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# Efficiency in Brazil's industrial sectors in terms of energy and sustainable development

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ARTICLE INFO

Available online 27 September 2013

*Keywords:*
Industrial sectors
Data envelopment analysis
Sustainable development
Energy

ABSTRACT

This article evaluates the efficiency of Brazil's industrial sectors from 1996 to 2009, taking into account energy consumption and respective contributions to the country's economic and social aspects. This analysis used a mathematical programming method called Data Envelopment Analysis (DEA), which enabled, from the SBM model and the window analysis, to evaluate the ability of industries to reduce energy consumption and fossil-fuel $CO_2$ emissions (inputs), as well as to increase the Gross Domestic Product (GDP) by sectors, the persons employed and personnel expenses (outputs). The results of this study indicated that the Textile sector is the most efficient industrial sector in Brazil, according to the variables used, followed by these sectors: Foods and Beverages, Chemical, Mining, Paper and Pulp, Nonmetallic and Metallurgical.



## 1. Introduction

Climate change poses major challenges to the planning and management policies of the domestic industrial sectors, as the complex interactions between the environment and the productive systems render difficult analyzing the reality by policymakers. This difficulty calls for more elaborate indicators that are conducive to an integrated assessment of the sustainability of productive sectors.

The term sustainable development owes its widespread usage to the Brundtland Commission Report (WCED, 1987), *Our Common Future*, which defined it as "development that meets the needs of the present without compromising the ability of the future generations to meet their own meets". With regard to production systems, Glavic and Lukman (2007) define the concept of "sustainable production" as the creation of goods using processes and systems that are non-polluting, that conserve energy and natural resources in economically viable, safe and healthy ways for employees, communities, and consumers and which are socially and creatively rewarding for all stakeholders for the short- and long-term future.

However, most of the current production processes that massively utilize nonrenewable natural and partially recyclable resources rarely fully meet all requirements related to sustainable production, particularly those related to mitigating global warming.

The data presented in the last Intergovernmental Panel on Climate Change (IPCC, 2007) indicate that global warming is largely due to human activity, especially human-caused $CO_2$ emissions. Thus, fossil fuel burning has been shown to be responsible for approximately 85% of all anthropogenic $CO_2$ emission produced yearly.

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1462-9011/$ – see front matter 
http://dx.doi.org/10.1016/j.envsci.2013.08.007

Silva and Guerra (2009) explain that the use of fossil fuels has driven the world economy since the Industrial Revolution, with energy representing an essential component for the social and the economic development of a nation and its supply an essential pre-requisite to human activities.

Therefore, the environmental implications of the production and use of energy resources represent a major challenge for developed and developing countries, since the production, distribution, processing and consumption of energy should be directed to ensure development, without increasing it negative effects on society and the environment. As a result, the analysis of the relationship between energy consumption, economic growth and carbon emissions, has become the subject of several international studies in recent years.

Belke et al. (2011), for example, analyzed the long-term relationship between energy consumption and real Gross Domestic Product (GDP) of 25 OECD countries from 1981 to 2007. Ramanathan (2006) used DEA (Data Envelopment Analysis) to analyze the relationship between $CO_2$ emissions, GDP growth and energy consumption from 1980 to 2001. Moreover, Blancard and Hoarau (2013) used the DEA method to build a sustainability index for Small Island Developing States (SIDS), considering the carbon footprint, the GDP penalized by economic vulnerability, and also longevity and knowledge. Finally, the study by Niu et al. (2011) was conducted to evaluate the causality between energy consumption, GDP growth and carbon emissions for eight Asia-Pacific countries from 1971 to 2005, using panel data.

In their study, Niu et al. (2011) concluded that in developing countries the base carbon emissions, the per capita energy consumption and energy use efficiency are far lower than in developed countries, however, the $CO_2$ emissions per unit of energy use is higher. Although developing countries may reduce their $CO_2$ emissions per unit of energy use, total energy consumption will rise rapidly with economic development. Therefore, developing countries must determine how to undergo economic growth while conserving energy and reducing emissions.

Data from the National Energy Balance, BEN (2010), confirm this information for Brazil, from an ongoing series covering the period of 1970–2008, which shows that the overall trend has been the expansion of global energy consumption. From 1990 to 2008, for example, the cumulative growth was 77%, with total consumption increasing from 127.596 million toe to 226.393 million toe. The industrial sector is the largest energy consumer in Brazil, representing 34.6% of the country's total consumption (BEN, 2010).

Notwithstanding the study by Simões and La Rovere (2008), which analyzed the availability of renewable energy sources in Brazil, to conclude that Brazil's energy matrix is relatively clean, Brazil's internal use of renewable energy is of 43.7% (BEN, 2010), many of the activities of the industrial sector are still dependent on fossil fuels. The outcome is that the industry impacts the environment by emitting extremely high concentrations of greenhouse gases (GHG), increasing global warming, in addition to adding to the extensive mining in the form of fuel oil and coal. According to Freitas and Kaneko (2011), economic activities, together with demographic pressure, represent the leading forces that explain Brazil's emission increase. On the other hand, the main factors to mitigate emission are carbon intensity reductions and diversification of the energy mix toward cleaner sources.

Paz et al. (2007), who discussed the concepts of sustainability and ethics through the analysis of the Brazilian energy policy and its social and environmental implications, stresses that the dynamics of economic activities used to meet human needs should take into account the natural limiting factors, as for instance, energy production, transformation, distribution, and consumption conditions. In this context, according to Kolk and Pinkse (2004), companies currently face increasing pressure regarding the amount of fossil fuels used in their productive processes.

Considering that the industrial sector can significantly contribute to the challenge against climate change, several studies have been conducted focusing on environmental and economic aspects in the industry (Yellishetty et al., 2010; Oggioni et al., 2011; Scheneider et al., 2011; Tomasula and Nutter, 2011; Wernet et al., 2011; Hamzah et al., 2010; Berni et al., 2008; Narodoslawsky et al., 2008). However, most of these studies have focused on particular industrial sectors, processes or products.

Thus, notwithstanding the few works, such as Zhang et al. (2008), an eco-efficiency analysis for regional industrial systems in China by developing data envelopment analysis (DEA) based models, and Luken and Castellanos-Silveria (2011), which compared the changes in economic, environmental and social variables that occurred in the manufacturing industry in groups of developing countries, between 1990 and 2004, there are still ample opportunities for studies covering various industrial sectors and their contribution to promoting economic development with environmental respect and social improvement.

Since there is much discussion on how to define a multidimensional index of sustainability, combining economic, social and environmental aspects (Cracolici et al., 2010), and based on the definition by Glavic and Lukman (2007) of the sustainable production concept, the objective of this article is to analyze the efficiency of the main industrial sectors in Brazil, from 1996 to 2009, considering energy consumption and its contribution toward the economic and social aspects of the country.

Mao et al. (2011) conducted a similar study on multiple sustainability indicators using statistical data to analyze China's energy consumption and GHG emissions, by industrial subsystem and sector. Thus, compared to other works, this study stands out due to the fact it compares industrial sectors using an aggregate sustainable production index.

To reach this goal, a mathematical programming method called Data Envelopment Analysis (DEA) was used. This method, based on the SBM model and on the window analysis, enabled analyzing the efficiency of Brazil's industrial sectors to reduce energy consumption and $CO_2$ emissions from fossil fuels (inputs), while increasing the GDP by sectors, the persons employed and personnel expenses (outputs).

## 2. Methods

In this study the main Brazilian industrial sectors were selected, with data provided by the National Energy Balance