publicly and privately owned nuclear plants that were operated in 1989, as drawn from an international sample. He developed two linear programming models. The first included all the inputs used in electricity generation, and the second distinguished between discretionary and non-discretionary inputs.[16] He found evidence of improvement in labor productivity, which he adduced to labor shedding as part of the restructuring of the nuclear power industry. He tested the ownership productive efficiency hypothesis using statistical methods and the censored regression model. The null hypothesis of no difference in efficiency could not be rejected in the *ex ante* case, but was rejected in the *ex post* case. With the Tobit model, he examined the impact of the load, size, age, ownership, and technology factors and found load and age important determinants of efficiency. Interestingly, the dummy variable that was included to capture the effect ownership was found to be insignificant.

There are other studies that use non-parametric linear programming techniques to investigate the efficiency and performance aspects of privately and publicly owned utilities. The strength of the empirical studies outlined next, apart from their providing insights on the performance of various electricity utilities, is their providing additional heuristics for the performance assessment of electricity utilities.

For example, Cote's (1989) study on electricity utilities in the US found that co-operative utilities had the lowest technical inefficiency, followed by municipally owned utilities and, finally, privately owned utilities. He concluded that efficiency varied with the size of the firms.

Seitz (1971) evaluated the allocative, technical, and overall efficiencies

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utilization.

[16] Pollitt called these *ex ante* and *ex post*, respectively.

of steam-electric generation plants in the US electricity industry and estimated the industry's production function. Seitz, like Cote, found scale efficiency to be an important determinant of overall efficiency. The technique enabled the identification of excess factor use.

Pombo and Taborda (2004) measured the performance of 12 state electric power companies in Colombia before and after their 1994 regulatory reform and found an improvement in their power distribution and profitability rate in their post-reform years. However, a similar study was conducted by Estache, Tovarc, and Trujillod (2008), who assessed the performance change of a sample of 12 Sub-Saharan African government electric power companies since their main reform took place in the late 1990s. They noticed an improvement in the performance of those companies during the analysis period (1998-2005).

We can draw many inferences from these reviewed studies. First, there are key input and output variables that must be included in efficiency and performance analysis. Second, although the non-parametric linear programming technique in itself sheds light on performance, it becomes much more cogent when combined with some economic hypotheses. Third, the empirical evidence shows that there is no *a priori* case for the superiority of private ownership over public ownership, or vice versa. What these add up to is that a case by case approach has to be taken in performance assessment, not just in terms of the pertinent hypotheses but also the methodology.

Chapter 4. Research Methodology

Our research intend to assess and compare the performance of SNEL with other state electric power companies operating in SAPP (ENE of Angola, BPC of Botswana, LEC of Lesotho, ESCOM of Malawi, EDM of Mozambique, NamPower of Namibia, ESKOM of South Africa, SEB of Swaziland, TANESCO of Tanzania, ZESCO of Zambia, and ZESA of Zimbabwe). We used the DEA method to find the technical efficiency score of each company. Then we decomposed the change into the Technical Efficiency Change, Technology Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practices in the market (SAPP). After that, we estimated the Malmquist Index to follow the performance progress of each company. Finally, we used the OLS model in the second stage to assess the environmental factors that affect the efficiency of companies.

DEA is a non-parametric mathematical programming approach to frontier estimation. It was developed independent of the stochastic frontier approach over the past two decades. Farrell's (1957) approach to efficiency measurement consists of a conical hull of input-output vectors based on a production possibility set. The conical hull of vectors is constructed using linear programming (LP) techniques, for a single-output case, with a subset of the sample lying on the production possibility set and the rest lying above. Charnes, Cooper, and Rhodes (1978) reformulated this piecewise linear convex hull approach to the estimation of the technical efficiency and frontier models, to incorporate multiple-output, multiple-input technologies. Their approach assumes constant returns to scale (CRS) and is referred to as the *CRS DEA model*. This model is used here to assess the relative efficiency of homogeneous farms in transforming inputs into outputs.

Banker, Charnes, and Cooper (1984) extended the CRS model by relaxing the assumption of constant returns to scale to variable returns to scale (VRS). The model is known as the *VRS model*. The VRS DEA model differs from the CRS DEA model in that it envelops the data more closely, thereby producing technical efficiency estimates greater than or equal to those from the CRS DEA model.

Coelli (1995) reviewed and critiqued different DEA approaches.[17] DEA is both non-parametric and non-stochastic because it does not impose any a *priori* parametric restrictions on the underlying frontier technology (because it does not necessitate the specification of a functional form in the frontier methodology) and it does not require any distributional assumption for the technical inefficiency terms. Therefore, the method avoids the imposition of unwarranted structures on both the frontier technology and the inefficiency component that might distort the efficiency measures (Fare et al., 1985). DEA has the added advantages of evaluating the scale and the allocative and economic efficiencies. The minimum assumptions required for this DEA frontier methodology are the monotonicity and convexity of the efficient frontier (Banker et al., 1984).

DEA estimates efficiency relative to the Pareto-efficient frontier, which estimates the best performance (Murthi et al., 1997). Furthermore, DEA can obtain the target values based on the best practice units (peers) for each inefficient firm that can be used to provide guidelines for improved performance. However, the major shortcoming of DEA is that it is

[17]Seiford and Thrall (1990); Bjurek et al. (1990); Lovell (1993 and 1994); Charnes et al. (1995); Seiford (1996); and Au and Seiford (1993) also reviewed the non-parametric DEA approach.

deterministic and assumes a zero value for the stochastic random error component. Thus, in DEA, technical inefficiency reflects all unexplained variations of outputs, and therefore, the inefficiency of the observed firm is biased upwards. Moreover, since there is no measurement error or other random noise, and since the method is non-parametric, the efficiency measures cannot be subjected to statistical tests.

DEA can be used to estimate both technical and economic efficiency depending on the type of data available (cross-section or panel) and the kind of variables available (quantities only, or quantities and prices). Technical efficiency can be measured from quantity data for inputs and outputs, and measures of economic efficiency require both quantity and price data. Estimation of technical and allocative efficiency assumes behavioral goals, such as cost minimization or profit maximization, and a two-stage procedure. The first estimates technical efficiency, and the second measures economic efficiency. Allocative efficiency is calculated from economic and technical efficiency.

Adjusting for the environmental variables is another extension of the basic DEA method to evaluate some factors that could influence the efficiency of a firm, where such factors are not traditional inputs and are assumed to be not under the control of the manager. There are a number of possible approaches to the consideration of environmental variables, such as the “three stages” method proposed by Charnes, Cooper, and Rhodes (1981), which includes the environmental variable(s) directly in the linear programming formula of Ferrier and Lovell (1990). The two-stage approach that involves a DEA problem in the first-stage analysis and regresses the efficiency score from the first stage in the second stage using the Tobit or OLS model is recommended in most cases. Some considerable advantages of this approach are that both continuous and categorical variables can be easily accommodated in the second step, and a hypothesis test can be conducted to see if the variables significantly affect the efficiencies.

DEA gives either the maximum output for a given input level or uses the minimum input for a given output level. Thus, the analysis of efficiency can have an input-saving or output-augmenting interpretation.

4.1 CCR Model

This is one of the most basic DEA models proposed by Charnes, Cooper, and Rhodes (1978) based on Farrell's (1957) method of measuring efficiency. They introduced the term Decision-Making Unit (DMU) to describe the organization whose efficiency is being studied, which can, for example, be a company, a department store, or a bank branch, with common inputs and outputs. A DMU is an entity that converts inputs to outputs and has a certain degree of managerial freedom in decision-making.

Charnes et al. (1978) generalized the concept of the classical engineering ratio to multiple inputs and outputs. They proposed that the efficiency of a DMU can be obtained as the maximum ratio of the weighted outputs to the weighted inputs, subject to the condition that the same ratio for all the DMUs must be less than or equal to 1.

Suppose there are n DMUs: DMU_1, DMU_2, …, and DMU_n, with m inputs: X_1, X_2, ..., X_m and s outputs: Y_1, Y_2,…, and Y_s. The following fractional programming model can be solved to obtain the efficiency score and the input and output weights.

4.1.1 CCR Input-Oriented Model

Charnes et al. (1978) generalized the concept of the classical engineering ratio to multiple inputs and outputs. They proposed that the efficiency of a DMU can be obtained as the maximum ratio of weighted outputs to weighted inputs, subject to the condition that the same ratio for all the DMUs must be less than or equal to 1.

Suppose there are n DMUs: DMU_1, DMU_2, …, and DMU_n, with *m* inputs: X_l, X_2, ..., and X_m, and s outputs: Y_1, Y_2, …, and Y_s. The following fractional programming mode1 can be solved to obtain the efficiency score and the input and output weights.

$$max \quad h_0 = \frac{\sum_{r=l}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{4.1}$$

$$s.t. \ \frac{\sum_{r=l}^{s} u_r y_{r0}}{\sum_{i=l}^{m} v_i x_{ij}} \leq 1 \quad j = 1, \ldots, n$$

$$u_r, v_i \geq 0 \quad r = 1, \ldots, s \quad i = 1, \ldots, m$$

Here, x_{ij} and y_{rj}, (al1 non-negative) are the inputs and outputs of the *j*th DMU, and v_i and u_r are the input and output weights (also referred to as *multipliers*).

The objective is to obtain weights (v_i, u_r) that maximize the efficiency (ratio) of DMU_0, which is the DMU under evaluation. The constraints mean that the efficiency of none of the DMUs should exceed 1, while using the same multipliers.

The aforementioned fractional programming model can be transformed to a linear programming problem (Charnes, 1962).

$$max \ \ h_0 = \sum_{r=1}^{s} u_r \, y_{r0}$$

$$s.t. \ \sum_{i=1}^{m} v_i \, x_{i0} = 1 \tag{4.2}$$

$$\sum_{r=1}^{s} u_r \, y_{rj} - \sum_{i=1}^{m} v_i \, x_{ij} \leq 0 \ \ j = 1, \dots, n$$

$$u_r, v_i \geq 0 \ \ r = 1, , \dots, s \quad i = 1, \dots, m$$

The fractional program is equivalent to the linear program, and they have the same optimal objective value, *ho**.

When DMU has *ho** < 1, it is CCR-inefficient. Therefore, there must be at least one constraint for which the optima1 weights (v_i* and u_r*) produce equality between the left and right sides; otherwise, *ho** could be enlarged. This means that there must be at least one CCR-efficient DMU_0. The set of CCR-efficient DMUs is called the *efficient reference set* or the *peer group for DMU_0*. Actually, the existence of these efficient units forces DMU to be inefficient. The set of efficient units form the efficient frontier. Figure 4-1 shows the efficient frontier and the production possibility set for the CCR model in two dimensions, the single-input case and the single-output case.

The dual problem in (4.2) is expressed as follows.

$min \ \Theta$

$$s.t. \ \ \Theta x_{i0} - \sum_{j=1}^{n} \lambda_j \, x_{ij} \geq 0 \quad i = 1, \dots, m \tag{4.3}$$

$$\sum_{j=1}^{n} \lambda_j \, y_{rj} \geq y_{r0} \quad r = 1, \dots, s$$

$$\lambda_j \geq 0 \quad j = 1, \ldots, n$$

In the aforementioned formula, Θ and λ_j *(j = l, ..., and n)* are the dual variables of the linear program mode1 (4.2). The scalar variable 0 is the (proportional) reduction, which should be applied to all inputs of DMU, to make them efficient. This reduction is applied to all inputs simultaneously; and since the result radially moves toward the envelopment surface, the efficiency is called *radial efficiency*.

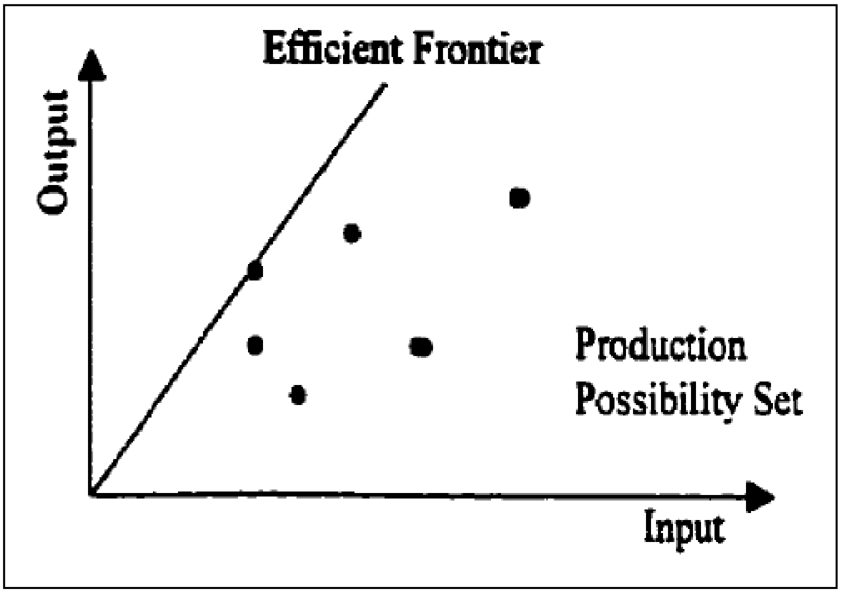

Figure 4-1. CCR Production Possibility Set and Frontier

Source: Modified from Cooper et al., 2007

To transform the dual problem into the linear programming standard form, the slack variables s^- and s^+ should be added to the model. *Slack variables* is a standard LP terminology for additional variables added to the model to convert inequality constraints to equality constraints. This DEA terminology is also used when further improvement in specific inputs or outputs is possible.

The standard linear program is as follows (Cooper, 2007).

$$min\ \Theta$$

$$s.t.\ \ \Theta x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0 \quad i = 1, \dots, m \tag{4.4}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0} \quad r = 1, \dots, s$$

$$\lambda_j, s_r^+, s_i^- \geq 0 \ \ j = l, \dots, n \quad r = l, \dots, s \quad i = l, \dots, m$$

If Θ for a DMU is 1.0 but the slack variables are not zero, it means further improvements in the efficiency of this DMU are possible by reducing (increasing) specific inputs (outputs). Charnes, Cooper, and Rhodes (1978) removed this ambiguity by amending the objective function to maximize the slack variables, but in a manner that did not impair the minimization of Θ. This resulted in the following amended objective function.

$$min \quad \Theta - \varepsilon \sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+$$

$$s.t.\ \ \Theta x_{i0} \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0 \ \ i = 1, \dots, m \tag{4.5}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0} \quad r = 1, \dots, s$$

$$\lambda_j,\ s_r^+, s_i^- \geq 0 \ \ j = 1, \dots, n \quad i = l, \dots, m \quad r = 1, \dots, s$$

where in ε is a very small constant usually set as 10^{-6} (Norman, 1991). Therefore, the optimization can be achieved in two steps: first, the maximal reduction of inputs is computed (by the optimal Θ^*), then movement on the efficient frontier is achieved using the slack variables s^- and s^+.

Note that improper selection of a value for ε can result in serious errors, and was indicated via computational testing in the study of Ali (1993). Cooper et al. (2007) mentioned that it is not advisable to represent ε with a small number because it can lead to errors, besides which it is not even necessary to explicitly specify a value for ε. A two-phase procedure was described in (Cooper, 2007) that eliminates the difficulty with choosing the ε value. In Phase I, the optimal objective value of Θ (Θ^*) is computed; then in Phase II, the sum of the input excess and the output shortfalls will be maximized while setting Θ at Θ^*. The reader is referred to (Cooper, 2007) for further discussion in this area.

DMU is efficient if and only if $\Theta = 1$ and all slacks are zero. $\Theta^* < 1$ and non-zero slacks indicate the sources and amount of inefficiencies. To determine the efficiency of all DMUs, a separate LP must be solved for each.

The linear program (4.2) is also referred to as the *multiplier form*, and the dual program (4.3), as the *envelopment form*, from which the name *Data Envelopment Analysis* was derived (Cooper, 2007). As shown in Figure 4-1, all the data are inside the frontier and hence, are enveloped by the efficient frontier.

It is advisable to solve the CCR model using the dual (envelopment) form (Cooper, 2007). In DEA, the number of DMUs *(n)* is much larger than the sum of the inputs and outputs *(m+s),* so it is easier to solve the dual (envelopment), which has *m+s* constraints, than the primal (envelopment), which has n constraints. Another reason is that the interpretation of the solutions of the dual (envelopment) is more straightforward than the interpretation of the primal (envelopment). The results give the possible proportional reduction in the inputs and the amount of slacks, which indicate the improvement possibilities for an inefficient unit.

Up to this point, we have considered a version of the CCR model that seeks to minimize inputs while producing at least the given output levels. This is called the *input-oriented model*. The envelopment surface for the CCR input-oriented model, and the projections of the inefficient units (B, C, and D) to this efficient frontier in the case of one input and one output, are shown in Figure 4-2.

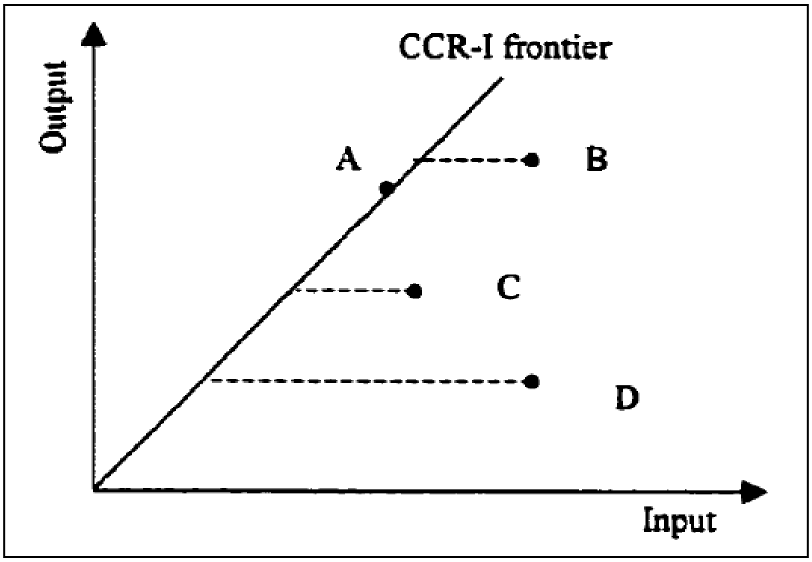

Fig. 4-2. Envelopment Surface and Projection in the CCR-I Model

Source: Modified from Cooper et al. 2007

4.1.2 CCR Output-Oriented Model

There is another type of CCR model, the output-oriented model, which aims to maximize outputs while not exceeding the observed input levels. The primal (multiplier) form of output-oriented CCR is as follows.

$$
\begin{aligned}
& min \quad q_0 = \textstyle\sum_{i=1}^{m} v_i\, x_{i0} \\
& s.t. \ \sum_{r=1}^{m} u_r y_{r0} = 1 \\
& \sum_{i=1}^{m} v_i\, x_{i0} - \sum_{r=1}^{s} u_r\, y_{rj} \geq 0 \quad j = 1, \ldots, n \\
& \qquad u_i, v_r \geq \varepsilon \quad i = 1, \ldots, m, \ \ r = 1, \ldots, s
\end{aligned}
\tag{4.6}
$$

and the dual for it is formulated as follows.

$$
\begin{aligned}
& max \quad z_0 = \Phi + \varepsilon \textstyle\sum_{r=1}^{s} s_r^{+} + \varepsilon \textstyle\sum_{i=1}^{m} s_i^{-} \\
& s.t. \quad \Phi y_{r0} - \sum_{j=1}^{n} \lambda_j\, y_{rj} + s_r^{+} = 0 \quad r = 1, \ldots, s \\
& \sum_{j=1}^{n} \lambda_j\, x_{ij} + s_i^{-} = x_{i0} \quad i = 1, \ldots, m \\
& \qquad \lambda_j, s_i^{-}, s_r^{+} \geq 0 \quad j = 1, \ldots, n \quad i = 1, \ldots, m \quad r = 1, \ldots, s
\end{aligned}
\tag{4.7}
$$

In the dual model, maximum output augmentation is accomplished through the variable Φ if $\Phi > 1.0$; and/or if the slacks are not zero, the unit is inefficient. To improve inefficient units, first, a proportional increase of Φ in all the outputs is required, and then further improvement of the envelopment surface may be needed based on positive slack variables. As illustrated in Figure 4-3, the envelopment surface in the CCR output-oriented model is the same as in the CCR input-oriented model. However, the projection of inefficient units to the envelopment surface is different.

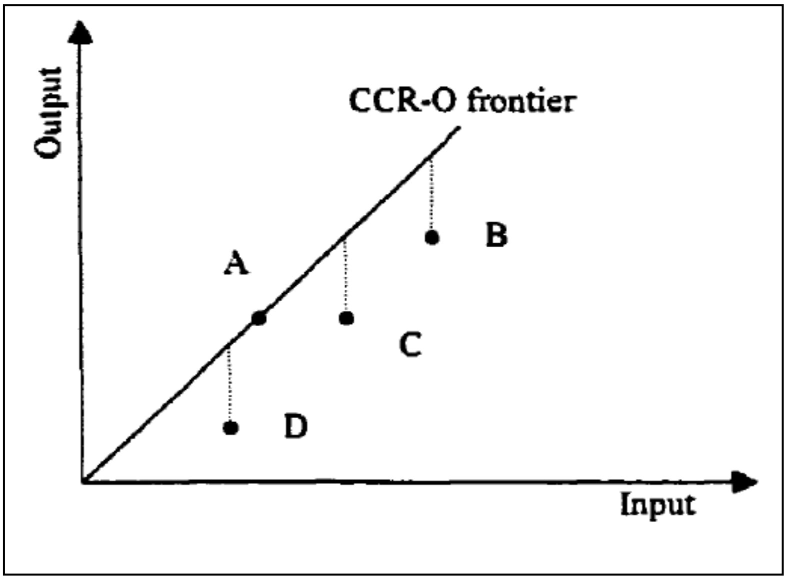

Fig. 4-3. Envelopment Surface and Projection in the CCR-O Model

Source: Modified from Cooper et al. 2007

A DMU is characterized as efficient in an input-oriented CCR model if and only if it is characterized as efficient in the corresponding output-oriented CCR model.

4.2 BCC Model

The CCR model evaluates both technical and scale efficiency via the optimal value of the ratio form. The envelopment in CCR is the constant returns to scale, which means a proportional increase in inputs results in a proportional increase in outputs.

Banker et al. (1984) developed a model for estimating the pure technical efficiency of DMUs with reference to the efficient frontier. It determines if a DMU is operating in an increasing, decreasing, or constant return to scale.

4.2.1 BCC Input-Oriented Model

The BCC input-oriented mode1 evaluated the efficiency of DMU_0 by solving the following linear program.

$$max\ \ h_0 = \sum_{r=1}^{s} u_r\, y_{r0} + u_0$$

$$s.t.\ \ \textstyle\sum_{i=l}^{m} v_i\, x_{i0} = 1 \qquad (4.8)$$

$$\sum_{r-1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} + u_0 \leq 0 \quad j = 1, \dots, n$$

$$u_r, v_i \geq \varepsilon \quad r = 1, \dots, s \quad i = 1, \dots, m$$

$$u_0\ \ free$$

The dual form of this program is expressed as follows.

$$min\ \ \Theta - \varepsilon \textstyle\sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+ \qquad (4.9)$$

$$s.t.\ \ \Theta x_{i0} - \sum_{j=1}^{n} \lambda_j\, x_{ij} - s_0^- = 0 \quad i = 1, \dots, m$$

$$\sum_{j=l}^{n} \ddot{e}_j\, y_r - s_r^+ = y_{r0} \quad r = 1, \dots, s$$

$$\sum_{j=l}^{n} \ddot{e}_j = 1 \quad j = 1, \dots, n$$

$$\lambda_j,\ \ s_r^+, s_i^- \geq 0 \qquad j=1,\dots,n \quad i=1,\dots,m \quad r=1,\dots,s$$

A unit is BCC-efficient if and only if $\Theta^* = 1$ and all the slacks are zero. The envelopment surface in the BCC model is the variable return to scale, which is the result of the presence of the convexity constraint ($\sum \lambda_j = 1$) in the dual (envelopment) and, equivalently, the presence of u_0, which is an unconstrained variable, in the primal problem. Figure 4-4 is a two-dimensional example of the envelopment surface and projections to this frontier.

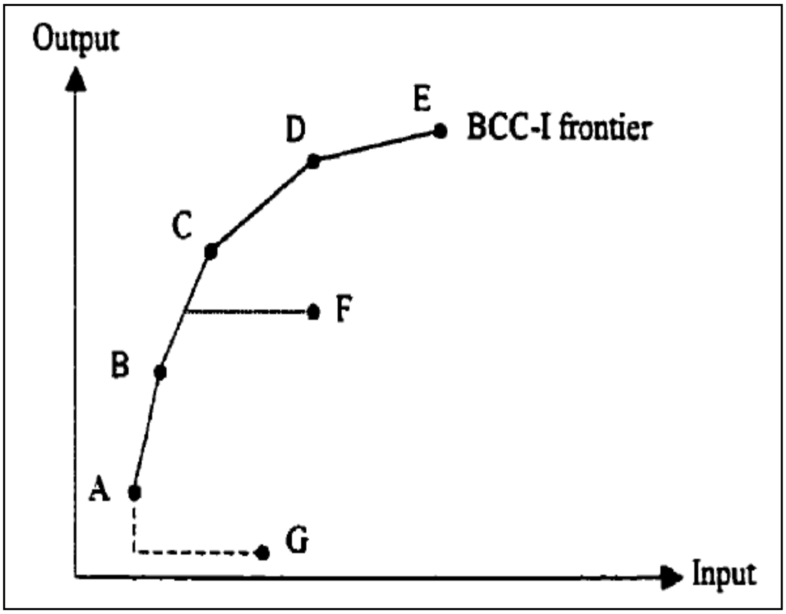

Fig. 4-4. Envelopment Surface and Projection in the BCC-I Model

Source: Modified from Cooper et al. 2007

Inefficient units are projected to the efficient frontier, first by reducing their input, and then by accommodating the slack variables, if any.

Units A, B, C, D, and E are the efficient units and form the efficient frontier. Units F and G are inefficient. To make unit F efficient, a proportional decrease in its input is needed. For unit G, first, a reduction in its input level and then an increase in its output are needed, since its non-zero output slack indicates that further improvement is possible.

If a unit is characterized as efficient in the CCR model, it will also be characterized as efficient in the BCC model, but the converse is not necessarily true.

4.2.2 BCC Output-Oriented Model

While the envelopment surface for the BCC output-oriented model is the same as that for the BCC input-oriented model, the projections to the envelopment surface in the two models differ. The objective in BCC-O is to maximize the output production while not exceeding the actual input level. Equation (4.10) gives the primal formulation for the BCC output-oriented model.

$$\begin{aligned}
& min \quad q_0 \textstyle\sum_{i=l}^{m} v_i \, x_{i0} + v_0 \\
& s.t. \ \sum_{r=1}^{m} u_r \, y_{r0} = 1 \\
& \sum_{i=1}^{m} v_i \, x_{ij} - \sum_{r=1}^{s} u_r \, y_{rj} + v_0 \quad j = 1, \dots, n \\
& \qquad u_i, v_r \geq \varepsilon \quad i = 1, \dots, m \quad r = 1, \dots, s
\end{aligned} \tag{4.10}$$

The dual (envelopment) form of the problem is as follows.

$$\begin{aligned}
& max \quad z_0 = \Phi + \varepsilon \textstyle\sum_{r=1}^{s} s_r^+ + \varepsilon \sum_{i=1}^{m} s_i^- \\
& s.t. \quad \Phi y_{r0} - \sum_{j=1}^{n} \lambda_j \, y_{rj} + s_r^+ = 0 \quad r = 1, \dots, s \\
& \sum_{j=1}^{n} \lambda_j \, x_{i0} + s_i^- = x_{i0} \quad i = 1, \dots, m
\end{aligned} \tag{4.11}$$

$$\sum_{j=1}^{n} \ddot{e}_j = 1$$

$$\ddot{e}_j, s_i^-, s_r^+ \geq 0 \quad j = 1, \ldots, n \quad i = 1, \ldots, m \quad r = 1, \ldots, s$$

For the BCC output-oriented models, similar to the CCR output-oriented models, maximal output augmentation is accomplished through Φ. Based on this model, a unit is efficient if and only if $\Phi^* = 1$ and all the slacks are zero. To show graphically the difference between the BCC-1 and BCC-O models in projecting inefficient units to the efficient envelopment surface, consider the BCC-1 example in Figure 4-4, now shown as BCC-O in Figure 4-5.

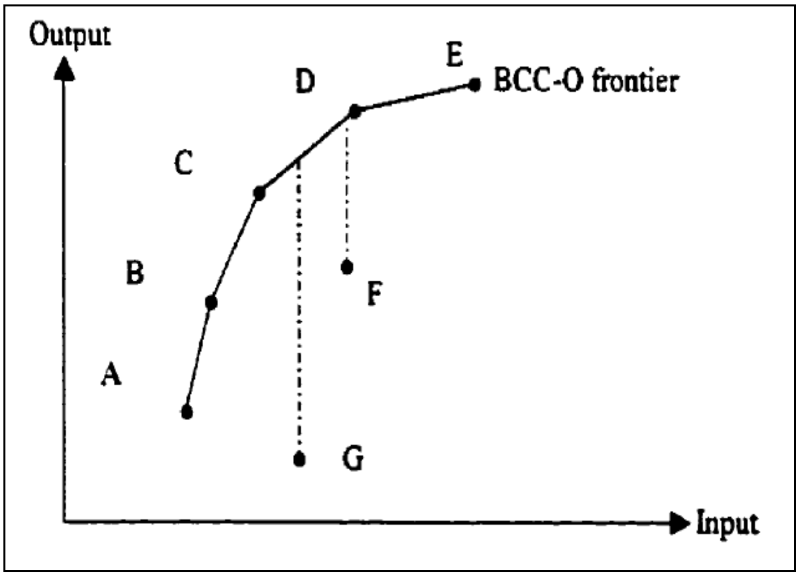

Fig. 4-5.Envelopment Surface and Projection in the BCC-O Model

Source: Modified from Cooper et al. 2007

As shown in Figure 4-5, while the envelopment surface of BCC-O is identical to the envelopment surface of BCC-1 (Figure 3-4), units F and G are projected to significantly different points on the envelopment surface.

4.3 Additive Model

In the preceding models (CCR and BCC), the projection of inefficient units to the envelopment surface is based on the model orientation. An input-oriented model focuses on maximal movement toward the frontier through the proportional reduction of its inputs, whereas an output-oriented model does this through proportional augmentation of outputs. Charnes et al. (1985) introduced the additive model, which combines the two orientations in one model. In this model, the inefficient units are projected onto the envelopment surface by decreasing their inputs and increasing their outputs simultaneously.

The primal (multiplier form) problem of the additive model can be expressed as follows.

$$max \quad w_0 \sum_{r=1}^{s} u_r\, y_{r0} - \sum_{i=1}^{m} v_i\, x_{i0} + u_0$$

(4.12)

$$\sum_{r=1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} + u_0 \leq 0 \qquad j = 1, \dots, m$$

$$u_r, v_i \geq 1 \quad r = 1, \dots, s \quad i = 1, \dots, m$$

$$u_0 \ free$$

The dual (envelopment form) is as follows.

$$min \quad z_0 = -\varepsilon \sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+$$

$$s.t. \quad x_{i0} - \sum_{j=1}^{n} \lambda_j\, x_{i0} - s_i^- = 0 \qquad i = 1, \dots, m$$

(4.13)

$$\sum_{j=l}^{n} \lambda_j\, y_{rj} - s_r^+ = y_{r0} \qquad r=1,\dots,s$$

$$\sum_{j=1}^{n} \lambda_j = 1 \quad j = 1, \dots, n$$

$$\ddot{e}_j, s_r^+, s_i^- \geq 0 \quad j = 1, \dots, n \quad i = 1, \dots, m \quad r = 1, \dots, s$$

DMU_0 is efficient if and only if $z_o^* = w_o^* = 0$. When any of the slack variables, s^- or s^+, is not zero, it means DMUo is inefficient, and the slack values identify the sources and amounts of inefficiency in the corresponding inputs and outputs. A unit is Additive-efficient if and only if it is BCC-efficient, which is proven in (Cooper, 2007) as a theorem.

The one-input, one-output example in Figure 4-6 shows the envelopment surface and the way inefficient units are projected onto the frontier in the Additive model.

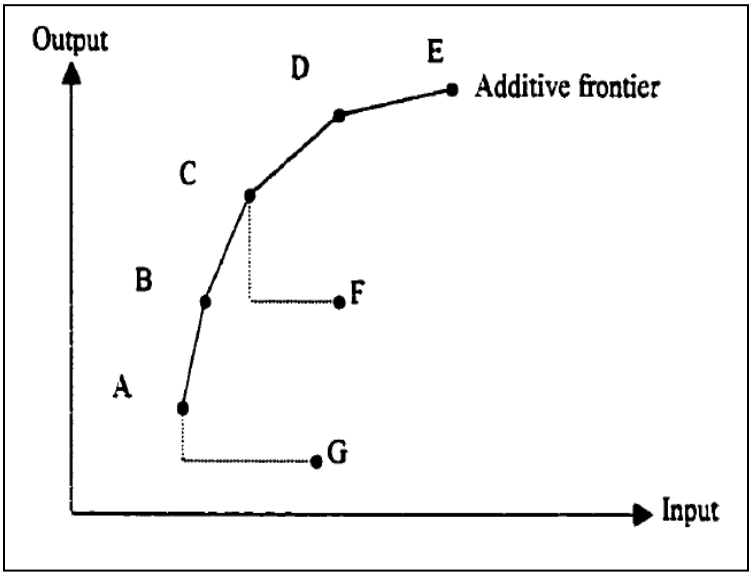

Fig. 4-6. Envelopment Surface and Projection in the Additive Model

Source: Modified from Cooper et al. 2007

The envelopment surface in the Additive model is the same as that in the BCC model, which is a variable return to scale. This is due to the presence of the convexity constraint in the dual (envelopment) and equivalently, u_0, in the primal problem.

4.4 Multiplicative Model

In the preceding DEA models, efficiency is viewed as the sum of the outputs divided by the sum of the inputs. This means that adding one more output results in an added input without any effect on the other outputs. However, in some processes, the output levels (or input levels) may be interdependent (Sherman, 1988). Charnes et al. (1982) suggested an alternative formula for the DEA, to reflect these interactions. In their model, efficiency is measured as the multiplicative combination of the outputs divided by the multiplicative combination of the inputs. The theory on which the model is based is similar to that of the CCR model, and implies that in the Multiplicative model, the DMU is efficient if and only if all the stacks are zero. The envelopment surface in the multiplicative model is piecewise log-Iinear instead of piecewise linear, which is the envelopment surface for the other DEA models. Sherman (1988) mentioned that the Multiplicative model would be used in a situation where the management's insight indicates that the production process is represented more by a multiplicative relationship.

4.5 Malmquist Index

As discussed by Färe et al. (1994), the Malmquist Productivity Index was introduced by Caves, Christensen, and Diewert (1982) after Sten Malmquist proposed constructing quantity indexes as ratios of distance functions.[18]

[18]See for details: Malmquist, Sten (1953). "Index Numbers and Indifference Curves."

In the discussion of Coelli et al. (2005), they stated that distance functions can be used in the context of multiple-output, multiple-input technology. In the applications, only data on input and output quantities are required. Distance functions can be specified as input and output distance functions. An input distance function characterizes the production technology by aiming at proportionally contracting an input vector towards the production frontier; whereas an output distance function considers a maximal proportional expansion of the output vector.

Suppose we define productivity technology set *S* as follows.

$$S=\{(x,y): x \text{ can produce } y\} \tag{4.13}$$

This set consists of all input-output vectors ***(x, y)***, such that **x** can produce **y**.

Equivalently, this set can be represented by output and input sets, respectively, as follows.

$$P(x) = \{y:x \text{ can produce } y\} = \{y:(x,y) \in S\}; \tag{4.14}$$

$$P(x) = \{x:x \text{ can produce } y\} = \{x:(x,y) \in S\}; \tag{4.15}$$

where in ***P(x)*** is the output set and ***L(x)*** is the input set. For any input-output combinations, their output and input distance function expressions are defined as follows.

$$d_0(x,y) = min\{\Theta:(y/\Theta) \in P(x)\} \tag{4.16}$$

$$d_0(x,y) = min\{\delta:(y/\delta) \in L(x)\} \tag{4.17}$$

Trabajos de Estatistica," 4 (1).

From the output distance function (4.16), we can see that when Θ is minimized, y/Θ is maximized. That is, the distance from a sub-optimal input-output combination *P* (or Q, respectively) to the production frontier *(xs, ya) [(xt, yd)]* is minimized (shown in Figure 4-7). Thus, this distance function measures the maximum possible output (frontier output) that an agent can produce given a fixed amount of inputs, relative to its current production level. Therefore, it is a measure of technical efficiency.

Figure 4-7 presents a graphical expression of a simple single-input, single-output constant-return-to-scale (CRS) production frontier. A point to note is the implementation of the "time period" into the distance function.

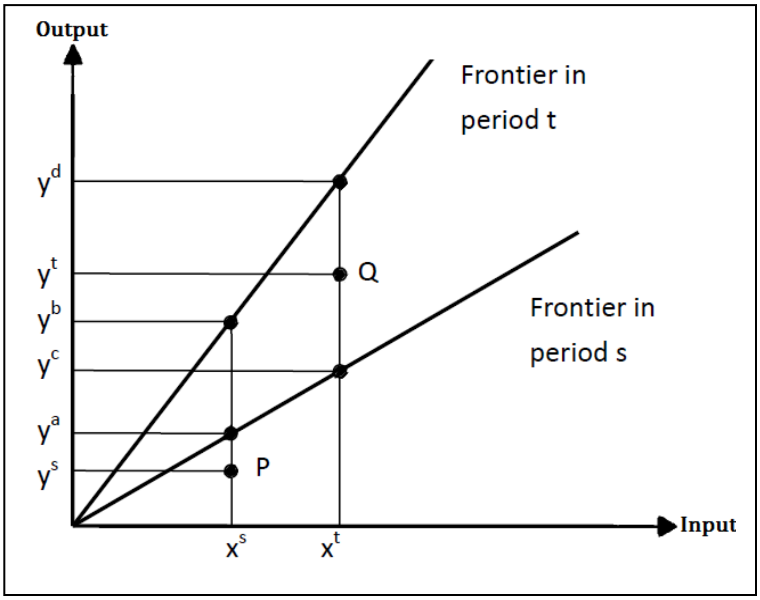

Fig 4-7. Decomposition of the Malmquist Productivity Index
Source: Modified from Cooper et al. 2007

They are denoted by *s* and *t*, as the first period and the second period, respectively. In this case, we will have one output distance function for each period. They are d_0^s *(x,y)* and d_0^t *(x,y)*, respectively. Points *P* and *Q* in Figure 4-7 represent the input-output combinations of an agent in period *s* and period *t*, respectively. In both periods, it is producing inefficiently because in period *s* (and period *t*, respectively), with input x^s (x^t), it should be able to produce y^a (y^d) if it has achieved full technical efficiency. According to Figure 4-7, the technical efficiency can be measured by y^s/y_a in period s (y^t/y^d for period *t*).

The Malmquist Productivity Index is derived exactly from the aforementioned distance functions. In this paper, the output-oriented Malmquist Productivity Index is applied for the analysis. Therefore, the following illustration will focus only on the output-oriented approach.[19]

The Malmquist Index is constructed by measuring the radial distance of the observed output and input vectors in two consecutive periods, relative to a benchmark production technology. The output-oriented Malmquist Index focuses on the maximum output(s) level one can produce, given an input vector and a production technology, relative to the observed level of output(s). Using distance functions, we can express the Malmquist Productivity Index in period *s* as follows.

$$m_0^s(y_s, y_t, x_s, x_t) = \frac{d_0^s(y_t, x_t)}{d_0^s(y_s, x_s)} \tag{4.18}$$

With reference to Figure 4-7, the Malmquist Productivity Index in period *s* can also be derived as follows.

$$m_0^s(y_s, y_t, x_s, x_t) = \frac{y_t/y_c}{y_s/y_a} = \frac{y_t/y_s}{y_c/y_a} \tag{4.19}$$

There lie two implications. First, m_0^s equals the ratio of the technical efficiency in period *t*, y_t/y_c, using the benchmark technology in period *s*, to

[19]Please see Coelli et al. (c1998) for the input-oriented approach.

the technical efficiency in period *s*, ${}^{y_s}/_{y_a}$, using the technology in the same period. Second, it is also equal to the ratio of the output growth ${}^{y_t}/_{y_s}$, to the movement along the production frontier in period *s*: ${}^{y_c}/_{y_a}$. The index is interpreted as follows: if $m_0^s > 1$, there is an increase in productivity; if $m_0^s = 1$, there is no change in productivity; and if $m_0^s < 1$, , there is a decrease in productivity.

Since the Malmquist Productivity Index can be defined using the period *s* technology or the period *t* technology, the Malmquist TFP Index is defined as the geometric mean of the Malmquist Productivity Index based on the period *s* and period *t* technologies, as a Fisher ideal index. It is given in the following equations.

$$m_0 \ (y_s, y_t, x_s, x_t) = [m_0^s(y_s, y_t, x_s, x_t) \ m_0^t(y_s, y_t, x_s, x_t)]^{1/2} \tag{4.20}$$

$$=[\frac{d_0^s(y_t,x_t)}{d_0^s(y_s,x_s)} * \frac{d_0^t(y_t,x_t)}{d_0^t(y_s,x_s)}]^{1/2} \tag{4.21}$$

$$= \frac{d_0^t(y_t,x_t)}{d_0^s(y_s,x_s)}[\frac{d_0^s(y_t,x_t)}{d_0^t(y_t,x_t)} * \frac{d_0^s(y_s,x_s)}{d_0^t(y_s,x_s)}]^{1/2} \tag{4.22}$$

Referring to Figure 4-7, $m_0 = \frac{y_t/y_d}{y_s/y_a}[\frac{y_t/y_c}{y_t/y_d} * \frac{y_s/y_a}{y_s/y_b}]^{1/2}$. Following Fare et al. (1994), we can also derive (4.22), wherein the ratio outside the brackets measures the change in technical efficiency between period *s* and period *t*. The geometric mean of the two ratios inside the brackets captures the shift in technology (production frontier) between the two periods. That is, the Malmquist TFP Index can be decomposed into the Technical Efficiency Change (4.23), Technological Change (4.24), Pure Technical Efficiency Change (4.25), and Scale Efficiency Change (4.26), as follows.

$$\text{Technical Efficiency Change} = \frac{d_0^t(CRS)(y_t, x_t)}{d_0^s(CRS)(y_s, x_s)} \quad (4.23)$$

$$\text{Technological Change} = \left[\frac{d_0^s(y_t, x_t)}{d_0^t(y_t, x_t)} * \frac{d_0^s(y_s, x_s)}{d_0^t(y_s, x_s)}\right]^{1/2} \quad (4.24)$$

$$\text{Pure Technical Efficiency Change} = \frac{d_0^t(VRS)(y_t, x_t)}{d_0^s(VRS)(y_s, x_s)} \quad (4.25)$$

$$\text{Scale Efficiency Change} = \frac{d_0^t(CRS)(y_t, x_t)}{d_0^s(CRS)(y_s, x_s)} / \frac{d_0^t(VRS)(y_t, x_t)}{d_0^s(VRS)(y_s, x_s)} \quad (4.26)$$

Though the Malmquist TFP Index appears to be more complicated, its interpretation remains the same as that of the simple Malmquist Productivity Index.

Under such decomposition, the Malmquist TFP Index allows researchers to distinguish between these two effects. Färe et al. (1994) suggested that the Technical Efficiency Change component captures the catching-up effect usually seen in developing economies by the diffusion of technology, as well as the variation in capacity utilization and the differences in the structure of the economy. On the other hand, he expects the Technological Change component to reflect the inter-temporal advances in production technology and the Scale Efficiency Change to measure the improvement efficiency when a company moves closer to the most productive scale size.

Chapter 5. Data Analysis

5.1 Data

Since SAPP is composed of 12 member countries, each country is represented by its state electric power company (ENE for Angola, BPC for Botswana, SNEL for DR Congo, LEC for Lesotho, ESCOM for Malawi, EDM for Mozambique, NamPower for Namibia, ESKOM for South Africa, SEB for Swaziland, TANESCO for Tanzania, ZESCO for Zambia, and ZESA for Zimbabwe). For this study, we used data on those companies for the period spanning 2004 to 2013. It is important to specify that each year, SAPP publishes its annual reports and posts it on its website,[20] from which we sourced our data. However, the SAPP annual reports data consist only of the Installed Capacity (MW), Maximum Demand (MW), Maximum Demand Growth (%), Number of Employees, Number of Consumers, Sales (Gwh), Sales Growth (%), Generation Sent Out (Gwh), Net Imports (Gwth), Net Exports (Gwth), Transmission System Losses (%), Revenue (US$ Million), Debtor Days, Rate of Return, and Net Income (US$ Million).

Selection of Input and Output Variables

Selection of input and output variables is among the most important tasks of performance analysis. The choice of variables depends not just on the methodology and the technical requirements of the DEA method. No universally applicable rational template is available for the selection of variables. In general, the inputs must reflect the resources used and the

[20] Southern African Power Pool, 2004-2013. Annual Reports, http://www.sapp.co.zw/areports.html, accessed on September 10, 2003.

outputs must reflect the bulk of the electricity produced. A study of standard literature reveals significant insights on the choice of variables. Jamasb and Pollitt (2001) outlined the most widely used variables based on international experience. However, in our study, the choice of variables is also consistent with the methods used in the studies of Mohd-Yunos et al. (1996) and Estache et al. (2008). We used three inputs and one output. For the inputs, we used Transmission System Losses (%) as the proxy of Electricity Loss; Installed Capacity (MW); and Number of Employees as the proxy of Labor. For the output, we used Generation (Gwh). Table 5-1 shows the summary statistics of the data that we used in this study.

Table 5-1. Summary Statistics of Input and Output Variables

Variables	Obs.	Mean	St. Dev.	Minimum	Maximum
Generation (Gwh)	120	22023.67	62305.51	99	239108
Electricity loss (%)	120	9.116667	5.983427	2	26
Installed Capacity (MW)	120	4393.467	11779.48	51	44175
Labor	120	5769.983	8907.576	439	39222

Selection of the DEA Method

For the choice of the DEA method with which to assess the companies' efficiency, we referred to the preview study of Boussofiane et al. (1997), who used both the constant returns to scale (CRS) and variable returns to scale (VRS) model in UK privatization. They found that except for two firms (out of 11), the results were similar, irrespective of whether constant or variable returns were assumed. However, this depends on whether or not the variable returns to scale assumption was invoked. Smith (1993) demonstrates that the inappropriate use of the VRS assumption can lead to widely inflated efficiency estimates when the sample size is small, as it is this study. As a result, Boussofiane et al. (1997) put more weight on the CRS DEA model. This study followed a similar approach (because we also used a small sample size in our study); and in this context, the CCR model is well adapted. Moreover, the CCR Input-oriented Model was preferred because most of the state electric power companies in SAPP are often burdened with operational costs in the energy sector. Thus, it is suggested that costs be reduced rather than increasing the volume of services provided (and from this principle, we executed the Frontier Projection Analysis). Finally, to measure the performance of those companies over time, we used the Malmquist Index. To compute our results, we used DEAP V 2.1.[21]

5.2 CCR Model and Malmquist Index Results

5.2.1 CCR Model

The CCR model provides the results of the performance of a DMU at a particular point in time relative to a set of peers. The technical efficiency, radial movement, and slack movement of each DMU were computed. The results suggest that the average score of each company is between 0 and 1 (Figure 5-1). From 2004- 2013, we regrouped three categories of companies as follows.

- Efficient companies, which had a score of 1. Among these were LEC and ESKOM, which appeared consistently on the reference frontier curve in all the years.

[21]Centre of Efficiency and Productivity Analysis: DEAP V 2.1 http://www.uq.edu.au/economics/cepa/deap.php, accessed on October 15, 2013.

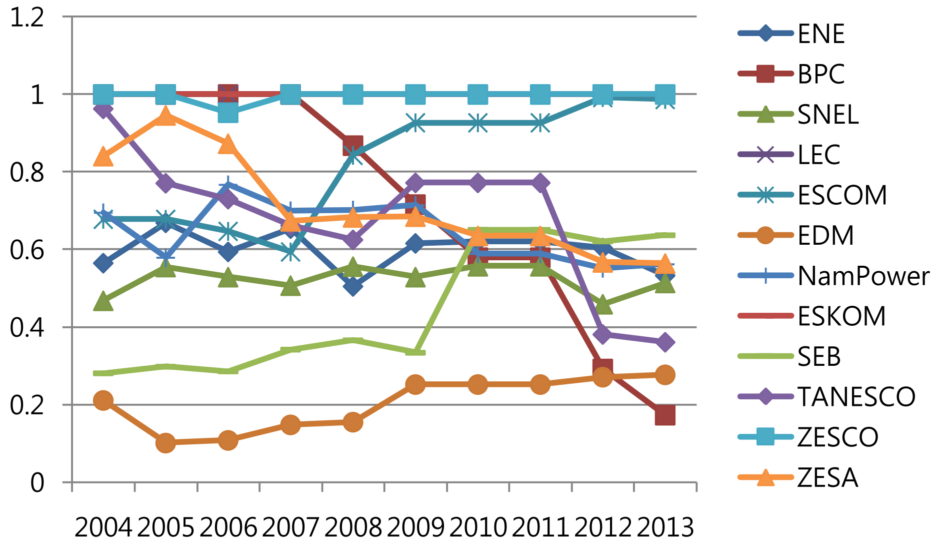

Figure 5-1. Trend of Technical Efficiency Scores for Companies

- Companies with an average efficient score higher than 0.6 (ENE, BPC, ESCOM, TANESCO, ZESCO, and ZESA). BPC was efficient only from 2003 to 2007; but in the following years, its efficiency sharply decreased. ZESA was also efficient, but its efficiency dropped slightly in 2006 and recovered slightly in 2007.

- Companies with an efficient score lower than 0.6. In this group was SNEL, EDM, NamPower, and SEB.

The efficiency of LEC and ESKOM can be explained by their ability to generate sufficient power while operating in their full installed capacity (100% for LEC and 87.7% for ESKOM, respectively) and minimizing their electricity loss.

The efficiency of ESKOM is based on its self-sustainable power generation policy dating back to the apartheid regime. Before the democratization of South Africa in 1994, the apartheid regime built many coal power plants because of the country's abundant supply of coal.

During that time, ESKOM overspent on the provision of too much generation capacity in the 1980s, when more than 30 coal power stations were built across the country to generate electricity. Between 1983 and 2005, it did not build any new generating plant; and between 2001 and 2005, it did not add capacity. After 2005, however, while demand was fast approaching the total available capacity, capacity was added to increase the power generation. Since 2010, South Africa has adopted the "New Build Programme"[22] to increase its generation capacity from about 45,000 MW to 85,000 MW between 2010 and 2030 to meet its projected demand growth. Yet in 2013, ESKOM was able to generate 237,430 Gwh of electricity output.

As for the energy efficiency of Lesotho's electric power company (LEC), in the late 1990s, the country implemented its Energy Policy of 1989, which targeted the country's economic development and ensured the national energy security instead of depending totally on imports from South Africa. In 2000, the country put in service its Muela 72MW hydropower station. It estimated the plant's output as more than enough to meet local demand during off-peak periods and in summer. The excess generated during these periods is exported. However, shortfalls emerge during peak periods and in winter.

Except in 2009, ZESCO was also among the efficient companies in SAPP. It maintained its efficiency because of the "National Energy Policy"[23] of 1994,

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[22]Source: Reported by KPMG's Global Infrastructure & Projects Group Africa Team, Johannesburg, South Africa (2011), "Sub-Saharan Power Outlook," http://www.kpmg.com/ZA/en/IssuesAndInsights/ArticlesPublications/General-Industries Publications/Documents/Sub-Saharan%20Electricity%20Outlook%20Brochure.pdf., accessed November 27, 2013.

[23]Source: Reported by CORE International, Inc. (2004). Energy Service Delivery in

which contributed to the progressive increase in the sources of electricity generation to meet the national demand and the demand of mining companies. In 2013, SAPP estimated the total installed capacity of ZESCO as about 1,870 MW and its total generated electricity, as 11,381 Gwh (SAPP, 2013). However, the company's inefficiency in 2006 is attributed to the periodical drought that affected the Zambian River and then affected electricity production at hydropower plants.

Concerning the electricity sector in Botswana, it is dominated by BPC. Electricity generation has been dominated by an overdependence on coal as a primary source of energy, largely because of its abundance and alleged cost-effectiveness. Energy efficiency efforts started in 2000. However, since 2008, Botswana has had a consistent electricity deficit, which peaked at 1174.83 Kilowatts (KWh)[24] per capita. This is due to declining electricity generation and a persistent increase in electricity consumption, which has had a negative impact on BPC's efficiency.

From 2004 to 2013, SNEL was also found inefficient because its technical efficiency score was around 0.5. Its inefficiency can be explained by its inability to generate enough electricity with respect to its total installed capacity. According to SNEL (2010), its electricity production system provides only more or less than a third of its total capacity (2,442 MW), with only 47 percent of its production equipment in working condition. The case of its Inga (I and II) hydropower plants, the true hearts of the electrical system in

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Zambia. Washington, DC, USA. Retrieved from http://www.coreintl.com/.../Energy%20Service%20Delivery%20in%20Zambia.

[24]Clean Energy Info Portal – reegle: Botswana. http://www.reegle.info/policy-and-regulatory-overviews/BW, accessed November 27, 2013 from

the DR Congo, illustrates well the general state of SNEL's network and the challenges it is facing. Currently, only three of the six groups of the Inga I work due to maintenance and repairs. Inga II suffers from both technical design issues and lack of maintenance and replacement parts. Both plants (Inga I and II) need urgent repairs, as well as major rehabilitation and reliability overhaul. Of the 52 major thermal groups in the DR Congo before the war (1996-2001), only 22 are now working. To these problems, we can add the problem of the aging and lack of maintenance of some power infrastructure that cause very frequent power outages. All these issues are among the causes of SNEL's inefficiency.

5.2.2 Malmquist Index

The Malmquist Index captures two important sources of productivity changes: gains through technical efficiency changes and technological change.

Technical efficiency change means the level to which firms improve or worsen their efficiency. Figure 5-2 reveals that LEC and ESKOM did not progress in terms of technical efficiency change during each period in our analysis.

Moreover, SNEL caught up with 18.6% in 2004-2005. In this period, its labor increased by 14.7%; its electricity loss, by 12.5%; and its generation sent out, by 16.27%. In fact, right after the reign of relative peace across the country, the establishment of the transition government[25] played a key role in the increase in SNEL's employment and its rehabilitation of its electricity generation capacity.

[25]Source: Transition Government of the DR Congo (Wilkipedia Online, http://en.wikipedia.org/wiki/Transitional_Government_of_the_Democratic_Republic_of_the_Congo, accessed November 28, 2013).

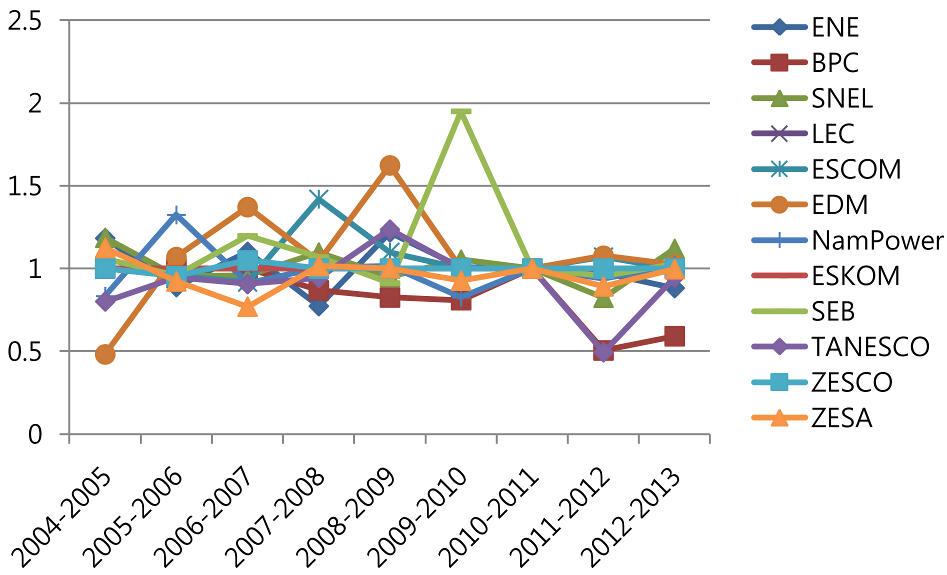

Figure 5-2. Trend of the Malmquist Index (Technical Efficiency Change) for Companies

During such transition period, the government target was the improvement of business and the economy in the country. For that, the development of the mining sector was very important, because the state did not have the funds to deal with mining activities and it was assumed that attracting foreign investors to the mining sector would boost the country's economy. Thus, increasing electricity generation[26] allowed mining operators to increase the annual production and helped improve the economic activities in the country. Some electricity generated was exported to SAPP to respond to the regional power demand. It should also be noted that the mobilization of human resources in SNEL was essential to achieving the company's assigned objective during this period. SNEL also had two successive periods (2005-

[26]Source reported by Comité de Pilotage de la Réforme des Entreprises du Portefeuille de l'Etat (2008), Rapport Annuel, http://www.copirep.cd/index.php/ressources/banque-de-donnees/category/41-rapports-annuels-du-copirep?download=109:rapport-annuel, accessed on November 28, 2013, p. 40.

2006 and 2006-2007) of negative technical efficiency change characterized by constant declines in labor and generation sent out, and hikes in electricity loss. Nevertheless, in 2007- 2008, SNEL improved with a 9.7%, and the period was marked by a 22.84% increase in electricity generation sent out, a 7.7% increase in labor, and an 11.59% drop in electricity loss. The rehabilitation of Zongo Hydropower[27] played a considerable role in the improvement of SNEL's power generation and had some impact on the company's technical efficiency change.

During all the periods, the highest progress was made by SEB, which improved by 9.5% in 2009-2010, followed by EDM, which progressed by 1.62% in 2008-2009. In 2010-2011, all the companies in the SAPP market did not progress in terms of technical efficiency change. This could be attributed to the effect of the global financial recession. However, in the last period, 2012-2013, SNEL caught up again, with an 11.9% improvement. In this period, SNEL slightly increased its electricity generation by 8.89%, and reduced its labor and electricity loss by 1.56% and 0.7%, respectively. As usual, the economic activities[28] across the country (including mining and electricity exports) were considered among the factors that stimulated this progress.

Technological change expresses the change in the efficient frontiers between two different periods. Figure 5-3 shows that most of the companies

[27] Source: Reported by Radio Okapi (2007). Réhabilitation du barrage de Zongo: Résoudra ou résoudra pas le problème de délestage en Rd Congo? http://radiookapi.net/emissions-2/2007/10/02/rehabilitation-du-barrage-de-zongo-resoudra-ou-resoudra-pas-le-probleme-de-delestage-en-rd-congo/, accessed November 28, 2013.

[28] According to Congo Opportunity Media (2013), the electricity sector has also contributed to the current economic progress in the DR Congo. http://www.congoopportunities.net/rdc-bonne-electricite-forte-economie-le-secteur-minier-cible/, accessed on November 28, 2013.

seemed to evolve along the non-progress line and had almost the same value of technological change in all the periods. This implies that most of the companies applied the same production technologies and innovations in power generation. In 2007-2008, most of the companies regressed in terms of technological change, except for ESKOM, which improved significantly by 67.7%. Thus, this was used as the reference for all the periods. SNEL's regression in terms of technological change was attributed to its inability to use technologically advanced equipment to contribute to the outward shift of the production frontier in that period.

Figure 5-3. Trend of the Malmquist Index (Technological Change) for Companies

In two successive periods (2009-2010 and 2010-2011), most of the companies did not improve in terms of technological change, except for ESKOM and ZESA, which evolved negatively in 2009-2010. Thus, the non-progress of technological change in those periods is attributed to the global financial recession.

From 2011-2012, SNEL improved by 11.5%. This could be attributed to its routine maintenance of some of its power infrastructure.

Scale Efficiency indicates if the DMUs are producing at the most efficient size. Figure 5-4 shows the scale efficiency means (2004-2013) of all the companies. In this figure, EDM and SEB reveal an increasing return to scale. ESKOM, LEC, and ZESCO each operated at a constant return of scale.

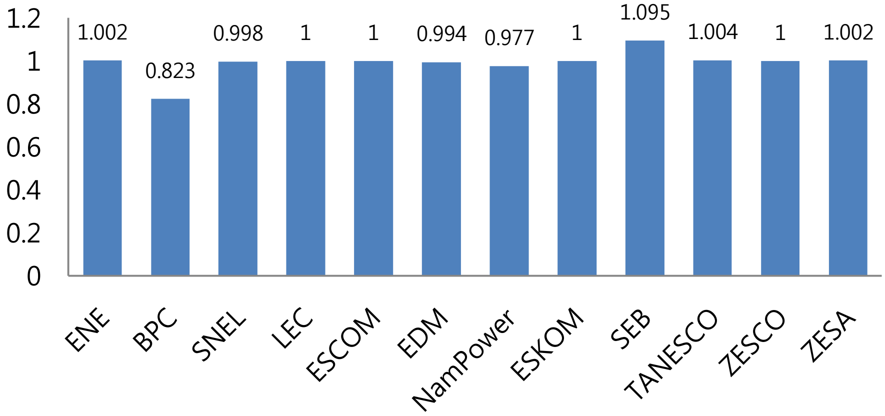

Figure 5-4. Scale Efficiency Means (2004-2013) for Companies

Regarding SNEL, the scale efficiency effect had a negative contribution to the company's productivity growth over our analysis period. The scale efficiency effect of SNEL decreased to 0.998 on the average. This indicates that SNEL operated at a decreasing return to scale because its operation scale significantly expanded its labor, increased it electricity loss, and made its installed capacity by electricity generation less than its inputs expansion.

The Malmquist Index corresponds to the product of technical change and technological change. Figure 5-5 shows that the trend of the Malmquist Index appears similar to the technical efficiency change trend because most of the companies used the same technology in the SAPP market. However, the companies that registered an improvement in their technical efficiency change improved their productivity. The best-practice companies are SEB and

ESKOM, which obtained 1.95 (2009-2010) and 1.667 (2007-2008), respectively, followed by EDM and Nampower, which achieved 1.461 (2006-2007) and 1.396 (2005-2006), respectively. For SNEL, its best-performance periods are 2004-2005, 2009-2010, and 2012-2013, during which it got 1.165, 1.054, and 1.089, respectively. The last period (2012-2013) is the best-performance period for all the categories of companies.

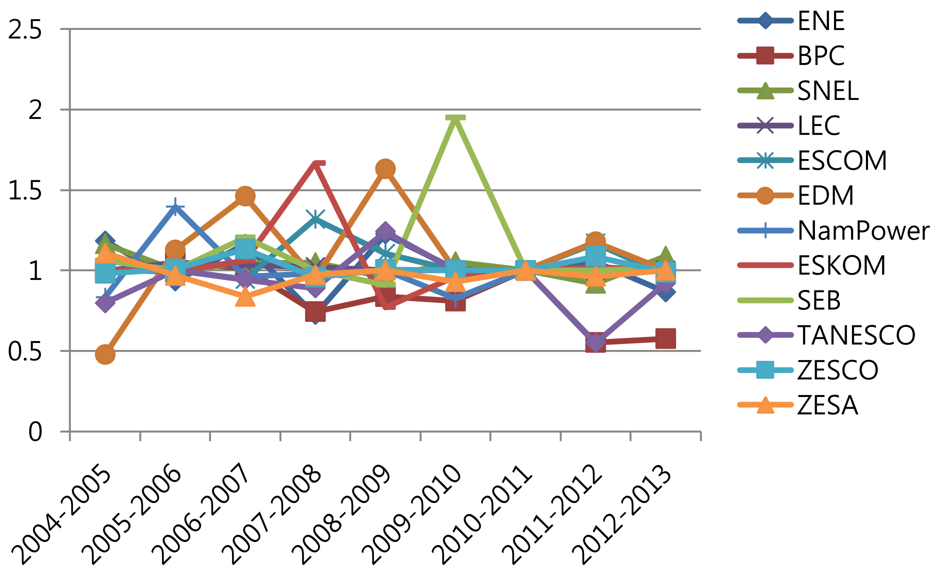

Figure 5-5. Trend of the Malmquist Index for Companies

SNEL's lowest-performance periods were 2008-2009 and 2011-2012, during which it scored 0.956 and 0.919, respectively. Both periods reflected its regression in terms of technical efficiency change. The results also suggest that in 2010-2011, all the companies in the region did not progress in terms of productivity change. This could also be attributed to the global financial recession.

The Malmquist Index summary provides the average values of the productivity change of the companies during our analysis period. Figure 5-6 suggests that throughout our study period, LEC, ESCOM, EDM, ESKOM, SEB, and ZESCO registered a positive productivity change over time of 1-9.7%. Moreover, ENE and SNEL did not improve their productivity change in our study period, as shown by their score of 1.

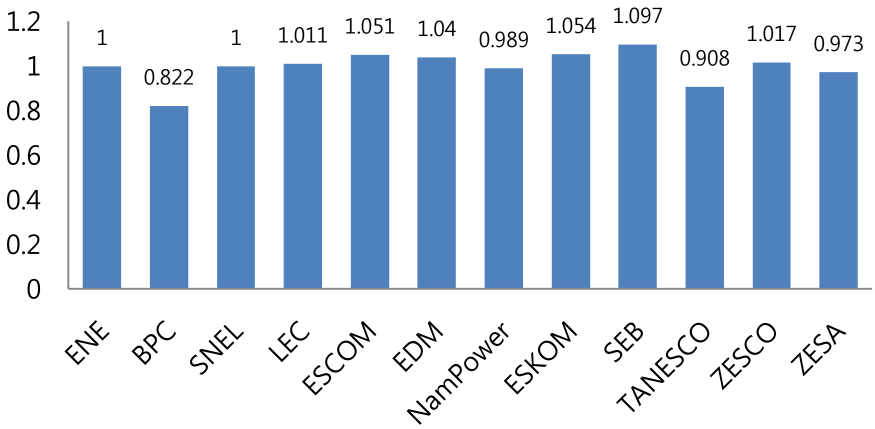

Figure 5-6. Malmquist Index Summary for Companies (2004- 2013)

Finally, the worst performers among the companies are BPC, Nampower, TANESCO, and ZESA because they regressed in terms of productivity change at values below 1. However, based on our findings, it seems that the companies that positively progressed in terms of productivity change are those that developed a regulatory authority[29] in their energy sector. Thus, it is important to assess the impact of a regulatory authority hypothesis on the companies' efficiency in the second stage.

[29] According to Estache et al. (2008), LEC, ESCOM, EDM, ESKOM, SEB, and ZESCO have developed a regulatory authority in their energy sector, p. 1971.

5.3 Environmental Factors Analysis

5.3.1 Description of Variables

To assess the impact of environmental factors on the companies' efficiencies, we used the regression model and the following variable human resources, income per capita, regulatory authority, competition in electricity generation, government ownership, vertical integration, competition in electricity distribution, electricity net exports (Gwh), the country's size (Skm) and urban population (%).

1. Human Resources (hr)

Human Resources is the division of a company that is focused on activities relating to its employees. It has the ability to create firms that are more intelligent, flexible, and competent than their rivals through the application of policies and practices concentrated on recruiting, selecting, and training employees, and directing their efforts to the corporate resources bundle of the organization. These can consolidate the company's performance, give it a competitive advantage, and sustain its positive corporate performance, as Wright (1998) and Sang (2005) confirmed. In this research, we estimated that all the companies operate in their respective country and rely on their local human resources. However, we used the Education Index provided by the United Nations Development Programme (UNDP) as proxy for the availability of the skilled professionals required by companies.

2. Income per Capita (inc)

Income per capita measures the amount of money being earned per person in a certain area. It can apply to the average per-person income for a city, region, or country and is used as a means of evaluating the living conditions and quality of life in different areas. The income per capita in Sub-Saharan Africa is still low. The World Bank (2010) argues that the dismal economic and social development record of Sub-Saharan Africa over the past 40 years is well known. The per capita income growth of the region over the period has been static, and over the past 20 years, negative. Its average incomes in 2000 were about 10% lower than in 1980. Increases in public spending have generally not been matched by significant improvements in access to public services. Chronic fiscal and monetary imbalances in many countries have resulted in high exchange rate risks and high real domestic currency interest rates, both deterring private investment by national and foreign investors. In this study, the GDP per capita (current US $) was used as proxy for the income per capita. The data were collected from the World Bank.[30]

3. Regulatory Authority (rg)

An adequate and effective regulatory authority is essential to ensuring supply reliability, continuous investments, reasonable pricing, and proper market behavior. In a regulated market where competition is minimal or lacking, the regulator's role is to provide oversight that would ensure that consumers receive reliable and safe supply of electricity at reasonable prices, and to provide energy companies some flexibility as to how to meet their performance goals. This is only if an independent regulatory authority is established in a country's energy sector. However, in most developing countries, many energy sector regulatory authorities suffer from the problem of dependency because they are directly controlled by the government. In our study, we used dummies to specify countries that have regulated their energy

[30]World Bank: http://data.worldbank.org/, accessed November 30, 2013.

sector and those that have not yet regulated their energy sector.

4. Competition in Electricity Generation (cg)

Although a competitive industry provides many advantages (fostering of innovation, provision of new services, price reduction, more jobs, etc.), the empirical studies conducted by Caves and Baron (1990), Green and Mayes (1991), and Caves et al. (1992) found that an increase in the market concentration above a certain threshold tends to reduce companies' efficiency, but in a competitive market, companies achieve production efficiency because they produce at the lowest point. It is from this fact that we chose the competition in electricity generation as an independent variable to assess its impact on company efficiency. For our study, we used dummies to specify countries that are competitive in electricity generation in the energy sector and those that are not.

5. Government Ownership (go)

The ownership structure is one of the important factors that determine the efficiency level of a corporation (Berle and Means, 1932). In our context, all the companies operating in the SAPP market are owned by their respective governments. We used a dummy for this variable.

6. Vertical Integration (vi)

In a corporate strategy, vertical integration sometimes provides a certain advantage. It can be viewed as a way of capturing rent and firm-specific assets when it is difficult to sell in intermediate markets (Penrose, 1999), and of developing new capabilities. However, in other cases, it can reduce the performance of a company whenever the company follows a different objective at the same moment. We used a dummy for this variable.

7. Competition in Electricity Distribution (cd)

Competition in electricity distribution enhances technical efficiency primarily because it provides greater discipline than regulatory oversight in ensuring that the lowest-cost producer builds and operates distribution assets and offers reliable services. This benefit of competition is why many purchasers of all types of goods and services rely on competitive bids. In the real world, different suppliers may increase their efforts to reduce their costs and mark-ups, to lower the overall cost of their service to customers and improve their service. We also used a dummy to represent countries that are competitive in electricity distribution in the energy sector and those that are not.

8. Electricity Net Exports (exp)

Electricity exports are the products of the process of producing electricity in one country and selling or trading it to another country. This also constitutes one of the tasks of SAPP; as part of its regional mission, it enables countries with electric power to export them in the Southern African region. Exports provide some advantages for companies such as increases in sales and profits, expansion of global market share, earning of foreign exchange for the country, and enhancement of regional performance and competitiveness**.** Data on electricity net exports (Gwh) were also collected from the SAPP annual report.

9. Country's Size (cz)

The size of a company's host country also affects the company's efficiency, because it is acknowledged that the larger the country's land area is, the more resources and infrastructure the company would require expanding its activities through the country. The country's size could also contribute to the increase in the company's electricity loss, because a country with a larger land area would require long-distance[31] transmission from the hydropower or thermal power station. For our study, data on the countries' sizes (Skm) were also collected from the World Bank database.

10. Urban Population (urb)

The urban population[32] refers to the population living in an area characterized by a higher population density and vast human features (cities, towns, or conurbations), in comparison to the areas surrounding it. However, it is often acknowledged that life standards[33] in urban areas are higher, as are urban population expenditures. Thus, a company that provides services to urban populations might enjoy enhanced performance in terms of sales and profits.

5.3.2 Hypothesis

Referring to the previous study, Pombo et al. (1994) assessed determinants of efficiency by using the Tobit model at the second stage of DEA and found that, holding other factors constant, the regulatory framework had positive effects on the efficiency of electric utilities in Colombia. This finding was consistent with that of another previous study (Pombo and Ramiz, 2003) on the analysis

[31] According to Wong (2011), losses tend to be higher since the transmission system is composed of longer and lower-voltage transmission lines, which cause more losses. The location of a generator with respect to the grid and with respect to the load (where the energy is consumed) affects the volume of line losses that occur. http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf, accessed on November 28, 2013.

[32] The UN (2012) argues that 309 million Sub-Saharan Africans out of a total estimated population of 843 million live in urban areas. At 36.7%, this represents the lowest urban proportion of all major world regions. In contrast, Europe is 72.9% urban; North America, 82.2%; and Latin America and the Caribbean, 79.1% in the same year (UN, 2012).

[33] Polèse (2009) demonstrates in detail that while urbanization takes place as per capita wealth increases, many countries -- including many in the developing world -- can sustain a very high level of urbanization without levels of wealth corresponding to what might be expected in northern, more developed countries. Aside from oil-rich desert countries, most wealthy countries are also highly urbanized.

of the efficiency of electricity generation in Colombia. Such study also found that the ownership of electric power companies does not guarantee the improvement of their efficiency (since ownership as an explanatory factor turned out insignificant). Similarly, Pillit (1995) found that ownership does not guarantee the improvement of plants. The study of Pombo et al. (1994) found that large efficient electric utilities can be used as benchmarks by small inefficient utilities.

Moreover, in our study, we assumed that the regulatory authority had a negative effect on the companies' efficiency because in developing countries, most regulatory authorities have direct ties with government departments and do not promote innovation nor ensure supply reliability, continuous investments, and reasonable pricing to contribute to the improvement of the efficiency of electric power companies.

5.3.3 Regression Model

In our study, we used the Panel OLS model to estimate the impact of environmental factors on the companies' efficiency.

Consider the following linear regression equation.

$$y_{ij}t = \beta_0 t + \beta_1 x_{ij} t + z'_j t \gamma + u_{ij} t + \varepsilon_j t \tag{5.1}$$

In this equation, y_{ij} is the dependent variable, j = 1, …g means "group," t = 1, 2, 3, 4…, and 10 years, I = 1, 2, 3, 4..., and 12 companies, x_{ij} is a vector of explanatory variables, z_j is a vector of explanatory variables common to members of group j, and u refers to the i.i.d. normal errors, which are independent of the i.i.d. group errors ε. Traditionally, the OLS coefficient estimators, R^2 and Adjusted-R^2, are computed using the following formula.

$$\hat{\beta} = (X^{'}X)^{-1}X^{'}y \tag{5.2}$$

The proportion of variation in y is "explained" by the regression on the j independent variables.

$$R^2 = r^2_{Y\bullet 1,\ldots,k} = \frac{\sum_{i=1}^{n}\left(\hat{Y}_i - \overline{Y}\right)^2}{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2} = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{5.3}$$

To compare models with different sets of independent variables in terms of their predictive capabilities, we used the Adjusted-R^2 (which penalizes models with unnecessary or redundant predictors).

$$Adj - R^2 = r^2_{adj} = 1 - \left(\frac{n-1}{n-k-1}\right)\left(\frac{SSE}{SST}\right) = 1 - \left[\left(1 - r^2_{Y\bullet 1,\ldots,k}\right)\left(\frac{n-1}{n-k-1}\right)\right] \tag{5.4}$$

By incorporating the dummy variable, $d_jt = z_j'ty + \varepsilon_jt$, (5.1) can be rewritten as follows.

$$y_{ij}t = \beta_0t + \beta_1x_{ij}t + d_jt + u_{ij}t \tag{5.5}$$

From (5.5), our model is represented as follows.

$$DEA_t = \beta_{ot} + \beta_1hr_t + \beta_2inc_t + \beta_3ca_t + \beta_4rg_t + \beta_5cg_t + \beta_6go_t + \beta_7vi_t + \beta_8cd_t + \beta_9imp_t + \beta_{10}exp_t + \beta_{11}cz_t + \beta_{12}urb_t + u_t \tag{5.6}$$

Finally, for the linear (straight-line) regression model, the elasticity is as follows.

$$\varepsilon = \frac{dln(y)}{dx(x)} = \frac{\frac{dy}{dy}}{\frac{dx}{dx}} \tag{5.7}$$

5.3.4 Interpretation of Results

Tables 5-2 and 5-3 show that the coefficient of the human resources, income per capita, competition in electricity generation, vertical integration, competition in electricity distribution, and electricity net exports and urban population were statistically significant at 99%. The magnitudes of the 7 coefficients were practically significant. We also found that even though the important constant of our model (regulatory authority) and the country's size constant were statistically insignificant, they still had the expected sign and also boosted the R^2 and Adjusted-R^2 of the coefficients of the significant variables. However, the resulting government ownership coefficient was omitted.

Our findings suggest that human resources affect the efficiency of companies positively, holding other variables constant. A one-unit increase in human resources increases a company's efficiency value by 0.0935309 units. To put it differently, a percentage change in human resources leads to a 0.80% increase in a company's efficiency. This implies that the companies were able to use skilled and well-trained employees to consolidate their performance, create innovative and competitive advantage, and sustain their positive corporate performance. Thus, human resources is one of the important factors that contribute positively to the efficiency of electric power companies in

Table5-2. Second-Stage Regression Results

	DEA
hr	0.1055973 **(7.69)
inc	-0.0001313 **(-6.57)
rg	-0.0138786 **(-0.23)
cg	-0.3101605 **(-5.64)
vi	-0.2589586 **(-3.55)
cd	0.4495562 **(7.13)
exp	0.0000506 **(5.34)
cz	-8.56e-08 **(-1.89)
urb	0.0173058 **(6.15)
constant	-.0234978 **(-0.15)
R-squared	0.5260
Adj. R^2	0.4872
Observations	120
No. of company	12
	DEA
hr	0.1055973 **(7.69)

**Significant at 1%

Table 5-3. Elasticity of Variables

	$\boldsymbol{\varepsilon}$
hr	0.9005208 **(7.55)
inc	-0.4367568 **(-6.48)
rg	-0.0118113 **(-0.23)
cg	-0.3345972 **(-5.59)
vi	-0.3104014 **(-3.53)
cd	0.3233171 **(7.02)
exp	0.07892 **(5.29)
cz	-0.0929554 **(-1.89)
urb	0.917563 **(6.08)
y	0.695225
	$\boldsymbol{\varepsilon}$
hr	0.9005208 **(7.55)

**Significant at 1%

the SAPP market..

The interpretations of the following variables are similar to that of the human resources variable.

The result for the income per capita suggests that a one-unit increase in the income per capita will decrease a company’s efficiency value by 0.0001072. Likewise, a company’s efficiency decreases by 0.36% for each additional percentage change in its income per capita. Two factors may explain this finding. The first factor concerns inadequate power supply, and the second is related to the high average price of electricity in the region. Inadequate power supply takes a heavy toll on all layers of society in Africa. Even currently, domestic and private consumers are experiencing frequent outages, which mean big losses in forgone sales and damaged equipment. Regarding the high price of electricity in the region, according to Eberhard (2008), the average price of power in Sub-Saharan Africa is high by international standards. The average tariff in the region rose from $0.07 per Kwh in 2001 to $0.13 per Kwh in 2005, around twice that in other parts of the developing world, and almost at par with that in high-income countries. Comparing the average electricity tariff and the low income of the population in the region (World Bank, 2010),[34] most people often cannot afford to use electricity services. Consequently, both mentioned issues may compel most consumers to substitute complementary capital (for backup generators and cheap energy[35] sources) for deficient public services.

The competition in electricity generation coefficient suggests that a one-unit increase in competition in electricity generation decreases a company's efficiency value by 0.2824925 units. In the same manner, a company's efficiency decreases by 0.30% for each additional change in competition in electricity generation. This is because most of the SAPP member countries could not develop good regulators in their respective energy sectors to secure companies competing in electricity generation from some possible prevailing barriers (JKNU,[36] 2008). Thus, JKNU (2008) found that companies that are

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[34]The World Bank (2010) also argues that 63% of the Sub-Saharan Africa population lives in rural areas.

[35]The Infrastructure Consortium for Africa (2011) also reported that Sub-Saharan Africa is characterized by wide disparities in electricity consumption per capita, and that traditional fuels (especially wood and its derivatives) are consumed much more in the region.

[36]John Kwoka Northeastern University found that scale economies, high cost of

susceptible to developing scale excess in the competition in electricity generation would more readily and cheaply expand out in the face of entry, thereby denying the entrant its expected market opportunity and negatively affecting the entrant's profitability and performance. Moreover, in such market, companies dealing with the high cost of capital and long lead times of projects may face market risks, that is, uncertainties in future market conditions and in the price that the project's output will command over the payback horizon, and negative profitability (in the context of Sub-Saharan Africa, because its population's income is too low to expect any possible expense recovery).

The findings with regard to the vertical integration coefficient reveal that a one-unit increase in vertical integration decreases a company's efficiency value by 0.2192665 units. To put it differently, a company's efficiency decreases by 0.26% for each additional change in its vertical integration. This means that dealing more with generation, transmission, and distribution will likely reduce the efficiency of a vertically integrated electric power company. This is because of the multiple objectives that the company pursues whenever it is dealing at the same time with generation, distribution, and transmission. Therefore, unbundling the company's activities into separate and standard activities could be suggested to enable efficient allocation of its resources.

The coefficient of competition in electricity distribution more significantly affected the companies' efficiency than the other variables, and suggests that a one-unit increase in competition in electricity distribution increases the efficiency of a company by 0.4409879 units. To put it differently, a company's efficiency increases by 0.32% for each additional change in its

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capital, and long lead times are prevailing barriers of competition in electricity generation.

competition in electricity distribution. Thus, the number of operators in the electricity distribution market may enhance the efficiency of a company. As mentioned earlier, competition in electricity distribution enhances technical efficiency primarily because it provides greater discipline than regulatory oversight in ensuring that the lowest-cost producer builds and operates distribution assets and offers reliable services.

The results of the companies' net electricity exports demonstrate that increasing one unit of net electricity exports increases a company's efficiency value by 0.0000799 units. Similarly, the company's efficiency increases by 0.12% for an additional change in net electricity exports. This implies that companies that are exporting electricity would likely not only increase in efficiency, but also increase in sales and profits, gain global market share, and earn foreign exchange for the country. Unfortunately, SNEL was found in the category of companies that annually decrease their electricity exports (e.g., in 2012-2013, SNEL decreased its electricity exports by 59.6%).

Regarding the urban population coefficient, we found that one unit increase in the urban population increases a company's efficiency by 0.0186262. To put it differently, the company's efficiency increases by 0.99% for each additional change in the urban population. This can be explained by the fact that companies operating in Sub-Saharan Africa drew some advantages in the urban area due to the conditions of life there. Yet, people living there are much more willing to spend to maintain their life standard. Thus, the growth[37] of the urban population had a positive impact on the

[37] According to the African Development Bank Group (2012), Sub-Saharan Africa has experienced an unprecedented rate of urban growth, outpacing other regions. http://www.afdb.org/fileadmin/uploads/afdb/Documents/PolicyDocuments/FINAL%20Briefing%20Note%204%20Africas%20Demographic%20Trends.pdf, accessed on November 30, 2013.

companies' efficiency.

Our important coefficient, the "regulatory authority," which is negative, means that it is an obstacle for the companies. This is because as mentioned earlier, in most developing countries, many energy sector regulatory authorities have direct ties with the government and are handled by it. Nevertheless, a commonly advised solution to this problem is to increase the independence of the regulator. This may work if the independent regulatory authority can tie its hands in a way that the government cannot,[38] or if the regulator has a greater concern for its reputation than has the government.

The country's size coefficient is also negative. This implies that the larger the size of a country is, the more the important companies require efforts, resources, and infrastructure to expand their activities throughout the country. This corresponds to the context of centralized electricity generation. Reducing the regional operation of a company by half would also reduce the inefficiency by half. Moreover, as mentioned earlier, the country's size could contribute to the increase in electricity loss, which prevails whenever electricity is mainly produced at large generation facilities and shipped over a long distance through the transmission and distribution grids to the end-consumers. In terms of size, the DR Congo is the second largest country in Africa (surface area: 2,345,409 Skm) and the largest country in Sub-Saharan Africa. The DR Congo's electric power company (SNEL) has the monopoly over the entire country. This implies that the issue of size has a negative impact on SNEL's efficiency. This is because as SNEL's services are centralized, it requires too much and makes considerable efforts to provide its

[38]For example, if the regulator is constrained by the judiciary but the executive is not, the regulator could commit itself through a legal agreement. However, if the objectives of the regulator and the government align, then an independent regulator may simply ask the government to help "untie" its hands. This argument seems unsatisfactory if both parties are strictly benevolent.

services over the entire DR Congo.

Finally, the result of government ownership is omitted. Regarding this result, we assume that in our research, the ownership does not guarantee the improvement of the company's efficiency.

5.4 Benchmark Analysis

We analyzed the study results to determine the best-performing companies. We did this using the Benchmark Analysis. Regarding this, the CCR model results also provided some frontier benchmarks that were referred to efficient reference sets for each company.

5.4.1 Efficient Reference Sets

The presentation in Table 5-4 summarizes some efficient reference sets for SNEL from 2004 to 2013. The efficiency reference set indicates the relatively efficient units whose positions on the frontier are the best possible positions

Table 5-4. Efficient Reference Sets for SNEL (2004-2013)

Year	Company 1	Company 2	Company 3	Company 4	Total No. of Companies
2004	LEC	ESKOM	BPC	ZESCO	4
2005	LEC	ESKOM	BPC	ZESCO	4
2006	LEC	ESKOM	BPC		3
2007	LEC	ESKOM	BPC	ZESCO	4
2008	LEC	ESKOM		ZESCO	3
2009	LEC	ESKOM		ZESCO	3
2010	LEC	ESKOM		ZESCO	3
2011	LEC	ESKOM		ZESCO	3
2012	LEC	ESKOM		ZESCO	3
2013	LEC	ESKOM		ZESCO	3

against which the inefficient units were most clearly determined to be inefficient.

The results reveal that from 2003 to 2007, BPC was to be an efficient reference set for SNEL. However, after 2007, BPC failed to evolve on the efficient frontier and became inefficient.

ZESCO was also an efficient reference set, except in 2006, from which time the company lost its efficiency. The results also showed that some companies – LEC and ESKOM -- appeared successively as efficient reference sets during all the periods of our analysis. Thus, for SNEL to improve its efficiency, it has to follow the footsteps of LEC and ESKOM.

5.4.2 Frontier Projections

Table 5-5 shows the percentage of the mean projected value of each indicator for each company.

Table 5-5. Mean Percentage Projections of the Indicators to the Frontier for each Company (2004 -2013)

		Indicators			
			Inputs		Output
Countries	Companies	Electricity Loss	Installed Capacity	Labor	Generation
Angola	ENE	-47.85%	-40.18%	-44.56%	0%
Botswana	BPC	-30.81%	-27.91%	-51.99%	0%
DR Congo	SNEL	-47.68%	-47.68%	-56.18%	0%
Malawi	ESCOM	-17.98%	-17.98%	-53.10%	0%
Mozambique	EDM	-79.98%	-79.63%	-92.98%	0%
Namibia	NamPower	-55.18%	-35.52%	-35.52%	0%
Swaziland	SEB	-65.34%	-55.31%	-69.39%	0%
Tanzania	TANESCO	-31.93%	-31.84%	-50.54%	0%
Zimbabwe	ZESA	-28.97%	-28.97%	-42.12%	0%

This is obtained first by subtracting the original value of each company's indicators by their respective radial and slack movements with respect to their year (2004-2013), then by converting each obtained value of each year in percentage and finally, by computing their mean.

However, we should recall that the purpose of the frontier projections is to make inefficient companies efficient by bringing them to the frontier with respect to the efficient reference sets. This purpose is implemented from the principle of the CCR input-oriented model, which minimizes inputs while producing at least the given output levels. The negative sign that is expected for the inputs means a projected reduction while keeping the output constant.

The electricity loss projections suggest that reducing the electricity loss much more while keeping the output constant will make a company appear efficient; otherwise, it will make a company inefficient. Our analysis reveals that in Sub-Saharan Africa, the average projected electricity loss for SNEL is -47.68%. This corresponds to the overall amount of the electricity loss that SNEL should reduce to enhance its efficiency, while holding the electricity generation constant. EDM and SEB are companies that were highly affected by the electricity loss, since their respective average projected electricity losses are -79.98% and -65.34%. However, ESCOM and ZESA have low average projected electricity losses of -17.98% and -28.97%, respectively. As mentioned previously, long transmission lines contribute to electricity loss. The United Nations Economic Commission for Africa (2007) also stated that poor maintenance of the transmission and distribution system is also among the factors that are causing electricity loss, which is undermining the financial[39] performance of the electricity utilities.

[39] The United Nations Economic Commission for Africa (2007) stated that by controlling high system losses and low electrification levels, combined with higher

Regarding the installed capacity projection for each company, as the technical efficiency computed herein is based on the ability of a company to efficiently convert its resources into outputs, the companies' installed capacities are input variables that cannot be technically reduced. In the generation sector, the efficiency of a company is described by the sufficient amount of electricity it produces with respect to its installed capacity. Yet in Africa, most plants do not generate enough electricity because they do not operate at full capacity. As much as one quarter of that capacity is unavailable because of aging plants and poor maintenance.

The average projected installed capacity for SNEL to the frontier is -47.68%. To put it differently, the average unavailable installed capacity for SNEL is -47.68%. This finding is consistent with the argument in SNEL's report (2005), which says that in the DR Congo, most hydropower and thermal power plants are not in operation due to aging and technical problems. Other electricity plants are being decommissioned because their operation period have reached 25 years. Besides, the findings reveal that ESCOM seems to be the company in the region that is planning to catch up by increasing its power generation trend. This is because Malawi's electric power company (ESCOM) makes a large portion of its installed capacity available for electricity generation (its installed capacity projection is -35.52%). This can also explain ESCOM's yearly increasing technical efficiency trend, as shown in Figure 5-1.

The labor indicators reveal that EDM and SEB also have the highest percentages of labor overstaffing among the companies in SAPP. The -56.18% labor projection for SNEL corresponds to the percentage of employees that SNEL should reduce to enhance its efficiency and catch up with its efficient

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tariff levels, electricity utilities should be able to realize higher revenue levels.

reference sets.

Chapter 6. Policy Implications and Conclusion

6.1 Policy Implications

Referring to our findings, we prescribed policy implications to provide innovative ideas for enhancing SNEL's performance level. However, these suggested implications (below) should be considered in making any reformative decision in the energy sector in the DR Congo.

Income per capita is one of the important factors that determine the efficiency level of electric power companies. Our findings revealed that an increase in income per capita has a negative impact on the efficiency of companies. This is because as mentioned previously, the electricity services in most Sub-Saharan African countries are unreliable due to the problem of outages, and are characterized by high prices of services. Both situations compel most consumers in the region to substitute complementary capital (for backup generators and cheap energy sources) for deficient public services. Therefore, it is important for companies to ensure reliability of their services by guaranteeing full-time electricity supply to consumers. This could be done by maintaining and replacing some power infrastructure, because from the regional aspect, most power infrastructure are suffering from aging and are becoming almost unused. Companies should also promote cheaper sources of energy (biomass: fuelwood, biogas, and biofuels) for affordability and diversification. However, promoting biomass as an alternative energy source for generating electrical power has some economic benefits. Moreover, it can be a useful source of energy in remote areas and small industrial areas. One of the most important advantages of biomass is its cheap prices. Moreover, it is a readily available source of energy. In addition, it is a continuous and long-term source, and it can be found easily, any time and almost anywhere.

Despite all the possible advantages of competition in electricity generation, our results revealed the contrary. They showed that competition in electricity generation in the energy sector in each country in Sub-Saharan Africa has a negative impact on the companies' efficiency. It was argued that this was because of the weakness of the regulation for preventing some possible prevailing barriers (scale economies, high cost of capital, and long lead times) during the competition in electricity generation. It was previously mentioned that JKNU (2008) revealed the negative impact of those barriers to competition in electricity generation in the electricity market in the US when there is no regulation. They may have a significant negative impact on the companies' profitability and performance. To address these issues, it may be better for the electricity generation activity of each SAPP member country to establish a coherent legislation and regulation in its country's energy sectors. However, the role of legislation here would be to remove legal, economic, and social barriers, and the regulation would protect the state electric company from anticompetitive special interests (OAS,[40] 2013).

Another important factor that determines the level of efficiency of a state electric power company in SAPP is vertical integration. The traditional structure of electric power industry countries involves large vertically integrated electric companies that perform four functions: generation, transmission, distribution, and supply. In an industrial organization, vertical integration constitutes a best strategy aim of a single diversified firm producing an output bundle rather than separate specialized firms splitting up the production of each output, or subset of outputs. However, our study

[40]Source: Organization of American States (OAS): Government's Role in the Electricity Sector, http://www.oas.org/dsd/publications/Unit/oea79e/ch08.htm#b.%20GOVERNMENT&146;S%20REGULATORY%20ROLE, accessed November 28, 2013.

findings revealed that vertical integration is disadvantageous for enhancing state electric power companies. Consequently, unbundling SNEL into different subsidiary entities would also be one of the best strategies for improving company efficiency and would keep the company safe from the negative effects of vertical integration (withholding of information, administrative inefficiencies due to the complexity of the company's management, production costs, etc.). The role of SNEL's subsidiary entities would be to perform each different function in the electricity sector in the DR Congo (generation, transmission, distribution and supply). This implies that SNEL would have three different autonomic subsidiaries, each with different functions.

The purpose of SAPP is to promote electricity trade among its member countries. Despite some advantages that electricity exports vide, our results suggested that electricity net exports in SAPP had positive effects on the efficiency of the companies. Regarding this, SAPP should encourage its member countries to promote and increase electricity exports in the region and also, and that must be done by maintaining and repairing power infrastructures and also by building[41] new power generation infrastructures or developing other local cheaper source of energy. Since, the objective here is to satisfy the regional demand.

Even though most of energy markets in the SAPP member countries are monopolies, the result revealed that competition in electricity distribution has a positive effect on the companies' efficiency. This finding also has an important implication in the energy market in the DR Congo, since inside the

[41] According to the World Energy Council (2008), with the projects of Inga III and Grand Inga hydropowers, the DR Congo will become a bigger exporter of energy in Africa through possible interconnection links from Southern Africa up to Southern Europe.

country, SNEL has the monopoly of the market. However, opening the distribution market to private competitors may enhance SNEL's efficiency and improve service delivery quality. Consumers would also definitely benefit from this process because competition in electricity distribution would allow them to choose among providers and service options. This combination of open entry for suppliers and choice for customers provides the benefits of competitive markets (e.g., efficient resource allocation, accurate price signals, and incentives for innovation) and limits competitors' ability to exercise market power. Customers are protected from open-ended commitments to pay above-market costs that would not occur in a competitive market. This does not mean that entry into markets will be costless or easy, but rather, that all actual competitors, incumbents, and new entrants alike will have made (and potential competitors could make) the investments and commitments needed for them to compete in the market.

The benchmark analysis revealed that ESKOM and LEC appear to be efficient reference sets for SNEL. This implies that cooperation between state electric powers companies evolving in the SAPP market should be initiated to allow them to gain experience and knowhow from efficient companies. ESKOM was established in 1923, and its success is attributed to its range of power stations, good understanding of the cost of yearly internally electricity, 30-year optimization of dispatch, good staff and good software for analyzing electricity problems; whereas Lesotho, a country enclaved by South Africa, learned to improve the efficiency trend of its state electric power company (LEC) through ESKOM.

Electricity loss is one of the problems in the energy sector in Africa because it negatively affects companies' performance. Electricity loss in Africa is caused by the problems of aging and the long distance of most transmission and distribution lines from hydropower or thermal power stations to the distribution centers of consumers. To overcome the problems pertaining to electricity loss, companies should use short, appropriate, and updated electric power transmission lines from generation centers to high-voltage distribution systems. However, Tallapragada et al. (2009) also proposed some recommendations to address this problem, some of which are improving billing and collection, establishing a GIS/GPS-based inventory of all distribution infrastructure (such as poles and transformers), improving metering, establishing benchmarks of performance in areas of greatest loss (for both system losses and collection losses) to set targets, monitoring of improvement over time, etc.

To overcome the effect of unavailable or decreasing installed capacity that most state electric power companies in Sub-Saharan Africa face, the results of the analysis conducted in our research suggest the reappearance of power plants (hydropower and thermal power plants). This can be realized by injecting sufficient funds in power generation and initiating some Public-Private Partnerships. SNEL is currently rehabilitating and building some power plants (Inga I, Inga II, Inga III, Grand Inga, Zongo I, Zongo II, etc.). Once they are completed, they will significantly increase the power generation of SNEL and will make it one of the important electricity exporters in Africa.

One of the issues that affects most state electric companies in SAPP is the problem of strong government control of such companies. In their research on the managerial form of companies, Chang and Singh (1997) argue that the government's rigid and bureaucratic supervision make companies inefficient.

To deal with this problem, Rasiah (2012) found that the separation[42] of ownership and control provides a more efficient hierarchical decision-making system for the company to reach its goal. Referring to this finding, we noticed that South Africa’s electric power company (ESKOM) has also opted for partial separation of ownership and control through managed liberalization since the late 1990s (Greenpeace Africa, 2012). As a result, ESKOM has improved in terms of management, consults its shareholders in most of its decisions to formulate policies, is increasing its generation capacity by introducing nuclear power, and has become the world’s 11th largest power utility in terms of power generation capacity. Therefore, this form of governance testifies that there is much room for the improvement of SNEL’s governance form because the company should have privileged economic interests rather than political interests.

6.2 Conclusion

In this thesis, we attempted to assess the relative performance of the DR Congo’s electric power company (SNEL) in SAPP. We particularly focused our attention on two aspects: technical efficiency and productivity change. We decomposed the productivity change into the Technical Efficiency Change, Technological Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practice in the market (SAPP). We also sought to assess the impact of environmental factors

[42]According to the principal-agent theory, the shareholders (government) own the company, and the managers (agent) control the company. The shareholders own the residual claims of the company. However, they do not have sufficient direct control over management decision-making and cannot participate in the day-to-day management of the company. Thus, managers would have an incentive to act in their self-interest rather than protect the shareholders’ interest, and this could lead to an agency problem. There are a few ways to solve the agency conflict, such as by giving incentives to both parties to align their goals.

on the efficiency of the companies by using the OLS model in the second stage. Thus, our results are easy to summarize.

We found that in the period of our analysis (2004-2013), SNEL was inefficient because its technical efficiency score was steadily around 0.5. From this result, we assumed that the inefficiency of SNEL was due to its inability to generate enough power despite its total installed capacity. Moreover, South Africa's electric power company (ESKOM) and Lesotho's electric power company's (LEC) were the efficient reference sets for SNEL because they evolved along the efficient frontier all the years.

The Technical Efficiency Change revealed that the best performance period for SNEL was 2004-2005, because during this period, SNEL caught up with 18%. Besides, the Technological Change results suggested that most of the companies applied the same production technologies and innovations in their respective power generation activities. From the Scale Efficiency Means, we noticed that SNEL did not operate at the most efficient size, whereas EDM and SEB operated at an increasing return to scale. Consequently, the summary of the Malmquist Index suggested that SNEL did not improve its productivity change in the period of our analysis (2004-2013).

In the second-stage regression analysis, we found that even though the important constant of our model (regulatory authority) was insignificant, the environmental factors that contributed positively to the companies' efficiency are human resources, competition in electricity distribution, electricity net exports, and urban population. On the other hand, the income per capita, competition in electricity generation and vertical integration affected negatively the companies' efficiency.

From the abovementioned results, we established policy implications for the enhancement of the performance of SNEL. These can be summarized as follows: ensuring of reliability of services by guaranteeing full-time electricity supply to consumers; establishment of coherent legislative and regulation in the energy sector; unbundling of SNEL into different subsidiary entities; promotion of the regional electricity exports (by maintaining, repairing and building of power generation infrastructures); opening of the distribution market to private competitors; initiation of cooperation between state electric power companies in the SAPP market; use of short, appropriate, and updated electric power transmission lines from generation centers to high-voltage distribution systems; injection of sufficient funds into power generation and initiation of some Public-Private Partnerships; and finally, adoption of partial separation of ownership and control in the company's management.

This study is the first empirical documentation of performance assessment in the energy sector in the DR Congo. For managers, it provides a reliable scientific measure and perspective of SNEL's efficiency and serves as an invaluable source of information for identifying benchmarks. For policymakers and the government, with the current liberalization of the electricity sector in the DR Congo, this study provides invaluable insights on, and a more reliable guide to, monitoring and evaluating the impact of operations within and outside SNEL as well as the general progress of SNEL. Currently in the DR Congo, as most public companies are in the process of reform, the approach used in this study can also be applied to those companies to assess and follow their efficiency progress. However, due to the lack of reliable data, this thesis has been restricted to electricity generation; and the analysis of the various activities and aspects of electricity production will give the study more policy latitude. For instance, the analysis of electricity distribution and supply could be used to assess the efficiency of these activities in the electricity industry in the DR Congo. Therefore, further research in these areas can be suggested.

6.3 Limitations of the Study

The first problem that surfaced in the research was the difficulty in accessing information in the energy sectors of African countries. The other limitations of this research pertained to the following drawbacks of the DEA method.

- It measures the relative performance and not the absolute performance.
- Because it is non-parametric, statistical testing is difficult.
- Being an optimization technique, it does not measure the possibility of preventing errors.
- The addition of a new unit to investigate previews units changes the performance scores of all the units.
- Changes in the type and number of inputs may change the results of the evaluation of the research.

Bibliography

[1] Ackermann, T., Andersson, G., & Soder, L. (2001). Distributed Generation: A Definition. *Electric Power Systems Research*, 57 (1), 195–204. Doi:10.1016/S0378-7796(01)00101-8.

[2] African Development Bank Group (2012). Briefing Notes for AFDB's Long-Term Strategy, Briefing (Note 4). Africa's Demographic Trends: Mubila Maurice. Retrieved from http://www.afdb.org/fileadmin/uploads/afdb/Documents/PolicyDocuments/FINAL%20Briefing%20Note%204%20Africas%20Demographic%20Trends.pdf.

[3] Ahuja, G. & Majumdar, S.K. (1998). An assessment of the Performance of Indian state – Owned Enterprises. *Journal of Productivity Analysis*, 9 (2), 113-132.

[4] Aka, L.A. (2004). Gestion des Entreprises publiques. Rehabilitation des Entreprises publiques de la RDC. Retrieved from La Conscience. Retrieved from http://www.laconscience.com/Rehabilitation-des-Entreprises-publiques-de-la-RDC.html.

[5] Ali, A.I., & Seiford, L.M. (1993). The Mathematical Programming Approach to Efficiency Analysis, In Fried, H.O., C.A.K. Lovell and S.S. Schmidt (eds), The Measurement of Productive Efficiency: Techniques and Applications (pp. 120-159). Oxford: Oxford University Press.

[6] Alejandro, M., Panizza, U., & Yanez, M. (2007). Bank Ownership and Performance: Does Politics Matter. *Journal of Banking and Finance*, 31 (1), 219-241. Retrieved from

http://ideas.repec.org/p/chb/bcchwp/356.html.

[7] Andrikopoulos, A., & Vlachou, A. (1995). The Structure and Efficiency of the Publicly Owned Electric Power Industry of Greece. *The Journal of Energy and Development*, 19 (1), 57 -79.

[8] Ang, J.S., & Ding, D.K. (2006). Government Ownership and the performance of Government-Linked Companies: The Case of Singapore. *Journal of Multinational. Financial Management*, 16 (1), 64-88.

[9] Averch, H., & Johnson, L. (1962). Behaviour of the Firm under Regulatory Constraint. *American Economic Review*, 52 (5), 1052-1068.

[10] Babalola, R. (1999). Technical Efficiency and Impact of Ownership on Performance: The Case of The Nigerian Electricity Industry. Available from the University of Surrey. Dissertations & Theses database. Retrieved from http://epubs.surrey.ac.uk/2814/.

[11] Bagdadioglu, N., Price, C., & Weyman-Jones, T. (1994). Efficiency and Ownership in Electricity Distribution: A Non-Parametric Model of the Turkish Experience.' *Energy Economics*, 18 (1), 1 - 23.

[12] Banker, R.D. (1984). Estimating Most Productive Scale Size Using Data Envelopment Analysis. *European Journal of Operational Research*, 17 (1), 35-44.

[13] Banker, R.D., & Morey, R. (1986). The Use of Categorical Variables in Data Envelopment Analysis. *Management Science*, 32 (12), 1613-1627.

[14] Bjurek, H., Hjalmarsson, L., & Forsund, F.R. (1990). Deterministic Parametric and Nonparametric Estimation of Efficiency in Service

Production: *A Comparison, Journal of Econometrics*, 46 (1), 213-227.

[15] Bongos, R. (2011, November 29). La problématique de la gouvernance d'entreprises publiques au Congo-Kinshasa. Retrieved from Afrique Redaction. Retrieved from http://www.afriqueredaction.com/article-la-problematique-de-la-gouvernance-d-entreprises-publiques-au-congo-kinshasa-90519222.html.

[16] Bourdman, A.E., & Vining, A.R. (1989). Ownership and Performance in Competitive Environment: A Comparison of the Performance of Private, Mixed and State-Owned Enterprises. *Journal of Law and Economics*, 32 (1), 1-33.

[17] Boussofiane, A., Martin, S., & Parker, D., (1997). The impact on technical efficiency of the UK privatization programme. *Applied Economics*, 29 (1), 297-310.

[18] Boycko, M., Shleifer, A., & Vishny, R.W. (1996). A Theory of Privatization. *Economic Journal*, 106 (1), 309-319.

[19] Bozec, R. (2003). Corporatization Process and the Financial Performance of Canadian state- Owned Enterprises". *The International Journal of Public Sector Management*, 16 (1), 27-47.

[20] Caves, W.D., Christensen, L. R., & Diewert E.W. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometria*, 50 (6), 1393-1414.

[21] Caves, R., & Barton, D. (1990). Technical Efficiency in U.S. Manufacturing Industries. Cambridge, Massachusetts: MIT Press.

[22] Caves, R., & Associates (1992). Industrial Efficiency in Six Nations.

Cambridge, Massachusetts: MIT Press.

[23] Centre of Efficiency and Productivity Analysis (2013): DEAP V 2.1. Retrieved October 15th, 2013 from http://www.uq.edu.au/economics/cepa/deap.php.

[24] Chanakira, M. (2011). SADC Regional Economic Integration in the Energy Industry. Retrieved from www.dounia-risri.com/IMG/pdf/Dounia4_pp64-78.pdf.

[25] Chang, H., & Singh, A. (1997). Policy Arena: Can Large Firms be Run Efficiently Without Being Bureaucratic?. *Journal of International Development*, 9 (6), 865-875.

[26] Charnes, A., & Cooper, W.W. (1962). Programming with Linear Fractionals. *Naval Res. Logist. Quart*., 9 (3,4), 181-185.

[27] Charnes, A., Cooper, W.W., & Rhodes, E. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operation Research*, 2 (1), 429-444.

[28] Charnes, A., Cooper, W.W., & Rhodes, E. (1981). Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through. *Management Science*, 27(6), 668–697.

[29] Charnes, A., Cooper, W.W., & Seiford, L. (1982). A Multiplicative Model for Efficiency Analysis. *Socie. Econ. Plan, Sci*., 16 (5), 223-224.

[30] Chames, A., Cooper, W.W., GoIany, B., & Seiford, L. (1985). Foundations of Data Envelopment Analysis for Pareto- Koopmans Efficient Empirical Production Functions. *Journal of Econometrics*, 3

(1), 91-107.

[31] Charnes, A., Cooper, W.W., Lewin, A.Y. & Seiford, L.M. (1995). Data Envelopment Analysis: Theory, Methodology and Applications (Ed.). *Kiuwer Academic Publishers*. Boston.

[32] Clark, M., & Marks, J. (1999). African Power Projects. *Financial Times Energy*. London, United Kingdom.

[33] Clean Energy Info Portal – reegle (2013). Botswana. Retrieved November 27th, 2013 from http://www.reegle.info/policy-and-regulatory-overviews/BW.

[34] Coad, A., Segarra, A., & Teruel, M. (2010). Like milk or wine: Does firm performance improve with age? (Science Direct). *Structural Change and Economic Dynamics.*24 (1), 173-189. Retrieved from http://www.sciencedirect.com/science/article/pii/S0954349X12000422.

[35] Coelli, T.J. (1995). Recent Developments in Frontier Modelling and Efficiency Measurement, Australian. *Journal of Agricultural Economics*, 39 (1), 219-245. Doi: 10.1111/j.1467-8489.1995.tb00552.x.

[36] Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., & Battese, G.E. (2005). An Introduction to Efficiency and Productivity Analysis (2nd ed.).New York: Springer.

[37] Coelli, T.J. (2012). A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Paper 96/08. Department of Econometrics, University of New England Armidale, Australia.

[38] Cooper, W., Seiford, L., & Tone, K.. (2007). Data Envelopment

Analysis. A Comprehensive Text with Models, Applications, References and DEA-Solver Software. (2nd ed.). New York: Springer.

[39] Comité de Pilotage de la Réforme des Entreprises du Portefeuille de l'Etat (2008). Rapport Annuel.

[40] Congo Opportunity Media (2013). RDC: Bonne électricité, forte économie. Le secteur minier ciblé. Retrieved November 27th, 2013 from http://www.congoopportunities.net/rdc-bonne-electricite-forte-economie-le-secteur-minier-cible/.

[41] CORE International, Inc. (2004). Energy Service Delivery in Zambia. Washington, DC, USA.Retrieved from http://www.coreintl.com/.../Energy%20Service%20Delivery%20in%20Zambia.

[42] Cornelia R. K., & Hennings, W. (2009) Sustainability evaluation of decentralized electricity generation. *Renewable and Sustainable Energy Reviews*, 13 (1), 583–593. Doi: http://dx.doi.org/10.1016/j.rser.2007.11.003.

[43] Cote, D.O. (1989). Firm Efficiency and Ownership Structure: The Case of US Electric Utilities using Panel Data. *Annals / Public and Co-operative Economics*, 60 (4), 431 - 450. Doi: 10.1111/j.1467-8292.1989.tb01338.x.

[44] Crosby, P.B.(1979). Quality is free, New York: McGraw-Hill.

[45] Deming , W.E. (1982). Quality, Productivity, and Competitive Position. Cambridge, Massachusetts: MIT Center for Advanced Engineering Study.

[46] Dewenter, K. L., & Malatesta, P.H. (2001). State – Owned and Privately Owned Firms: An Empirical Analysis of Profitability, Leverage, and Labor Intensity. *American Economic Review*, 91 (1), 320-334. Doi: 10.2478/v10135-012-0006-6.

[47] Eberhard A., Foster, V., Garmendia, C.B., Ouedraogo, F., Camos, D., & Shkaratan, M. (2008). Africa Infrastructure Country Diagnostic. Underpowered: The State of the Power Sector in Sub-Saharan Africa. *World Bank*. Washington, USA. Retrieved November 15th, 2013, from http://www.eu-africa-infrastructure-tf.net/attachments/library/aicd-background-paper-6-power-sect-summary-en.pdf.

[48] Engineering News (2005). SA's first Electricity Distributor by July. Retrieved from www.engineeringnews.co.za/eng/news/today.

[49] Eskom Holding Limited (2006). Annual Report. Sandton, Johannesburg, South Africa.

[50] Estache, A., Tovarc, B., & Trujillod, L., (2008). How efficient are African electricity companies? Evidence from the Southern African countries (Science Direct). *Energy Policy*, 36 (6), 1969–1979. http://dx.doi.org/10.1016/j.enpol.2008.02.011.

[51] Esseqqat, H. (2011). Les Energies Renouvelables en République. Démocratique du Congo. Programme des Nations Unies pour l'Environnement (PNUE). Nairobi, Kenya.

[52] Fama, E., & Jensen, M.C. (1983). Separation of Ownership and Control. *Journal of Law and Economics*, 26 (2), 301-326. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.195.3211&rep=rep1&type=pdf.

[53] Fama, E. (1980). Agency Problems and the Theory of the Firm. *Journal of Political Economy*, 88 (2), 288-307. Retrieved from http://business.illinois.edu/josephm/BA549_Fall%202010/Session%205/Fama%20(1980).pdf.

[54] Fare, R, Grosskopf, S., & Logan, L. (1985). 'The Relative Performance of Public1y Owned and Privately-Owned Electric Utilities. *Journal of Public Economics*, 26 (1), 89 – 106.

[55] Fare, R., Grosskopf, S., Logan, L., & Lovell, K. (1985). "Measuring Efficiency in Production: With an Application to Electric Utilities," in A. Dogramaci and N .R. Adam (eds.), Managerial Issues in Productivity Analysis.

[56] Fare, R., Grosskopf, S., Yaisawarng, S., Li, S.K. & Wang, Z. (1990). Productivity Growth in Illinois Electric Utilities. *Resources and Energy*, 12 (1), 383 - 398.

[57] Färe, R., S. Grosskoff, Norris, M., & Zhongyang, Z. (1994). Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries. *The American Economic Review*, 84 (1), 66-83.

[58] Farinos, J.E., Garcia, C.J., & Ibanez, A.M. (2007). Operating and Stock Market Performance of State-Owned Enterprise Privatization. *International Review of Financial Analysis*, 16 (4), 367.

[59] Farrell, M.J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society*, SeriesA (General), 12(3), 153-290.

[60] Ferrier, G.D. & Lovell, C.A.K. (1990). Measuring Cost Efficiency in Banking: Econometric and Linear Programming Evidence. *Journal of Econometrics*, 46(1), 229–245.

[61] Golany, B., & Roll, Y. (1989). An Application Procedure for DEA. *OMEGA International Journal of Management Science*, 17 (3), 237 - 250. Doi:10.1016/0305-0483(89)90029.

[62] Green, A., & Mayes, D. (1991). Technical Inefficiency in Manufacturing Industries. *Economic Journal*, 101(1), 523-538.

[63] Greenpeace Africa (2012). The Eskom factor: Power politics and the electricity sector in South Africa. Johannesburg, South Africa. Retrieved from http://www.greenpeace.org/africa/Global/africa/publications/coal/TheEskomFactor.pdf.

[64] Griliches, Z. (1971). Introduction: Hedonic price indexes revisited. In Price indexes and quality change, (Ed.) Z. Griliches, (pp.3-15). Cambridge, MA.: *Harvard University Press.*

[65] Harvard ManageMotor (2007). Performance Measurement. Retrieved October 4th, 2013 from http://www.vital.co.kr/demo/hmm10/performance_measurement/why_measure_business_performance.html.

[66] Hwang, H., &Lee, J.D. (2012). Profitability and productivity changes in the Korean electricity industry. *Energy Policy*, 52(1), 531-542. Retrieved from http://dx.doi.org/10.1016/j.enpol.2012.10.006.

[67] Infrastructure Consortium for Africa (2008). Regional Power Status in

African Power Pools. Report. Retrived from http://www.icafrica.org/fileadmin/documents/Knowledge/Energy/ICA_RegionalPowerPools_Report.pdf.

[68] International Energy Agency (1994). Electricity Supply Industry, OECD, 65.

[69] International Energy Agency (1996). Energy Policy of South Africa. Paris. OECD/lEA.

[70] Jamasb, T. & Pollitt, M. (2001). Benchmarking and Regulation: International Electricity Experience. *Utilities Policy*, 9 (1), 107-130.

[71] Jaunky., C. (2013). Divergence in Technical Efficiency of Electric Utilities: Evidence from the SAPP. *Energy Policy,* 62 (1), 419-430.

[72] John Kwoka Northeastern University (2008). Barriers to New Competition in Electricity Generation. Report to the American Public Power Association.

[73] Jones, L. P. (1991). Performance Evaluation for Public Enterprises, (18^{th}Ed.) Washington, D.C., U.S.A., World Bank. Cambridge, MA.: *Harvard University Press.*

[74] Journal le Potential (2005). Le Tariff d'Electricite en RDC. Gombe, Kinshasa, RDC.

[75] Journal le Potential (2006). SNEL et Les Companies Minieres. Gombe, Kinshasa, RDC.

[76] Juran, J.M.(1988). Juran's Quality Control Handbook, (4^{th} Ed.), New York: McGraw-Hill: 2-2 and 2-3.

[77] Kasemuana M.,S. (2009). Democratic Republic of Congo. Energy Systems: Vulnerability – Adaptation – Resilience (VAR). Helio International. Retrivied from http://www.helio-international.org/varrdc.en.pdf.

[78] Kellen, V. (2003). Business Performance Measurement. At the Crossroads of Strategy, Decision-Making. Learning and Information Visualization. Chicago: DePaul University. Retrieved from http://sopinion8ed.wordpress.com/2013/02/07/why-measure-business-performance.

[79] KPMG (2011). Global Infrastructure & Projects Group Africa Team, Johannesburg, South Africa. "Sub- Saharan Power Outlook, Retrieved from http://www.kpmg.com/ZA/en/IssuesAndInsights/ArticlesPublications/General-Industries Publications/Documents/Sub-Saharan%20Electricity%20Outlook%20Brochure.pdf.

[80] Kole, S.R., & Harold J. M. (1997). The Government as a Shareholder: A case from the United States. *The Journal of Law and Economics*, 40(1), 1-22. Retrieved from http://links.jstor.org/sici?sici=00222186%28199704%2940%3A1%3C1%3ATGAASA%3E2.0.CO%3B2-L.

[81] Krueger, O. (1990). Government Failure in Development. *Journal of Economic Perspectives*, 4(3), 9-23. Doi: 10.1257/jep.4.3.9.

[82] Lancaster, K. (1979). Variety, Equity, and Efficiency, New York: *Columbia University Press.*

[83] Lovell, C.A.K. (1993). Production Frontiers and Productive Efficiency,

In Fried, H.O. C.A.K. Lovell and S.S. Schmidt (Eds), The Measurement of Productive Efficiency: Techniques and Applications, (pp. 3-67). *Oxford University Press*.

[84] Lovell, C.A.K. (1994). Linear Programming Approaches to the Measurement and Analysis of Productive Efficiency, 2 (1), 175-248.

[85] Mahoney, J. (1992). The Choice of Organizational Form: Vertical Financial Ownership Versus Other versus Methods of Vertical Integration. *Strategic Management Journal*, 13 (1), 559-584.

[86] Malmquist, S. (1953). Index Numbers and Indifference Curves. *Trabajos de Estatistica*, 4 (1), 209-42.

[87] Massey, P. (1997). Proposals for the Electricity Supply Industry in Ireland: Comments on the Consultation Paper published by the Department of Transport, Energy and Communications. Competition Authority. Discussion Paper. Retrieved from http://www.tca.ie/images/uploaded/documents/Discussion_Paper_3.pdf.

[88] McGuiness, P.B. & Ferguson M.J. (2005). The Ownership Structure of Listed Chinese State-Owned Enterprises and its Relation to Corporate Performance. *Applied Financial Economics*, 15 (4), 231-246. Retrieved from http://ideas.repec.org/a/taf/apfiec/v15y2005i4p231-246.html.

[89] Megginson, L., & Netter, J. (2001). From State to Market: A Survey of Empirical Studies on Privatization. *Journal of Economic Literature*, 39(2), 321-389. Doi: 10.1257/jel.39.2.321.

[90] Meenakumari, R., & Kamaraj, N. (2008). Measurement of Relative Efficiency of State Owned Electric Utilities in India Using Data

Envelopment Analysis. *Modern Applied Science, 2(5), 61-71*. Retrieved from http://www.ccsenet.org/journal/index.php/mas/article/download/2205/2059.

[91] Ministere de l'Energy de la RD Congo (2010). La Problematique du Secteur de l'Energie en Republique Democratique du Congo. Kinshasa-RDC.

[92] Ministere de l'Energie (2011). Le Sector de l'Energie de la RD Congo.

[93] Ministere du Portefeuille de la RDC. Retrieved October 15th, 2013 from http://www.ministèreduportefeuille.org,

[94] Mohd –Yunos, J., & Hawdon, D. (1996). The Efficiency of the National Electricity Board in Malaysia- an Intercountry Comparison. Department of Economics, University of Surrey. Retrieved from http://ideas.repec.org/p/sur/seedps/84.html.

[95] Murthi, B.P.S., Choi, Y.K., & Desai, P. (1997). Efficiency of Mutual Funds and Portfolio Performance Measurement: A Nonparametric Approach, *European Journal of Operational Research*, 98 (1), 408-418.

[96] Musaba, L. (2005). The Development of the SAPP Competitive Electricity Market. Inaugural IEEE PES *2005 Conference and Exposition in Africa*. Durban, South Africa, 11-15.

[97] Norberg, V. (2000). Creating Incentives for Environmentally Enhancing Technological Change: Lessons from 30 years of U.S. Energy Technology Policy.*Technological Forecasting and Social Change*, 65

(1), 125-148.

[98] Norman, M., & Stroker, B. (1991). Data Envelopment Analysis -The Assessment of Performance, John Willy & Sons.

[99] Omran, M. (2004). The Performance of State-Owned Enterprises and Newly Privatized Firms: Does Privatization really matters. *World Development*, 32 (6), 1019-1041.

[100] Organization of America State (OAS): Government's Role in the Electricity Sector. Retrieved December 11st, 2013, from http://www.oas.org/dsd/publications/Unit/oea79e/ch08.htm#b.%20GOVERNMENT&146;S%20REGULATORY%20ROLE.

[101] Polèse, M. (2009). The Wealth and Poverty of Regions. Why Cities Matter. Chicago: *University of Chicago Press.*

[102] Penrose, E. (2009). The Theory of the Growth of the Firm. *Oxford University Press.*

[103] Pollitt, M. (1995), Ownership and Performance in Electric Utilities: The International Evidence on Privatisation and Efficiency. *Oxford University Press.*

[104] Pollitt, M. (1996). Ownership and Performance in Electric Utilities. *The Energy Journal*, 17 (3), 105-107.

[105] Pombo, C., & Ramirez, M. (2001). Privatization in Colombia: A plant performance analysis. Borradores de Investigación.vVolume 458 of Research Network Working Papers. Issue 21 of Serie documentos / Universidad del Rosario, Facultad de Economía.

[106] Pombo, C., & Taborda, R. (2004). Performance and Efficiency in Colombia's Power Distribution System: Effects of the 1994 Reform.

[107] Public Entrpries: ESKOM. Retrieved December 01st, 2013 from http://www.dpe.gov.za/state-4_eskom.

[108] Radio Okapi (2007). Réhabilitation du barrage de Zongo: Résoudra ou résoudra pas le problème de délestage en Rd congo? Retrieved November 28th, 2013 from http://radiookapi.net/emissions-2/2007/10/02/rehabilitation-du-barrage-de-zongo-resoudra-ou-resoudra-pas-le-probleme-de-delestage-en-rd-congo/.

[109] Ramamutri, R. (1987). Performance Evaluation of State-Owned Enterprises in Theory and Practice. *Management Science*, 33 (7), 876-893.

[110] Rasiah, D. (2012). The Separation of Ownership and Control in Malaysian Domestic Companies. *International Conference on Economics, Business Innovation*. IPEDR, 38 (1). IACSIT Press, Singapore. Retrieved December 19th, 2013 from http://www.ipedr.com/vol38/024-ICEBI2012-A10014.pdf.

[111] Reichheld, F.F., & Sasser, W.E. (1990). Zero Defections: Quality Comes To Services, *Harvard Business Review*, 68 (1), 105-111.

[112] Sang, C. (2005). Relationship between Human Resource Management Practices and the Perception of Organizational Performance, Roles of Management Style, Social Capital, and Culture: Comparison between Manufacturing Firms in Cambodia and Taiwan. Available from Electronic Theses & Dissertations Service. Retrieved from http://etds.lib.ncku.edu.tw/etdservice/view_metadata?etdun=U0026081

2200911341.

[113] Seiford, L.M. & Thrall, R.M. (1990). Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis. *Journal of Econometrics*, 46 (1), 7-38.

[114] Seiford, L.M. (1996). Data Envelopment Analysis: The Evolution of the State of the Art (1978-1997). *Journal of Productive Analysis*, 7 (1), 99-138.

[115] Seitz, W.D. (1971). Productive Efficiency in the Steam-Electric Generating Industry. *Journal of Political Economy*, 79 (4), 878 - 886.

[116] Sherman, R.D. (1988). Service Organization Productivity Management. Hamilton: The Society of Management Accountants of Canada.

[117] Smith, P. (1993). Outcome Related Performance Indicators and Organizational Control in the Public Sector, *British Journal of Management,* 4 (1), 135-151.

[118] Societe National D'electricite (2000). Trente ans de vie de SNEL (Thirty years of the existence of SNEL). Gombe, Kinshasa, RDC.

[119] Societe National d'Electricite (2010). Plan de Sauvetage et de Redressement. Gombe, Kinshasa, RDC.

[120] Southern African Power Pool. Annual Reports (2004-2013). Retrieved September 25th, 2013 from http://www.sapp.co.zw/areports.html.

[121] Southern African Power Pool, (2009). Potential of Regional Power. Sector Integration. Economic Consulting Associates Limited. London, UK, 9-13.

[122] Tallapragada, P., Shkaratan, M., Izaguirre, A.K., Helleranta, J., Rahman, S. & Bergman, S. (2009). Monitoring Performance of Electric Utilities: Indicators and Benchmarking in Sub-Saharan Africa. World Bank. Retrieved November 14th, 2013 from http://documents.worldbank.org/curated/en/2009/01/16338434/sub-saharan africa-monitoring-performance-electric-utilities-indicators-benchmarking-sub saharan-africa.

[123] Transition Government of the DR Congo (Wilkipedia Online,). Retrieved November 28th, 2013 from http://en.wikipedia.org/wiki/Transitional_Government_of_the_Democratic_Republic_of_the_Congo.

[124] Tshibangu, C.M. (2009). Les Entreprises Publiques Congolaises Face à la Crise Economique Cas de la Regideso de 2006 à 2008. Institut Supérieur du Commerce de Kinshasa. Available from Memoire Online. Retrieved November 30th, 2013 from : http://www.memoireonline.com/10/10/4015/m_Les-entreprises-publiques-congolaises-face--la-crise-economique-cas-de-la-REGIDESO-de-2006--20015.html.

[125] United Nations Population Division (2012). World Urbanization Prospects: The 2011 Revision and File 1. New York: United Nations. Retrieved November 30th, 2013 from http://esa.un.org/unpd/wup/CD-ROM/Urban-Rural-Population.htm.

[126] United Nations Development Program. Retrieved November 30th, 2013 from http://hdrstats.undp.org/en/tables/.

[127] Uprety, K. (2002). Transboundary Energy Security: Emerging Legal

and Institutional Framework for Electricity Trading in Southern Africa. *Journal of Energy and Natural Resources*, 20 (1), 383.

[128] Vasylenko, S. (2008). Does Efficiency of Electricity Destribution Company Influence the Value of the Company? Master of Arts in Economics National University "Kyiv-Mohyla Academy. Retrieved from http://kse.org.ua/uploads/file/library/2008/vasylenko.doc.

[129] Vickers, J., & Yarrow, G. (1991). Economic Perspectives on Privatization. *Journal of Economic Perspectives*, 5(2), 111-132.

[130] Wooldridge, J.M. (2009). Introductory Econometrics. A Modern Approach. (4th Ed.). South Western Cengage Learning, 587-604.

[131] Wong, L. (2011). A Review of Transmission Losses in Planning Studies. California Energy Commission, Retrieved November 28th, 2013 from http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf.

[132] World Bank (1995). Bureaucrats in Business. New York: *Oxford University Press*.

[133] World Bank (2001). Regional Electricity Markets Interconnections Phase I. Identification of Issues for the Development of Regional Power Market In South America. Retrieved November 16th, 2013 from http://documents.worldbank.org/curated/en/2001/12/1735287/regional-electricity-markets-interconnections-phase-1-identification-issues-development-regional-power-markets-south-america.

[134] World Bank (2010). Sustainable Development in the Developing Countries. Poverty Reduction and Economic Management Network.

Economic Policy and Debt Department.

[135] World Bank. Retrieved from November 30th, 2013. http://data.worldbank.org/.

[136] World Energy Council (2008). How to make the Grand Inga Hydropower Project happen for Africa. London, UK. Retrieved from http://www.worldenergy.org/documents/ingaprojectfinal.pdf.

[137] Wright, P. (1998). Introduction: Strategic Human Resource Management. Research in the 21st Century. HRM Rev. 8(3), 187-152.

Appendix A: Regression Model

```
regress dsc hr gdp rg cg go vi cd exp cz urb if (dsc>0)
note: go omitted because of collinearity

      Source |       SS       df       MS              Number of obs =     120
-------------+------------------------------           F(  9,   110) =   13.56
       Model |  4.37137931     9  .485708812           Prob > F      =  0.0000
    Residual |  3.93963563   110  .035814869           R-squared     =  0.5260
-------------+------------------------------           Adj R-squared =  0.4872
       Total |  8.31101493   119  .069840462           Root MSE      =  .18925

------------------------------------------------------------------------------
         dsc |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          hr |   .1055973   .0137327     7.69   0.000     .0783823    .1328122
         inc |  -.0001313     .00002    -6.57   0.000     -.000171   -.0000917
          rg |  -.0138786   .0603891    -0.23   0.819    -.1335556    .1057984
          cg |  -.3101605   .0549592    -5.64   0.000    -.4190768   -.2012442
          go |  (omitted)
          vi |  -.2589586   .0730263    -3.55   0.001    -.4036795   -.1142376
          cd |   .4495562   .0630926     7.13   0.000     .3245214     .574591
         exp |   .0000506   9.49e-06     5.34   0.000     .0000318    .0000695
          cz |  -8.56e-08   4.54e-08    -1.89   0.062    -1.75e-07    4.29e-09
         urb |   .0173058    .002814     6.15   0.000      .011729    .0228825
       _cons |  -.0234978   .1570683    -0.15   0.881    -.3347704    .2877748
------------------------------------------------------------------------------
```

Appendix B: Elasticity of Variables

```
mfx compute, eyex at (mean)

Elasticities after regress

      y  = Fitted values (predict)

         =    .695225
------------------------------------------------------------------------------
variable |      ey/ex    Std. Err.     z    P>|z|  [    95% C.I.   ]      X
---------+--------------------------------------------------------------------
      hr |   .9005208      .11923    7.55   0.000   .666836  1.13421   5.9288
     inc |  -.4367568      .06738   -6.48   0.000  -.568816 -.304698  2311.79
      rg |  -.0118113      .05139   -0.23   0.818  -.112543   .08892  .591667
      cg |  -.3345972      .05987   -5.59   0.000  -.451939 -.217255      .75
      vi |  -.3104014      .08787   -3.53   0.000  -.482628 -.138175  .833333
      cd |   .3233171      .04608    7.02   0.000   .232999  .413635       .5
     exp |     .07892      .01492    5.29   0.000   .049678  .108162  1083.41
      cz |  -.0929554      .04931   -1.89   0.059  -.189601   .00369   755093
     urb |    .917563      .15093    6.08   0.000   .621739  1.21339  36.8612
------------------------------------------------------------------------------
```

Appendix C: Trend of Technical Efficiency Scores for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004	0.565	1	0.468	1	0.678	0.211	0.695	1	0.281	0.963	1	0.841
2005	0.669	1	0.555	1	0.678	0.101	0.579	1	0.298	0.771	1	0.946
2006	0.594	1	0.529	1	0.647	0.108	0.767	1	0.286	0.73	0.953	0.873
2007	0.654	1	0.507	1	0.594	0.148	0.7	1	0.342	0.662	1	0.673
2008	0.505	0.868	0.556	1	0.843	0.155	0.702	1	0.366	0.625	1	0.683
2009	0.616	0.716	0.529	1	0.927	0.252	0.714	1	0.334	0.772	1	0.685
2010	0.621	0.579	0.557	1	0.927	0.252	0.589	1	0.651	0.772	1	0.635
2011	0.621	0.579	0.557	1	0.927	0.252	0.589	1	0.651	0.772	1	0.635
2012	0.604	0.292	0.459	1	0.992	0.271	0.552	1	0.621	0.381	1	0.567
2013	0.533	0.173	0.514	1	0.987	0.277	0.562	1	0.637	0.361	1	0.564

Appendix D: Trend of the Malmquist Index (Technical Efficiency Change) for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004-2005	1.183	1	1.186	1	1	0.481	0.833	1	1.06	0.801	1	1.125
2005-2006	0.888	1	0.953	1	0.955	1.069	1.324	1	0.959	0.948	0.953	0.922
2006-2007	1.101	1	0.959	1	0.918	1.371	0.912	1	1.197	0.906	1.049	0.77
2007-2008	0.773	0.868	1.097	1	1.419	1.044	1.004	1	1.069	0.944	1	1.016
2008-2009	1.219	0.825	0.95	1	1.099	1.623	1.016	1	0.912	1.235	1	1.002
2009-2010	1.008	0.809	1.054	1	1	1	0.825	1	1.95	1	1	0.927
2010-2011	1	1	1	1	1	1	1	1	1	1	1	1
2011-2012	0.973	0.505	0.824	1	1.07	1.077	0.938	1	0.955	0.494	1	0.892
2012-2013	0.882	0.591	1.119	1	0.995	1.023	1.018	1	1.026	0.947	1	0.996

Appendix E: Trend of the Malmquist Index (Technological Change) for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004-2005	1	0.994	0.983	0.996	1	0.992	1	1	1.001	0.995	0.982	0.984
2005-2006	1.05	1.05	1.049	1.049	1.047	1.054	1.054	0.995	1.042	1.055	1.05	1.05
2006-2007	1.057	1.013	1.09	1.034	1.03	1.066	1.056	1.061	1.007	1.04	1.085	1.087
2007-2008	0.938	0.872	0.956	1.022	0.929	0.904	0.978	1.677	0.936	0.942	0.959	0.958
2008-2009	1.006	1.005	1.006	1	1.005	1.005	0.985	0.923	1	1.006	1.006	0.998
2009-2010	1	1	1	1	1	1	1	0.963	1	1	1	1.002
2010-2011	1	1	1	1	1	1	1	1	1	1	1	1
2011-2012	1.084	1.098	1.115	1	1.092	1.093	1.066	1.022	1.048	1.115	1.087	1.079
2012-2013	0.981	0.974	0.973	1	0.978	0.977	0.983	1	0.988	0.973	0.988	1.004

Appendix F: Trend of the Malmquist Index for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004-2005	1.183	0.994	1.165	0.996	1	0.477	0.833	1	1.061	0.797	0.982	1.107
2005-2006	0.933	1.05	1	1.049	1	1.127	1.396	0.995	1	1	1.008	0.968
2006-2007	1.163	1.013	1.045	1.034	0.945	1.461	0.963	1.061	1.205	0.943	1.133	0.838
2007-2008	0.725	0.744	1.049	1.022	1.318	0.944	0.981	1.667	1	0.89	0.959	0.973
2008-2009	1.226	0.837	0.956	1	1.105	1.631	1.001	0.772	0.912	1.242	1.006	1
2009-2010	1.008	0.809	1.054	1	1	1	0.825	0.963	1.95	1	1	0.929
2010-2011	1	1	1	1	1	1	1	1	1	1	1	1
2011-2012	1.055	0.552	0.919	1	1.169	1.178	1	1.022	1	0.55	1.087	0.963
2012-2013	0.865	0.576	1.089	1	0.973	1	1	1	1.014	0.921	0.988	1

초 록

본 석사학위 논문에서는 2004년에서 2013년까지 콩고 민주공화국의 전력 회사(SNEL)를 남아프리카 전력 풀(앙골라, 보츠와나, 레소토, 말라위, 모잠비크, 나미비아, 남아프리카, 스와질란드, 탄자니아, 잠비아 및 짐바브웨)에 속한 다른 전력 회사들과 비교함으로써 SNEL의 성능을 계측하고자 하였다.

본 연구에서는 각 회사의 기술적 효율 점수를 산출하기 위하여 자료 포락 분석(DEA)법, 특히 Charnes, Cooper 및 Rhodes (CCR) 모델을 사용하였다. 이후 변화 내용을 기술적 효율 변화, 기술적 변화 및 스케일 효율 평균으로 구분하여 전력 시장(SAPP)에서의 최고 기량을 따라잡기 위하여 일부 회사가 얼마만큼의 노력을 기울였는가를 얻고자 하였다. 그런 다음, 각 회사의 성능 발전을 추적하기 위하여 Malmquist 지수를 산출하였다. 최종적으로는, 회사의 효율에 환경적 인자가 미치는 효과를 평가하기 위하여 두 번째 단계에서 OLS 모델을 사용하였다.

얻어진 결과는 SNEL이 비효율적이며 성능이 본 연구의 분석 기간 동안 진보하지 않았던 것으로 나타났다. 본 모델에서의 중요한 상수(규제당국)가 통계적으로 유의미한 수준은 아니었지만, 인력, 전력 분배에서의 경쟁, 전력 최종 수출 및 도시 인구와 같은 인자들은 통계적으로 유의미한 수준이었으며, 회사 효율에 긍정적으로 기여하였다. 하지만, 1인당 소득, 전력 생산에서의 경쟁, 그리고 수직 통합과 같은 다른 요인들도 통계적으로 유의미한 수준이었지만, 회사의 효율에 부정적인 영향을 미쳤다. 마지막으로, SNEL에 대한 성능 경향을 증진시키기 위하여 정책적 함의가 제시되었다.

주요어 : 콩고 민주공화국, SNEL, SAPP, DEA, CCR 모델, Malmquist 지수.

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이 논문을 공학석사학위 논문으로 제출함

2014 년 02 월

서울대학교 대학원

협동과정 기술경영경제정책전공

Jerold Bongu Barabutu

제럴드 본구 의 석사학위 논문을 인준함

2014 년 02 월

위 원 장 강연석 (인)

부위원장 김태유 (인)

위 원 이현강 (인)

Abstract

Measuring the Performance of the DR Congo's Electric Power Company (SNEL)

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Technology Management, Economics and Policy Program

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This masters' thesis sought to measure the performance of the DR Congo's electric power company (SNEL) by comparing it with other state electric power companies in SAPP (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe) from 2004 to 2013.

In our research, we used the Data Envelopment Analysis (DEA) method, especially the Charnes, Cooper, and Rhodes (CCR) model, to find the technical efficient score of each company. Then we decomposed the change into the Technical Efficiency Change, Technological Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practice in the electricity market (SAPP). After that, we estimated the Malmquist Index to follow the performance progress of each company. Finally, we used the OLS model in the second stage to assess the environmental factors that affected the efficiency of the companies.

The results revealed that SNEL was inefficient and its performance did not progress during the period of our analysis. Even though the important constant of our model (regulatory authority) was statistically insignificant, factors such as human resources, competition in electricity distribution, electricity net exports and the urban population were statistically significant and contributed positively to the companies' efficiency. However, other factors, such as income per capita, competition in electricity generation and vertical integration were also statistically significant, but affected negatively the companies' efficiency. Finally, policy implications were suggested to enhance SNEL's performance trend.

Keywords: DR Congo, SNEL, SAPP, DEA, CCR model, Malmquist Index

Student Number: 2011-22942

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Abbreviations

BPC	Botswana Power Company
DR Congo	Democratic Republic of Congo
EDM	Electricidade de Mocambique
ESCOM	Electricity Supply Corporation of Malawi
ESKOM	Eskom Holdings, South Africa
ENE	Empresa Nacional de Electricidade
NamPower	Namibian National Utility
LEC	Lesotho Electricity Corporation
OECD	Organization for Economic Co-operation and Development
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SNEL	Societe Nationale d'Electricite
SEB	Swaziland Electricity Board
TANESCO	Tanzania Electricity Supply Company Ltd
ZESA	Zimbabwe Electricity Supply Authority

Chapter 1. Introduction

1.1 Background

The focus on the measurement of the performance of state-owned electric power companies has received considerable attention from scholars and practitioners in energy policy literature. Both practitioners and scholars are increasingly looking for ways to amend and improve the performance of electric power companies mainly to maximize their profit (Vasylenko, 2008 and Hwang & Lee, 2012). One of the key areas in corporate strategy is ensuring that the performance measurement provides an orientation for the firm. As a result, many analytical tools are being developed to assess the performance of state electric power companies, to define the appropriate policies for changing the firms' management methods. According to Kellen (2002) and Harvard Business School[1] (2007), organizations measure the performance for several purposes: improvement, planning and forecasting, competition, reward, and regulatory and standard compliance.

On the performance of state electric power companies, the World Bank (1995) and Megginson and Netter (2001) have found that in most developing countries, state electric power companies are inefficient and perform more poorly than private electric power companies. This was the case in India when Meenakumari and Kamaraj measured in 2008 the relative efficiency of 29 state electric power companies and found 22 of them inefficient. Babalola (1999) measured the performance of the National Electric Power of Nigeria

[1]Harvard ManageMotor (2007). Performance Measurement. http://www.vital.co.kr/demo/hmm10/performance_measurement/why_measure_business_performance.html, accessed October 4, 2013.

(NEPD) and assumed factors that influenced the company's performance. However, he found the company's performance disappointing. Mohd-Yunos and Hawdon (1996) also measured the performance of the National Electricity Board of Malaysia and concluded that the company was performing poorly.

On the other hand, Pombo and Taborda (2004) measured the performance of 12 state electric power companies in Colombia before and after their 1994 regulatory reform and found an improvement in their power distribution and profitability rate in their post-reform years. Estache, Tovarc, and Trujillod (2008) assessed the performance change of sample Sub-Saharian African government electric power companies since their main reform took place in the late 1990s and noticed an improvement in the performance of those companies.

In the case of the Democratic Republic of Congo (DR Congo), "La Societe National D' Electricite" (SNEL), similar to any other state electric power company, had sought to measure its performance. The company is under the trusteeship of the Ministry of Energy, which seeks to ensure effective administrative, supervisory, regulatory, and technical control of the energy business in the DR Congo and of the company. However, since the establishment of SNEL in 1970, it has continuously evolved into an industry monopoly. According to the Ministry of Energy (2011), SNEL owns 58 hydropower plants and 52 thermal power plants, 38 high-voltage posts, and a 6,500Km network in the country.

1.2 Problem Statement

The problem of the sector is principally that there is no empirical documentation of performance assessments in the energy sector in the DR

Congo for both research and industrial management. Even though there had been several attempts by the Ministry of Energy to encourage SNEL to improve its performance (ME[2], 2011), there is no empirical information on the performance measurement of SNEL. Therefore, since SNEL is mandated to and aims to ensure efficiency in power supply and profit maximization, it is critical for its management to be empirically informed about how well it is performing in the Southern African Power Pool (SAPP). In fact, one of the problems of the energy sector in the DR Congo is that even though SNEL is vertically integrated and evolving as a monopoly with a commercial and technical mission, it seems to be failing in achieving its mission because of some endogenous and exogenous factors that may be a permanent panacea for its performance. Among the endogenous factors is the company's poor corporate governance, which is manifested by its low level of efficiency, lack of investments, lack of transparency and accountability, deterioration of power infrastructure (due to aging and lack of proper and sustainable maintenance), etc. Among the exogenous factors are the volatile overall macroeconomic conditions, institutional and legal changes, absolute interference of politics with the company management, vertical integration, electricity net imports, and size of the country (Bongos, 2011). All these factors are seen to be affecting SNEL's performance and its achievement of its goal from the perspective of commercialization and profit maximization.

1.3 Research Questions

To test the aforementioned hypothesis, this study seeks to answer the following specific research questions.

[2]Ministere de l'Energy de la RD Congo (2010). La Problematique du Secteur de l'Energie en Republique Democratique du Congo. Kinshasa- RDC.

- How efficient is SNEL compared to other state-owned companies in the Southern African Power Pool (SAPP)?
- How has SNEL evolved dynamically through the years with respect to efficiency and productivity?
- What are the environmental factors that affect the efficiency of SNEL?
- What possible policies can be prescribed to enhance SNEL's efficiency and productivity?

To answer these questions, we used the CCR model to calculate the technical efficiency score of each company (to answer the first Research Question). Then we decomposed the change into Technical Efficiency Change, Technological Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practice in the SAPP market (to answer the second Research Question). After that, we used the OLS model to assess the environmental factors that are affecting the efficiency of the companies (to answer the third Research Question). From the technical efficiency score results, we determined the best-practice companies, which serve as benchmarks for SNEL. Finally, from all the results, policy implications were prescribed to enhance the performance of SNEL (to answer the third Research Question).

1.4 Hypothesis

To achieve the aforementioned objective, the main hypothesis of this study is that SNEL, as a state-owned company operating in a developing country, is inefficient (World Bank, 1995 and Megginson & Netter, 2001), similar to other state-owned companies in the SAPP (ENE of Angola, BPC of Botswana, LEC of Lesotho, ESCOM of Malawi, EDM of Mozambique, NamPower of Namibia, ESKOM of South Africa, SEB of Swaziland, TANESCO of Tanzania, ZESCO of Zambia, and ZESA of Zimbabwe).

1.5 Purpose and Objectives of the Study

With respect to the identified research problem, the main purpose of this study is to measure the performance of the DR Congo's electric power company (SNEL) and to prescribe some policies to enhance the company's efficiency.

Since our analysis covers the period span from 2004 to 2013, the objectives of this study are:

- To examine the efficiency of SNEL compared to other state electric power companies in the SAPP market;
- To examine the SNEL dynamic progress;
- To determine the environmental factors that affect SNEL;
- To describe some policies to improve SNEL's efficiency and productivity.

1.6 Significance of the Study

The study is very significant, in many ways, to SNEL managers, policymakers, and the government of the DR Congo. To the SNEL management, the study findings will provide a reliable scientific measure, and perspective for describing and evaluating the level, of the company's efficiency. It will also serve as an invaluable source of information and benchmarks for SNEL to improve its efficiency level. This will provide empirical support for the SNEL management's strategic decisions in several critical operating areas (generation-transmission-distribution). For the DR Congo policymakers and government, with the current liberalization of the country's electricity sector, the findings and results of this study will provide invaluable insights and a more reliable guide to monitoring and evaluating the impact of operations within and outside SNEL, as well as the general progress of SNEL.

1.7 Delimitation of the Study

This study is delimited to the performance of 12 state electric power companies (ENE of Angola, BPC of Botswana, SNEL of DR Congo, LEC of Lesotho, ESCOM of Malawi, EDM of Mozambique, NamPower of Namibia, ESKOM of South Africa, SEB of Swaziland, TANESCO of Tanzania, ZESCO of Zambia, and ZESA of Zimbabwe) in the SAPP and covers the period of 2004-2013. It excludes private electric power companies operating in the Southern African Region.

1.8 Structure of the Thesis

The study is organized into six chapters. Chapter 1 gives the Introduction, Background, Problem Statement, Research Questions, Hypothesis, Purpose and Objectives, Significance, and Delimitation of the Study, and the Structure of the Thesis.

Chapter 2 provides an Overview of the Electricity Industry: Electricity Supply Industry, Southern African Power Pool and the Electricity Sector in the DR Congo.

Chapter 3 reviews relevant literature on the Productivity and Efficiency of State-owned Companies and Electric Power Companies.

Chapter 4 introduces the following research methodologies: the CCR

Model, BCC Model, Additive Model, Multiplicative Model, and Malmquist Index.

Chapter 5 presents the study Data, CCR Model and Malmquist Index Results, Environmental Factors Analysis, and Benchmark Analysis.

Finally, Chapter 6 presents the Policy Implications and Conclusion (including the Limitations of the Study).

Chapter 2. Electricity Industry Overview

2.1 Electricity Supply Industry

The electricity supply industry can be functionally divided into generation, transmission, distribution, and supply (Massey, 1997). The functions are differentiated technologically and economically, and regulatory reform has tended to proceed at this level of disaggregation.

Generation is the production of electricity. It involves the transformation of another form of energy into electrical energy. Electricity production may use oil, natural gas, coal, nuclear power, hydropower (falling water), renewable fuels, wind turbines, and photovoltaic technologies. The different generating technologies are differentiated according to their cost structures. The main cost components of electricity generation are (delivered) fuel prices, capital costs, and operating and maintenance costs. The costs are also influenced by the performance of the generating technology (capacity factor, thermal efficiency, and operating life).[3] According to JKNU,[4] nuclear generation has high capital costs due in part to long construction lead times (interest charges) and decommissioning costs (costs of retiring a plant at the end of its design life). The high fixed costs are also due to public opposition to nuclear technology and waste disposal. On the other hand, nuclear technology has low fuel and operating costs (variable costs); and these costs remain relatively constant over the lifetime of a nuclear plant. Hydro generation costs depend largely on the geography and climate. The hydro generation variable

[3]According to the International Energy Agency (1994), the capacity factor is the utilization of capacity. Thermal efficiency is the ability to generate electricity output per unit of fuel input. The operating life is the scheduled lifetime of a plant.
[4]JKNU: John Kwoka Northeastern University.

costs are low. The costs of coal, oil, and natural-gas-fired generation consist mainly of input fuel prices, so the variable costs of fossil-fuel generation are higher than those of nuclear generation.[5] However, fossil-fuel generation tends to have lower fixed costs than nuclear generation, particularly in the case of gas-fired plants, which have very short construction lead times.

Transmission and distribution comprise the "wires" functions. Transmission is the high-voltage transport of electricity. However, transmission is not merely transportation, but it also involves the management of dispersed generators in a grid to maintain a suitable voltage and frequency and to prevent system breakdown. Transmission is a natural monopoly because competition in transmission would result in duplication of the existing network (duplication of high-voltage AC networks and competing grid coordinators would increase transmission costs). Regulation of transmission typically involves rate-of-return regulation of prices, which, in the classic study of Averch and Johnson (1962), has been shown to lead to over-investment in capital and, consequently, failure to minimize costs.

Distribution is the low-voltage transport of electricity. Similar to transmission, it is generally considered a natural monopoly; competition would similarly entail duplication of the existing set of "wires." Unlike transmission, there are no benefits to its integration with generation.

Finally, supply of electricity is the sale of electricity to end-users. This includes metering, billing, and marketing, and may be wholesale or retail. Supply is not considered a natural monopoly, nor are there significant advantages to its integration with other functions. Each of these different functions of the electricity supply industry contributes to the costs of

[5] Oil prices are perceived as volatile and risky, and coal prices may increase with environmental restrictions on coal.

providing electricity to final users.

Furthermore, the economic and technological features of the electricity supply industry have stimulated the evolution of its regulation, ownership, and market structure. Since transmission and distribution are natural monopolies, the industry as a whole is deemed a natural monopoly, which suggests that an efficient regulatory framework would be a legal monopoly. On the other hand, a monopoly also leads to deadweight losses when a profit-maximizing monopolist charges prices that exceed the marginal cost. Historically, this has led governments to adopt one of two approaches to the electricity sector: a publicly owned integrated monopoly, or privately owned regulated firms. Many countries (e.g., Ireland, France, Greece, and Italy) consolidated and nationalized their electricity supply industries into state-owned, legal monopolies under the assumption that a state-owned enterprise does not maximize profit, so public ownership should lead to greater consumer welfare. A variant of this approach is regional, legal monopolies, where public enterprise and monopoly occur at the regional level (e.g., Germany). In the case of private but regulated monopolies, firms are presumed to maximize profits, so regulation is used to reduce deleterious impacts on consumer welfare. Regulators of privately owned monopolies concentrate on pricing, often using rate-of-return regulation. The United States and Japan provide examples of investor-owned but regulated regional monopolies. Even in the case of the United States, however, regional governments retain a marked ownership and operative role in segments of the industry. Regardless of whether electric utilities are public or private, or centralized or regional, in most countries, vertical unbundling has only recently begun.

Additionally, technological preferences have influenced ownership and market structure. Certain generation technologies such as hydropower have frequently resulted in state ownership; the state often had the property rights and financial resources needed for large-scale hydroelectric projects. Other shifts in preferences have changed the minimum efficient scale of production. For example, in the aftermath of oil shocks, preferences shifted toward large-scale nuclear projects; whereas with the advent of the Combined Cycle Gas Turbine (CCGT), preferences have shifted toward small-scale CCGT plants. Larger-scale technologies with high fixed costs often lead to state financing, whereas smaller-scale technologies leave more room for private ownership.

2.2 Southern African Power Pool

According to Musaba (2005), the Southern African Power Pool (SAPP) was created in August 1995 at the Southern African Development Community (SADC) summit held in Johannesburg, South Africa. The SADC government members signed an Inter-governmental Memorandum of Understanding for the formation of an electricity power pool in the region under the name of the Southern African Power Pool (SAPP). SAPP is now an association of 12 member countries (Angola, Botswana, DR Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe) represented by their respective state electric power companies (Table 2-1) and organized by SADC.

SADC aims to promote regional integration, and has mandated SAPP to promote electricity trading among SADC members states so that they can all share the available energy resources in the region. SAPP is governed by four agreements: the *Inter-governmental Memorandum of Understanding*, which enabled the establishment of SAPP; the *Inter-utility Memorandum of Understanding*, which established the SAPP basic management and operating

Table 2-1. Electricity Sector in Selected Sub-Saharan Africa Countries

Country	Operator in Distribution	Competition in Generation	Private Role in Distribution	Sector Regulator	Vertical Integration	Main Electricity Source
Angola	Empresa Distribuicao Electricidade (EDEL)	Yes (2003)	No	No	No D–EDEL G and T–ENE	T
Botwana	BPC	No	No	No	Yes	T+I
DR Congo	SNEL	No	No	No	Yes	H
Lesotho	LEC	Yes	Yes	yes	Yes	H+I
Malawi	ESCOM	No	Yes Management contract (SA's TSI) (2001)	yes	Yes	H
Mozambique	EDM	Yes	Yes Management contract and small contracts	Yes Advisor (2000), Regulator (2004)	Yes but 2 more firms in G No horizontal and vertical unbundling	H+I
Namibie	4 Regional Electricity Distributors (2002)	Yes	Yes	Yes (2000)	No	H+I
South Africa	ESKOM	Yes	No	Yes (1995)	Yes But many small D firms	T
Swaziland	SEB	Yes	No	Yes (2002)	Yes	H+I
Tanzania	TANESCO	Yes	Yes Management contract (NetGroup) (2002)	No	Yes	H
Zambia	CAPC+ZESCO	Yes	Yes	Yes (1999–2000)	Yes But 2 big firm	H
Zimbabwe	CAPC+ZESA	Yes	No	No	Yes But 2 firms	H+I

Note: Tr= Transmission, G= Generation, D= Distribution, H= Hydro, T= Thermal, I= Iimport.

Source: Estache et al., 2008

principles; the *Agreement Between Operating Members*, which established the specific rules of operation and pricing; and the *Operating Guidelines*, which provide standards and operating guidelines (Musaba, 2005). The SAPP annual report (2009) argues that the current generation mix in SAPP is 74.3% coal, 20.1% hydro, 4% nuclear, and 1.6% diesel and gas. Coal is predominantly generated in the south (South Africa, Botswana, and Zimbabwe), and hydropower, in the Zambezi Basin (Zambia, Zimbabwe, Mozambique, and Malawi) in the north, the DR Congo, and Cunene (Angola and Namibia). The nuclear power station is in the Western Cape (South Africa), which is far from the coal-fired power plants in the northern and eastern provinces. Most of the diesel power plants are for small isolated rural networks. Coal -fired plants make up the bulk of the 42,000 MW of installed capacity of South Africa's state electric power company (ESKOM). South Africa accounts for more than 80% of the total generation in SAPP, and thus, coal accounts for three-quarters of the total SAPP generation. Outside South Africa, the dominant energy resource is hydropower. The DR Congo has more than 400 TWh/year of economically exploitable hydropower. Further south, the Zambezi, Cunene, and Kwanza river basins have another 100 TWh/year potential.

Even though the region is still dominated by coal generation, SAPP is expecting to meet the future growth in electricity demand in South Africa by developing environmentally clean hydropower in the northern part of the market (Northern SAPP). According to SNEL (2010), the prime target for hydro development is a unique site on the Congo River, called "Inga". Inga has 40,000 MW of hydro potential in a setting where virtually no civil engineering works would be required and where the environmental impact would be minimal. At present, only 1,775 MW has been installed in the Inga site. There are also significant sites on the Zambezi River, as shown in Table 2-2.

Table 2-2. Significant Hydropower Sites on Congo and Zambezi Rivers

River Basin	Site	Potential (MW)	Installed Capacity (MW)
Congo	Inga	40,000	1,775
Zambezi	Batoka Gorge	1,600	
(Zambia/Zimbabwe)	Devil's Gorge	1,240	
	Kariba	2,130	1,470
	Mupata	1,200	
	Kafue Gorge	1,740	990
	Itezhi tezhi	120	
Zambezi (Mozambique)	Cahora Bassa	3,275	2,075
	Mepanda Uncua	1,780	
	Lupata	654	
	Boroma	444	
Total		54,183	6,977

Source: Southern African Power Pool, 2010

The SADC region is connected by two different power transmission networks: the North Zone and the South Zone. The northern transmission network includes SNEL (DR Congo), ZESCO (Zambia), and ZESA (Zimbabwe). The southern network comprises Eskom (South Africa), BPC (Botswana), and NamPower (Namibia) (SAPP, 2012). The positive impact of these transmission networks in the SADC countries is that it enables member countries to purchase electricity and to sell it to the public: A number of countries in SADC are not yet interconnected, such as Tanzania, Malawi, and Angola (SAPP, 2012). However, SAPP has established some projects to link such countries in the market.

Trade in electricity services is already widespread in the region, and mostly occurs between South Africa and Mozambique. Most of the countries in the region are totally dependent on imports.[6] Due to the regional nature of SAPP, exports have been favored over domestic demand due to the assured enormous revenues from exports.[7] For instance, Zambia and DR Congo derive enormous revenues from selling hydropower to South Africa. Nevertheless, despite the development of operating guidelines for the SAPP DAM,[8] very little progress has been made on that front largely due to the limited excess capacity with which to trade in the competitive market.[9]

Where electricity generation is not enough to meet domestic needs, countries need to purchase power from their neighbors within the region and elsewhere. In this regard, the region is too dependent on South Africa's electric power company (ESKOM) for electricity provision (since South Africa is the main exporter and importer, accounting for approximately 80% of the total electricity trade in the region). Yet ESKOM is currently running out of excess capacity, as domestic demand is outstripping supply. Hence, as the demand for power in South Africa increases, the likelihood of regional deficits also expands. This chronic shortage is expected to continue. The net effect is that in the foreseeable future, the entire region will need a considerable increase in generation capacity to meet the growth in demand. While South Africa will probably remain the key market for such power, regional countries will also need to address the much increased local demand and attract new investors.

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[6] Namibia, Botswana, and Swaziland are totally dependent on South Africa for their energy needs.
[7] Source: Uprety, K. (2002), p. 383.
[8] Day Ahead Market.
[9] Chanakira, M., SADC Regional Economic Integration in the Energy Industry. Accessed October 26, 2013 from www.dounia-risri.com/IMG/pdf/Dounia4_pp64-78.pdf.

2.3 Electricity Sector in the DR Congo

According to the SNEL annual report (SNEL, 2010), the DR Congo gained independence on 30 June 1960, the electricity sector had been the responsibility of the state company “Regie de Distribution des Eaux” (REGIDESO), along with six other private utility companies, namely, Cometrick, Forces de I’Est, Forces du Bas Congo, Societe Generale Congolaise des Forces Hydroelectrique (SOGEFOR), Societe Generale Africaine d’Electricite (SOGELEC), and COGELIN. The electricity sector in the DR Congo is managed by SNEL, established by Presidential Decree No. 73/033 on 16 May 1970. In the same context, the SNEL annual report (2000) states that the government approved SNEL’s construction of the first phase of its Inga 1 hydropower project. Before the establishment of SNEL, the government proclaimed Presidential Decree No. 67-391 on 23 September 1967 for the establishment of a financial control and technical committee for the construction of the hydroelectric power station of Inga I. This committee was replaced by SNEL and became the national electricity company of the DR Congo in 1970.

With the commissioning of the first phase of Inga I in 1972, SNEL became responsible for the generation, transmission, and distribution of electricity across the country. It also assumed the responsibility of REGIDESO, which today holds the responsibility for water distribution in the DR Congo (a state-owned company). Besides REGIDESO, the government nationalized six private companies, which distributed electricity around the country. At that time, the government began a process of absorbing private utilities around the country into SNEL. This process ended in July 1974, when SNEL had achieved a monopoly on the generation, transmission, and distribution of electricity within the country (SNEL, 2000).

The SNEL annual report (2000) argues that on 5 May 1978, the former President of the DR Congo, Joseph Mobutu SeSe SeKo, signed Presidential Decree No. 78/196 approving the status of SNEL. Since then, SNEL has operated as a state company under the legal framework of the Public Enterprise Act. Its four key purposes are (Esseqqat, 2011):

- To promote electrification in rural areas;
- To reduce the gap in the energy supply in provinces;
- To increase the electrification rate all over the country; and
- To promote electricity exports.

Since 2010, SNEL has been transformed into a Limited Company with Limited Liability (LLC). It includes a General Assembly and Shareholders (the state is currently the sole shareholder).

The company is currently under the control of the Ministry of Energy and the Ministry of Public Enterprises. Below is the summary of their functions:

- The Ministry of Energy is the government institution that ensures effective administrative, supervisory, regulatory, and technical control of the energy business in the DR Congo and the company. Its main mission is to:

  - design, propose, and implement the policy adopted by the government in the areas of electricity generation, transmission, distribution, and supply;

  - grant and, if necessary, remove the licensing operators acts within its jurisdiction (upon the recommendation of the regulatory authority); and

- ensure compliance with legislation and regulations;

- The Ministry of Public Enterprises is the government institution that ensures financial control of the company.

Under the trusteeship of SNEL, we have “La Direction de l’Electrification Rurale” (DER). Its mission is to identify and develop electrification projects in rural areas.

Besides SNEL, the following organizations comprise the institutional framework.

- REGIDESO is the public water utility.

- CNE, or “La Comission Nationale d’Energie” (the R&D body in the energy sector), specifically its Department of Electricity and Renewable Energy, is an advisory body under the supervision of the Ministry of Energy that collects, processes, and analyzes the energy database to establish balance and energy indicators that will facilitate the implementation of coherent and efficient energy strategies by the political authorities.

- SGE, or “le Secrétariat Général de l’Energie,” is the administrative mother entity in the energy sector in the DR Congo. It establishes mandatory policies and is responsible for enforcing the terms of the sector. Each of its divisions grants building permits for small hydro projects and amenities. Finally, it also has the power to control and sanction operators. It plays the role of facilitator and intermediary between private developers of renewable energy projects and the public sector.

- CATE**,** or “La Cellule d’Appui Technique à l’Energie,” is attached to the Office of the Ministry of Energy. Its main mission is to provide institutional support to the Ministry of Energy and ensure capacity building in the government and in energy companies in the public sector. In particular, it performs the following tasks that are relevant to the audience, design, implementation, and monitoring of projects and investments in the sector of energy programs:

  - analysis and coordination of the presentation of investment projects and programs of different donors;

  - mnitoring and definition of sectoral strategies in the medium and long terms;

  - ctribution to technical and financial arrangements for water and electricity projects;

  - rpresentation of the overall responsibility for, and coordination of, sectoral projects or investment programs with bilateral and multilateral donors on infrastructure and other projects under the Ministry of Energy.

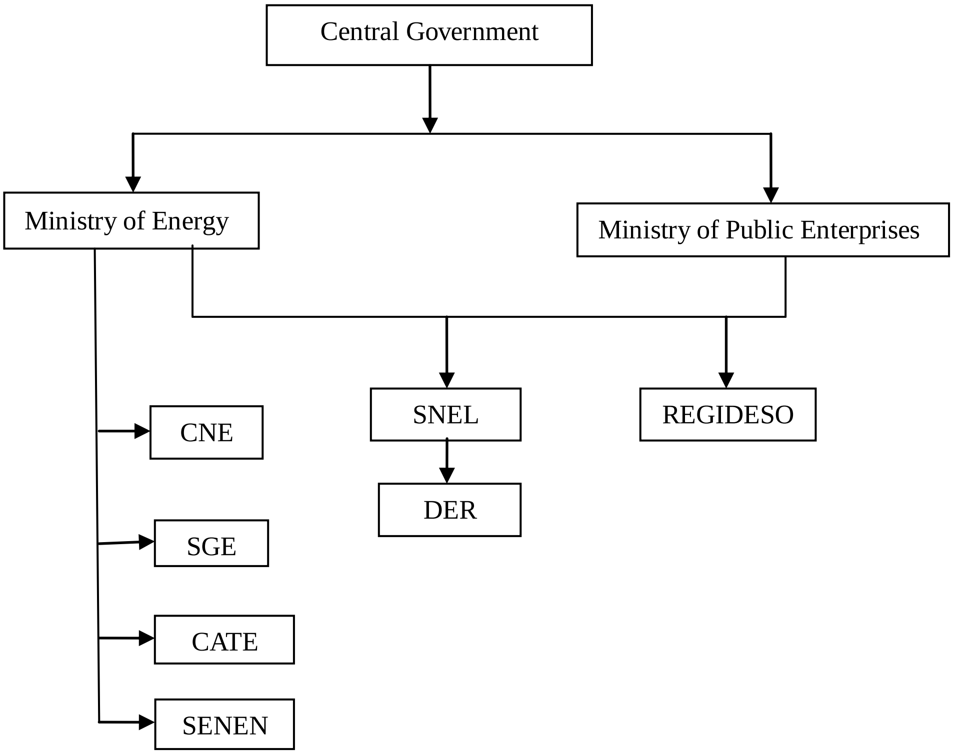
- SENEN, or **“**Le Service National des Energies Nouvelles,” under the trusteeship of the Ministry of Rural Development, also collaborates with the Ministry of Energy to promote renewable energy in rural areas.

Finally, in compliance with the new policy of the electricity sector in the DR Congo, which has yet to be approved, the following three new agencies will be created.

- L’Autorité de Régulation Nationale du secteur de l’Electricité- will be responsible for regulating the electricity sector and protecting the interests of consumers and operators at the national and provincial levels.

- L'Agence d'Electrification Nationale (AGENA) will be responsible for the promotion of private-sector participation in electrification projects in rural areas.

- L'Agence pour le Fonds National Electrification (FONEL) will be responsible for regulating procedures for awarding subsidies and loans to private operators.



Source: Esseqqat, 2011

Since the establishment of the sector, the energy policies of the DR Congo in general and of the electrical system in particular have been characterized by a strongly centralized focus of national magnitude and a strong sense of commitment from the State. This philosophy had initial moderate success, but has completely collapsed throughout the years. The results reflect an almost imminent failure, and the present situation seems completely irreversible unless there is a change in the energy policy of the country.

The rate of electrification (Table 2-3) of the DR Congo is still among the lowest in Africa. The use of even the least sophisticated energy models, such as WASP[10] or MAED,[11] seems impossible, taking into account the disintegration of the electrical system, despite the country's resource potential.

According to Kasemuana (2009), the Energy Policy of the DR Congo's energy sector is based on the following objectives.

- To alleviate poverty and illiteracy;
- To develop an 'extrovert' economy with projects that integrate rural areas and economically viable regions (and where the energy component of the project involves the design of micro or mini electricity power plants with capacities not exceeding 20 MW);

[10]The "Wien Automatic System Planning" Package model permits the user to find an optimal expansion plan for a power generation system over a long period and within the constraints defined by the planner, which IAEA maintains. So far, four versions of WASP have been created, which have been distributed to several hundred users.

[11]The "Model for the Analysis of Energy Demand" evaluates future energy demand based on medium- to long-term scenarios of socioeconomic, technological, and demographic development. Energy demand is disaggregated into a large number of end-use categories that correspond to different goods and services. The influences of social, economic, and technological driving factors from a given scenario are estimated. These are combined to give an overall picture of future energy demand growth.

Table 2-3. General Operations in the SAPP (2013)

Country	State Company	Installed Capacity MW	Net Electricity Imports Gwh	Net Electricity Exports Gwh	Generation Sent Out Gwh	Electrification Rate %
Angola	ENE	1,793	49	0	5,613	40.2
Botswana	BPC	252	3017	0	372	45.4
DR Congo	SNEL	2,442	562	69	7,021	
Lesotho	LEC	72	49	7.4	486	15.2
Malawi	ESCOM	287	0	19.1	1,809	8.7
Mozambique	EDM	227	89	330	390	15.0
Namibia	NamPower	393	1591	36	1,305	48.8
South Africa	ESKOM	44,170	413	4089	237,430	75.8
Swaziland	SEB	70.6	773	0	288.1	-
Tanzania	TANESCO	1,380	2192	0	3,034	14.8
Zambia	ZESCO	1,870	164	65.6	11,381	18.5
Zimbabwe	ZESA	2,045	1076	701	6,951	36.9

Sources: Southern African Power Pool and the World Bank (2013)

- To implement major industrial projects that demand large amounts of electricity;
- To construct hydroelectric plants at numerous sites throughout the country (Initially, the focus will be on isolated grids, which will later be interconnected.).

Moreover, with the restructuring plan of the government, the objectives of the new policy can now be summarized as follows (SNEL, 2010).

- To promote competition and distribution in the power sector;
- To develop other sources of power;

- To cover progressively the electricity needs of the country (households, rural communities, etc.).

On the generation side, according to the SNEL annual report (2010), the DR Congo has several hydropower and thermal stations across the country, even though a number of these do not produce at full capacity. There are other stations that require refurbishment.

A negative aspect is that most of the hydropower plants do not contribute to the electrification of rural areas in the DR Congo. Therefore, many rural households do not have access to electricity. The benefit of having access to electricity is that it could contribute to the socioeconomic development of the country. Similarly, the establishment of Inga II in 1982 was also portrayed as essentially an economic development project for the country, providing energy infrastructure to the mining sector in Katanga Province, as well as to energy-intensive industries in Kinshasa and other provinces.

Currently, most hydropower and thermal power plants are not being operated due to aging and technical problems. Other electricity plants are being decommissioned. This means the operation period of the power plant has reached 25 years. The establishment of SNEL in the DR Congo is closely linked to the development policies adopted by the country, since SNEL decided to implement a development policy that included skills development for its staff.[12] It was argued that the application of the policy would have improved electrification and offered far wider access throughout the country (SNEL, 2010).

With respect to exports (Table 2-3 also shows the electricity exported in

[12]Initially, most senior staff were foreigners, specifically from Belgium and France. The government changed the situation in 1989 by allowing Congolese citizens to manage SNEL (SNEL, 2000).

SAPP in 2012), the DR Congo is interconnected to the following countries:

- Congo-Brazaville via the Western Network;
- Rwanda and Burundi via the Eastern Network;
- Zambia, Zimbabwe, and South Africa via the Southern Networks (This is in accordance with the SAPP Market.).

Besides these interconnected lines, the DR Congo also supplies power to the following isolated centers in neighboring countries:

- Nocqui (Angola), to which medium-voltage energy is supplied from the network of Matadi (DR Congo);
- Mobayi Mbongo (Central African Republic), to which energy is supplied from central Mobayi (DR Congo);
- Cyangugu Kamembe (Rwanda) and Bujumbura (Burundi), to which energy is supplied from central Ruzizi1 (DR Congo).

As for imports (Table 2-3 shows the electricity imported in SAPP in 2012), the DR Congo imports electricity from neighboring countries and supplies it to its isolated border centers that are far from its existing networks. This is the case with Mokambo, Sakania, and Kasenga, all located in Katanga province, the energy of which comes from Zambia.

Chapter 3. Literature Review

3.1 Performance and Efficiency of State-owned Companies

It has long been the conviction that public enterprises or government-administered organizations are more concerned with social, political, and all but the economic outcomes of business activities. In Africa, especially in the DR Congo, most managers of government-related companies are appointed by the government and often do not have real business knowhow and skills. Moreover, their investment and business decisions may be mainly politically rather than commercially motivated. The inefficiency of such companies is due also to their investment relationship with the government and their management systems. What makes matters worse is that these managers are generally too risk-averse and have no incentives to venture into risky but potentially economically rewarding projects.

It is argued by many that the inefficiency of companies is due in part to their ownership. Boycko et al. (1996) stated that politicians cause state-owned companies to employ excess labor. Furthermore, as Krueger argued (1990), state-owned companies may be pressured to hire politically connected people rather than left alone to tap the market for professionals, or pressured to pursue goals other than profit maximization (Ramamutri, 1987). Jones (1991) argued, however, that corporatizations can manage state-owned enterprises with clear goals, around which government policies must be formulated. A related reason usually put forward as a possible explanation for the inefficient and negative performance of state-owned companies is the government's rigid and bureaucratic supervision of these institutions (based on form, not substance) (Chang & Singh, 1997). Additionally, there are almost no incentives for managers to pursue efficiency and profitability for their institutions. Easy access to low-cost, guaranteed, or recommended government financing may weaken managers' drive towards efficient utilization of resources and reduce threats of job loss, job stagnancy, or even bankruptcy. However, state–owned enterprises in some countries performed poorly even after reforms were introduced (Christensen, 1998).

Moreover, it may be argued that the principal-agent relationship of the type shown in the study of Fama (1980) and Fama and Jensen (1983) is not as strict or as profit-oriented as in privately-owned companies. The objective in public or state-owned companies is not to pursue profit maximization, but to ensure that rules and regulations are adhered to and followed even at the expense of profitability. Vickers and Yarrow (1991) argued that privatization could improve the performance of publicly-owned organizations, solve agency problems, and improve efficiency.

These lines of arguments found some support in empirical studies in this area. For example, Ahuja and Majumdar (1998) used Data Envelopment Analysis (DEA) to examine the performance of 68 Indian state-owned enterprises in the manufacturing sector from 1987 to 1991. The study found that state-owned enterprises were performing more poorly than their privately-owned counterparts. Similarly, Dewenter and Malatesta (2001) used various net- income-based measures and multivariate regressions to process a large data set so as to measure the profitability of state-owned companies and private companies that are included in Fortune magazine's Global 500 for 1975, 1985, and 1995. Their results indicate that state-owned companies are significantly less profitable than privately-owned firms. Evidence of the inferior performance of state-owned companies can be seen in the array of studies that had been initially conducted to examine the effect of privatization on corporate performance. For example, a recent study of Farinos et al. (2007) found significant operating performance improvement in Spanish state-owned enterprises that were privatized through public share issue offerings from 1990 to 2001.

On the other hand, the poor performance of state-owned companies has also found comparable empirical support in literature. Some authors contend that state-owned companies are not always inherently less efficient than private corporations. Private firms may, at times, be less efficient than state-owned firms. Among the cited reasons for the possible inefficiency of private enterprises is the inadequacy of their corporate governance. Even bureaucracy may be a common factor in these situations (Chang and Singh, 1997). Further arguments in defense of state-owned companies are based on the concentrated government ownership of such companies. For example, Dewenter and Malatesta (1997) argued that the government, as a blockholder in state-owned companies, is in a better position to closely monitor the managers of state-owned companies than dispersed owners in private companies.

Some studies tried to conceptually examine ownership structures outside the dual public-private ownership context. A study of McGuiness et al. (2005) using regression analysis considered two forms of ownership structure of Chinese-listed companies. The study mainly examined the effects of state and foreign ownership on the performance of the listed Chinese companies. It also examined state-owned enterprises with substantial foreign ownership. It found a negative association between the free-float size and the corporate performance. The study also found that despite a sizable foreign ownership state, such stakes are not significantly associated with corporate performance.

Some argue that government ownership is an important signal to the market because it gives a company credibility and assures investors and markets, contractors, and suppliers of the government's readiness to insure transactions with them. A study of Bourdman and Vining (1989) used the OLS model to examine samples of three ownership-based categories of companies: state-owned, privately-owned, and mixed-owned. The study found that partial privatization, with the government retaining some equity ownership, was a viable and better strategy for a government that plans to move away from state ownership. A study of Ang and Ding (2006) compared the financial and market performance of state-owned companies and private companies in Singapore and found that the state-owned companies have better corporate governance and higher valuations than the private companies. Omran (2004) also showed that Egyptian privatized firms do not exhibit significant improvement in performance, unlike state-linked companies. Similar results, but for different reasons, were shown by studies in highly developed economies such as that of Bozec (2003) in Canada and Kole and Mulherin (1997) in the United States. The U.S. study found that in that country, companies in which the government owned an interest (between 35-100%) performed almost as well as private-sector firms in the same industry. The results are attributed to the existence of a monitoring mechanism in the government-owned companies that is similar to that in private-sector firms.

A recent and more comprehensive study was conducted by Micco et al. (2007), which examined a large sample of commercial banks in 179 countries from 1995 to 2002. The objective of the study was to examine the relationship between bank ownership and performance and to test if there is a political factor effect. State-owned banks operating in developing countries tend to have lower profitability, lower margins, and higher overhead costs than their privately-owned counterparts. This relationship was weaker in the case of industrial countries.

In the case of the state-owned companies in the DR Congo, Aka (2004) argued that in the 1970s, the state-owned companies outperformed the private companies and contributed over 60% to the country's GDP. However, because of the different crises that the country faced in the last decades, the state-owned companies appeared inefficient and less productive (Tshibangu, 2009).

According to Tshibangu (2009), these multiple and various forms of political and economic instability have pushed the Congolese government to consider the establishment of new intervention structures to reverse the trend. One of the structures engendered by the State with the support of partners is: "le Comité de Pilotage de la Reforme des Entreprises Publiques" (COPIREP), which is the steering committee for the reform of public enterprises and is responsible for implementing the policy on the reform of public enterprises especially in sectors considered profitable for the State: mining, energy, transport, telecommunications, and finance. The reform of state-owned companies in the DR Congo was finally implemented in 2008. This plan for progressive government disengagement changed the status of nearly 50 parastatal companies, with 20 transformed into commercial companies; five, into other public institutions; and five, into public services companies. Four were dissolved or liquidated.[13] Among the transformed companies were GECAMINES, OKIMO, REGIDESO, SNEL, COHYDRO, SNCC, ONATRA, LAC, OCPT and SONAS.

This process is not privatization but a measure that should ultimately lead

[13]Source: Ministere du Portefeuille de la RDC. http://www.ministèreduportefeuille.org, accessed October 15, 2013.

to progressive disengagement of the government from state-owned enterprises. The main objective of the laws passed by Parliament is to improve the productivity and competitiveness of companies under the Ministry of Public Enterprises.

Tshibangu (2009) argued that after the one-year legal timeframe for the transformation of public enterprises as stipulated in the decree of 24 April 2009, no public company that was transformed into a commercial company was able to produce a detailed financial situation report. COPIREP, which drives the process on behalf of the government, has sounded the alarm by requesting that a technical note be sent to the Prime Minister in early April. Thus, COPIREP has requested an extension period for the release of the reform process, which is blocked for the moment by the difficulty of improving the financial situation of the transformed enterprises.

3.2 Performance and Efficiency of Electric Power Companies

From the international perspective, there is a growing volume of literature on studies of the efficiency of electric power companies. The more popular research topics are the development of efficiency rankings and comparisons of company performance. On this point, we highlight herein the scope of the empirical literature that exists in our field of research.

Andrikopoulos and Vlachou (1995) examined the structure and productivity growth in the Greek Public Power Corporation (GPPC) over the period of 1970-1989. Their study entailed estimating a translog cost function to investigate the implication of public ownership on technology and the price of capital vis-a-vis economies of scale.

Instead of demonstrating the impact of ownership, what they succeeded in showing is that economies of scale with respect to capacity contribute significantly to the rate of growth in the total factor productivity. They inferred that policies that are bound to decrease significantly the scale of operation of the GPPC would reduce the company's productivity performance. Based on their findings, they concluded that a GPPC, although publicly owned and operated, was relatively efficient and exhibited, over a wide range of outputs, economies of scale that contributed the most to the rate of growth in the total factor productivity.

Bagdadioglu et al. (1996), in a study of efficiency and ownership in electricity distribution in Turkey, used a non-parametric model to estimate technical and scale efficiency so as to establish a benchmark measure for the relative performance of publicly operated organizations and their private counterparts. The primary goal of their study was to assess the impact and effect of privatization on the reform program of the Turkish electricity industry.

Although their results showed better technical and allocative efficiency scores for privately operated distribution organizations, they indicated that such did not necessarily imply the success of private ownership in electricity distribution, more so as they also observed technically efficient and scale-efficient publicly owned distribution organizations and the fact that government was selective in the utilities it privatized first.

Thus, they stressed caution in interpreting such results as confirming that privatization results in higher efficiency, as some public utilities were among the efficient subsets. They argued that it is difficult to disentangle the direction of causality. Examining the factors and sources of inefficiency extended the scope of their analysis further. Market characteristics were invoked as explanatory variables. Their general conclusion, given sample size limitations, is that scale inefficiency contributed significantly to overall inefficiency.

In a study of Golany et al. (1994), they used DEA to measure and evaluate the operating efficiency of electricity plants under the auspices of the Israeli Electric Corporation (lEC). They posited that given the capital intensity of IEC, marginal improvements in the performance of the electricity industry may result in significant monetary benefits in terms of investment expenditures.

Furthermore, the use of the non-parametric approach is strengthened by the multiple nature of the electricity industry. The adoption of the analytical approach was justified on the grounds that *ex ante* assumption of efficiency in production cannot be taken for granted given the pervasive government involvement and the heavy-handed approach to the regulation of the electricity industry, what with the geopolitical sensitivity of Israel.

The significance of the aforementioned study is undermined by the failure to posit theoretical hypotheses as the bases of the performance. As the geopolitical sensitivity of the industry might be a necessary condition for government involvement, it is not enough to justify public provision or poor performance.

Mohd-Yunos and Hawdon (1997) assessed the efficiency and productivity of the Malaysian Electricity Board (NEB). Their study focused on efficiency as premised on the notion of economic rectitude in electricity production, or, in other words, how to establish an efficient way to operate and manage the electricity utility in Malaysia. The underlying argument is that the public ownership aspect of the electricity industry of developing countries has adversely affected the cost and effectiveness of their electricity policy. This is the same rationale behind the World Bank's advocacy of reduction of state involvement and promotion of privatization.

The empirical findings of Mohd-Yunos and Hawdon showed that the Malaysian Electricity Board (NEB) ranked 18th among 27 countries with respect to technical efficiency. Using the Malmquist productivity index, they also decomposed productivity into its constituents. They found that the productivity growth due to technological shift is not accompanied by the catching-up effect in productivity movement.

Mohd-Yunos and Hawdon estimated that the NEB could reduce costs by over 40 percent of 1987 prices. They showed that the DEA method has the capacity to indicate the feasible benefits from continued improvement in the technical efficiency of electricity production. A key conclusion of their study is that a change in ownership does not in itself lead to improvement in efficiency performance. A similar finding of the study of Bagdadioglu et al. (1996) showed that some publicly owned firms performed as well as privately owned firms among sample firms in developing countries.

Fare[14] et al. (1985), in a study of electricity utilities in Illinois, relaxed their restrictive assumption of the structure of production technology and developed non-parametric mathematical programming models capable of decomposing and evaluating the various components of technical efficiency.

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[14] The study of Fare et al. (1990) was conducted in the same spirit as that of Fare (1985) but investigated the productivity growth of utilities in Illinois between 1975 and 1981 using the Malmquist index approach. They decomposed productivity growth into parts -- one that accounted for efficiency changes, and another that accounted for shifts in the production frontier. They found the rates of productivity growth stable over the period, but they observed deterioration due to technological regression between 1976 and 1977.

They specified one output, the electricity generated (Kwh), and three inputs, labor (the average number of employees), fuel (Btu), and generating capacity (MW). In addition to the data on physical inputs and outputs, additional data on boiler turbine generator units, output prices, first year of commercial operation, regulatory region, and earned rate of return were used to explain the pattern of the calculated efficiencies.

They evaluated the following efficiency measures: technical efficiency, congestion, scale efficiency, and overall efficiency. Their results showed that scale inefficiency (95.6 %) is more pervasive than congestion. They inferred that this was the main contributor to the disparity they found between the overall efficiency (90.2 %) and the pure technical efficiency (97.7 %). As to the scale efficiency, only three plants were operating at their optimal scale. The larger plants operated with increasing returns to scale, but the smaller plants were in the decreasing-returns-to-scale region of the production frontier.

Pollitt (1995) examined the ownership and performance hypothesis from the various aspects of electricity services using both parametric and non-parametric techniques on a cross-country sample. Consistent with the battery of evidence for the ownership and performance debate, his results showed that there are no significant differences between the two distinct ownership types.

A more important aspect of Pollitt's study is the realization that the two techniques, the parametric and non-parametric techniques, for measuring efficiency yield similar results. To further the efficiency evaluation, using the censored regression approach, the Tobit model, Pollitt regressed the efficiency measures against some explanatory variables. The load factor emerged as a major determinant of efficiency.[15]

[15]This is not surprising given that the load factor measures the success of capital

Pollitt (1996) examined the relative efficiencies of 78 publicly and privately owned nuclear plants that were operated in 1989, as drawn from an international sample. He developed two linear programming models. The first included all the inputs used in electricity generation, and the second distinguished between discretionary and non-discretionary inputs.[16] He found evidence of improvement in labor productivity, which he adduced to labor shedding as part of the restructuring of the nuclear power industry. He tested the ownership productive efficiency hypothesis using statistical methods and the censored regression model. The null hypothesis of no difference in efficiency could not be rejected in the *ex ante* case, but was rejected in the *ex post* case. With the Tobit model, he examined the impact of the load, size, age, ownership, and technology factors and found load and age important determinants of efficiency. Interestingly, the dummy variable that was included to capture the effect ownership was found to be insignificant.

There are other studies that use non-parametric linear programming techniques to investigate the efficiency and performance aspects of privately and publicly owned utilities. The strength of the empirical studies outlined next, apart from their providing insights on the performance of various electricity utilities, is their providing additional heuristics for the performance assessment of electricity utilities.

For example, Cote's (1989) study on electricity utilities in the US found that co-operative utilities had the lowest technical inefficiency, followed by municipally owned utilities and, finally, privately owned utilities. He concluded that efficiency varied with the size of the firms.

Seitz (1971) evaluated the allocative, technical, and overall efficiencies

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utilization.

[16]Pollitt called these *ex ante* and *ex post*, respectively.

of steam-electric generation plants in the US electricity industry and estimated the industry's production function. Seitz, like Cote, found scale efficiency to be an important determinant of overall efficiency. The technique enabled the identification of excess factor use.

Pombo and Taborda (2004) measured the performance of 12 state electric power companies in Colombia before and after their 1994 regulatory reform and found an improvement in their power distribution and profitability rate in their post-reform years. However, a similar study was conducted by Estache, Tovarc, and Trujillod (2008), who assessed the performance change of a sample of 12 Sub-Saharan African government electric power companies since their main reform took place in the late 1990s. They noticed an improvement in the performance of those companies during the analysis period (1998-2005).

We can draw many inferences from these reviewed studies. First, there are key input and output variables that must be included in efficiency and performance analysis. Second, although the non-parametric linear programming technique in itself sheds light on performance, it becomes much more cogent when combined with some economic hypotheses. Third, the empirical evidence shows that there is no *a priori* case for the superiority of private ownership over public ownership, or vice versa. What these add up to is that a case by case approach has to be taken in performance assessment, not just in terms of the pertinent hypotheses but also the methodology.

Chapter 4. Research Methodology

Our research intend to assess and compare the performance of SNEL with other state electric power companies operating in SAPP (ENE of Angola, BPC of Botswana, LEC of Lesotho, ESCOM of Malawi, EDM of Mozambique, NamPower of Namibia, ESKOM of South Africa, SEB of Swaziland, TANESCO of Tanzania, ZESCO of Zambia, and ZESA of Zimbabwe). We used the DEA method to find the technical efficiency score of each company. Then we decomposed the change into the Technical Efficiency Change, Technology Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practices in the market (SAPP). After that, we estimated the Malmquist Index to follow the performance progress of each company. Finally, we used the OLS model in the second stage to assess the environmental factors that affect the efficiency of companies.

DEA is a non-parametric mathematical programming approach to frontier estimation. It was developed independent of the stochastic frontier approach over the past two decades. Farrell's (1957) approach to efficiency measurement consists of a conical hull of input-output vectors based on a production possibility set. The conical hull of vectors is constructed using linear programming (LP) techniques, for a single-output case, with a subset of the sample lying on the production possibility set and the rest lying above. Charnes, Cooper, and Rhodes (1978) reformulated this piecewise linear convex hull approach to the estimation of the technical efficiency and frontier models, to incorporate multiple-output, multiple-input technologies. Their approach assumes constant returns to scale (CRS) and is referred to as the *CRS DEA model*. This model is used here to assess the relative efficiency of homogeneous farms in transforming inputs into outputs.

Banker, Charnes, and Cooper (1984) extended the CRS model by relaxing the assumption of constant returns to scale to variable returns to scale (VRS). The model is known as the *VRS model*. The VRS DEA model differs from the CRS DEA model in that it envelops the data more closely, thereby producing technical efficiency estimates greater than or equal to those from the CRS DEA model.

Coelli (1995) reviewed and critiqued different DEA approaches.[17] DEA is both non-parametric and non-stochastic because it does not impose any a *priori* parametric restrictions on the underlying frontier technology (because it does not necessitate the specification of a functional form in the frontier methodology) and it does not require any distributional assumption for the technical inefficiency terms. Therefore, the method avoids the imposition of unwarranted structures on both the frontier technology and the inefficiency component that might distort the efficiency measures (Fare et al., 1985). DEA has the added advantages of evaluating the scale and the allocative and economic efficiencies. The minimum assumptions required for this DEA frontier methodology are the monotonicity and convexity of the efficient frontier (Banker et al., 1984).

DEA estimates efficiency relative to the Pareto-efficient frontier, which estimates the best performance (Murthi et al., 1997). Furthermore, DEA can obtain the target values based on the best practice units (peers) for each inefficient firm that can be used to provide guidelines for improved performance. However, the major shortcoming of DEA is that it is

[17] Seiford and Thrall (1990); Bjurek et al. (1990); Lovell (1993 and 1994); Charnes et al. (1995); Seiford (1996); and Au and Seiford (1993) also reviewed the non-parametric DEA approach.

deterministic and assumes a zero value for the stochastic random error component. Thus, in DEA, technical inefficiency reflects all unexplained variations of outputs, and therefore, the inefficiency of the observed firm is biased upwards. Moreover, since there is no measurement error or other random noise, and since the method is non-parametric, the efficiency measures cannot be subjected to statistical tests.

DEA can be used to estimate both technical and economic efficiency depending on the type of data available (cross-section or panel) and the kind of variables available (quantities only, or quantities and prices). Technical efficiency can be measured from quantity data for inputs and outputs, and measures of economic efficiency require both quantity and price data. Estimation of technical and allocative efficiency assumes behavioral goals, such as cost minimization or profit maximization, and a two-stage procedure. The first estimates technical efficiency, and the second measures economic efficiency. Allocative efficiency is calculated from economic and technical efficiency.

Adjusting for the environmental variables is another extension of the basic DEA method to evaluate some factors that could influence the efficiency of a firm, where such factors are not traditional inputs and are assumed to be not under the control of the manager. There are a number of possible approaches to the consideration of environmental variables, such as the “three stages” method proposed by Charnes, Cooper, and Rhodes (1981), which includes the environmental variable(s) directly in the linear programming formula of Ferrier and Lovell (1990). The two-stage approach that involves a DEA problem in the first-stage analysis and regresses the efficiency score from the first stage in the second stage using the Tobit or OLS model is recommended in most cases. Some considerable advantages of this approach are that both continuous and categorical variables can be easily accommodated in the second step, and a hypothesis test can be conducted to see if the variables significantly affect the efficiencies.

DEA gives either the maximum output for a given input level or uses the minimum input for a given output level. Thus, the analysis of efficiency can have an input-saving or output-augmenting interpretation.

4.1 CCR Model

This is one of the most basic DEA models proposed by Charnes, Cooper, and Rhodes (1978) based on Farrell's (1957) method of measuring efficiency. They introduced the term Decision-Making Unit (DMU) to describe the organization whose efficiency is being studied, which can, for example, be a company, a department store, or a bank branch, with common inputs and outputs. A DMU is an entity that converts inputs to outputs and has a certain degree of managerial freedom in decision-making.

Charnes et al. (1978) generalized the concept of the classical engineering ratio to multiple inputs and outputs. They proposed that the efficiency of a DMU can be obtained as the maximum ratio of the weighted outputs to the weighted inputs, subject to the condition that the same ratio for all the DMUs must be less than or equal to 1.

Suppose there are n DMUs: DMU_1, DMU_2, …, and DMU_n, with m inputs: X_1, X_2, ..., X_m and s outputs: Y_1, Y_2,…, and Y_s. The following fractional programming model can be solved to obtain the efficiency score and the input and output weights.

4.1.1 CCR Input-Oriented Model

Charnes et al. (1978) generalized the concept of the classical engineering ratio to multiple inputs and outputs. They proposed that the efficiency of a DMU can be obtained as the maximum ratio of weighted outputs to weighted inputs, subject to the condition that the same ratio for all the DMUs must be less than or equal to 1.

Suppose there are n DMUs: DMU_1, DMU_2, …, and DMU_n, with *m* inputs: X_l, X_2, ..., and X_m, and s outputs: Y_1, Y_2, …, and Y_s. The following fractional programming mode1 can be solved to obtain the efficiency score and the input and output weights.

$$max \quad h_0 = \frac{\sum_{r=l}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{4.1}$$

$$s.t. \ \frac{\sum_{r=l}^{s} u_r y_{r0}}{\sum_{i=l}^{m} v_i x_{ij}} \leq 1 \quad j = 1, \dots, n$$

$$u_r, v_i \geq 0 \quad r = 1, \dots, s \quad i = 1, \dots, m$$

Here, x_{ij} and y_{rj}, (al1 non-negative) are the inputs and outputs of the *j*th DMU, and v_i and u_r are the input and output weights (also referred to as *multipliers*).

The objective is to obtain weights (v_i, u_r) that maximize the efficiency (ratio) of DMU_0, which is the DMU under evaluation. The constraints mean that the efficiency of none of the DMUs should exceed 1, while using the same multipliers.

The aforementioned fractional programming model can be transformed to a linear programming problem (Charnes, 1962).

$$max \;\; h_0 = \textstyle\sum_{r=1}^{s} u_r \, y_{r0}$$

$$s.t. \; \sum_{i=1}^{m} v_i \, x_{i0} = 1 \qquad (4.2)$$

$$\sum_{r=1}^{s} u_r \, y_{rj} - \sum_{i=1}^{m} v_i \, x_{ij} \leq 0 \;\; j = 1, \ldots, n$$

$$u_r, v_i \geq 0 \;\; r = 1, , \ldots, s \quad i = 1, \ldots, m$$

The fractional program is equivalent to the linear program, and they have the same optimal objective value, *ho**.

When DMU has *ho** < 1, it is CCR-inefficient. Therefore, there must be at least one constraint for which the optima1 weights (v_i* and u_r*) produce equality between the left and right sides; otherwise, *ho** could be enlarged. This means that there must be at least one CCR-efficient DMU_0. The set of CCR-efficient DMUs is called the *efficient reference set* or the *peer group for* DMU_0. Actually, the existence of these efficient units forces DMU to be inefficient. The set of efficient units form the efficient frontier. Figure 4-1 shows the efficient frontier and the production possibility set for the CCR model in two dimensions, the single-input case and the single-output case.

The dual problem in (4.2) is expressed as follows.

$min \; \Theta$

$$s.t. \;\; \Theta x_{i0} - \sum_{j=1}^{n} \lambda_j \, x_{ij} \geq 0 \quad i = 1, \ldots, m \qquad (4.3)$$

$$\textstyle\sum_{j=1}^{n} \lambda_j \, y_{rj} \geq y_{r0} \quad r = 1, \ldots, s$$

$$\lambda_j \geq 0 \quad j = 1, \dots, n$$

In the aforementioned formula, Θ and λ_j *(j = l, ..., and n)* are the dual variables of the linear program mode1 (4.2). The scalar variable 0 is the (proportional) reduction, which should be applied to all inputs of DMU, to make them efficient. This reduction is applied to all inputs simultaneously; and since the result radially moves toward the envelopment surface, the efficiency is called *radial efficiency*.

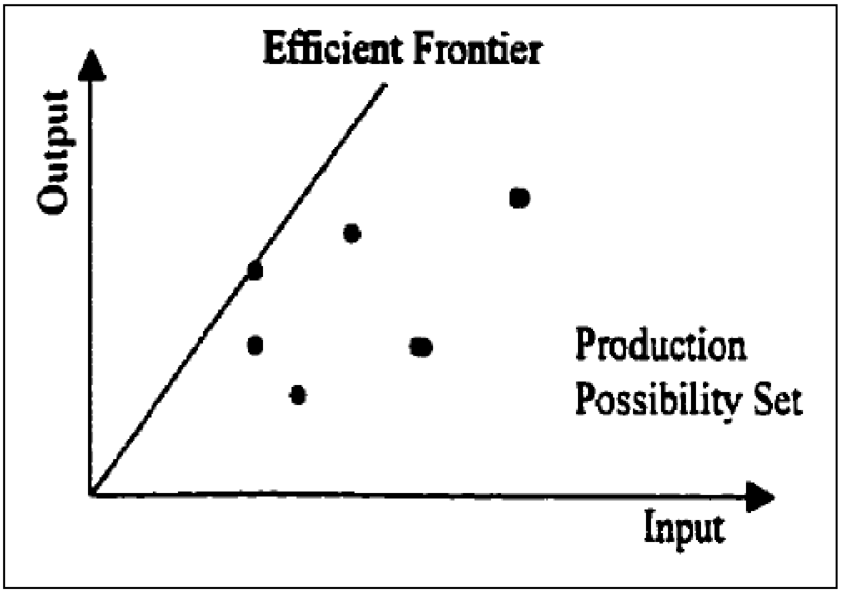

Figure 4-1. CCR Production Possibility Set and Frontier

Source: Modified from Cooper et al., 2007

To transform the dual problem into the linear programming standard form, the slack variables s^- and s^+ should be added to the model. *Slack variables* is a standard LP terminology for additional variables added to the model to convert inequality constraints to equality constraints. This DEA terminology is also used when further improvement in specific inputs or outputs is possible.

The standard linear program is as follows (Cooper, 2007).

$min\ \Theta$

$$s.t.\quad \Theta x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0 \quad i = 1, \dots, m \tag{4.4}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0} \quad r = 1, \dots, s$$

$$\lambda_j, s_r^+, s_i^- \geq 0 \quad j = l, \dots, n \quad r = l, \dots, s \quad i = l, \dots, m$$

If Θ for a DMU is 1.0 but the slack variables are not zero, it means further improvements in the efficiency of this DMU are possible by reducing (increasing) specific inputs (outputs). Charnes, Cooper, and Rhodes (1978) removed this ambiguity by amending the objective function to maximize the slack variables, but in a manner that did not impair the minimization of Θ. This resulted in the following amended objective function.

$$min\quad \Theta - \varepsilon \sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+ \tag{4.5}$$

$$s.t.\quad \Theta x_{i0} \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0 \quad i = 1, \dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0} \quad r = 1, \dots, s$$

$$\lambda_j,\ s_r^+, s_i^- \geq 0 \quad j = 1, \dots, n \quad i = l, \dots, m \quad r = 1, \dots, s$$

where in $\boldsymbol{\varepsilon}$ is a very small constant usually set as 10^{-6} (Norman, 1991). Therefore, the optimization can be achieved in two steps: first, the maximal reduction of inputs is computed (by the optimal Θ^*), then movement on the efficient frontier is achieved using the slack variables s^- and s^+.

Note that improper selection of a value for ε can result in serious errors, and was indicated via computational testing in the study of Ali (1993). Cooper et al. (2007) mentioned that it is not advisable to represent ε with a small number because it can lead to errors, besides which it is not even necessary to explicitly specify a value for ε. A two-phase procedure was described in (Cooper, 2007) that eliminates the difficulty with choosing the ε value. In Phase I, the optimal objective value of Θ (Θ^*) is computed; then in Phase II, the sum of the input excess and the output shortfalls will be maximized while setting Θ at Θ^*. The reader is referred to (Cooper, 2007) for further discussion in this area.

DMU is efficient if and only if $\Theta = 1$ and all slacks are zero. $\Theta^* < 1$ and non-zero slacks indicate the sources and amount of inefficiencies. To determine the efficiency of all DMUs, a separate LP must be solved for each.

The linear program (4.2) is also referred to as the *multiplier form*, and the dual program (4.3), as the *envelopment form*, from which the name *Data Envelopment Analysis* was derived (Cooper, 2007). As shown in Figure 4-1, all the data are inside the frontier and hence, are enveloped by the efficient frontier.

It is advisable to solve the CCR model using the dual (envelopment) form (Cooper, 2007). In DEA, the number of DMUs (n) is much larger than the sum of the inputs and outputs $(m+s)$, so it is easier to solve the dual (envelopment), which has $m+s$ constraints, than the primal (envelopment), which has n constraints. Another reason is that the interpretation of the solutions of the dual (envelopment) is more straightforward than the interpretation of the primal (envelopment). The results give the possible proportional reduction in the inputs and the amount of slacks, which indicate the improvement possibilities for an inefficient unit.

Up to this point, we have considered a version of the CCR model that seeks to minimize inputs while producing at least the given output levels. This is called the *input-oriented model*. The envelopment surface for the CCR input-oriented model, and the projections of the inefficient units (B, C, and D) to this efficient frontier in the case of one input and one output, are shown in Figure 4-2.

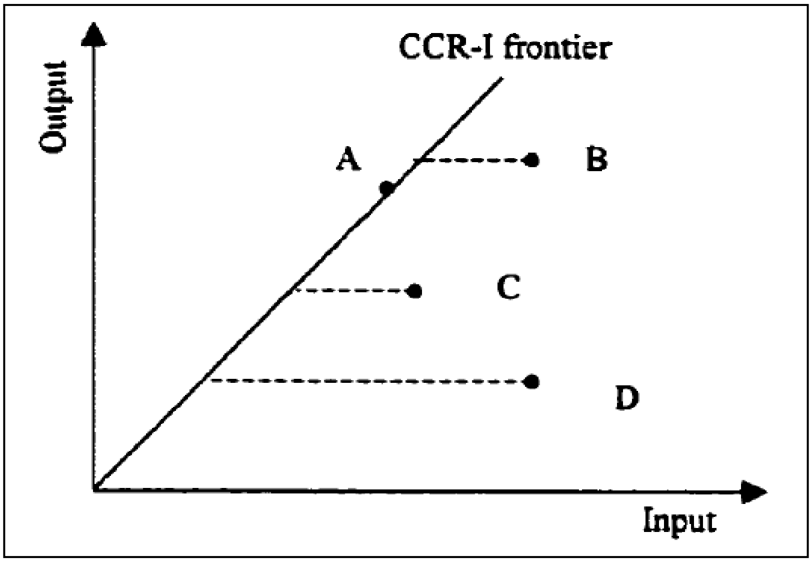

Fig. 4-2. Envelopment Surface and Projection in the CCR-I Model

Source: Modified from Cooper et al. 2007

4.1.2 CCR Output-Oriented Model

There is another type of CCR model, the output-oriented model, which aims to maximize outputs while not exceeding the observed input levels. The primal (multiplier) form of output-oriented CCR is as follows.

$$min \quad q_0 = \sum_{i=1}^{m} v_i \, x_{i0}$$

$$s.t. \ \sum_{r=1}^{m} u_r y_{r0} = 1 \tag{4.6}$$

$$\sum_{i=1}^{m} v_i \, x_{i0} - \sum_{r=1}^{s} u_r \, y_{rj} \geq 0 \quad j = 1, \dots, n$$

$$u_i, v_r \geq \varepsilon \quad i = 1, \dots, m, \ \ r = 1, \dots, s$$

and the dual for it is formulated as follows.

$$max \quad z_0 = \Phi + \varepsilon \sum_{r=1}^{s} s_r^{-+} + \varepsilon \sum_{i=1}^{m} s_i^{-}$$

$$s.t. \quad \Phi y_{r0} - \sum_{j=1}^{n} \lambda_j \, y_{rj} + s_r^{+} = 0 \quad r = 1, \dots, s \tag{4.7}$$

$$\sum_{j=1}^{n} \lambda_j \, x_{ij} + s_i^{-} = x_{i0} \quad i = 1, \dots, m$$

$$\lambda_j, s_i^{-}, s_r^{+} \geq 0 \quad j = 1, \dots, n \quad i = 1, \dots, m \quad r = 1, \dots, s$$

In the dual model, maximum output augmentation is accomplished through the variable Φ if $\Phi > 1.0$; and/or if the slacks are not zero, the unit is inefficient. To improve inefficient units, first, a proportional increase of Φ in all the outputs is required, and then further improvement of the envelopment surface may be needed based on positive slack variables. As illustrated in Figure 4-3, the envelopment surface in the CCR output-oriented model is the same as in the CCR input-oriented model. However, the projection of inefficient units to the envelopment surface is different.

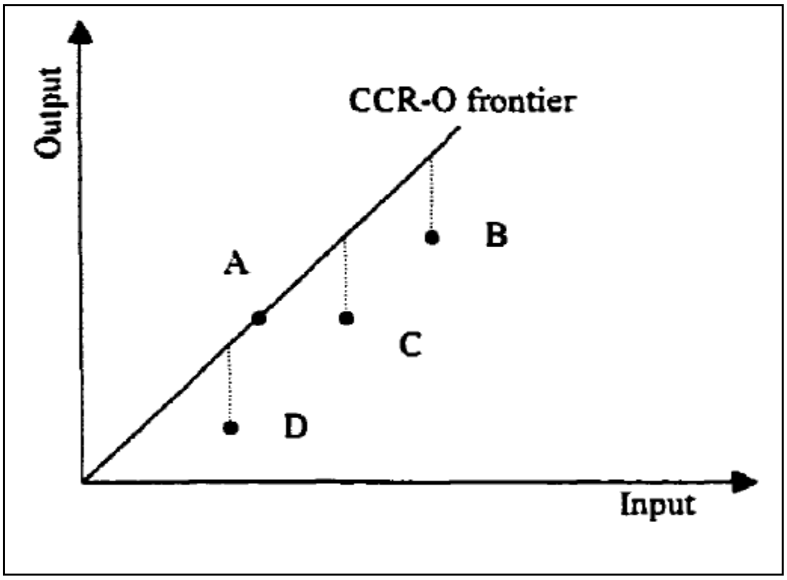

Fig. 4-3. Envelopment Surface and Projection in the CCR-O Model

Source: Modified from Cooper et al. 2007

A DMU is characterized as efficient in an input-oriented CCR model if and only if it is characterized as efficient in the corresponding output-oriented CCR model.

4.2 BCC Model

The CCR model evaluates both technical and scale efficiency via the optimal value of the ratio form. The envelopment in CCR is the constant returns to scale, which means a proportional increase in inputs results in a proportional increase in outputs.

Banker et al. (1984) developed a model for estimating the pure technical efficiency of DMUs with reference to the efficient frontier. It determines if a DMU is operating in an increasing, decreasing, or constant return to scale.

4.2.1 BCC Input-Oriented Model

The BCC input-oriented mode1 evaluated the efficiency of DMU_0 by solving the following linear program.

$$max\ \ h_0 = \sum_{r=1}^{s} u_r\, y_{r0} + u_0$$

$$s.t.\ \ \textstyle\sum_{i=l}^{m} v_i\, x_{i0} = 1 \qquad (4.8)$$

$$\sum_{r-1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} + u_0 \leq 0 \quad j = 1, \dots, n$$

$$u_r, v_i \geq \varepsilon \quad r = 1, \dots, s \quad\ i = 1, \dots, m$$

$$u_0\ \ free$$

The dual form of this program is expressed as follows.

$$min \quad \Theta - \varepsilon \textstyle\sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+ \qquad (4.9)$$

$$s.t.\ \ \Theta x_{i0} - \sum_{j=1}^{n} \lambda_j\, x_{ij} - s_0^- = 0 \quad i = 1, \dots, m$$

$$\sum_{j=l}^{n} \ddot{e}_j\, y_r - s_r^+ = y_{r0} \quad r = 1, \dots, s$$

$$\sum_{j=l}^{n} \ddot{e}_j = 1 \quad j = 1, \dots, n$$

$$\lambda_j,\ \ s_r^+, s_i^- \geq 0 \qquad j=1,\dots,n \quad i=1,\dots,m \quad r=1,\dots,s$$

A unit is BCC-efficient if and only if $\Theta^* = 1$ and all the slacks are zero. The envelopment surface in the BCC model is the variable return to scale, which is the result of the presence of the convexity constraint ($\sum \lambda_j = 1$) in the dual (envelopment) and, equivalently, the presence of u_0, which is an unconstrained variable, in the primal problem. Figure 4-4 is a two-dimensional example of the envelopment surface and projections to this frontier.

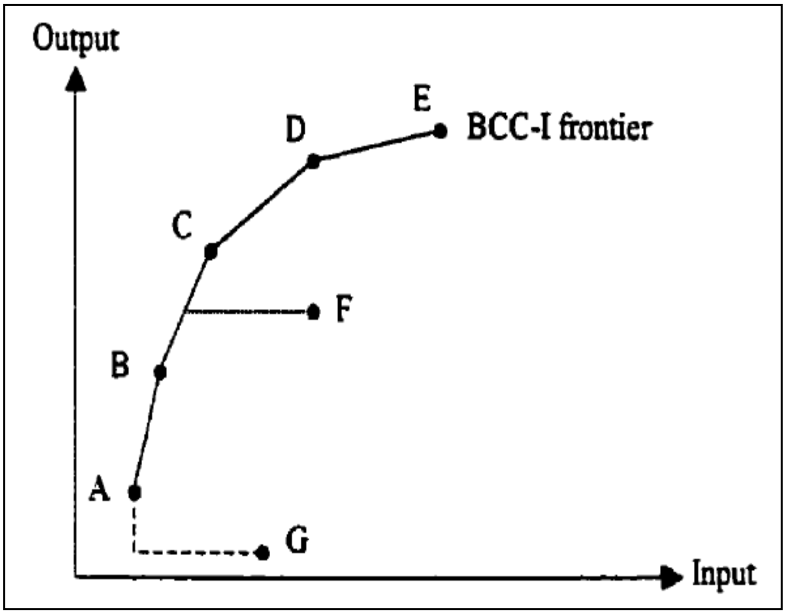

Fig. 4-4. Envelopment Surface and Projection in the BCC-I Model

Source: Modified from Cooper et al. 2007

Inefficient units are projected to the efficient frontier, first by reducing their input, and then by accommodating the slack variables, if any.

Units A, B, C, D, and E are the efficient units and form the efficient frontier. Units F and G are inefficient. To make unit F efficient, a proportional decrease in its input is needed. For unit G, first, a reduction in its input level and then an increase in its output are needed, since its non-zero output slack indicates that further improvement is possible.

If a unit is characterized as efficient in the CCR model, it will also be characterized as efficient in the BCC model, but the converse is not necessarily true.

4.2.2 BCC Output-Oriented Model

While the envelopment surface for the BCC output-oriented model is the same as that for the BCC input-oriented model, the projections to the envelopment surface in the two models differ. The objective in BCC-O is to maximize the output production while not exceeding the actual input level. Equation (4.10) gives the primal formulation for the BCC output-oriented model.

$$
\begin{aligned}
& min \quad q_0 \textstyle\sum_{i=l}^{m} v_i\, x_{i0} + v_0 \\
& s.t. \quad \sum_{r=1}^{m} u_r\, y_{r0} = 1 \\
& \sum_{i=1}^{m} v_i\, x_{ij} - \sum_{r=1}^{s} u_r\, y_{rj} + v_0 \quad j = 1, \dots, n \\
& \qquad\qquad u_i, v_r \geq \varepsilon \quad i = 1, \dots, m \quad r = 1, \dots, s
\end{aligned}
\tag{4.10}
$$

The dual (envelopment) form of the problem is as follows.

$$
\begin{aligned}
& max \quad z_0 = \Phi + \varepsilon \textstyle\sum_{r=1}^{s} s_r^{+} + \varepsilon \sum_{i=1}^{m} s_i^{-} \\
& s.t. \quad \Phi y_{r0} - \sum_{j=1}^{n} \lambda_j\, y_{rj} + s_r^{+} = 0 \quad r = 1, \dots, s \\
& \sum_{j=1}^{n} \lambda_j\, x_{i0} + s_i^{-} = x_{i0} \quad i = 1, \dots, m
\end{aligned}
\tag{4.11}
$$

$$\sum_{j=1}^{n} \ddot{e}_j = 1$$

$$\ddot{e}_j, s_i^-, s_r^+ \geq 0 \quad j = 1, \ldots, n \quad i = 1, \ldots, m \quad r = 1, \ldots, s$$

For the BCC output-oriented models, similar to the CCR output-oriented models, maximal output augmentation is accomplished through Φ. Based on this model, a unit is efficient if and only if $\Phi^* = 1$ and all the slacks are zero. To show graphically the difference between the BCC-1 and BCC-O models in projecting inefficient units to the efficient envelopment surface, consider the BCC-1 example in Figure 4-4, now shown as BCC-O in Figure 4-5.

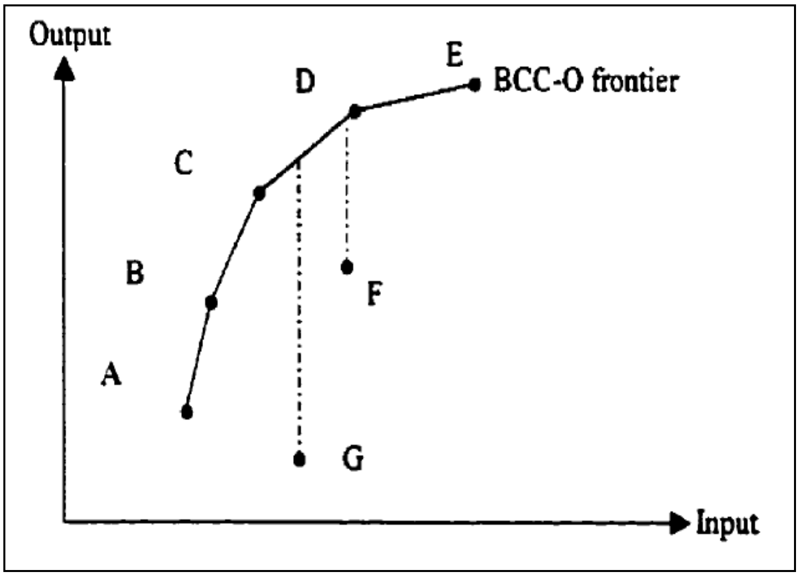

Fig. 4-5.Envelopment Surface and Projection in the BCC-O Model

Source: Modified from Cooper et al. 2007

As shown in Figure 4-5, while the envelopment surface of BCC-O is identical to the envelopment surface of BCC-1 (Figure 3-4), units F and G are projected to significantly different points on the envelopment surface.

4.3 Additive Model

In the preceding models (CCR and BCC), the projection of inefficient units to the envelopment surface is based on the model orientation. An input-oriented model focuses on maximal movement toward the frontier through the proportional reduction of its inputs, whereas an output-oriented model does this through proportional augmentation of outputs. Charnes et al. (1985) introduced the additive model, which combines the two orientations in one model. In this model, the inefficient units are projected onto the envelopment surface by decreasing their inputs and increasing their outputs simultaneously.

The primal (multiplier form) problem of the additive model can be expressed as follows.

$$max \quad w_0 \textstyle\sum_{r=1}^{s} u_r\, y_{r0} - \sum_{i=1}^{m} v_i\, x_{i0} + u_0$$

$$\sum_{r=1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} + u_0 \leq 0 \qquad j = 1, \dots, m \tag{4.12}$$

$$u_r, v_i \geq 1 \quad r = 1, \dots, s \quad i = 1, \dots, m$$

$$u_0 \ free$$

The dual (envelopment form) is as follows.

$$min \quad z_0 = -\varepsilon \sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+$$

$$s.t. \quad x_{i0} - \textstyle\sum_{j=1}^{n} \lambda_j\, x_{i0} - s_i^- = 0 \qquad i = 1, \dots, m \tag{4.13}$$

$$\textstyle\sum_{j=l}^{n} \lambda_j\, y_{rj} - s_r^+ = y_{r0} \qquad r=1,\dots,s$$

$$\sum_{j=1}^{n} \lambda_j = 1 \quad j = 1, \dots, n$$

$$\ddot{e}_j, s_r^+, s_i^- \geq 0 \quad j = 1, \dots, n \quad i = 1, \dots, m \quad r = 1, \dots, s$$

DMU_0 is efficient if and only if $z_o^* = w_o^* = 0$. When any of the slack variables, s^- or s^+, is not zero, it means DMUo is inefficient, and the slack values identify the sources and amounts of inefficiency in the corresponding inputs and outputs. A unit is Additive-efficient if and only if it is BCC-efficient, which is proven in (Cooper, 2007) as a theorem.

The one-input, one-output example in Figure 4-6 shows the envelopment surface and the way inefficient units are projected onto the frontier in the Additive model.

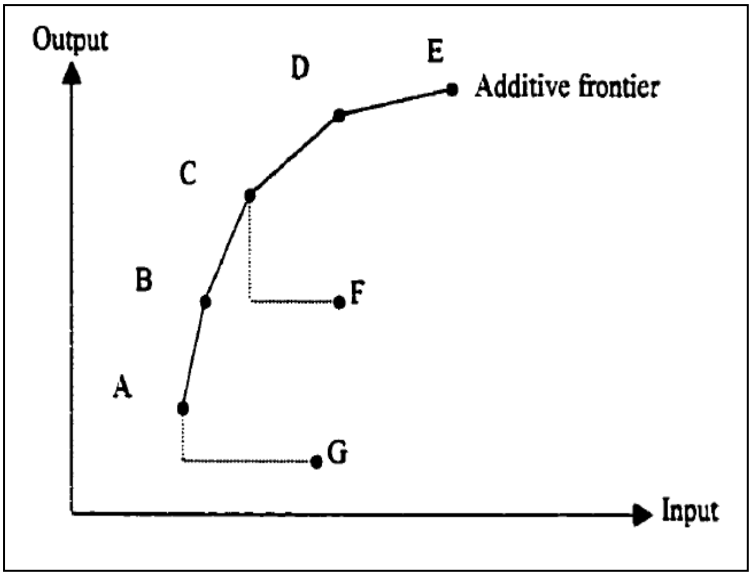

Fig. 4-6. Envelopment Surface and Projection in the Additive Model

Source: Modified from Cooper et al. 2007

The envelopment surface in the Additive model is the same as that in the BCC model, which is a variable return to scale. This is due to the presence of the convexity constraint in the dual (envelopment) and equivalently, u_0, in the primal problem.

4.4 Multiplicative Model

In the preceding DEA models, efficiency is viewed as the sum of the outputs divided by the sum of the inputs. This means that adding one more output results in an added input without any effect on the other outputs. However, in some processes, the output levels (or input levels) may be interdependent (Sherman, 1988). Charnes et al. (1982) suggested an alternative formula for the DEA, to reflect these interactions. In their model, efficiency is measured as the multiplicative combination of the outputs divided by the multiplicative combination of the inputs. The theory on which the model is based is similar to that of the CCR model, and implies that in the Multiplicative model, the DMU is efficient if and only if all the stacks are zero. The envelopment surface in the multiplicative model is piecewise log-Iinear instead of piecewise linear, which is the envelopment surface for the other DEA models. Sherman (1988) mentioned that the Multiplicative model would be used in a situation where the management's insight indicates that the production process is represented more by a multiplicative relationship.

4.5 Malmquist Index

As discussed by Färe et al. (1994), the Malmquist Productivity Index was introduced by Caves, Christensen, and Diewert (1982) after Sten Malmquist proposed constructing quantity indexes as ratios of distance functions.[18]

[18]See for details: Malmquist, Sten (1953). "Index Numbers and Indifference Curves."

In the discussion of Coelli et al. (2005), they stated that distance functions can be used in the context of multiple-output, multiple-input technology. In the applications, only data on input and output quantities are required. Distance functions can be specified as input and output distance functions. An input distance function characterizes the production technology by aiming at proportionally contracting an input vector towards the production frontier; whereas an output distance function considers a maximal proportional expansion of the output vector.

Suppose we define productivity technology set S as follows.

$$S=\{(x,y): x \text{ can produce y}\} \quad (4.13)$$

This set consists of all input-output vectors $(\mathbf{x}, \mathbf{y})$, such that $\mathbf{x}$ can produce $\mathbf{y}$.

Equivalently, this set can be represented by output and input sets, respectively, as follows.

$$P(x) = \{y{:}x \text{ can produce } y\} = \{y{:}(x,y) \in S\}; \quad (4.14)$$

$$P(x) = \{x{:}x \text{ can produce } y\} = \{x{:}(x,y) \in S\}; \quad (4.15)$$

where in $P(\mathbf{x})$ is the output set and $L(\mathbf{x})$ is the input set. For any input-output combinations, their output and input distance function expressions are defined as follows.

$$d_0(x,y) = min\{\Theta{:}(y/\Theta) \in P(x)\} \quad (4.16)$$

$$d_0(x,y) = min\{\delta{:}(y/\delta) \in L(x)\} \quad (4.17)$$

Trabajos de Estatistica," 4 (1).

From the output distance function (4.16), we can see that when *Θ* is minimized, *y/Θ* is maximized. That is, the distance from a sub-optimal input-output combination *P* (or Q, respectively) to the production frontier *(xs, ya) [(xt, yd)]* is minimized (shown in Figure 4-7). Thus, this distance function measures the maximum possible output (frontier output) that an agent can produce given a fixed amount of inputs, relative to its current production level. Therefore, it is a measure of technical efficiency.

Figure 4-7 presents a graphical expression of a simple single-input, single-output constant-return-to-scale (CRS) production frontier. A point to note is the implementation of the "time period" into the distance function.

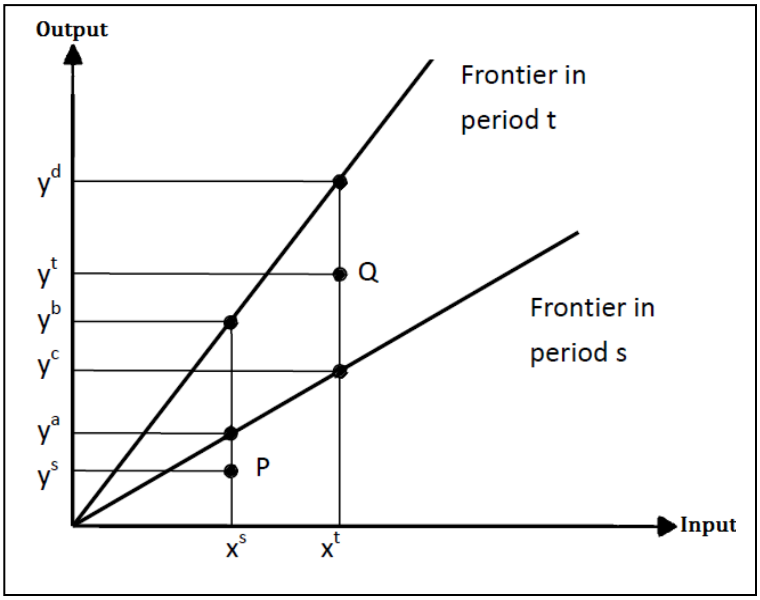

Fig 4-7. Decomposition of the Malmquist Productivity Index
Source: Modified from Cooper et al. 2007

They are denoted by *s* and *t*, as the first period and the second period, respectively. In this case, we will have one output distance function for each period. They are d_0^s *(x,y)* and d_0^t *(x,y)*, respectively. Points *P* and *Q* in Figure 4-7 represent the input-output combinations of an agent in period *s* and period t, respectively. In both periods, it is producing inefficiently because in period s (and period t, respectively), with input x^s (x^t), it should be able to produce y^a (y^d) if it has achieved full technical efficiency. According to Figure 4-7, the technical efficiency can be measured by y^s/y_a in period s (y^t/y^d for period t).

The Malmquist Productivity Index is derived exactly from the aforementioned distance functions. In this paper, the output-oriented Malmquist Productivity Index is applied for the analysis. Therefore, the following illustration will focus only on the output-oriented approach.[19]

The Malmquist Index is constructed by measuring the radial distance of the observed output and input vectors in two consecutive periods, relative to a benchmark production technology. The output-oriented Malmquist Index focuses on the maximum output(s) level one can produce, given an input vector and a production technology, relative to the observed level of output(s). Using distance functions, we can express the Malmquist Productivity Index in period s as follows.

$$m_0^s(y_s, y_t, x_s, x_t) = \frac{d_0^s(y_t, x_t)}{d_0^s(y_s, x_s)} \tag{4.18}$$

With reference to Figure 4-7, the Malmquist Productivity Index in period s can also be derived as follows.

$$m_0^s(y_s, y_t, x_s, x_t) = \frac{{y_t}/{y_c}}{{y_s}/{y_a}} = \frac{{y_t}/{y_s}}{{y_c}/{y_a}} \tag{4.19}$$

There lie two implications. First, m_0^s equals the ratio of the technical efficiency in period t, ${\mathrm{y_t}}/{\mathrm{y_c}}$, using the benchmark technology in period s, to

[19]Please see Coelli et al. (c1998) for the input-oriented approach.

the technical efficiency in period *s*, ${}^{y_s}/_{y_a}$, using the technology in the same period. Second, it is also equal to the ratio of the output growth ${}^{y_t}/_{y_s}$, to the movement along the production frontier in period *s*: ${}^{y_c}/_{y_a}$. The index is interpreted as follows: if $m_0^s > 1$, there is an increase in productivity; if $m_0^s = 1$, there is no change in productivity; and if $m_0^s < 1$, , there is a decrease in productivity.

Since the Malmquist Productivity Index can be defined using the period *s* technology or the period *t* technology, the Malmquist TFP Index is defined as the geometric mean of the Malmquist Productivity Index based on the period *s* and period *t* technologies, as a Fisher ideal index. It is given in the following equations.

$$m_0 \ (y_s, y_t, x_s, x_t) = [m_0^s(y_s, y_t, x_s, x_t) \ m_0^t(y_s, y_t, x_s, x_t)]^{1/2} \tag{4.20}$$

$$=[\frac{d_0^s(y_t,x_t)}{d_0^s(y_s,x_s)} * \frac{d_0^t(y_t,x_t)}{d_0^t(y_s,x_s)}]^{1/2} \tag{4.21}$$

$$= \frac{d_0^t(y_t,x_t)}{d_0^s(y_s,x_s)}[\frac{d_0^s(y_t,x_t)}{d_0^t(y_t,x_t)} * \frac{d_0^s(y_s,x_s)}{d_0^t(y_s,x_s)}]^{1/2} \tag{4.22}$$

Referring to Figure 4-7, $m_0 = \frac{{}^{y_t}/_{y_d}}{{}^{y_s}/_{y_a}}[\frac{{}^{y_t}/_{y_c}}{{}^{y_t}/_{y_d}} * \frac{{}^{y_s}/_{y_a}}{{}^{y_s}/_{y_b}}]^{1/2}$. Following Fare et al. (1994), we can also derive (4.22), wherein the ratio outside the brackets measures the change in technical efficiency between period *s* and period *t*. The geometric mean of the two ratios inside the brackets captures the shift in technology (production frontier) between the two periods. That is, the Malmquist TFP Index can be decomposed into the Technical Efficiency Change (4.23), Technological Change (4.24), Pure Technical Efficiency Change (4.25), and Scale Efficiency Change (4.26), as follows.

Technical Efficiency Change = $\frac{d_0^t(CRS)(y_t,x_t)}{d_0^s(CRS)(y_s,x_s)}$ (4.23)

Technological Change = $[\frac{d_0^s(y_t,x_t)}{d_0^t(y_t,x_t)} * \frac{d_0^s(y_s,x_s)}{d_0^t(y_s,x_s)}]^{1/2}$ (4.24)

Pure Technical Efficiency Change = $\frac{d_0^t(VRS)(y_t,x_t)}{d_0^s(VRS)(y_s,x_s)}$ (4.25)

Scale Efficiency Change = $\frac{d_0^t(CRS)(y_t,x_t)}{d_0^s(CRS)(y_s,x_s)} / \frac{d_0^t(VRS)(y_t,x_t)}{d_0^s(VRS)(y_s,x_s)}$ (4.26)

Though the Malmquist TFP Index appears to be more complicated, its interpretation remains the same as that of the simple Malmquist Productivity Index.

Under such decomposition, the Malmquist TFP Index allows researchers to distinguish between these two effects. Färe et al. (1994) suggested that the Technical Efficiency Change component captures the catching-up effect usually seen in developing economies by the diffusion of technology, as well as the variation in capacity utilization and the differences in the structure of the economy. On the other hand, he expects the Technological Change component to reflect the inter-temporal advances in production technology and the Scale Efficiency Change to measure the improvement efficiency when a company moves closer to the most productive scale size.

Chapter 5. Data Analysis

5.1 Data

Since SAPP is composed of 12 member countries, each country is represented by its state electric power company (ENE for Angola, BPC for Botswana, SNEL for DR Congo, LEC for Lesotho, ESCOM for Malawi, EDM for Mozambique, NamPower for Namibia, ESKOM for South Africa, SEB for Swaziland, TANESCO for Tanzania, ZESCO for Zambia, and ZESA for Zimbabwe). For this study, we used data on those companies for the period spanning 2004 to 2013. It is important to specify that each year, SAPP publishes its annual reports and posts it on its website,[20] from which we sourced our data. However, the SAPP annual reports data consist only of the Installed Capacity (MW), Maximum Demand (MW), Maximum Demand Growth (%), Number of Employees, Number of Consumers, Sales (Gwh), Sales Growth (%), Generation Sent Out (Gwh), Net Imports (Gwth), Net Exports (Gwth), Transmission System Losses (%), Revenue (US$ Million), Debtor Days, Rate of Return, and Net Income (US$ Million).

Selection of Input and Output Variables

Selection of input and output variables is among the most important tasks of performance analysis. The choice of variables depends not just on the methodology and the technical requirements of the DEA method. No universally applicable rational template is available for the selection of variables. In general, the inputs must reflect the resources used and the

[20] Southern African Power Pool, 2004-2013. Annual Reports, http://www.sapp.co.zw/areports.html, accessed on September 10, 2003.

outputs must reflect the bulk of the electricity produced. A study of standard literature reveals significant insights on the choice of variables. Jamasb and Pollitt (2001) outlined the most widely used variables based on international experience. However, in our study, the choice of variables is also consistent with the methods used in the studies of Mohd-Yunos et al. (1996) and Estache et al. (2008). We used three inputs and one output. For the inputs, we used Transmission System Losses (%) as the proxy of Electricity Loss; Installed Capacity (MW); and Number of Employees as the proxy of Labor. For the output, we used Generation (Gwh). Table 5-1 shows the summary statistics of the data that we used in this study.

Table 5-1. Summary Statistics of Input and Output Variables

Variables	Obs.	Mean	St. Dev.	Minimum	Maximum
Generation (Gwh)	120	22023.67	62305.51	99	239108
Electricity loss (%)	120	9.116667	5.983427	2	26
Installed Capacity (MW)	120	4393.467	11779.48	51	44175
Labor	120	5769.983	8907.576	439	39222

Selection of the DEA Method

For the choice of the DEA method with which to assess the companies' efficiency, we referred to the preview study of Boussofiane et al. (1997), who used both the constant returns to scale (CRS) and variable returns to scale (VRS) model in UK privatization. They found that except for two firms (out of 11), the results were similar, irrespective of whether constant or variable returns were assumed. However, this depends on whether or not the variable returns to scale assumption was invoked. Smith (1993) demonstrates that the inappropriate use of the VRS assumption can lead to widely inflated efficiency estimates when the sample size is small, as it is this study. As a result, Boussofiane et al. (1997) put more weight on the CRS DEA model. This study followed a similar approach (because we also used a small sample size in our study); and in this context, the CCR model is well adapted. Moreover, the CCR Input-oriented Model was preferred because most of the state electric power companies in SAPP are often burdened with operational costs in the energy sector. Thus, it is suggested that costs be reduced rather than increasing the volume of services provided (and from this principle, we executed the Frontier Projection Analysis). Finally, to measure the performance of those companies over time, we used the Malmquist Index. To compute our results, we used DEAP V 2.1.[21]

5.2 CCR Model and Malmquist Index Results

5.2.1 CCR Model

The CCR model provides the results of the performance of a DMU at a particular point in time relative to a set of peers. The technical efficiency, radial movement, and slack movement of each DMU were computed. The results suggest that the average score of each company is between 0 and 1 (Figure 5-1). From 2004- 2013, we regrouped three categories of companies as follows.

- Efficient companies, which had a score of 1. Among these were LEC and ESKOM, which appeared consistently on the reference frontier curve in all the years.

[21] Centre of Efficiency and Productivity Analysis: DEAP V 2.1 http://www.uq.edu.au/economics/cepa/deap.php, accessed on October 15, 2013.

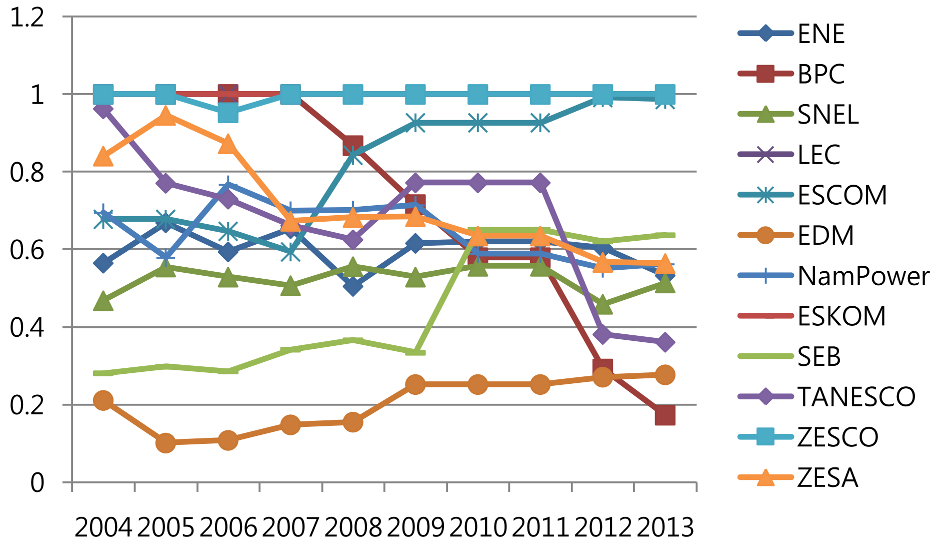

Figure 5-1. Trend of Technical Efficiency Scores for Companies

- Companies with an average efficient score higher than 0.6 (ENE, BPC, ESCOM, TANESCO, ZESCO, and ZESA). BPC was efficient only from 2003 to 2007; but in the following years, its efficiency sharply decreased. ZESA was also efficient, but its efficiency dropped slightly in 2006 and recovered slightly in 2007.

- Companies with an efficient score lower than 0.6. In this group was SNEL, EDM, NamPower, and SEB.

The efficiency of LEC and ESKOM can be explained by their ability to generate sufficient power while operating in their full installed capacity (100% for LEC and 87.7% for ESKOM, respectively) and minimizing their electricity loss.

The efficiency of ESKOM is based on its self-sustainable power generation policy dating back to the apartheid regime. Before the democratization of South Africa in 1994, the apartheid regime built many coal power plants because of the country's abundant supply of coal.

During that time, ESKOM overspent on the provision of too much generation capacity in the 1980s, when more than 30 coal power stations were built across the country to generate electricity. Between 1983 and 2005, it did not build any new generating plant; and between 2001 and 2005, it did not add capacity. After 2005, however, while demand was fast approaching the total available capacity, capacity was added to increase the power generation. Since 2010, South Africa has adopted the "New Build Programme"[22] to increase its generation capacity from about 45,000 MW to 85,000 MW between 2010 and 2030 to meet its projected demand growth. Yet in 2013, ESKOM was able to generate 237,430 Gwh of electricity output.

As for the energy efficiency of Lesotho's electric power company (LEC), in the late 1990s, the country implemented its Energy Policy of 1989, which targeted the country's economic development and ensured the national energy security instead of depending totally on imports from South Africa. In 2000, the country put in service its Muela 72MW hydropower station. It estimated the plant's output as more than enough to meet local demand during off-peak periods and in summer. The excess generated during these periods is exported. However, shortfalls emerge during peak periods and in winter.

Except in 2009, ZESCO was also among the efficient companies in SAPP. It maintained its efficiency because of the "National Energy Policy"[23] of 1994,

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[22]Source: Reported by KPMG's Global Infrastructure & Projects Group Africa Team, Johannesburg, South Africa (2011), "Sub-Saharan Power Outlook," http://www.kpmg.com/ZA/en/IssuesAndInsights/ArticlesPublications/General-Industries Publications/Documents/Sub-Saharan%20Electricity%20Outlook%20Brochure.pdf., accessed November 27, 2013.

[23]Source: Reported by CORE International, Inc. (2004). Energy Service Delivery in

which contributed to the progressive increase in the sources of electricity generation to meet the national demand and the demand of mining companies. In 2013, SAPP estimated the total installed capacity of ZESCO as about 1,870 MW and its total generated electricity, as 11,381 Gwh (SAPP, 2013). However, the company's inefficiency in 2006 is attributed to the periodical drought that affected the Zambian River and then affected electricity production at hydropower plants.

Concerning the electricity sector in Botswana, it is dominated by BPC. Electricity generation has been dominated by an overdependence on coal as a primary source of energy, largely because of its abundance and alleged cost-effectiveness. Energy efficiency efforts started in 2000. However, since 2008, Botswana has had a consistent electricity deficit, which peaked at 1174.83 Kilowatts (KWh)[24] per capita. This is due to declining electricity generation and a persistent increase in electricity consumption, which has had a negative impact on BPC's efficiency.

From 2004 to 2013, SNEL was also found inefficient because its technical efficiency score was around 0.5. Its inefficiency can be explained by its inability to generate enough electricity with respect to its total installed capacity. According to SNEL (2010), its electricity production system provides only more or less than a third of its total capacity (2,442 MW), with only 47 percent of its production equipment in working condition. The case of its Inga (I and II) hydropower plants, the true hearts of the electrical system in

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Zambia. Washington, DC, USA. Retrieved from http://www.coreintl.com/.../Energy%20Service%20Delivery%20in%20Zambia.

[24]Clean Energy Info Portal – reegle: Botswana. http://www.reegle.info/policy-and-regulatory-overviews/BW, accessed November 27, 2013 from

the DR Congo, illustrates well the general state of SNEL's network and the challenges it is facing. Currently, only three of the six groups of the Inga I work due to maintenance and repairs. Inga II suffers from both technical design issues and lack of maintenance and replacement parts. Both plants (Inga I and II) need urgent repairs, as well as major rehabilitation and reliability overhaul. Of the 52 major thermal groups in the DR Congo before the war (1996-2001), only 22 are now working. To these problems, we can add the problem of the aging and lack of maintenance of some power infrastructure that cause very frequent power outages. All these issues are among the causes of SNEL's inefficiency.

5.2.2 Malmquist Index

The Malmquist Index captures two important sources of productivity changes: gains through technical efficiency changes and technological change.

Technical efficiency change means the level to which firms improve or worsen their efficiency. Figure 5-2 reveals that LEC and ESKOM did not progress in terms of technical efficiency change during each period in our analysis.

Moreover, SNEL caught up with 18.6% in 2004-2005. In this period, its labor increased by 14.7%; its electricity loss, by 12.5%; and its generation sent out, by 16.27%. In fact, right after the reign of relative peace across the country, the establishment of the transition government[25] played a key role in the increase in SNEL's employment and its rehabilitation of its electricity generation capacity.

[25]Source: Transition Government of the DR Congo (Wilkipedia Online, http://en.wikipedia.org/wiki/Transitional_Government_of_the_Democratic_Republic_of_the_Congo, accessed November 28, 2013).

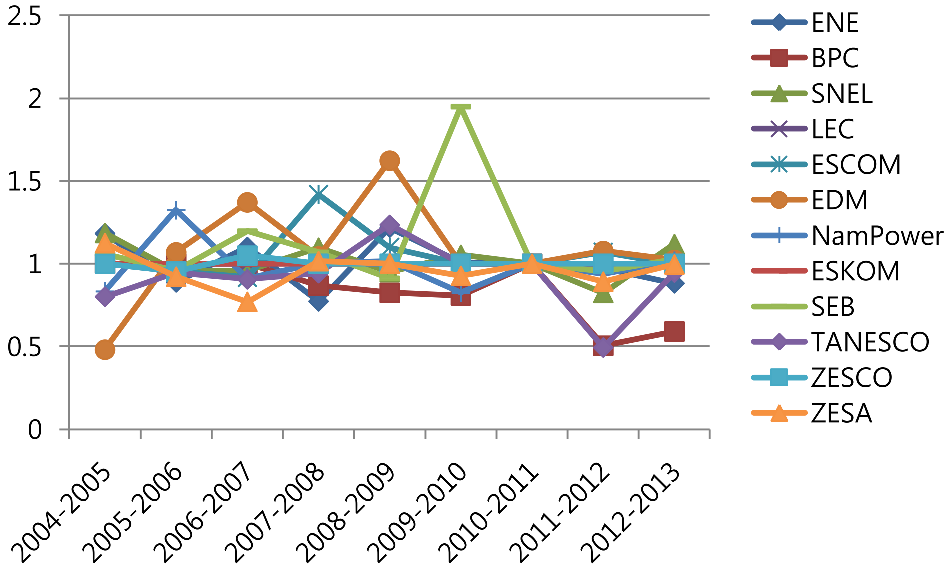

Figure 5-2. Trend of the Malmquist Index (Technical Efficiency Change) for Companies

During such transition period, the government target was the improvement of business and the economy in the country. For that, the development of the mining sector was very important, because the state did not have the funds to deal with mining activities and it was assumed that attracting foreign investors to the mining sector would boost the country's economy. Thus, increasing electricity generation[26] allowed mining operators to increase the annual production and helped improve the economic activities in the country. Some electricity generated was exported to SAPP to respond to the regional power demand. It should also be noted that the mobilization of human resources in SNEL was essential to achieving the company's assigned objective during this period. SNEL also had two successive periods (2005-

[26]Source reported by Comité de Pilotage de la Réforme des Entreprises du Portefeuille de l'Etat (2008), Rapport Annuel, http://www.copirep.cd/index.php/ressources/banque-de-donnees/category/41-rapports-annuels-du-copirep?download=109:rapport-annuel, accessed on November 28, 2013, p. 40.

2006 and 2006-2007) of negative technical efficiency change characterized by constant declines in labor and generation sent out, and hikes in electricity loss. Nevertheless, in 2007- 2008, SNEL improved with a 9.7%, and the period was marked by a 22.84% increase in electricity generation sent out, a 7.7% increase in labor, and an 11.59% drop in electricity loss. The rehabilitation of Zongo Hydropower[27] played a considerable role in the improvement of SNEL's power generation and had some impact on the company's technical efficiency change.

During all the periods, the highest progress was made by SEB, which improved by 9.5% in 2009-2010, followed by EDM, which progressed by 1.62% in 2008-2009. In 2010-2011, all the companies in the SAPP market did not progress in terms of technical efficiency change. This could be attributed to the effect of the global financial recession. However, in the last period, 2012-2013, SNEL caught up again, with an 11.9% improvement. In this period, SNEL slightly increased its electricity generation by 8.89%, and reduced its labor and electricity loss by 1.56% and 0.7%, respectively. As usual, the economic activities[28] across the country (including mining and electricity exports) were considered among the factors that stimulated this progress.

Technological change expresses the change in the efficient frontiers between two different periods. Figure 5-3 shows that most of the companies

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[27] Source: Reported by Radio Okapi (2007). Réhabilitation du barrage de Zongo: Résoudra ou résoudra pas le problème de délestage en Rd Congo? http://radiookapi.net/emissions-2/2007/10/02/rehabilitation-du-barrage-de-zongo-resoudra-ou-resoudra-pas-le-probleme-de-delestage-en-rd-congo/, accessed November 28, 2013.

[28] According to Congo Opportunity Media (2013), the electricity sector has also contributed to the current economic progress in the DR Congo. http://www.congoopportunities.net/rdc-bonne-electricite-forte-economie-le-secteur-minier-cible/, accessed on November 28, 2013.

seemed to evolve along the non-progress line and had almost the same value of technological change in all the periods. This implies that most of the companies applied the same production technologies and innovations in power generation. In 2007-2008, most of the companies regressed in terms of technological change, except for ESKOM, which improved significantly by 67.7%. Thus, this was used as the reference for all the periods. SNEL's regression in terms of technological change was attributed to its inability to use technologically advanced equipment to contribute to the outward shift of the production frontier in that period.

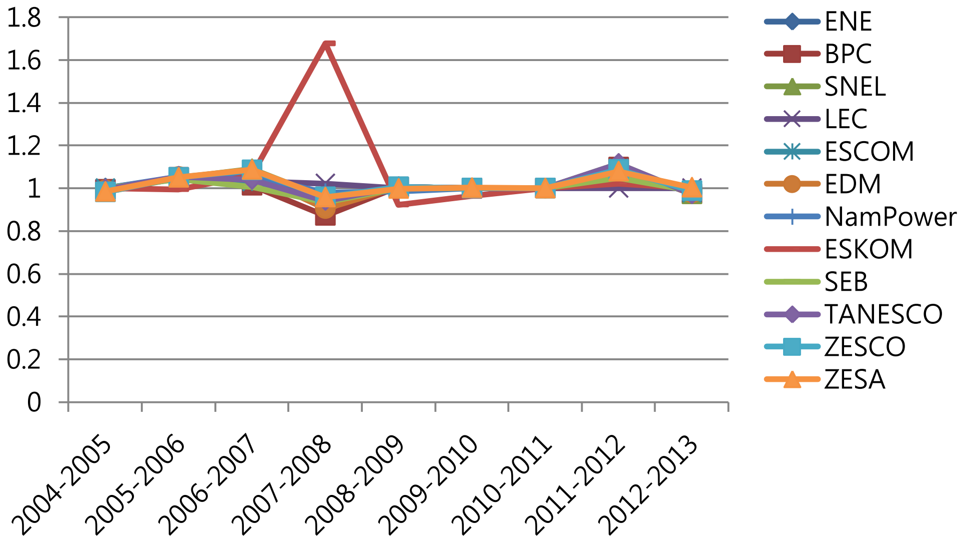

Figure 5-3. Trend of the Malmquist Index (Technological Change) for Companies

In two successive periods (2009-2010 and 2010-2011), most of the companies did not improve in terms of technological change, except for ESKOM and ZESA, which evolved negatively in 2009-2010. Thus, the non-progress of technological change in those periods is attributed to the global financial recession.

From 2011-2012, SNEL improved by 11.5%. This could be attributed to its routine maintenance of some of its power infrastructure.

Scale Efficiency indicates if the DMUs are producing at the most efficient size. Figure 5-4 shows the scale efficiency means (2004-2013) of all the companies. In this figure, EDM and SEB reveal an increasing return to scale. ESKOM, LEC, and ZESCO each operated at a constant return of scale.

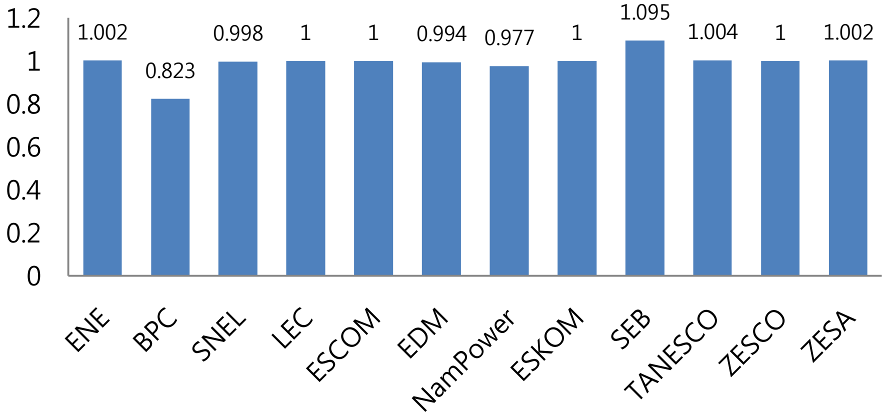

Figure 5-4. Scale Efficiency Means (2004-2013) for Companies

Regarding SNEL, the scale efficiency effect had a negative contribution to the company's productivity growth over our analysis period. The scale efficiency effect of SNEL decreased to 0.998 on the average. This indicates that SNEL operated at a decreasing return to scale because its operation scale significantly expanded its labor, increased it electricity loss, and made its installed capacity by electricity generation less than its inputs expansion.

The Malmquist Index corresponds to the product of technical change and technological change. Figure 5-5 shows that the trend of the Malmquist Index appears similar to the technical efficiency change trend because most of the companies used the same technology in the SAPP market. However, the companies that registered an improvement in their technical efficiency change improved their productivity. The best-practice companies are SEB and

ESKOM, which obtained 1.95 (2009-2010) and 1.667 (2007-2008), respectively, followed by EDM and Nampower, which achieved 1.461 (2006-2007) and 1.396 (2005-2006), respectively. For SNEL, its best-performance periods are 2004-2005, 2009-2010, and 2012-2013, during which it got 1.165, 1.054, and 1.089, respectively. The last period (2012-2013) is the best-performance period for all the categories of companies.

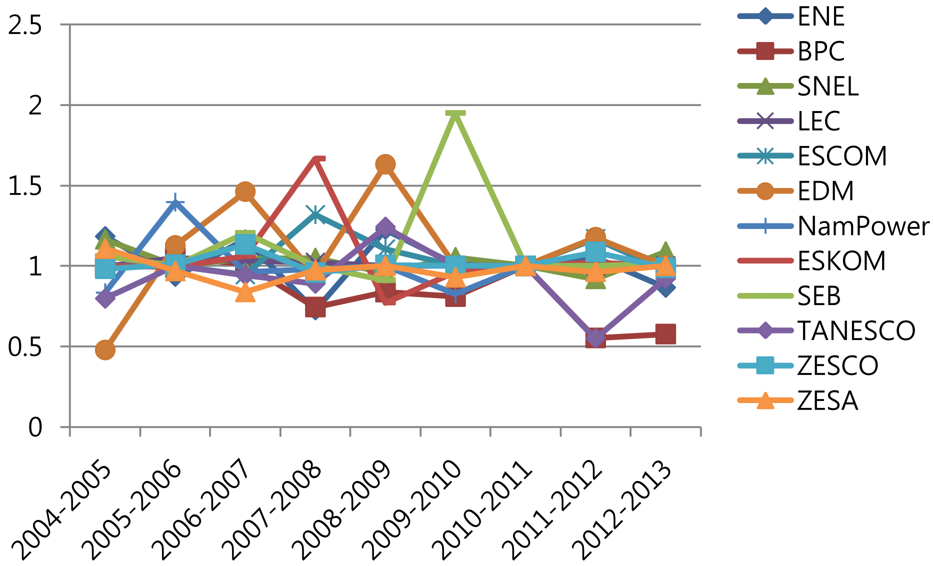

Figure 5-5. Trend of the Malmquist Index for Companies

SNEL's lowest-performance periods were 2008-2009 and 2011-2012, during which it scored 0.956 and 0.919, respectively. Both periods reflected its regression in terms of technical efficiency change. The results also suggest that in 2010-2011, all the companies in the region did not progress in terms of productivity change. This could also be attributed to the global financial recession.

The Malmquist Index summary provides the average values of the productivity change of the companies during our analysis period. Figure 5-6 suggests that throughout our study period, LEC, ESCOM, EDM, ESKOM, SEB, and ZESCO registered a positive productivity change over time of 1-9.7%. Moreover, ENE and SNEL did not improve their productivity change in our study period, as shown by their score of 1.

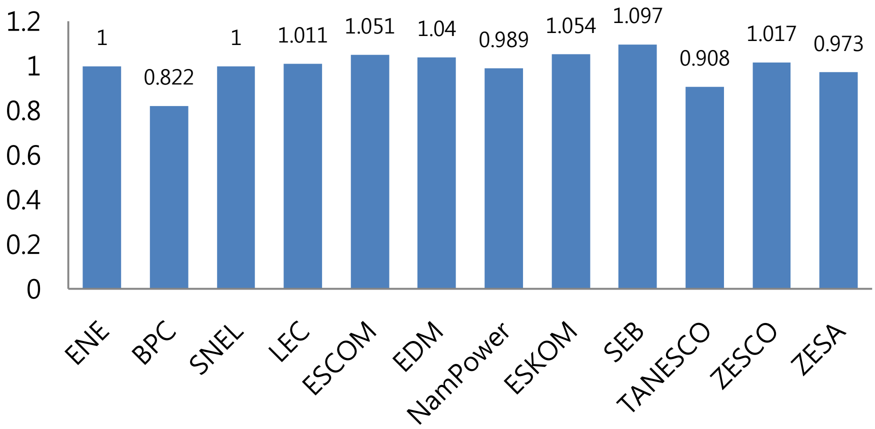

Figure 5-6. Malmquist Index Summary for Companies (2004- 2013)

Finally, the worst performers among the companies are BPC, Nampower, TANESCO, and ZESA because they regressed in terms of productivity change at values below 1. However, based on our findings, it seems that the companies that positively progressed in terms of productivity change are those that developed a regulatory authority[29] in their energy sector. Thus, it is important to assess the impact of a regulatory authority hypothesis on the companies' efficiency in the second stage.

[29]According to Estache et al. (2008), LEC, ESCOM, EDM, ESKOM, SEB, and ZESCO have developed a regulatory authority in their energy sector, p. 1971.

5.3 Environmental Factors Analysis

5.3.1 Description of Variables

To assess the impact of environmental factors on the companies' efficiencies, we used the regression model and the following variable human resources, income per capita, regulatory authority, competition in electricity generation, government ownership, vertical integration, competition in electricity distribution, electricity net exports (Gwh), the country's size (Skm) and urban population (%).

1. Human Resources (hr)

Human Resources is the division of a company that is focused on activities relating to its employees. It has the ability to create firms that are more intelligent, flexible, and competent than their rivals through the application of policies and practices concentrated on recruiting, selecting, and training employees, and directing their efforts to the corporate resources bundle of the organization. These can consolidate the company's performance, give it a competitive advantage, and sustain its positive corporate performance, as Wright (1998) and Sang (2005) confirmed. In this research, we estimated that all the companies operate in their respective country and rely on their local human resources. However, we used the Education Index provided by the United Nations Development Programme (UNDP) as proxy for the availability of the skilled professionals required by companies.

2. Income per Capita (inc)

Income per capita measures the amount of money being earned per person in a certain area. It can apply to the average per-person income for a city, region, or country and is used as a means of evaluating the living conditions and quality of life in different areas. The income per capita in Sub-Saharan Africa is still low. The World Bank (2010) argues that the dismal economic and social development record of Sub-Saharan Africa over the past 40 years is well known. The per capita income growth of the region over the period has been static, and over the past 20 years, negative. Its average incomes in 2000 were about 10% lower than in 1980. Increases in public spending have generally not been matched by significant improvements in access to public services. Chronic fiscal and monetary imbalances in many countries have resulted in high exchange rate risks and high real domestic currency interest rates, both deterring private investment by national and foreign investors. In this study, the GDP per capita (current US $) was used as proxy for the income per capita. The data were collected from the World Bank.[30]

3. Regulatory Authority (rg)

An adequate and effective regulatory authority is essential to ensuring supply reliability, continuous investments, reasonable pricing, and proper market behavior. In a regulated market where competition is minimal or lacking, the regulator's role is to provide oversight that would ensure that consumers receive reliable and safe supply of electricity at reasonable prices, and to provide energy companies some flexibility as to how to meet their performance goals. This is only if an independent regulatory authority is established in a country's energy sector. However, in most developing countries, many energy sector regulatory authorities suffer from the problem of dependency because they are directly controlled by the government. In our study, we used dummies to specify countries that have regulated their energy

[30]World Bank: http://data.worldbank.org/, accessed November 30, 2013.

sector and those that have not yet regulated their energy sector.

4. Competition in Electricity Generation (cg)

Although a competitive industry provides many advantages (fostering of innovation, provision of new services, price reduction, more jobs, etc.), the empirical studies conducted by Caves and Baron (1990), Green and Mayes (1991), and Caves et al. (1992) found that an increase in the market concentration above a certain threshold tends to reduce companies' efficiency, but in a competitive market, companies achieve production efficiency because they produce at the lowest point. It is from this fact that we chose the competition in electricity generation as an independent variable to assess its impact on company efficiency. For our study, we used dummies to specify countries that are competitive in electricity generation in the energy sector and those that are not.

5. Government Ownership (go)

The ownership structure is one of the important factors that determine the efficiency level of a corporation (Berle and Means, 1932). In our context, all the companies operating in the SAPP market are owned by their respective governments. We used a dummy for this variable.

6. Vertical Integration (vi)

In a corporate strategy, vertical integration sometimes provides a certain advantage. It can be viewed as a way of capturing rent and firm-specific assets when it is difficult to sell in intermediate markets (Penrose, 1999), and of developing new capabilities. However, in other cases, it can reduce the performance of a company whenever the company follows a different objective at the same moment. We used a dummy for this variable.

7. Competition in Electricity Distribution (cd)

Competition in electricity distribution enhances technical efficiency primarily because it provides greater discipline than regulatory oversight in ensuring that the lowest-cost producer builds and operates distribution assets and offers reliable services. This benefit of competition is why many purchasers of all types of goods and services rely on competitive bids. In the real world, different suppliers may increase their efforts to reduce their costs and mark-ups, to lower the overall cost of their service to customers and improve their service. We also used a dummy to represent countries that are competitive in electricity distribution in the energy sector and those that are not.

8. Electricity Net Exports (exp)

Electricity exports are the products of the process of producing electricity in one country and selling or trading it to another country. This also constitutes one of the tasks of SAPP; as part of its regional mission, it enables countries with electric power to export them in the Southern African region. Exports provide some advantages for companies such as increases in sales and profits, expansion of global market share, earning of foreign exchange for the country, and enhancement of regional performance and competitiveness**.** Data on electricity net exports (Gwh) were also collected from the SAPP annual report.

9. Country's Size (cz)

The size of a company's host country also affects the company's efficiency, because it is acknowledged that the larger the country's land area is, the more resources and infrastructure the company would require expanding its activities through the country. The country's size could also contribute to the increase in the company's electricity loss, because a country with a larger land area would require long-distance[31] transmission from the hydropower or thermal power station. For our study, data on the countries' sizes (Skm) were also collected from the World Bank database.

10. Urban Population (urb)

The urban population[32] refers to the population living in an area characterized by a higher population density and vast human features (cities, towns, or conurbations), in comparison to the areas surrounding it. However, it is often acknowledged that life standards[33] in urban areas are higher, as are urban population expenditures. Thus, a company that provides services to urban populations might enjoy enhanced performance in terms of sales and profits.

5.3.2 Hypothesis

Referring to the previous study, Pombo et al. (1994) assessed determinants of efficiency by using the Tobit model at the second stage of DEA and found that, holding other factors constant, the regulatory framework had positive effects on the efficiency of electric utilities in Colombia. This finding was consistent with that of another previous study (Pombo and Ramiz, 2003) on the analysis

[31] According to Wong (2011), losses tend to be higher since the transmission system is composed of longer and lower-voltage transmission lines, which cause more losses. The location of a generator with respect to the grid and with respect to the load (where the energy is consumed) affects the volume of line losses that occur. http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf, accessed on November 28, 2013.

[32] The UN (2012) argues that 309 million Sub-Saharan Africans out of a total estimated population of 843 million live in urban areas. At 36.7%, this represents the lowest urban proportion of all major world regions. In contrast, Europe is 72.9% urban; North America, 82.2%; and Latin America and the Caribbean, 79.1% in the same year (UN, 2012).

[33] Polèse (2009) demonstrates in detail that while urbanization takes place as per capita wealth increases, many countries -- including many in the developing world -- can sustain a very high level of urbanization without levels of wealth corresponding to what might be expected in northern, more developed countries. Aside from oil-rich desert countries, most wealthy countries are also highly urbanized.

of the efficiency of electricity generation in Colombia. Such study also found that the ownership of electric power companies does not guarantee the improvement of their efficiency (since ownership as an explanatory factor turned out insignificant). Similarly, Pillit (1995) found that ownership does not guarantee the improvement of plants. The study of Pombo et al. (1994) found that large efficient electric utilities can be used as benchmarks by small inefficient utilities.

Moreover, in our study, we assumed that the regulatory authority had a negative effect on the companies' efficiency because in developing countries, most regulatory authorities have direct ties with government departments and do not promote innovation nor ensure supply reliability, continuous investments, and reasonable pricing to contribute to the improvement of the efficiency of electric power companies.

5.3.3 Regression Model

In our study, we used the Panel OLS model to estimate the impact of environmental factors on the companies' efficiency.

Consider the following linear regression equation.

$$y_{ij}t = \beta_0 t + \beta_1 x_{ij} t + z'_j t\gamma + u_{ij} t + \varepsilon_j t \tag{5.1}$$

In this equation, y_{ij} is the dependent variable, j = 1, …g means "group," t = 1, 2, 3, 4…, and 10 years, I = 1, 2, 3, 4..., and 12 companies, x_{ij} is a vector of explanatory variables, z_j is a vector of explanatory variables common to members of group j, and u refers to the i.i.d. normal errors, which are independent of the i.i.d. group errors ε. Traditionally, the OLS coefficient estimators, R^2 and Adjusted-R^2, are computed using the following formula.

$$\hat{\beta} = (X^{'}X)^{-1}X^{'}y \tag{5.2}$$

The proportion of variation in y is "explained" by the regression on the j independent variables.

$$R^2 = r^2_{Y\bullet 1,\ldots,k} = \frac{\sum_{i=1}^{n}\left(\hat{Y}_i - \overline{Y}\right)^2}{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2} = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{5.3}$$

To compare models with different sets of independent variables in terms of their predictive capabilities, we used the Adjusted-R^2 (which penalizes models with unnecessary or redundant predictors).

$$Adj - R^2 = r^2_{adj} = 1 - \left(\frac{n-1}{n-k-1}\right)\left(\frac{SSE}{SST}\right) = 1 - \left[\left(1 - r^2_{Y\bullet 1,\ldots,k}\right)\left(\frac{n-1}{n-k-1}\right)\right] \tag{5.4}$$

By incorporating the dummy variable, $d_j t = z_j' t\gamma + \varepsilon_j t$, (5.1) can be rewritten as follows.

$$y_{ij}t = \beta_0 t + \beta_1 x_{ij} t + d_j t + u_{ij} t \tag{5.5}$$

From (5.5), our model is represented as follows.

$$DEA_t = \beta_{ot} + \beta_1 hr_t + \beta_2 inc_t + \beta_3 ca_t + \beta_4 rg_t + \beta_5 cg_t + \beta_6 go_t + \beta_7 vi_t + \beta_8 cd_t + \beta_9 imp_t + \beta_{10} exp_t + \beta_{11} cz_t + \beta_{12} urb_t + u_t \tag{5.6}$$

Finally, for the linear (straight-line) regression model, the elasticity is as follows.

$$\varepsilon = \frac{dln(y)}{dx(x)} = \frac{\frac{dy}{dy}}{\frac{dx}{dx}} \tag{5.7}$$

5.3.4 Interpretation of Results

Tables 5-2 and 5-3 show that the coefficient of the human resources, income per capita, competition in electricity generation, vertical integration, competition in electricity distribution, and electricity net exports and urban population were statistically significant at 99%. The magnitudes of the 7 coefficients were practically significant. We also found that even though the important constant of our model (regulatory authority) and the country's size constant were statistically insignificant, they still had the expected sign and also boosted the R^2 and Adjusted-R^2 of the coefficients of the significant variables. However, the resulting government ownership coefficient was omitted.

Our findings suggest that human resources affect the efficiency of companies positively, holding other variables constant. A one-unit increase in human resources increases a company's efficiency value by 0.0935309 units. To put it differently, a percentage change in human resources leads to a 0.80% increase in a company's efficiency. This implies that the companies were able to use skilled and well-trained employees to consolidate their performance, create innovative and competitive advantage, and sustain their positive corporate performance. Thus, human resources is one of the important factors that contribute positively to the efficiency of electric power companies in

Table5-2. Second-Stage Regression Results

	DEA
hr	0.1055973 **(7.69)
inc	-0.0001313 **(-6.57)
rg	-0.0138786 **(-0.23)
cg	-0.3101605 **(-5.64)
vi	-0.2589586 **(-3.55)
cd	0.4495562 **(7.13)
exp	0.0000506 **(5.34)
cz	-8.56e-08 **(-1.89)
urb	0.0173058 **(6.15)
constant	-.0234978 **(-0.15)
R-squared	0.5260
Adj. R^2	0.4872
Observations	120
No. of company	12
	DEA
hr	0.1055973 **(7.69)

**Significant at 1%

Table 5-3. Elasticity of Variables

	ε
hr	0.9005208 **(7.55)
inc	-0.4367568 **(-6.48)
rg	-0.0118113 **(-0.23)
cg	-0.3345972 **(-5.59)
vi	-0.3104014 **(-3.53)
cd	0.3233171 **(7.02)
exp	0.07892 **(5.29)
cz	-0.0929554 **(-1.89)
urb	0.917563 **(6.08)
y	0.695225
	ε
hr	0.9005208 **(7.55)

**Significant at 1%

the SAPP market..

The interpretations of the following variables are similar to that of the human resources variable.

The result for the income per capita suggests that a one-unit increase in the income per capita will decrease a company's efficiency value by 0.0001072. Likewise, a company's efficiency decreases by 0.36% for each additional percentage change in its income per capita. Two factors may explain this finding. The first factor concerns inadequate power supply, and the second is related to the high average price of electricity in the region. Inadequate power supply takes a heavy toll on all layers of society in Africa. Even currently, domestic and private consumers are experiencing frequent outages, which mean big losses in forgone sales and damaged equipment. Regarding the high price of electricity in the region, according to Eberhard (2008), the average price of power in Sub-Saharan Africa is high by international standards. The average tariff in the region rose from $0.07 per Kwh in 2001 to $0.13 per Kwh in 2005, around twice that in other parts of the developing world, and almost at par with that in high-income countries. Comparing the average electricity tariff and the low income of the population in the region (World Bank, 2010),[34] most people often cannot afford to use electricity services. Consequently, both mentioned issues may compel most consumers to substitute complementary capital (for backup generators and cheap energy[35] sources) for deficient public services.

The competition in electricity generation coefficient suggests that a one-unit increase in competition in electricity generation decreases a company's efficiency value by 0.2824925 units. In the same manner, a company's efficiency decreases by 0.30% for each additional change in competition in electricity generation. This is because most of the SAPP member countries could not develop good regulators in their respective energy sectors to secure companies competing in electricity generation from some possible prevailing barriers (JKNU,[36] 2008). Thus, JKNU (2008) found that companies that are

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[34]The World Bank (2010) also argues that 63% of the Sub-Saharan Africa population lives in rural areas.

[35]The Infrastructure Consortium for Africa (2011) also reported that Sub-Saharan Africa is characterized by wide disparities in electricity consumption per capita, and that traditional fuels (especially wood and its derivatives) are consumed much more in the region.

[36]John Kwoka Northeastern University found that scale economies, high cost of

susceptible to developing scale excess in the competition in electricity generation would more readily and cheaply expand out in the face of entry, thereby denying the entrant its expected market opportunity and negatively affecting the entrant's profitability and performance. Moreover, in such market, companies dealing with the high cost of capital and long lead times of projects may face market risks, that is, uncertainties in future market conditions and in the price that the project's output will command over the payback horizon, and negative profitability (in the context of Sub-Saharan Africa, because its population's income is too low to expect any possible expense recovery).

The findings with regard to the vertical integration coefficient reveal that a one-unit increase in vertical integration decreases a company's efficiency value by 0.2192665 units. To put it differently, a company's efficiency decreases by 0.26% for each additional change in its vertical integration. This means that dealing more with generation, transmission, and distribution will likely reduce the efficiency of a vertically integrated electric power company. This is because of the multiple objectives that the company pursues whenever it is dealing at the same time with generation, distribution, and transmission. Therefore, unbundling the company's activities into separate and standard activities could be suggested to enable efficient allocation of its resources.

The coefficient of competition in electricity distribution more significantly affected the companies' efficiency than the other variables, and suggests that a one-unit increase in competition in electricity distribution increases the efficiency of a company by 0.4409879 units. To put it differently, a company's efficiency increases by 0.32% for each additional change in its

capital, and long lead times are prevailing barriers of competition in electricity generation.

competition in electricity distribution. Thus, the number of operators in the electricity distribution market may enhance the efficiency of a company. As mentioned earlier, competition in electricity distribution enhances technical efficiency primarily because it provides greater discipline than regulatory oversight in ensuring that the lowest-cost producer builds and operates distribution assets and offers reliable services.

The results of the companies' net electricity exports demonstrate that increasing one unit of net electricity exports increases a company's efficiency value by 0.0000799 units. Similarly, the company's efficiency increases by 0.12% for an additional change in net electricity exports. This implies that companies that are exporting electricity would likely not only increase in efficiency, but also increase in sales and profits, gain global market share, and earn foreign exchange for the country. Unfortunately, SNEL was found in the category of companies that annually decrease their electricity exports (e.g., in 2012-2013, SNEL decreased its electricity exports by 59.6%).

Regarding the urban population coefficient, we found that one unit increase in the urban population increases a company's efficiency by 0.0186262. To put it differently, the company's efficiency increases by 0.99% for each additional change in the urban population. This can be explained by the fact that companies operating in Sub-Saharan Africa drew some advantages in the urban area due to the conditions of life there. Yet, people living there are much more willing to spend to maintain their life standard. Thus, the growth[37] of the urban population had a positive impact on the

[37] According to the African Development Bank Group (2012), Sub-Saharan Africa has experienced an unprecedented rate of urban growth, outpacing other regions. http://www.afdb.org/fileadmin/uploads/afdb/Documents/PolicyDocuments/FINAL%20Briefing%20Note%204%20Africas%20Demographic%20Trends.pdf, accessed on November 30, 2013.

companies' efficiency.

Our important coefficient, the "regulatory authority," which is negative, means that it is an obstacle for the companies. This is because as mentioned earlier, in most developing countries, many energy sector regulatory authorities have direct ties with the government and are handled by it. Nevertheless, a commonly advised solution to this problem is to increase the independence of the regulator. This may work if the independent regulatory authority can tie its hands in a way that the government cannot,[38] or if the regulator has a greater concern for its reputation than has the government.

The country's size coefficient is also negative. This implies that the larger the size of a country is, the more the important companies require efforts, resources, and infrastructure to expand their activities throughout the country. This corresponds to the context of centralized electricity generation. Reducing the regional operation of a company by half would also reduce the inefficiency by half. Moreover, as mentioned earlier, the country's size could contribute to the increase in electricity loss, which prevails whenever electricity is mainly produced at large generation facilities and shipped over a long distance through the transmission and distribution grids to the end-consumers. In terms of size, the DR Congo is the second largest country in Africa (surface area: 2,345,409 Skm) and the largest country in Sub-Saharan Africa. The DR Congo's electric power company (SNEL) has the monopoly over the entire country. This implies that the issue of size has a negative impact on SNEL's efficiency. This is because as SNEL's services are centralized, it requires too much and makes considerable efforts to provide its

[38]For example, if the regulator is constrained by the judiciary but the executive is not, the regulator could commit itself through a legal agreement. However, if the objectives of the regulator and the government align, then an independent regulator may simply ask the government to help "untie" its hands. This argument seems unsatisfactory if both parties are strictly benevolent.

services over the entire DR Congo.

Finally, the result of government ownership is omitted. Regarding this result, we assume that in our research, the ownership does not guarantee the improvement of the company's efficiency.

5.4 Benchmark Analysis

We analyzed the study results to determine the best-performing companies. We did this using the Benchmark Analysis. Regarding this, the CCR model results also provided some frontier benchmarks that were referred to efficient reference sets for each company.

5.4.1 Efficient Reference Sets

The presentation in Table 5-4 summarizes some efficient reference sets for SNEL from 2004 to 2013. The efficiency reference set indicates the relatively efficient units whose positions on the frontier are the best possible positions

Table 5-4. Efficient Reference Sets for SNEL (2004-2013)

Year	Company 1	Company 2	Company 3	Company 4	Total No. of Companies
2004	LEC	ESKOM	BPC	ZESCO	4
2005	LEC	ESKOM	BPC	ZESCO	4
2006	LEC	ESKOM	BPC		3
2007	LEC	ESKOM	BPC	ZESCO	4
2008	LEC	ESKOM		ZESCO	3
2009	LEC	ESKOM		ZESCO	3
2010	LEC	ESKOM		ZESCO	3
2011	LEC	ESKOM		ZESCO	3
2012	LEC	ESKOM		ZESCO	3
2013	LEC	ESKOM		ZESCO	3

against which the inefficient units were most clearly determined to be inefficient.

The results reveal that from 2003 to 2007, BPC was to be an efficient reference set for SNEL. However, after 2007, BPC failed to evolve on the efficient frontier and became inefficient.

ZESCO was also an efficient reference set, except in 2006, from which time the company lost its efficiency. The results also showed that some companies – LEC and ESKOM -- appeared successively as efficient reference sets during all the periods of our analysis. Thus, for SNEL to improve its efficiency, it has to follow the footsteps of LEC and ESKOM.

5.4.2 Frontier Projections

Table 5-5 shows the percentage of the mean projected value of each indicator for each company.

Table 5-5. Mean Percentage Projections of the Indicators to the Frontier for each Company (2004 -2013)

		Indicators			
			Inputs		Output
Countries	Companies	Electricity Loss	Installed Capacity	Labor	Generation
Angola	ENE	-47.85%	-40.18%	-44.56%	0%
Botswana	BPC	-30.81%	-27.91%	-51.99%	0%
DR Congo	SNEL	-47.68%	-47.68%	-56.18%	0%
Malawi	ESCOM	-17.98%	-17.98%	-53.10%	0%
Mozambique	EDM	-79.98%	-79.63%	-92.98%	0%
Namibia	NamPower	-55.18%	-35.52%	-35.52%	0%
Swaziland	SEB	-65.34%	-55.31%	-69.39%	0%
Tanzania	TANESCO	-31.93%	-31.84%	-50.54%	0%
Zimbabwe	ZESA	-28.97%	-28.97%	-42.12%	0%

This is obtained first by subtracting the original value of each company's indicators by their respective radial and slack movements with respect to their year (2004-2013), then by converting each obtained value of each year in percentage and finally, by computing their mean.

However, we should recall that the purpose of the frontier projections is to make inefficient companies efficient by bringing them to the frontier with respect to the efficient reference sets. This purpose is implemented from the principle of the CCR input-oriented model, which minimizes inputs while producing at least the given output levels. The negative sign that is expected for the inputs means a projected reduction while keeping the output constant.

The electricity loss projections suggest that reducing the electricity loss much more while keeping the output constant will make a company appear efficient; otherwise, it will make a company inefficient. Our analysis reveals that in Sub-Saharan Africa, the average projected electricity loss for SNEL is -47.68%. This corresponds to the overall amount of the electricity loss that SNEL should reduce to enhance its efficiency, while holding the electricity generation constant. EDM and SEB are companies that were highly affected by the electricity loss, since their respective average projected electricity losses are -79.98% and -65.34%. However, ESCOM and ZESA have low average projected electricity losses of -17.98% and -28.97%, respectively. As mentioned previously, long transmission lines contribute to electricity loss. The United Nations Economic Commission for Africa (2007) also stated that poor maintenance of the transmission and distribution system is also among the factors that are causing electricity loss, which is undermining the financial[39] performance of the electricity utilities.

[39] The United Nations Economic Commission for Africa (2007) stated that by controlling high system losses and low electrification levels, combined with higher

Regarding the installed capacity projection for each company, as the technical efficiency computed herein is based on the ability of a company to efficiently convert its resources into outputs, the companies' installed capacities are input variables that cannot be technically reduced. In the generation sector, the efficiency of a company is described by the sufficient amount of electricity it produces with respect to its installed capacity. Yet in Africa, most plants do not generate enough electricity because they do not operate at full capacity. As much as one quarter of that capacity is unavailable because of aging plants and poor maintenance.

The average projected installed capacity for SNEL to the frontier is -47.68%. To put it differently, the average unavailable installed capacity for SNEL is -47.68%. This finding is consistent with the argument in SNEL's report (2005), which says that in the DR Congo, most hydropower and thermal power plants are not in operation due to aging and technical problems. Other electricity plants are being decommissioned because their operation period have reached 25 years. Besides, the findings reveal that ESCOM seems to be the company in the region that is planning to catch up by increasing its power generation trend. This is because Malawi's electric power company (ESCOM) makes a large portion of its installed capacity available for electricity generation (its installed capacity projection is -35.52%). This can also explain ESCOM's yearly increasing technical efficiency trend, as shown in Figure 5-1.

The labor indicators reveal that EDM and SEB also have the highest percentages of labor overstaffing among the companies in SAPP. The -56.18% labor projection for SNEL corresponds to the percentage of employees that SNEL should reduce to enhance its efficiency and catch up with its efficient

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tariff levels, electricity utilities should be able to realize higher revenue levels.

reference sets.

Chapter 6. Policy Implications and Conclusion

6.1 Policy Implications

Referring to our findings, we prescribed policy implications to provide innovative ideas for enhancing SNEL's performance level. However, these suggested implications (below) should be considered in making any reformative decision in the energy sector in the DR Congo.

Income per capita is one of the important factors that determine the efficiency level of electric power companies. Our findings revealed that an increase in income per capita has a negative impact on the efficiency of companies. This is because as mentioned previously, the electricity services in most Sub-Saharan African countries are unreliable due to the problem of outages, and are characterized by high prices of services. Both situations compel most consumers in the region to substitute complementary capital (for backup generators and cheap energy sources) for deficient public services. Therefore, it is important for companies to ensure reliability of their services by guaranteeing full-time electricity supply to consumers. This could be done by maintaining and replacing some power infrastructure, because from the regional aspect, most power infrastructure are suffering from aging and are becoming almost unused. Companies should also promote cheaper sources of energy (biomass: fuelwood, biogas, and biofuels) for affordability and diversification. However, promoting biomass as an alternative energy source for generating electrical power has some economic benefits. Moreover, it can be a useful source of energy in remote areas and small industrial areas. One of the most important advantages of biomass is its cheap prices. Moreover, it is a readily available source of energy. In addition, it is a continuous and long-term source, and it can be found easily, any time and almost anywhere.

Despite all the possible advantages of competition in electricity generation, our results revealed the contrary. They showed that competition in electricity generation in the energy sector in each country in Sub-Saharan Africa has a negative impact on the companies' efficiency. It was argued that this was because of the weakness of the regulation for preventing some possible prevailing barriers (scale economies, high cost of capital, and long lead times) during the competition in electricity generation. It was previously mentioned that JKNU (2008) revealed the negative impact of those barriers to competition in electricity generation in the electricity market in the US when there is no regulation. They may have a significant negative impact on the companies' profitability and performance. To address these issues, it may be better for the electricity generation activity of each SAPP member country to establish a coherent legislation and regulation in its country's energy sectors. However, the role of legislation here would be to remove legal, economic, and social barriers, and the regulation would protect the state electric company from anticompetitive special interests (OAS,[40] 2013).

Another important factor that determines the level of efficiency of a state electric power company in SAPP is vertical integration. The traditional structure of electric power industry countries involves large vertically integrated electric companies that perform four functions: generation, transmission, distribution, and supply. In an industrial organization, vertical integration constitutes a best strategy aim of a single diversified firm producing an output bundle rather than separate specialized firms splitting up the production of each output, or subset of outputs. However, our study

[40]Source: Organization of American States (OAS): Government's Role in the Electricity Sector, http://www.oas.org/dsd/publications/Unit/oea79e/ch08.htm#b.%20GOVERNMENT&146;S%20REGULATORY%20ROLE, accessed November 28, 2013.

findings revealed that vertical integration is disadvantageous for enhancing state electric power companies. Consequently, unbundling SNEL into different subsidiary entities would also be one of the best strategies for improving company efficiency and would keep the company safe from the negative effects of vertical integration (withholding of information, administrative inefficiencies due to the complexity of the company's management, production costs, etc.). The role of SNEL's subsidiary entities would be to perform each different function in the electricity sector in the DR Congo (generation, transmission, distribution and supply). This implies that SNEL would have three different autonomic subsidiaries, each with different functions.

The purpose of SAPP is to promote electricity trade among its member countries. Despite some advantages that electricity exports vide, our results suggested that electricity net exports in SAPP had positive effects on the efficiency of the companies. Regarding this, SAPP should encourage its member countries to promote and increase electricity exports in the region and also, and that must be done by maintaining and repairing power infrastructures and also by building[41] new power generation infrastructures or developing other local cheaper source of energy. Since, the objective here is to satisfy the regional demand.

Even though most of energy markets in the SAPP member countries are monopolies, the result revealed that competition in electricity distribution has a positive effect on the companies' efficiency. This finding also has an important implication in the energy market in the DR Congo, since inside the

[41] According to the World Energy Council (2008), with the projects of Inga III and Grand Inga hydropowers, the DR Congo will become a bigger exporter of energy in Africa through possible interconnection links from Southern Africa up to Southern Europe.

country, SNEL has the monopoly of the market. However, opening the distribution market to private competitors may enhance SNEL's efficiency and improve service delivery quality. Consumers would also definitely benefit from this process because competition in electricity distribution would allow them to choose among providers and service options. This combination of open entry for suppliers and choice for customers provides the benefits of competitive markets (e.g., efficient resource allocation, accurate price signals, and incentives for innovation) and limits competitors' ability to exercise market power. Customers are protected from open-ended commitments to pay above-market costs that would not occur in a competitive market. This does not mean that entry into markets will be costless or easy, but rather, that all actual competitors, incumbents, and new entrants alike will have made (and potential competitors could make) the investments and commitments needed for them to compete in the market.

The benchmark analysis revealed that ESKOM and LEC appear to be efficient reference sets for SNEL. This implies that cooperation between state electric powers companies evolving in the SAPP market should be initiated to allow them to gain experience and knowhow from efficient companies. ESKOM was established in 1923, and its success is attributed to its range of power stations, good understanding of the cost of yearly internally electricity, 30-year optimization of dispatch, good staff and good software for analyzing electricity problems; whereas Lesotho, a country enclaved by South Africa, learned to improve the efficiency trend of its state electric power company (LEC) through ESKOM.

Electricity loss is one of the problems in the energy sector in Africa because it negatively affects companies' performance. Electricity loss in Africa is caused by the problems of aging and the long distance of most transmission and distribution lines from hydropower or thermal power stations to the distribution centers of consumers. To overcome the problems pertaining to electricity loss, companies should use short, appropriate, and updated electric power transmission lines from generation centers to high-voltage distribution systems. However, Tallapragada et al. (2009) also proposed some recommendations to address this problem, some of which are improving billing and collection, establishing a GIS/GPS-based inventory of all distribution infrastructure (such as poles and transformers), improving metering, establishing benchmarks of performance in areas of greatest loss (for both system losses and collection losses) to set targets, monitoring of improvement over time, etc.

To overcome the effect of unavailable or decreasing installed capacity that most state electric power companies in Sub-Saharan Africa face, the results of the analysis conducted in our research suggest the reappearance of power plants (hydropower and thermal power plants). This can be realized by injecting sufficient funds in power generation and initiating some Public-Private Partnerships. SNEL is currently rehabilitating and building some power plants (Inga I, Inga II, Inga III, Grand Inga, Zongo I, Zongo II, etc.). Once they are completed, they will significantly increase the power generation of SNEL and will make it one of the important electricity exporters in Africa.

One of the issues that affects most state electric companies in SAPP is the problem of strong government control of such companies. In their research on the managerial form of companies, Chang and Singh (1997) argue that the government's rigid and bureaucratic supervision make companies inefficient.

To deal with this problem, Rasiah (2012) found that the separation[42] of ownership and control provides a more efficient hierarchical decision-making system for the company to reach its goal. Referring to this finding, we noticed that South Africa's electric power company (ESKOM) has also opted for partial separation of ownership and control through managed liberalization since the late 1990s (Greenpeace Africa, 2012). As a result, ESKOM has improved in terms of management, consults its shareholders in most of its decisions to formulate policies, is increasing its generation capacity by introducing nuclear power, and has become the world's 11th largest power utility in terms of power generation capacity. Therefore, this form of governance testifies that there is much room for the improvement of SNEL's governance form because the company should have privileged economic interests rather than political interests.

6.2 Conclusion

In this thesis, we attempted to assess the relative performance of the DR Congo's electric power company (SNEL) in SAPP. We particularly focused our attention on two aspects: technical efficiency and productivity change. We decomposed the productivity change into the Technical Efficiency Change, Technological Change, and Scale Efficiency Means to get a sense of how much effort some companies made to catch up with the best practice in the market (SAPP). We also sought to assess the impact of environmental factors

[42]According to the principal-agent theory, the shareholders (government) own the company, and the managers (agent) control the company. The shareholders own the residual claims of the company. However, they do not have sufficient direct control over management decision-making and cannot participate in the day-to-day management of the company. Thus, managers would have an incentive to act in their self-interest rather than protect the shareholders' interest, and this could lead to an agency problem. There are a few ways to solve the agency conflict, such as by giving incentives to both parties to align their goals.

on the efficiency of the companies by using the OLS model in the second stage. Thus, our results are easy to summarize.

We found that in the period of our analysis (2004-2013), SNEL was inefficient because its technical efficiency score was steadily around 0.5. From this result, we assumed that the inefficiency of SNEL was due to its inability to generate enough power despite its total installed capacity. Moreover, South Africa's electric power company (ESKOM) and Lesotho's electric power company's (LEC) were the efficient reference sets for SNEL because they evolved along the efficient frontier all the years.

The Technical Efficiency Change revealed that the best performance period for SNEL was 2004-2005, because during this period, SNEL caught up with 18%. Besides, the Technological Change results suggested that most of the companies applied the same production technologies and innovations in their respective power generation activities. From the Scale Efficiency Means, we noticed that SNEL did not operate at the most efficient size, whereas EDM and SEB operated at an increasing return to scale. Consequently, the summary of the Malmquist Index suggested that SNEL did not improve its productivity change in the period of our analysis (2004-2013).

In the second-stage regression analysis, we found that even though the important constant of our model (regulatory authority) was insignificant, the environmental factors that contributed positively to the companies' efficiency are human resources, competition in electricity distribution, electricity net exports, and urban population. On the other hand, the income per capita, competition in electricity generation and vertical integration affected negatively the companies' efficiency.

From the abovementioned results, we established policy implications for the enhancement of the performance of SNEL. These can be summarized as follows: ensuring of reliability of services by guaranteeing full-time electricity supply to consumers; establishment of coherent legislative and regulation in the energy sector; unbundling of SNEL into different subsidiary entities; promotion of the regional electricity exports (by maintaining, repairing and building of power generation infrastructures); opening of the distribution market to private competitors; initiation of cooperation between state electric power companies in the SAPP market; use of short, appropriate, and updated electric power transmission lines from generation centers to high-voltage distribution systems; injection of sufficient funds into power generation and initiation of some Public-Private Partnerships; and finally, adoption of partial separation of ownership and control in the company's management.

This study is the first empirical documentation of performance assessment in the energy sector in the DR Congo. For managers, it provides a reliable scientific measure and perspective of SNEL's efficiency and serves as an invaluable source of information for identifying benchmarks. For policymakers and the government, with the current liberalization of the electricity sector in the DR Congo, this study provides invaluable insights on, and a more reliable guide to, monitoring and evaluating the impact of operations within and outside SNEL as well as the general progress of SNEL. Currently in the DR Congo, as most public companies are in the process of reform, the approach used in this study can also be applied to those companies to assess and follow their efficiency progress. However, due to the lack of reliable data, this thesis has been restricted to electricity generation; and the analysis of the various activities and aspects of electricity production will give the study more policy latitude. For instance, the analysis of electricity distribution and supply could be used to assess the efficiency of these activities in the electricity industry in the DR Congo. Therefore, further research in these areas can be suggested.

6.3 Limitations of the Study

The first problem that surfaced in the research was the difficulty in accessing information in the energy sectors of African countries. The other limitations of this research pertained to the following drawbacks of the DEA method.

- It measures the relative performance and not the absolute performance.
- Because it is non-parametric, statistical testing is difficult.
- Being an optimization technique, it does not measure the possibility of preventing errors.
- The addition of a new unit to investigate previews units changes the performance scores of all the units.
- Changes in the type and number of inputs may change the results of the evaluation of the research.

Bibliography

[1] Ackermann, T., Andersson, G., & Soder, L. (2001). Distributed Generation: A Definition. *Electric Power Systems Research*, 57 (1), 195–204. Doi:10.1016/S0378-7796(01)00101-8.

[2] African Development Bank Group (2012). Briefing Notes for AFDB's Long-Term Strategy, Briefing (Note 4). Africa's Demographic Trends: Mubila Maurice. Retrieved from http://www.afdb.org/fileadmin/uploads/afdb/Documents/PolicyDocuments/FINAL%20Briefing%20Note%204%20Africas%20Demographic%20Trends.pdf.

[3] Ahuja, G. & Majumdar, S.K. (1998). An assessment of the Performance of Indian state – Owned Enterprises. *Journal of Productivity Analysis*, 9 (2), 113-132.

[4] Aka, L.A. (2004). Gestion des Entreprises publiques. Rehabilitation des Entreprises publiques de la RDC. Retrieved from La Conscience. Retrieved from http://www.laconscience.com/Rehabilitation-des-Entreprises-publiques-de-la-RDC.html.

[5] Ali, A.I., & Seiford, L.M. (1993). The Mathematical Programming Approach to Efficiency Analysis, In Fried, H.O., C.A.K. Lovell and S.S. Schmidt (eds), The Measurement of Productive Efficiency: Techniques and Applications (pp. 120-159). Oxford: Oxford University Press.

[6] Alejandro, M., Panizza, U., & Yanez, M. (2007). Bank Ownership and Performance: Does Politics Matter. *Journal of Banking and Finance*, 31 (1), 219-241. Retrieved from

http://ideas.repec.org/p/chb/bcchwp/356.html.

[7] Andrikopoulos, A., & Vlachou, A. (1995). The Structure and Efficiency of the Publicly Owned Electric Power Industry of Greece. *The Journal of Energy and Development*, 19 (1), 57 -79.

[8] Ang, J.S., & Ding, D.K. (2006). Government Ownership and the performance of Government-Linked Companies: The Case of Singapore. *Journal of Multinational. Financial Management*, 16 (1), 64-88.

[9] Averch, H., & Johnson, L. (1962). Behaviour of the Firm under Regulatory Constraint. *American Economic Review*, 52 (5), 1052-1068.

[10] Babalola, R. (1999). Technical Efficiency and Impact of Ownership on Performance: The Case of The Nigerian Electricity Industry. Available from the University of Surrey. Dissertations & Theses database. Retrieved from http://epubs.surrey.ac.uk/2814/.

[11] Bagdadioglu, N., Price, C., & Weyman-Jones, T. (1994). Efficiency and Ownership in Electricity Distribution: A Non-Parametric Model of the Turkish Experience.' *Energy Economics*, 18 (1), 1 - 23.

[12] Banker, R.D. (1984). Estimating Most Productive Scale Size Using Data Envelopment Analysis. *European Journal of Operational Research*, 17 (1), 35-44.

[13] Banker, R.D., & Morey, R. (1986). The Use of Categorical Variables in Data Envelopment Analysis. *Management Science*, 32 (12), 1613-1627.

[14] Bjurek, H., Hjalmarsson, L., & Forsund, F.R. (1990). Deterministic Parametric and Nonparametric Estimation of Efficiency in Service

Production: *A Comparison, Journal of Econometrics*, 46 (1), 213-227.

[15] Bongos, R. (2011, November 29). La problématique de la gouvernance d'entreprises publiques au Congo-Kinshasa. Retrieved from Afrique Redaction. Retrieved from http://www.afriqueredaction.com/article-la-problematique-de-la-gouvernance-d-entreprises-publiques-au-congo-kinshasa-90519222.html.

[16] Bourdman, A.E., & Vining, A.R. (1989). Ownership and Performance in Competitive Environment: A Comparison of the Performance of Private, Mixed and State-Owned Enterprises. *Journal of Law and Economics*, 32 (1), 1-33.

[17] Boussofiane, A., Martin, S., & Parker, D., (1997). The impact on technical efficiency of the UK privatization programme. *Applied Economics*, 29 (1), 297-310.

[18] Boycko, M., Shleifer, A., & Vishny, R.W. (1996). A Theory of Privatization. *Economic Journal*, 106 (1), 309-319.

[19] Bozec, R. (2003). Corporatization Process and the Financial Performance of Canadian state- Owned Enterprises". *The International Journal of Public Sector Management*, 16 (1), 27-47.

[20] Caves, W.D., Christensen, L. R., & Diewert E.W. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometria*, 50 (6), 1393-1414.

[21] Caves, R., & Barton, D. (1990). Technical Efficiency in U.S. Manufacturing Industries. Cambridge, Massachusetts: MIT Press.

[22] Caves, R., & Associates (1992). Industrial Efficiency in Six Nations.

Cambridge, Massachusetts: MIT Press.

[23] Centre of Efficiency and Productivity Analysis (2013): DEAP V 2.1. Retrieved October 15th, 2013 from http://www.uq.edu.au/economics/cepa/deap.php.

[24] Chanakira, M. (2011). SADC Regional Economic Integration in the Energy Industry. Retrieved from www.dounia-risri.com/IMG/pdf/Dounia4_pp64-78.pdf.

[25] Chang, H., & Singh, A. (1997). Policy Arena: Can Large Firms be Run Efficiently Without Being Bureaucratic?. *Journal of International Development*, 9 (6), 865-875.

[26] Charnes, A., & Cooper, W.W. (1962). Programming with Linear Fractionals. *Naval Res. Logist. Quart*., 9 (3,4), 181-185.

[27] Charnes, A., Cooper, W.W., & Rhodes, E. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operation Research*, 2 (1), 429-444.

[28] Charnes, A., Cooper, W.W., & Rhodes, E. (1981). Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through. *Management Science*, 27(6), 668–697.

[29] Charnes, A., Cooper, W.W., & Seiford, L. (1982). A Multiplicative Model for Efficiency Analysis. *Socie. Econ. Plan, Sci*., 16 (5), 223-224.

[30] Chames, A., Cooper, W.W., GoIany, B., & Seiford, L. (1985). Foundations of Data Envelopment Analysis for Pareto- Koopmans Efficient Empirical Production Functions. *Journal of Econometrics*, 3

(1), 91-107.

[31] Charnes, A., Cooper, W.W., Lewin, A.Y. & Seiford, L.M. (1995). Data Envelopment Analysis: Theory, Methodology and Applications (Ed.). *Kiuwer Academic Publishers*. Boston.

[32] Clark, M., & Marks, J. (1999). African Power Projects. *Financial Times Energy*. London, United Kingdom.

[33] Clean Energy Info Portal – reegle (2013). Botswana. Retrieved November 27th, 2013 from http://www.reegle.info/policy-and-regulatory-overviews/BW.

[34] Coad, A., Segarra, A., & Teruel, M. (2010). Like milk or wine: Does firm performance improve with age? (Science Direct). *Structural Change and Economic Dynamics.*24 (1), 173-189. Retrieved from http://www.sciencedirect.com/science/article/pii/S0954349X12000422.

[35] Coelli, T.J. (1995). Recent Developments in Frontier Modelling and Efficiency Measurement, Australian. *Journal of Agricultural Economics*, 39 (1), 219-245. Doi: 10.1111/j.1467-8489.1995.tb00552.x.

[36] Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., & Battese, G.E. (2005). An Introduction to Efficiency and Productivity Analysis (2nd ed.).New York: Springer.

[37] Coelli, T.J. (2012). A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Paper 96/08. Department of Econometrics, University of New England Armidale, Australia.

[38] Cooper, W., Seiford, L., & Tone, K.. (2007). Data Envelopment

Analysis. A Comprehensive Text with Models, Applications, References and DEA-Solver Software. (2nd ed.). New York: Springer.

[39] Comité de Pilotage de la Réforme des Entreprises du Portefeuille de l'Etat (2008). Rapport Annuel.

[40] Congo Opportunity Media (2013). RDC: Bonne électricité, forte économie. Le secteur minier ciblé. Retrieved November 27th, 2013 from http://www.congoopportunities.net/rdc-bonne-electricite-forte-economie-le-secteur-minier-cible/.

[41] CORE International, Inc. (2004). Energy Service Delivery in Zambia. Washington, DC, USA.Retrieved from http://www.coreintl.com/.../Energy%20Service%20Delivery%20in%20Zambia.

[42] Cornelia R. K., & Hennings, W. (2009) Sustainability evaluation of decentralized electricity generation. *Renewable and Sustainable Energy Reviews*, 13 (1), 583–593. Doi: http://dx.doi.org/10.1016/j.rser.2007.11.003.

[43] Cote, D.O. (1989). Firm Efficiency and Ownership Structure: The Case of US Electric Utilities using Panel Data. *Annals / Public and Co-operative Economics*, 60 (4), 431 - 450. Doi: 10.1111/j.1467-8292.1989.tb01338.x.

[44] Crosby, P.B.(1979). Quality is free, New York: McGraw-Hill.

[45] Deming , W.E. (1982). Quality, Productivity, and Competitive Position. Cambridge, Massachusetts: MIT Center for Advanced Engineering Study.

[46] Dewenter, K. L., & Malatesta, P.H. (2001). State – Owned and Privately Owned Firms: An Empirical Analysis of Profitability, Leverage, and Labor Intensity. *American Economic Review*, 91 (1), 320-334. Doi: 10.2478/v10135-012-0006-6.

[47] Eberhard A., Foster, V., Garmendia, C.B., Ouedraogo, F., Camos, D., & Shkaratan, M. (2008). Africa Infrastructure Country Diagnostic. Underpowered: The State of the Power Sector in Sub-Saharan Africa. *World Bank*. Washington, USA. Retrieved November 15th, 2013, from http://www.eu-africa-infrastructure-tf.net/attachments/library/aicd-background-paper-6-power-sect-summary-en.pdf.

[48] Engineering News (2005). SA's first Electricity Distributor by July. Retrieved from www.engineeringnews.co.za/eng/news/today.

[49] Eskom Holding Limited (2006). Annual Report. Sandton, Johannesburg, South Africa.

[50] Estache, A., Tovarc, B., & Trujillod, L., (2008). How efficient are African electricity companies? Evidence from the Southern African countries (Science Direct). *Energy Policy*, 36 (6), 1969–1979. http://dx.doi.org/10.1016/j.enpol.2008.02.011.

[51] Esseqqat, H. (2011). Les Energies Renouvelables en République. Démocratique du Congo. Programme des Nations Unies pour l'Environnement (PNUE). Nairobi, Kenya.

[52] Fama, E., & Jensen, M.C. (1983). Separation of Ownership and Control. *Journal of Law and Economics*, 26 (2), 301-326. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.195.3211&rep=rep1&type=pdf.

[53] Fama, E. (1980). Agency Problems and the Theory of the Firm. *Journal of Political Economy*, 88 (2), 288-307. Retrieved from http://business.illinois.edu/josephm/BA549_Fall%202010/Session%205/Fama%20(1980).pdf.

[54] Fare, R, Grosskopf, S., & Logan, L. (1985). 'The Relative Performance of Public1y Owned and Privately-Owned Electric Utilities. *Journal of Public Economics*, 26 (1), 89 – 106.

[55] Fare, R., Grosskopf, S., Logan, L., & Lovell, K. (1985). "Measuring Efficiency in Production: With an Application to Electric Utilities," in A. Dogramaci and N .R. Adam (eds.), Managerial Issues in Productivity Analysis.

[56] Fare, R., Grosskopf, S., Yaisawarng, S., Li, S.K. & Wang, Z. (1990). Productivity Growth in Illinois Electric Utilities. *Resources and Energy*, 12 (1), 383 - 398.

[57] Färe, R., S. Grosskoff, Norris, M., & Zhongyang, Z. (1994). Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries. *The American Economic Review*, 84 (1), 66-83.

[58] Farinos, J.E., Garcia, C.J., & Ibanez, A.M. (2007). Operating and Stock Market Performance of State-Owned Enterprise Privatization. *International Review of Financial Analysis*, 16 (4), 367.

[59] Farrell, M.J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society*, SeriesA (General), 12(3), 153-290.

[60] Ferrier, G.D. & Lovell, C.A.K. (1990). Measuring Cost Efficiency in Banking: Econometric and Linear Programming Evidence. *Journal of Econometrics*, 46(1), 229–245.

[61] Golany, B., & Roll, Y. (1989). An Application Procedure for DEA. *OMEGA International Journal of Management Science*, 17 (3), 237 - 250. Doi:10.1016/0305-0483(89)90029.

[62] Green, A., & Mayes, D. (1991). Technical Inefficiency in Manufacturing Industries. *Economic Journal*, 101(1), 523-538.

[63] Greenpeace Africa (2012). The Eskom factor: Power politics and the electricity sector in South Africa. Johannesburg, South Africa. Retrieved from http://www.greenpeace.org/africa/Global/africa/publications/coal/TheEskomFactor.pdf.

[64] Griliches, Z. (1971). Introduction: Hedonic price indexes revisited. In Price indexes and quality change, (Ed.) Z. Griliches, (pp.3-15). Cambridge, MA.: *Harvard University Press.*

[65] Harvard ManageMotor (2007). Performance Measurement. Retrieved October 4th, 2013 from http://www.vital.co.kr/demo/hmm10/performance_measurement/why_measure_business_performance.html.

[66] Hwang, H., &Lee, J.D. (2012). Profitability and productivity changes in the Korean electricity industry. *Energy Policy*, 52(1), 531-542. Retrieved from http://dx.doi.org/10.1016/j.enpol.2012.10.006.

[67] Infrastructure Consortium for Africa (2008). Regional Power Status in

African Power Pools. Report. Retrived from http://www.icafrica.org/fileadmin/documents/Knowledge/Energy/ICA_RegionalPowerPools_Report.pdf.

[68] International Energy Agency (1994). Electricity Supply Industry, OECD, 65.

[69] International Energy Agency (1996). Energy Policy of South Africa. Paris. OECD/lEA.

[70] Jamasb, T. & Pollitt, M. (2001). Benchmarking and Regulation: International Electricity Experience. *Utilities Policy*, 9 (1), 107-130.

[71] Jaunky., C. (2013). Divergence in Technical Efficiency of Electric Utilities: Evidence from the SAPP. *Energy Policy,* 62 (1), 419-430.

[72] John Kwoka Northeastern University (2008). Barriers to New Competition in Electricity Generation. Report to the American Public Power Association.

[73] Jones, L. P. (1991). Performance Evaluation for Public Enterprises, (18thEd.) Washington, D.C., U.S.A., World Bank. Cambridge, MA.: *Harvard University Press.*

[74] Journal le Potential (2005). Le Tariff d'Electricite en RDC. Gombe, Kinshasa, RDC.

[75] Journal le Potential (2006). SNEL et Les Companies Minieres. Gombe, Kinshasa, RDC.

[76] Juran, J.M.(1988). Juran's Quality Control Handbook, (4th Ed.), New York: McGraw-Hill: 2-2 and 2-3.

[77] Kasemuana M.,S. (2009). Democratic Republic of Congo. Energy Systems: Vulnerability – Adaptation – Resilience (VAR). Helio International. Retrivied from http://www.helio-international.org/varrdc.en.pdf.

[78] Kellen, V. (2003). Business Performance Measurement. At the Crossroads of Strategy, Decision-Making. Learning and Information Visualization. Chicago: DePaul University. Retrieved from http://sopinion8ed.wordpress.com/2013/02/07/why-measure-business-performance.

[79] KPMG (2011). Global Infrastructure & Projects Group Africa Team, Johannesburg, South Africa. "Sub- Saharan Power Outlook, Retrieved from http://www.kpmg.com/ZA/en/IssuesAndInsights/ArticlesPublications/General-Industries Publications/Documents/Sub-Saharan%20Electricity%20Outlook%20Brochure.pdf.

[80] Kole, S.R., & Harold J. M. (1997). The Government as a Shareholder: A case from the United States. *The Journal of Law and Economics*, 40(1), 1-22. Retrieved from http://links.jstor.org/sici?sici=00222186%28199704%2940%3A1%3C1%3ATGAASA%3E2.0.CO%3B2-L.

[81] Krueger, O. (1990). Government Failure in Development. *Journal of Economic Perspectives*, 4(3), 9-23. Doi: 10.1257/jep.4.3.9.

[82] Lancaster, K. (1979). Variety, Equity, and Efficiency, New York: *Columbia University Press.*

[83] Lovell, C.A.K. (1993). Production Frontiers and Productive Efficiency,

In Fried, H.O. C.A.K. Lovell and S.S. Schmidt (Eds), The Measurement of Productive Efficiency: Techniques and Applications, (pp. 3-67). *Oxford University Press*.

[84] Lovell, C.A.K. (1994). Linear Programming Approaches to the Measurement and Analysis of Productive Efficiency, 2 (1), 175-248.

[85] Mahoney, J. (1992). The Choice of Organizational Form: Vertical Financial Ownership Versus Other versus Methods of Vertical Integration. *Strategic Management Journal*, 13 (1), 559-584.

[86] Malmquist, S. (1953). Index Numbers and Indifference Curves. *Trabajos de Estatistica*, 4 (1), 209-42.

[87] Massey, P. (1997). Proposals for the Electricity Supply Industry in Ireland: Comments on the Consultation Paper published by the Department of Transport, Energy and Communications. Competition Authority. Discussion Paper. Retrieved from http://www.tca.ie/images/uploaded/documents/Discussion_Paper_3.pdf.

[88] McGuiness, P.B. & Ferguson M.J. (2005). The Ownership Structure of Listed Chinese State-Owned Enterprises and its Relation to Corporate Performance. *Applied Financial Economics*, 15 (4), 231-246. Retrieved from http://ideas.repec.org/a/taf/apfiec/v15y2005i4p231-246.html.

[89] Megginson, L., & Netter, J. (2001). From State to Market: A Survey of Empirical Studies on Privatization. *Journal of Economic Literature*, 39(2), 321-389. Doi: 10.1257/jel.39.2.321.

[90] Meenakumari, R., & Kamaraj, N. (2008). Measurement of Relative Efficiency of State Owned Electric Utilities in India Using Data

Envelopment Analysis. *Modern Applied Science, 2(5), 61-71*. Retrieved from http://www.ccsenet.org/journal/index.php/mas/article/download/2205/2059.

[91] Ministere de l'Energy de la RD Congo (2010). La Problematique du Secteur de l'Energie en Republique Democratique du Congo. Kinshasa-RDC.

[92] Ministere de l'Energie (2011). Le Sector de l'Energie de la RD Congo.

[93] Ministere du Portefeuille de la RDC. Retrieved October 15th, 2013 from http://www.ministèreduportefeuille.org,

[94] Mohd –Yunos, J., & Hawdon, D. (1996). The Efficiency of the National Electricity Board in Malaysia- an Intercountry Comparison. Department of Economics, University of Surrey. Retrieved from http://ideas.repec.org/p/sur/seedps/84.html.

[95] Murthi, B.P.S., Choi, Y.K., & Desai, P. (1997). Efficiency of Mutual Funds and Portfolio Performance Measurement: A Nonparametric Approach, *European Journal of Operational Research*, 98 (1), 408-418.

[96] Musaba, L. (2005). The Development of the SAPP Competitive Electricity Market. Inaugural IEEE PES *2005 Conference and Exposition in Africa*. Durban, South Africa, 11-15.

[97] Norberg, V. (2000). Creating Incentives for Environmentally Enhancing Technological Change: Lessons from 30 years of U.S. Energy Technology Policy.*Technological Forecasting and Social Change*, 65

(1), 125-148.

[98] Norman, M., & Stroker, B. (1991). Data Envelopment Analysis -The Assessment of Performance, John Willy & Sons.

[99] Omran, M. (2004). The Performance of State-Owned Enterprises and Newly Privatized Firms: Does Privatization really matters. *World Development*, 32 (6), 1019-1041.

[100] Organization of America State (OAS): Government's Role in the Electricity Sector. Retrieved December 11st, 2013, from http://www.oas.org/dsd/publications/Unit/oea79e/ch08.htm#b.%20GOVERNMENT&146;S%20REGULATORY%20ROLE.

[101] Polèse, M. (2009). The Wealth and Poverty of Regions. Why Cities Matter. Chicago: *University of Chicago Press.*

[102] Penrose, E. (2009). The Theory of the Growth of the Firm. *Oxford University Press.*

[103] Pollitt, M. (1995), Ownership and Performance in Electric Utilities: The International Evidence on Privatisation and Efficiency. *Oxford University Press.*

[104] Pollitt, M. (1996). Ownership and Performance in Electric Utilities. *The Energy Journal*, 17 (3), 105-107.

[105] Pombo, C., & Ramirez, M. (2001). Privatization in Colombia: A plant performance analysis. Borradores de Investigación.vVolume 458 of Research Network Working Papers. Issue 21 of Serie documentos / Universidad del Rosario, Facultad de Economía.

[106] Pombo, C., & Taborda, R. (2004). Performance and Efficiency in Colombia's Power Distribution System: Effects of the 1994 Reform.

[107] Public Entrpries: ESKOM. Retrieved December 01st, 2013 from http://www.dpe.gov.za/state-4_eskom.

[108] Radio Okapi (2007). Réhabilitation du barrage de Zongo: Résoudra ou résoudra pas le problème de délestage en Rd congo? Retrieved November 28th, 2013 from http://radiookapi.net/emissions-2/2007/10/02/rehabilitation-du-barrage-de-zongo-resoudra-ou-resoudra-pas-le-probleme-de-delestage-en-rd-congo/.

[109] Ramamutri, R. (1987). Performance Evaluation of State-Owned Enterprises in Theory and Practice. *Management Science*, 33 (7), 876-893.

[110] Rasiah, D. (2012). The Separation of Ownership and Control in Malaysian Domestic Companies. *International Conference on Economics, Business Innovation*. IPEDR, 38 (1). IACSIT Press, Singapore. Retrieved December 19th, 2013 from http://www.ipedr.com/vol38/024-ICEBI2012-A10014.pdf.

[111] Reichheld, F.F., & Sasser, W.E. (1990). Zero Defections: Quality Comes To Services, *Harvard Business Review*, 68 (1), 105-111.

[112] Sang, C. (2005). Relationship between Human Resource Management Practices and the Perception of Organizational Performance, Roles of Management Style, Social Capital, and Culture: Comparison between Manufacturing Firms in Cambodia and Taiwan. Available from Electronic Theses & Dissertations Service. Retrieved from http://etds.lib.ncku.edu.tw/etdservice/view_metadata?etdun=U0026081

2200911341.

[113] Seiford, L.M. & Thrall, R.M. (1990). Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis. *Journal of Econometrics*, 46 (1), 7-38.

[114] Seiford, L.M. (1996). Data Envelopment Analysis: The Evolution of the State of the Art (1978-1997). *Journal of Productive Analysis*, 7 (1), 99-138.

[115] Seitz, W.D. (1971). Productive Efficiency in the Steam-Electric Generating Industry. *Journal of Political Economy*, 79 (4), 878 - 886.

[116] Sherman, R.D. (1988). Service Organization Productivity Management. Hamilton: The Society of Management Accountants of Canada.

[117] Smith, P. (1993). Outcome Related Performance Indicators and Organizational Control in the Public Sector, *British Journal of Management,* 4 (1), 135-151.

[118] Societe National D'electricite (2000). Trente ans de vie de SNEL (Thirty years of the existence of SNEL). Gombe, Kinshasa, RDC.

[119] Societe National d'Electricite (2010). Plan de Sauvetage et de Redressement. Gombe, Kinshasa, RDC.

[120] Southern African Power Pool. Annual Reports (2004-2013). Retrieved September 25th, 2013 from http://www.sapp.co.zw/areports.html.

[121] Southern African Power Pool, (2009). Potential of Regional Power. Sector Integration. Economic Consulting Associates Limited. London, UK, 9-13.

[122] Tallapragada, P., Shkaratan, M., Izaguirre, A.K., Helleranta, J., Rahman, S. & Bergman, S. (2009). Monitoring Performance of Electric Utilities: Indicators and Benchmarking in Sub-Saharan Africa. World Bank. Retrieved November 14th, 2013 from http://documents.worldbank.org/curated/en/2009/01/16338434/sub-saharan africa-monitoring-performance-electric-utilities-indicators-benchmarking-sub saharan-africa.

[123] Transition Government of the DR Congo (Wilkipedia Online,). Retrieved November 28th, 2013 from http://en.wikipedia.org/wiki/Transitional_Government_of_the_Democratic_Republic_of_the_Congo.

[124] Tshibangu, C.M. (2009). Les Entreprises Publiques Congolaises Face à la Crise Economique Cas de la Regideso de 2006 à 2008. Institut Supérieur du Commerce de Kinshasa. Available from Memoire Online. Retrieved November 30th, 2013 from : http://www.memoireonline.com/10/10/4015/m_Les-entreprises-publiques-congolaises-face--la-crise-economique-cas-de-la-REGIDESO-de-2006--20015.html.

[125] United Nations Population Division (2012). World Urbanization Prospects: The 2011 Revision and File 1. New York: United Nations. Retrieved November 30th, 2013 from http://esa.un.org/unpd/wup/CD-ROM/Urban-Rural-Population.htm.

[126] United Nations Development Program. Retrieved November 30th, 2013 from http://hdrstats.undp.org/en/tables/.

[127] Uprety, K. (2002). Transboundary Energy Security: Emerging Legal

and Institutional Framework for Electricity Trading in Southern Africa. *Journal of Energy and Natural Resources*, 20 (1), 383.

[128] Vasylenko, S. (2008). Does Efficiency of Electricity Destribution Company Influence the Value of the Company? Master of Arts in Economics National University “Kyiv-Mohyla Academy. Retrieved from http://kse.org.ua/uploads/file/library/2008/vasylenko.doc.

[129] Vickers, J., & Yarrow, G. (1991). Economic Perspectives on Privatization. *Journal of Economic Perspectives*, 5(2), 111-132.

[130] Wooldridge, J.M. (2009). Introductory Econometrics. A Modern Approach. (4th Ed.). South Western Cengage Learning, 587-604.

[131] Wong, L. (2011). A Review of Transmission Losses in Planning Studies. California Energy Commission, Retrieved November 28th, 2013 from http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf.

[132] World Bank (1995). Bureaucrats in Business. New York: *Oxford University Press*.

[133] World Bank (2001). Regional Electricity Markets Interconnections Phase I. Identification of Issues for the Development of Regional Power Market In South America. Retrieved November 16th, 2013 from http://documents.worldbank.org/curated/en/2001/12/1735287/regional-electricity-markets-interconnections-phase-1-identification-issues-development-regional-power-markets-south-america.

[134] World Bank (2010). Sustainable Development in the Developing Countries. Poverty Reduction and Economic Management Network.

Economic Policy and Debt Department.

[135] World Bank. Retrieved from November 30th, 2013. http://data.worldbank.org/.

[136] World Energy Council (2008). How to make the Grand Inga Hydropower Project happen for Africa. London, UK. Retrieved from http://www.worldenergy.org/documents/ingaprojectfinal.pdf.

[137] Wright, P. (1998). Introduction: Strategic Human Resource Management. Research in the 21st Century. HRM Rev. 8(3), 187-152.

Appendix A: Regression Model

```
regress dsc hr gdp rg cg go vi cd exp cz urb if (dsc>0)
note: go omitted because of collinearity

      Source |       SS       df       MS              Number of obs =     120
-------------+------------------------------           F(  9,   110) =   13.56
       Model |  4.37137931     9  .485708812           Prob > F      =  0.0000
    Residual |  3.93963563   110  .035814869           R-squared     =  0.5260
-------------+------------------------------           Adj R-squared =  0.4872
       Total |  8.31101493   119  .069840462           Root MSE      =  .18925

------------------------------------------------------------------------------
         dsc |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          hr |   .1055973   .0137327     7.69   0.000     .0783823    .1328122
         inc |  -.0001313     .00002    -6.57   0.000     -.000171   -.0000917
          rg |  -.0138786   .0603891    -0.23   0.819    -.1335556    .1057984
          cg |  -.3101605   .0549592    -5.64   0.000    -.4190768   -.2012442
          go |  (omitted)
          vi |  -.2589586   .0730263    -3.55   0.001    -.4036795   -.1142376
          cd |   .4495562   .0630926     7.13   0.000     .3245214     .574591
         exp |   .0000506   9.49e-06     5.34   0.000     .0000318    .0000695
          cz |  -8.56e-08   4.54e-08    -1.89   0.062    -1.75e-07    4.29e-09
         urb |   .0173058    .002814     6.15   0.000      .011729    .0228825
       _cons |  -.0234978   .1570683    -0.15   0.881    -.3347704    .2877748
------------------------------------------------------------------------------
```

Appendix B: Elasticity of Variables

```
mfx compute, eyex at (mean)
Elasticities after regress
      y  = Fitted values (predict)
         =    .695225
------------------------------------------------------------------------------
variable |      ey/ex    Std. Err.     z    P>|z|  [    95% C.I.   ]      X
---------+--------------------------------------------------------------------
      hr |   .9005208      .11923    7.55   0.000   .666836  1.13421   5.9288
     inc |  -.4367568      .06738   -6.48   0.000  -.568816 -.304698  2311.79
      rg |  -.0118113      .05139   -0.23   0.818  -.112543   .08892  .591667
      cg |  -.3345972      .05987   -5.59   0.000  -.451939 -.217255      .75
      vi |  -.3104014      .08787   -3.53   0.000  -.482628 -.138175  .833333
      cd |   .3233171      .04608    7.02   0.000   .232999  .413635       .5
     exp |     .07892      .01492    5.29   0.000   .049678  .108162  1083.41
      cz |  -.0929554      .04931   -1.89   0.059  -.189601   .00369   755093
     urb |    .917563      .15093    6.08   0.000   .621739  1.21339  36.8612
------------------------------------------------------------------------------
```

Appendix C: Trend of Technical Efficiency Scores for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004	0.565	1	0.468	1	0.678	0.211	0.695	1	0.281	0.963	1	0.841
2005	0.669	1	0.555	1	0.678	0.101	0.579	1	0.298	0.771	1	0.946
2006	0.594	1	0.529	1	0.647	0.108	0.767	1	0.286	0.73	0.953	0.873
2007	0.654	1	0.507	1	0.594	0.148	0.7	1	0.342	0.662	1	0.673
2008	0.505	0.868	0.556	1	0.843	0.155	0.702	1	0.366	0.625	1	0.683
2009	0.616	0.716	0.529	1	0.927	0.252	0.714	1	0.334	0.772	1	0.685
2010	0.621	0.579	0.557	1	0.927	0.252	0.589	1	0.651	0.772	1	0.635
2011	0.621	0.579	0.557	1	0.927	0.252	0.589	1	0.651	0.772	1	0.635
2012	0.604	0.292	0.459	1	0.992	0.271	0.552	1	0.621	0.381	1	0.567
2013	0.533	0.173	0.514	1	0.987	0.277	0.562	1	0.637	0.361	1	0.564

Appendix D: Trend of the Malmquist Index (Technical Efficiency Change) for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004-2005	1.183	1	1.186	1	1	0.481	0.833	1	1.06	0.801	1	1.125
2005-2006	0.888	1	0.953	1	0.955	1.069	1.324	1	0.959	0.948	0.953	0.922
2006-2007	1.101	1	0.959	1	0.918	1.371	0.912	1	1.197	0.906	1.049	0.77
2007-2008	0.773	0.868	1.097	1	1.419	1.044	1.004	1	1.069	0.944	1	1.016
2008-2009	1.219	0.825	0.95	1	1.099	1.623	1.016	1	0.912	1.235	1	1.002
2009-2010	1.008	0.809	1.054	1	1	1	0.825	1	1.95	1	1	0.927
2010-2011	1	1	1	1	1	1	1	1	1	1	1	1
2011-2012	0.973	0.505	0.824	1	1.07	1.077	0.938	1	0.955	0.494	1	0.892
2012-2013	0.882	0.591	1.119	1	0.995	1.023	1.018	1	1.026	0.947	1	0.996

Appendix E: Trend of the Malmquist Index (Technological Change) for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004-2005	1	0.994	0.983	0.996	1	0.992	1	1	1.001	0.995	0.982	0.984
2005-2006	1.05	1.05	1.049	1.049	1.047	1.054	1.054	0.995	1.042	1.055	1.05	1.05
2006-2007	1.057	1.013	1.09	1.034	1.03	1.066	1.056	1.061	1.007	1.04	1.085	1.087
2007-2008	0.938	0.872	0.956	1.022	0.929	0.904	0.978	1.677	0.936	0.942	0.959	0.958
2008-2009	1.006	1.005	1.006	1	1.005	1.005	0.985	0.923	1	1.006	1.006	0.998
2009-2010	1	1	1	1	1	1	1	0.963	1	1	1	1.002
2010-2011	1	1	1	1	1	1	1	1	1	1	1	1
2011-2012	1.084	1.098	1.115	1	1.092	1.093	1.066	1.022	1.048	1.115	1.087	1.079
2012-2013	0.981	0.974	0.973	1	0.978	0.977	0.983	1	0.988	0.973	0.988	1.004

Appendix F: Trend of the Malmquist Index for Companies

	ENE	BPC	SNEL	LEC	ESCOM	EDM	Nam Power	ESKOM	SEB	TANE SCO	ZES CO	ZESA
2004-2005	1.183	0.994	1.165	0.996	1	0.477	0.833	1	1.061	0.797	0.982	1.107
2005-2006	0.933	1.05	1	1.049	1	1.127	1.396	0.995	1	1	1.008	0.968
2006-2007	1.163	1.013	1.045	1.034	0.945	1.461	0.963	1.061	1.205	0.943	1.133	0.838
2007-2008	0.725	0.744	1.049	1.022	1.318	0.944	0.981	1.667	1	0.89	0.959	0.973
2008-2009	1.226	0.837	0.956	1	1.105	1.631	1.001	0.772	0.912	1.242	1.006	1
2009-2010	1.008	0.809	1.054	1	1	1	0.825	0.963	1.95	1	1	0.929
2010-2011	1	1	1	1	1	1	1	1	1	1	1	1
2011-2012	1.055	0.552	0.919	1	1.169	1.178	1	1.022	1	0.55	1.087	0.963
2012-2013	0.865	0.576	1.089	1	0.973	1	1	1	1.014	0.921	0.988	1

초　　록

본 석사학위 논문에서는 2004년에서 2013년까지 콩고 민주공화국의 전력 회사(SNEL)를 남아프리카 전력 풀(앙골라, 보츠와나, 레소토, 말라위, 모잠비크, 나미비아, 남아프리카, 스와질란드, 탄자니아, 잠비아 및 짐바브웨)에 속한 다른 전력 회사들과 비교함으로써 SNEL의 성능을 계측하고자 하였다.

본 연구에서는 각 회사의 기술적 효율 점수를 산출하기 위하여 자료 포락 분석(DEA)법, 특히 Charnes, Cooper 및 Rhodes (CCR) 모델을 사용하였다. 이후 변화 내용을 기술적 효율 변화, 기술적 변화 및 스케일 효율 평균으로 구분하여 전력 시장(SAPP)에서의 최고 기량을 따라잡기 위하여 일부 회사가 얼마만큼의 노력을 기울였는가를 얻고자 하였다. 그런 다음, 각 회사의 성능 발전을 추적하기 위하여 Malmquist 지수를 산출하였다. 최종적으로는, 회사의 효율에 환경적 인자가 미치는 효과를 평가하기 위하여 두 번째 단계에서 OLS 모델을 사용하였다.

얻어진 결과는 SNEL이 비효율적이며 성능이 본 연구의 분석 기간 동안 진보하지 않았던 것으로 나타났다. 본 모델에서의 중요한 상수(규제당국)가 통계적으로 유의미한 수준은 아니었지만, 인력, 전력 분배에서의 경쟁, 전력 최종 수출 및 도시 인구와 같은 인자들은 통계적으로 유의미한 수준이었으며, 회사 효율에 긍정적으로 기여하였다. 하지만, 1인당 소득, 전력 생산에서의 경쟁, 그리고 수직 통합과 같은 다른 요인들도 통계적으로 유의미한 수준이었지만, 회사의 효율에 부정적인 영향을 미쳤다. 마지막으로, SNEL에 대한 성능 경향을 증진시키기 위하여 정책적 함의가 제시되었다.

주요어 : 콩고 민주공화국, SNEL, SAPP, DEA, CCR 모델, Malmquist 지수.

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