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Efficiency in Angolan thermal power plants: Evidence from cost structure and pollutant emissions

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ABSTRACT

This research focuses on the efficiency assessment of Angolan thermal power plants using a Slacks Based Model with undesirable (bad) outputs (SBM-Undesirable). In this research, SBM-Undesirable is used first in a two-stage approach to assess the relative efficiency for these power plants. The most frequent cost structure variables adopted by literature to characterize a productive technology are used. In the second stage, Beta Regression models are combined with SBM-Undesirable efficiency scores to produce a model for predicting energy production performance. Results indicate that thermal power plants in Angola that are intensive in capital—to the detriment of labor—and that present lower unit capacity costs are more efficient and less polluting. Results also indicate the absence of a learning curve for increasing efficiency in energy generation. Policy implications are derived.

1. Introduction

This paper analyzes the energy efficiency of Angolan thermal power plants using an SBM-Undesirable output model taking into account the impacts of CO2 emissions and of polluted water used to cool thermal plants. Precisely, this paper is focused on the technical efficiency as a whole of thermal plants in Angola, from which it is possible to derive an efficiency frontier of best practices for this industry. This research differs from those related to the thermodynamic efficiency of the thermal plants because it is rather focused on the machinery or equipment level at a particular facility.

Research on technical energy efficiency—referred from now on simply as "efficiency"—in thermal power plants has adopted several methods, but most are based on non-parametric frontiers such as DEA (Data Envelopment Analysis) – cf. Zhou et al. [1] and Mardani et al. [2] for comprehensive literature reviews. This paper innovates in this context, first by undertaking a review of energy efficiency in thermal power plants, and second by adopting as a research goal SBM-Undesirable combined with Beta Regression models in a two-stage approach. The motivations for the present research are threefold. First, this paper innovates on energy efficiency in thermal power plants and evaluates Angolan thermal plants for the first time. In this research, this relative analysis is undertaken for 32 power plants in Angola from 2010 to 2014, adopting for the first time the SBM-Undesirable and Beta Regression in a two-stage approach. Furthermore, the present analysis not only enables the ranking of the relative efficiency of the thermal power plants over the course of the years, but also presents a predictive focus on the slack potentials for reducing pollutant emissions. Finally, the paper contributes to the literature of thermal power plant efficiency by analyzing for the first time the efficiency drivers and pollutant emissions of thermal plants in terms of the cost structure variables commonly used to characterize productive technologies.

Although many papers have focused on the efficiency of power plants, few studies have investigated thermal plants in developing

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and emerging countries despite their increasing global importance in terms of energy production. From a historical perspective, relevant studies include Yaisawarng and Klein [3], who apply a Data Envelopment Analysis (DEA) model to analyze the effects of SO_2 control on the efficiency of US coal-fired power plants. Additionally, Färe et al. [4] analyze US fossil-fired utilities, breaking down overall productivity in terms of an environmental index and a productive efficiency index. Furthermore, Korhonen and Luptacik [5] analyze 24 coal-fired power plants in Europe with DEA models while taking undesirable outputs into account. Moreover, Yang and Pollitt [6] analyze Chinese coal-fired power plants with a DEA multi-stage model. Finally, Barros [7] analyzes the efficiency of Portuguese thermal plants accounting for CO2 emissions using a q distance frontier model. Therefore, this paper contributes to this restricted literature by focusing on Angolan thermal plants, thus filling a neglected research gap in energy production in African countries. Our study differs in several aspects. First, we focus on Angola, an important African country in terms of energy production, treating it in the context of "bad" outputs. Second, we use balanced panel data (2010–2014), which enables us to (a) track efficiency trends in energy production at Angolan thermal power plants over the course of time and (b) make an initial inference on the eventual existence of a learning curve. Finally, our study employs a different and more efficient methodology (SBM-Undesirable outputs model and Beta Regression) that enables us not only to estimate efficiency in energy production under the presence of bad outputs, but also to analyze how different variables related to the cost structure—which characterize a given productive technology—may influence efficiency levels in the energy production process. Bad outputs refer to the harmful or undesirable ones generated by a given productive process. In this research they specifically refer to the CO2 emissions and to the discharged polluted water that are also obtained when generating energy from thermal power plants in Angola. Differently from the traditional outputs, which are desirable and should be maximized, bad outputs should be minimized or kept under certain control levels.

The paper is structured as follows: The next section presents the contextual setting including a description of the thermal power plants in Angola under investigation. The literature survey is then presented in Section 3, followed in Section 4 by the SBM-Undesirable methodology. Section 5 presents the data and the prediction of efficiency levels using Beta Regression followed by a discussion of the results and the conclusion.

2. Contextual setting

Angola thermal power generation plants are public plants located near cities that burn fuel to produce electricity for local city consumption. The production is controlled by a national public company ENE-EP (Empresa Nacional de Electricidade - Empresa Pública), which operates in all 18 provinces. Electricity in the provinces and municipalities is controlled by ENE-EP, which has the requisite resources and technical capacity. A public company, EDEL-EP (Empresa de Distribuição de Electricidade - Empresa Pública), handles power distribution. Another company, a subsidiary of EDEL, handles power distribution in the Luanda region. Therefore, thermal energy is a monopoly in Angola and a uniform subsidized tariff applies nationwide, currently 3.5 Angolan kwanza per kilowatt-hour (kwh), the equivalent to 0.0004 USD per kwh at current exchange rates. From 2014 onwards, natural gas has been increasingly used instead of oil in energy production at Angolan thermal plants. One explanation for this change is that the average cost of production is 220 USD per megawatt-hour (MWh), which is considered high in the African context. According to studies developed by the Ministry of Energy and Water in Angola in 2011[1], these high costs of power supply are driven by high technical losses (about 15% of the power produced compared to the benchmark of 10%) and inadequacy and inefficiency of the generation infrastructure through three dimensions: (i) high variable costs of the technologies used (in particular the use of expensive fuels), (ii) higher per unit investment costs (vs. international benchmarks), and (iii) increased network downtime (reduced availability and use of generation assets). Specifically, the Cazenga (Luanda) power plant, one of the most important plants in the country due to its location, as well as the Malembo (Cabinda) plant, burn gas nowadays and the process of substitution continues.

Table 1 shows the varying production and capacity levels of the units, all of which are managed by ENE. Some thermal plants are not analyzed in this study that are managed by local companies such as Lucapa and Luxilo (managed by the Diamang company, Lunda), Tchamutete and Jamba (managed by Mineira do Lobito, Benguela province), Alto Catumbela (managed by Companhia de Celulose, Benguela), the Tentativa energy plant (managed by Açucureira de Angola, Luanda), Catumbela energy plant (managed by the Companhia Agricola Cassequel, Benguela), Porto Alexandre (managed by JPEA, Namibe), Lobito (managed by Companhia de Cimento de Angola), and Malembo (managed by JPEA, Cabinda). This is the context in which the public thermal power plants of Angola are analyzed.

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 [8,9], whereby an energy plant's competitive advantage is a function of the bundle of resources at its disposal (valuable—non-imitable—and non-substitutable), such as plant location and managerial style. In a monopoly context, these are distinguished resources that may explain efficiency differences along with the productive technology itself, which establishes limitations on short- and mid-term performance improvement up to a point. 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 are discussed in this section with a focus exclusively on thermal power plants.

The literature of energy plants includes Park and Lesourd [10], who assessed the efficiencies of 64 fuel power plants in South Korea. The authors showed that all fuel types presented similar performance. In addition, they found the efficiency of the oldest plants to be significantly lower than the newer ones. Possible explanations for this result may be related to inherent characteristics of older plants/technologies such as higher levels of technical losses, use of expensive fuels that are less efficient from a thermodynamic standpoint, and higher facility downtime due to maintenance and breakdowns. No significant difference was found when comparing the efficiencies of the plants in terms of geographical area.

Lam and Shiu [11] computed the efficiency of China's thermal power generation based on data for 1995 and 1996. In accordance to their findings, provinces along the eastern coast of China and

[1] http://www.minea.gv.ao/publicacoes/pgmonve/category/11-projectos.html?download=77:the%20national%20energy%20security%20%20strategy%20and%20policy.