Journal of Cleaner Production 115 (2016) 130–138

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Regional analysis across Colombian departments: a non-parametric study of energy use

Clara Inés Pardo Martínez [a, c, *], William H. Alfonso Piña [b]

[a] School of Administration, Universidad del Rosario, Bogotá, Colombia
[b] Faculty of Science Policy and Government, Urban Development and Management —Ekística— Universidad del Rosario, Bogotá, Colombia
[c] Colombian Observatory of Science and Technology (OCyT), Bogotá, Colombia

ARTICLE INFO

Article history:
Received 27 September 2015
Received in revised form
9 December 2015
Accepted 11 December 2015
Available online 21 December 2015

Keywords:
Colombian departments
Energy use
Data envelopment analysis
Panel data models

ABSTRACT

The analysis of energy use is important in emerging economies and especially in the manufacturing industries, as energy is a key factor of sustainable development. This research analyses and evaluates the features of regional energy use and efficiency across Colombian departments in the manufacturing industries for the period between 2005 and 2013 by applying two Malmquist data envelopment analysis models. The results indicate significant difference in energy use and efficiency across Colombian departments in the manufacturing industries. The results of the Malmquist indexes determine that various manufacturing industries across Colombian departments have a high potential to increase energy efficiency. Several manufacturing industries across Colombian departments have experienced gains in productivity, a growth in efficiency, an improvement in the relationship between inputs and outputs and scale production and advances in innovation through new technologies. This technique allows to make comparisons and improves energy policies to increase energy efficiency and decrease CO_2 emissions. The application of panel data models indicate that increases in energy prices, exports and productivity lead to better energy use, while a higher presence of energy intensive sectors and small and medium enterprises across Colombian departments reduce energy efficiency. The methods selected in this research generated consistent, robust and reliable estimates related to energy use and CO_2 emissions for regional studies. The findings of this study indicate that diverse energy policies should implement in the industrial sector across Colombian departments and that they should contribute to improvements in energy use, especially in small and medium companies and energy intensive sectors.

1. Introduction

Energy is used in large quantities to run industrial units, process materials and mine, transport goods and people and carry out the activities of daily life. This energy use is causing substantial environmental and social impacts, both in the form of local environmental damage as well as at the global climate scale (Gottschalk, 1996). Currently, the challenge is to reduce energy use while maintaining industrial and individual activities, with the aim of increasing development and living standards in an economically, environmentally and socially sustainable way (UNIDO, 2011).

Energy use is a vital input in the production of goods and services in the manufacturing industries, which account for a third of global energy demand (IEA, 2010). It is among the manufacturing industries where improvements in energy efficiency are among the least-cost options to decrease greenhouse gas (GHG) emissions today and in the coming decades. Moreover, improving energy efficiency has other benefits for achieving industrial and commercial competitiveness and energy security (Worrell et al., 2009) and the coverage of energy efficiency regulation worldwide extended to more than a quarter of global energy consumption, which is key to limit world energy demand growth (IEA, 2015).

Energy use can be measured with different techniques. The traditional measurement is energy intensity indicators that measure the quantity of energy required to perform an activity in monetary or physical units several studies have used these indicators e.g., Fiorito (2013) in the context of modern economies, and Hasanbeigi et al. (2012) for the textile industry in Iran.

* Corresponding author. School of Administration, Universidad del Rosario, Bogotá, Colombia.
E-mail addresses: cipmusa@yahoo.com, clara.pardo@urosario.edu.co (C.I. Pardo Martínez), William.alfonso@urosario.edu.co (W.H. Alfonso Piña).

http://dx.doi.org/10.1016/j.jclepro.2015.12.019
0959-6526/

Decomposition analysis is used in energy studies to determine the independently features affecting energy use e.g., Shao et al. (2014) used this technique to analysis industrial energy consumption in Tianjin, China, and Robaina-Alves et al. (2015) applied this technique to evaluate change in energy-related CO_2 emissions in Portuguese tourism. Econometric models are used to evaluate the effects of different variables on energy efficiency performance e.g., Wang et al. (2015) applied an econometric model based on panel data techniques to analysis the relationship between urbanization and energy use in Association of Southeast Asian Nations (ASEAN) countries, and Hashem et al. (2011) used econometric models to evaluate energy use patterns in canola production in Iran. In the last decades, Data Envelopment Analysis (DEA) has been utilized as a technique that allows to evaluate energy efficiency within a framework with inputs and outputs. These techniques have allowed increase the knowledge on energy trends and features from different approaches.

Data Envelopment Analysis (DEA) is used in this study taking into account its advantages to determine the role of input substitution in achieving energy efficiency and compare relative efficiency across of Decision Making Units (DMUs). This is a non-parametric technique to assess the performance or relative efficiencies of various entities or Decision Making Units (DMUs) on the basis of multiple energy inputs and gross production or carbon dioxide emissions as outputs, where the models are CCR (Charnes, Cooper and Rhodes) (Charnes et al., 1978) and BBC (Banker, Charnes and Cooper) (Banker et al., 1984).

This method has been conducted to analyse performance in energy sectors in many countries and to compare countries, regions and sectors. For example, Sözen and Alp (2009) used DEA to compare GHG emissions between Turkey and European Union countries, establishing that the trends of greenhouse and other harmful emissions is affected by combustion conditions, fuel sources, technology, and emission control policies and instruments. Hu et al. (2011) calculated the energy efficiency of 23 regions in Taiwan using a four-stage DEA procedure, and determined a worsening trend in the nation's energy efficiency over 1998–2007, with urban areas usually more efficient in energy use than rural areas. Wang et al. (2013) studied total-factor energy and environmental efficiency in 29 regions of China for the period 2000–2008, applying DEA techniques to assess the energy and environmental efficiency, showing that the eastern area of China has the best energy and environmental efficiency whereas in the western area the efficiency was the poorest. Suzuki et al. (2013) used a DEA model to evaluate energy-environment efficiency for ten regions in Japan, determining that the efficiency index of all DMUs reduces meaningfully in comparison with base period as a consequence of the negative effect of the Fukushima disaster and related efforts to increase thermal power generation with associated higher fuel costs and CO_2 emissions. Wang and Wei (2014) determined energy savings, energy efficiency and potential of emissions reduction for the industrial sector in 30 Chinese cities over 2006–2010 through DEA, concluding that energy use and CO_2 emissions have decreased since 2006 in the cities studied and that cities with higher level of economic developed showed higher efficiency. Goto et al. (2014) used DEA to evaluate in Japanese manufacturing industries operational efficiency, unified efficiency under natural disposability or natural and managerial disposability, finding that environmental regulation has been effective for improving the performance of Japanese manufacturing industries and that GHG emissions are a primary source of unified inefficiency in the industries analysed. Honma and Hu (2014) used DEA to determine the total-factor energy efficiency (TFEE) of industries in 14 developed countries over 1995–2005, concluding that benchmarking countries provides useful information about energy efficiency improvements among inefficient industries. They also found that to improve inefficient industries, the countries should adapt energy conservation technologies from benchmark countries with the best performance levels. These studies have demonstrated the importance of DEA to the analysis of energy and environmental efficiency from different approaches.

This background shows that considerable research has been conducted on energy efficiency using DEA. However, studies on the performance of energy efficiency in manufacturing industries across regions in developing countries are limited. Therefore, the main contribution of this research is in using data envelopment analysis (DEA) and Malmquist indices to evaluate energy use, efficiency and CO_2 emissions in the manufacturing industry across Colombian departments.[1] Different variables related to energy and development from particular to each department are considered, which has rarely been considered in this field. In second-stage, the Malmquist-DEA indices are included as independent variables in different regression models applying panel data analysis to establish that independent variables should affect the results of energy efficiency and CO_2 emissions in the manufacturing sector of Colombian departments. Thus, this study provides a more truthful measurement of energy efficiency and CO_2 emissions in industrial sector across regions and compares traditional measurement with relative efficiencies from DEA to determine its reliability and robustness, and contributes to the literature of regional energy efficiency and CO_2 emission measurements especially in the Colombian context as a case of Latin-American, where studies of energy efficiency and CO_2 emission performance and their determinants is quite new. The study also contributes to the limited empirical evidence on energy efficiency and CO_2 emission as a comparative analysis across regions and factors and variables that determine their trends in the industrial sector over time. The research question that guides this study is the following: *What are the factors that determine better performance as energy efficiency in the manufacturing sector across Colombian departments?*

This paper is structured into five sections. The methods and data used in this study, such as Malmquist-DEA, Wilcoxon rank-sum test, data panel model and data construction, to analyse and compare the energy efficiency performance of manufacturing industries across Colombian departments are explained in the second section. The next section includes results and the fourth section shows discussion and implications of this study. The fifth section concludes and provides some policy suggestions.

2. Methods and data construction

2.1. The Malmquist-DEA

Fig. 1 illustrates the framework applied in this research, following Caves et al. (1982), Fare et al. (1990, 1993). The production frontiers shown as non-parametric distance functions implies the efficient grade of output (y) that can be generated from a given grade of input (x), and the supposition is made that this frontier can have variation in a period time Caves et al. (1982), Hjalmarsson and Veiderpass (1992). Fig. 1 describes the frontiers where the present (t) and future (t + 1) time periods are measured subsequently. In the presence of inefficiency, the relative movement of any given Colombian department in a period time will therefore differ on both its position relative generating technical efficiency and the location of the frontier itself denominated technical change. If inefficiency is unobserved, the productivity

[1] In Colombia, departments are sub-national political territories.