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Efficiency in angolan hydro-electric power station: A two-stage virtual frontier dynamic DEA and simplex regression approach

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A B S T R A C T

This research focuses on the efficiency assessment of Angolan hydro-electric power stations using the VDRAM (Virtual Frontier Dynamic Range Adjusted Model) DEA. In VDRAM, the reference and the DMU evaluation sets are different, thus allowing higher score discrimination. In this research, the VDRAM model is used firstly in a two-stage approach. In the second stage, Simplex Regression is adopted to handle skewed and asymmetrical efficiency scores. Results indicate that energy efficiency of hydro-electric power stations in Angola is impacted by the river proximity, location of the station, and the cost structure. Results also indicate the inexistence of a learning curve. Policy implications are discussed in terms of possible measures such as privatization and human resource training so that a learning curve is boosted while labor costs are kept under control. Finally, the cost-structure advantages of water-to-wire power stations are also discussed observing sustainable development practices encompassing social, agricultural, and logistical aspects for the country.

1. Introduction

This paper analyzes the energy efficiency of Angolan hydro-electric power stations using a VDRAM-DEA model, taking into account the impacts of several contextual variables on energy efficiency. Research on energy efficiency in electric utilities has adopted several methods, but most are based on non-parametric frontiers such as DEA (Data Envelopment Analysis) – cf. Zhou et al. [1] and Liu et al. [2] for comprehensive literature reviews. Although many papers have focused on the efficiency of electric utilities, few studies have investigated hydro-electric power stations in developed and emerging countries, in spite of their increasing global importance in terms of energy production. From a historical perspective, relevant studies include Barros [3]; Barros and Peypoch [4]; Barros and Antunes [5]; Lins et al., [6]; Stein [7]; Barros et al. [8]; and Kim et al. [9]. This paper, therefore, innovates in this context first by undertaking a review of energy efficiency in hydro-electric power stations and second by adopting as a research goal of VDRAM-DEA combined with Simplex Regression models in a two-stage approach.

The motivations for this present research are as follows: First, according to Nkomo [10–12], Angola is one of the countries in the world most favored by the oil price boom in the last ten years with clear reflections on energy production, justifying the present research,[1,2,3]. Second, this paper builds upon previous studies related to energy utilities efficiency, evaluating the relative efficiency among Angolan hydro-electric power stations. To the best of our knowledge, this is the first time Angolan hydro-electric power stations have been analyzed. Third, the present analysis enables a ranking of the relative efficiency of the Angolan hydro-electric power stations while assessing the impact of different contextual variables related to river proximity, utility location, and cost structure on their efficiency levels.

Therefore, the objective of this study is to assess the determinants of Angolan hydro-electric power stations based on business related variables commonly found in the literature. Being more specific, this general objective translates into the following research questions that are further supported by the methodology and data:

(1) How do contextual variables related to the geographical location and to the cost structure of the hydro-electric power stations in Angola impact their efficiency levels?
(2) When depicting their efficiency evolution over the course of time, is

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[1] http://www.worldbank.org/en/country/angola/overview
[2] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101562/jrc101562_impact%20of%20low%20oil%20prices%2020160512.pdf
[3] http://www.tradingeconomics.com/angola/energy-production-kt-of-oil-equivalent-wb-data.html

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it possible to affirm that hydro-electric power stations in Angola present a learning curve or do they remain stagnant over the course of time?

In order to achieve this general objective and answer these specific questions, an efficiency analysis is developed in a two-stage approach: VDRAM DEA model efficiency estimates are computed first, which are then followed by Simplex regression. Frequently, researchers are dealing with situations where they are interested in modeling proportions, percentages, or values, such as efficiency scores, within the open interval (0; 1) according to one or several covariates within the architecture of the regression. For this type of variable, the normal assumption it is not supported, invalidating conclusions that could be obtained from these results. The response variable's asymmetry and multicollinearity are two of the most frequent problems that the normal model cannot deal with. In this situation, some alternatives have been developed such as Beta regression that bring with them the general linear model advantages and the Simplex distribution, which is part of a more general class of models called the dispersion models [13]. This paper is structured as follows: after this introduction, the contextual setting is presented including a description of the Angolan hydro-electric power stations. The literature survey is then presented followed by the methodology section where the two-stage VDRAM-Simplex regression is further discussed. Section 5 presents the data followed by the discussion of the results and the conclusion in Section 6.

2. Contextual Setting

The Angolan hydro-electric energy plants are presented in Table 1. Most are located on two Angolan rivers: the Catumbela and the Kwanza. Angola's major rivers are Kwanza, Cunene, and Dande with Catumbela situated in northern Angola and Cunene located in the southern part of the country. All these rivers flow into the Atlantic Ocean with the exception of the Cubango River that disappears into the Kalahari Desert.

The public energy company of Angola manages these energy plants. Angola aims to increase the capacity of energy production from 2008 to 2017 with the completion of projects in the field of production, expansion of the Cambambe dam from 180 to 960 MW, the construction of the new Lauca Dam with 2067 MW, and the completion of the combined cycle power plant dam of Soyo with 750 MW. These investments are currently being made by means of the rehabilitation of the older dams. Cambambe is the oldest water energy plant that started its operation during the colonial period in 1963. It serves Luanda city and its neighboring cities. Capanda started its operation in 1982 and produced energy in 2004 and it is one of the largest electric plants of Angola. It serves Pungo Andongo, Kwanza Norte, Kwanza Sul, Bengo, Uíge, and Luanda. Luachimo is located near Dundo and started operations in 1957. Matala, located in Lubango, started its operation in 1954. Biolio is located in Benguela. Lomaum Dam is a privately owned hydroelectric dam. Completed in 1965, it initially produced 20 MW of power supplying electricity to the towns of Lobito, Benguela, and Huambo. This dam was destroyed in 1983 by UNITA after Angola gained independence. Chicapa, located in Lunda North, started its operation in 1988. Chiumbe Dala, located in Bie near Dala city in Lund South, supplies Luena city. NGove Dam, located in Caala District in Rio Cunene near Namibia is a joint reconstruction project of Angola and Namibia. The dam construction started in 1969, though it was damaged in 1990 during the civil war. It is connected to Huambo City and Bie. Mabubas Dam, located in the northern Bengo province in Barra do Dande River in northern Angola, is the main source of electricity for northern Angola. This dam began running in 1981 and has been recently renovated.

3. Theoretical background and literature review

From the early 1980s, different researches have used the DEA approach as a cornerstone tool to assess electric utilities efficiency levels under different governance schemes, most of them with respect to regulatory regimes and ownership structures. A theoretical framework for public monopolies can with advantage rely on a resource-based theory [14,15] whereby an energy plant's competitive advantage is a function of the bundle of resources at its disposal (valuable – i.e. non-imitable – and non-substitutable) such as a plant's location and managerial style. In a monopoly context, these are distinguished resources that may explain efficiency differentials as well as the productive technology itself, which establishes, up to a point, limitations on short- and mid-term performance improvement. DEA helps not only in benchmarking individual firms against best practices, but also in determining the roots of inefficiencies, shedding light on critical issues that assist regulators in policy-making. Several important DEA researches in the areas of energy generation efficiency focusing exclusively on thermal power plants are discussed in this section.

The literature on hydro-electric power station efficiency is relatively scarce and includes Barros [3] who analyzed the productivity of Portuguese dams with a Malmquist index, Barros and Peypoch [4] who analyzed the Portuguese hydric plants with a stochastic regression frontier, and Jacobson and Delucchi [16] who discussed the energy demand with a focus on renewable energy. More recently, Barros and Antunes [5] analyzed the Portuguese wind farms with homogenous and heterogeneous stochastic frontier and Barros et al. [8] analyzed the Chinese hydro-electric plants with a finite mixture stochastic model allowing for alternative technologies. Wang et al. [17] analyzed the hydropower efficiency of Canadian dams using the TOPSIS model. Pang et al. [18] analyzed hydropower generation within the context of clean energy use on total-factor efficiencies under the simultaneous consideration of economic output, energy conservation, and emission reduction, putting 87 countries during 2004–2010 into perspective. Their results show that clean energy consumption significantly increases the total-factor emissions reduction efficiency while significantly decreasing the total-factor energy efficiency.

Table 1
List of Angolan hydro-electric energy plants.
Source: Empresa Nacional de Electricidade (ENE-EP)

	Hydric energy plants	Location	Production (MWh)	Capacity (MW)	Kwanza River	Catumbela River
1	Cambambe	Cuanza-Norte	180	192	1	0
2	Capanda	Malange	510	520	1	0
3	Luachimo	Lunda Sul	8	10	1	0
4	Matala	Lubango	38.2	40.8	0	1
5	Biopio	Benguela	10	14.4	1	0
6	Lomaum	Benguela	45	50	1	0
7	Chicapa	Lunda Norte	14	16	0	1
8	Chiumbe Dala	Bíe	10	12	0	1
9	NGove	Huambo	55	60	0	0
10	Mabubas	Luanda	26	28	0	0