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Is energy utilization among Chinese provinces sustainable?

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ABSTRACT

With the advent of China's reformation and open policy, its economy and levels of urbanization experienced explosive growth. However, the widely employed "high input, high pollution" style of resource consumption violates the green growth principle, and is imposing increasing pressure on both the energy infrastructure and the environment. Due to the complex relationships between resources, energy, urbanization, and the environment, it is imperative to explore methods that maximize total-factor energy efficiency and reduce environmental pollution, to achieve green growth. The slack-based measure (SBM) of efficiency was used to evaluate the total-factor energy efficiencies of 29 Chinese provinces for specific periods. Further, we leveraged the Malmquist index to explore efficiency trends from 2005 to 2014. The results show that urbanization and energy efficiency are positively correlated, whereas decreasing ratings in some provinces indicate economic recession or severe environmental pollution. Almost two-thirds of the measured provinces are energy inefficient, but have shown slow but clear improvement, indicating the huge potential for growth. Based on the findings, Chinese provinces are allocated to three categories, and policy recommendations and implementation measures are discussed, for improving total-factor energy efficiency nationwide.

1. Introduction

China's economic momentum has spiked aggressively in recent years, and the country continues to play a major role in the process of economic globalization. Following such rapid development, environmental damage has become a severe problem and the availability of natural resources has sharply declined. The Chinese Government has increased investment in energy infrastructure construction and pushed for new technologies to supply power more effectively. Energy resources are materials and natural processes that have the ability to provide widespread power under present socioeconomic conditions. Coal and petroleum are two relevant modern energy resources.

Although production efficiency has greatly improved since the Industrial Revolution, the main resources for developing machine production, such as iron ore, coal and petroleum, are still in short supply. Due to its energy-intensive economy, China has the highest national annual energy consumption (Statistical Review of World Energy, 2015). From 2012 to 2013, China's annual energy consumption increased by 15.4%, to 3.75 billion tons of standard coal equivalent (TCE), of which coal, oil and natural gas accounted for 68%, 19% and 4.4%, respectively (China Statistical Yearbook, 2015). In 2012, China's energy consumption per 10,000 Yuan GDP was 0.76 TCE, a 6% decrease compared with 2010. This is a result of China recently advocating the development of renewable and clean energy while decreasing the use of non-renewable energy. It is important to note that many people continue to use less efficient energy sources, such as coal and oil, both of which provide little energy for pollution they create. Despite this, alternative energies with high efficiency and low environmental impact are also becoming more prevalent, including geothermal and hydropower systems, nuclear power, wind power and natural gas.

China's rapid economic growth and associated high energy-consumption in both imply huge social costs, including water pollution, health and safety problems, poor air quality, and resource shortages on both local and global scales (He et al., 2002). For example, Song et al. (2015a) demonstrated that the economic scale effect significantly explained the increased carbon emissions in the Yangtze River Delta region. Among 500 developed cities in China, fewer than five achieve the World Health Organization standards for air quality. China contains some of the most polluted places in the world. The main reason for these problems is the emission of sulfur dioxide, nitrogen oxides, and smoke from heavy chemical industries, coal plants and the over-exploitation of natural resources.

By seeking to reduce the consumption of resources and energy to ease environmental pressure, efficiency emerges as the most important factor. Improving energy efficiency is key to solving the energy problem and is a major goal that China is pursuing for the sake of current and future economic growth (Dan, 2007). Additionally, efficiency is an important index of energy utilization and the degree of pollution. Enhancing energy efficiency is vital for economic development and urbanization,

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as well as energy safety and environmental protection. Efficiency can also help elucidate the complex relationships between economics, environmental protection, and energy consumption. There is an extensive literature on evaluating energy efficiency, employing different methods and from various perspectives (see Table 1). The two main methods for evaluating energy efficiency are single-factor and total-factor energy efficiency. The single-factor method is a traditional approach that describes energy efficiency as energy consumption per unit GDP. Empirical results show that this method is simple and effective. However, the method is unrealistic without considering other factors such as industrial structure and technical progress. Due to the presence of additional factors that affect energy efficiency, it is necessary to adjust the model accordingly. Total-factor energy efficiency has been studied in both developing countries (Hu and Wang, 2006; Zhang et al., 2011) and developed countries (Honma and Hu, 2013; Wang et al., 2012a, 2012b). In the face of increasingly serious environmental and resource issues, many researchers have combined environmental problems into the total-factor energy evaluation. Previous studies utilized various input and output indicators to evaluate total-factor energy efficiency.

Desirable outputs of total-factor energy efficiency can be represented by many indicators. The most common measure of nationwide economic performance is GDP. Recent research has discussed the relationship between GDP and energy consumption. Soytas and Sari (2003) found a stationary linear co-integrating relationship between GDP and energy consumption. Reducing per unit GDP energy consumption is a major goal of China's economic development. However, GDP only presents the sum gross values of all residential and institutional units, and is therefore an absolute figure. The present study introduces urbanization rate (defined as the ratio of urban population to total population) to model how this relates to efficiency. According to China Statistical Yearbook, we use the ratio of urban population to the total population to calculate the urbanization rate. Fig. 1 shows the GDP and urbanization rates of Chinese provinces. Due to intensive energy exploitation and usage, China's urbanization rate is growing much faster than ever before. According to data from the DRCNET Statistical Database System, the rate of urbanization has increased by 1.36% (year on year) since 2000. In 2012, China's annual urbanization rate reached 52.57% as a result of rapid growth of the urban economy, increasing population, building density, and improvements to health care, etc. In other words, China's energy demand is rapidly growing during the current urbanization phase (Lin and Ouyang, 2014). Hence, the 16th and 18th Communist Party of China National Congress proposed introducing new strategies for urbanization to achieve sustainable development. These new strategies emphasize intelligence, intensive management of industry, environmental protection, and low-carbon technologies. The core of this new model of urbanization construction is people, as reflected in labor worker's benefits, infrastructure construction, and quality-of-life improvements. There are several ways by which energy usage can promote urbanization. Firstly, energy use can increase production to provide sufficient products, food, etc. to fulfill the needs of the increasingly urban population, which can also facilitate the transport construction between urban areas and rural areas. Secondly, energy-related construction provides a rural employment and creates the conditions for rural development. Thirdly, increasing energy usage provides better infrastructures, which speeds up the urbanization process. A number of studies have examined the relationship between urbanization and energy consumption. However, there are no widely accepted conclusions at an international level. Most studies have found that the significance of the relationship between urbanization and energy consumption varies across regions according to the level of development. Zhang and Lin (2012) found that the effects of urbanization on energy consumption vary across regions, and observed greater consequences in the western region of China. However, most studies agree that there is positive link between urbanization and energy consumption. Jones (1991) indicated that a 10% increase in the proportion of the population living in cities would increase energy consumption per capita by approximately 4.5% of GDP. Li et al. (2011) found that urbanization is one of the main factors affecting China's energy consumption. Shahbaz et al. (2015) found that urbanization is a major contributor to energy consumption in Malaysia. Al-mulali et al. (2013) used dynamic ordinary least square to validate the long-term bi-directional positive relationship between urbanization and consumption; similar results were found by Wang et al. (2014).

There are many kinds of undesirable outputs. The coal consumption in China accounted for approximately 69.8% of the total energy consumption in 2014 and produces massive amounts of CO_2, SO_2, smoke, and dust. Large proportions of industrial and residential wastewater and solid wastes are caused by energy consumption.

In China, there is a stable long-term relationship between energy consumption, GDP and the urbanization level when energy consumption is the dependent variable (Liu, 2009; Ramanathan, 2006). (Wang et al., 2014) pointed out that the relationships between urbanization, energy consumption, and CO_2 emissions are bidirectional and causal, whereas urbanization and energy consumption maintain a one-way positive relationship. In conclusion, China's economy encountered a resource bottleneck because of the cause-and-effect relationship between environmental and urbanization influences.

Table 1 also summarizes various methods of evaluating total-factor energy efficiency. These can be broadly classified as either parametric or non-parametric, both having specific adaptive conditions and application methods. Parametric methods estimate parameters and calculate efficiency by building a production function, such as stochastic frontier analysis (SFA), which is complicated by the need to estimate unknown parameters. SFA models are usually employed when there is a clear

Table 1
Summary of inputs/outputs and methodology of total-factor energy evaluation.

Study	Inputs	Outputs	Method
Jiang and Lin (2012)	Household energy consumption	Residential CO_2 emissions	Gray model
Shahbaz et al. (2015)	Household energy consumption	Residential CO_2 emissions	STIRPAT model
Al-mulali et al. (2012)	Energy consumption	CO_2 emissions	Fully modified ordinary least squares model
Kasman and Duman (2015)	Energy consumption and trade	CO_2 emissions and economic growth	Panel cointegration methods and panel causality tests
Honma and Hu (2008)	Biomass energy, labor, capital stock, energy consumption and total sown areas of farm crops	GDP	Data envelopment analysis (DEA)
Wang et al. (2012a, 2012b)	Energy consumption, average remaining balance of capital assets and average amount of working force	The gross industrial output	Data envelopment analysis (DEA)
(Li and Hu, 2012)	Total energy consumption, capital stock and labor	CO_2 and SO_2	Slack-based model
Zhang and Xie (2015)	The gross product, labor, capital stock and energy consumption	CO_2	Non-radial efficiency model.
Rao et al. (2012)	Labor, capital stock and energy consumption	GDP,	Slack-based model
Li and Shi (2014)	Capital, labor, energy	GDP, wastes	Super-SBM model and the Tobit regression model.
Zhang and Kim (2014)	Capital, labor, energy, turnover of each company	Gas emission	Sequential slack-based efficiency measure model