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Environmental efficiency and energy consumption of highway transportation systems in China

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ABSTRACT

With the rapid development of the Chinese economy and urbanization process, an increasingly large urban transport system has led to increasingly serious resource and environmental problems in China. We combined the super-efficiency slack-based measure model, including undesirable outputs, with the window data envelopment analysis model, which managed panel data, to calculate the environmental efficiencies of highway transportation systems in regions of China. This measured the level of sustainable development in China's highway transportation systems. Furthermore, we calculated the consumption redundancy of gasoline and diesel, and the excess emissions of nitrogen oxides and particulate matter. We analyzed the correlativity among environmental efficiency, nitrogen oxide efficiency, and particulate matter efficiency to research the state of energy consumption and atmospheric pollution on the highway transportation systems in China. The results showed that the overall level of environmental efficiency of highway transportation systems in China was not optimal, with great differences between regions. Most regions had problems with excessive energy consumption and motor vehicle pollution. The Chinese government needs to control both energy consumption and pollutant emissions to manage the environmental problem of atmospheric pollution.

1. Introduction

Since China's reform and opening-up, the Chinese economy has developed rapidly, but energy and environmental problems have developed owing to high energy consumption. This high energy consumption seriously restrains China's economic and social sustainable development. The issues of how to alleviate climate pollution, such as haze, and to guarantee the population's health have become important subjects for the Chinese people and the Chinese economy. The main sources of atmospheric pollution in China are coal and oil. The most important tools to combat haze are energy conservation, emission reduction, energy structure adjustment, and structural reform.

To cope with the change in the global climate, China has reinforced resource conservation and management, strengthened environmental protection, and implemented the "green and low-carbon" initiative in the 12th Five Year Plan for 2011–2015. Recently, its government stated that the main goal of China's economic and social development would be an energy consumption decrease of more than 3.1% and to decrease major pollutants consistently.

To adhere to this new directive, China will have to identify and tackle its environmental issues. Oil-fired pollutants are one of the main sources of atmospheric pollution. Most oil-fired pollutants come from the energy consumption of motor vehicles. With the rapid development of the Chinese economy and urbanization process, larger transport systems have increased the influence of transportation on resources and the environment exponentially. Among the various types of transportation, highway transportation is the largest contributor to resource consumption and environmental pollution. The main resources consumed by highway transportation are land use and energy consumption. Environmental pollution is mainly caused by vehicle emissions of atmospheric pollutants and noise pollution caused by road traffic.

In order to measure the sustainable development of highway transportation systems and further analyze the energy consumption and atmospheric pollution of regions' highway transportation systems, we used the super-efficiency slack-based measure (SBM) model to include undesirable outputs and calculate the environmental efficiency of highway transportation systems in the regions of China. We focused on the problems of energy consumption and pollutant emissions, which are the major problems of highway

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transportation; these are also the most serious threats for atmospheric pollution.

In what follows, we review some of the most relevant literature on the energy and environmental problems of transportation systems in China (Section 2). The indicator selection and data sources are presented in Section 3, and a case study of the environmental efficiency of highway transportation systems in regions of China in Section 4. There is further discussion of the state of energy consumption and pollutant emissions in Section 5, and we draw conclusions in Section 6.

2. Literature review

Issues of sustainable consumption and production have been explored in recent years, and some researchers have identified the major factors for improving consumption and production (Tseung et al., 2013). In the 1990s, scholars from all fields began to pay attention to the energy consumption and environmental pollution of transportation systems.

Regarding the evaluation of environmental pollution, although the number of vehicles in China is not large, as pointed out by Walsh (1999), the pollution caused by transportation cannot be ignored. Some researchers have explored the current status of the road transportation industry and forecast future trends of oil demand and CO_2 emissions in China (He et al., 2005). There are several crucial problems and challenges for the development of Chinese transportation (Zhou and Szyliowicz, 2006). In recent years, more and more attempts have been made to explore the status and tendencies of the transportation industry in China. Hu et al. (2010) indicated that by 2030, the vehicle population in China will be 400 million, and fuel demand will be 350 million tons if the current pattern continues. Measuring sustainable production indicators has been identified as a very important environmental activity (Tseng, 2013). For example, Zhou et al. (2010) researched the effects of temporary transportation control measures on urban motor vehicle emissions during the 2008 Olympic Games in Beijing. The results showed that reasonable traffic system improvement strategies could effectively control total motor vehicle emissions in Beijing after the Olympic Games. Yan and Crookes (2010) presented the current status of China's road transport industry in terms of vehicles, infrastructure, energy use, and emissions and analyzed the implemented mitigation measures and future measures. Zhang et al. (2011) analyzed the current status of transportation energy consumption in China and identified the relationships between transportation energy consumption and its impacted factors.

In order to facilitate change, strong national leadership is required to help integrate accessibility and mobility objectives into the urban development of expanding Chinese cities (Yang and Gakenheimer, 2007). The exergy method of assessing the energy utilization of the transportation industry in China was proposed by Ji and Chen (2006). The exergy method is used to assess the transportation system waste gases CO_2, NO_x, and SO_2 emitted from fossil fuel consumption in China (Ji et al., 2009). Methodologically, the dynamics model is useful in the assessment of passenger transport. By developing a system dynamics model for policy assessment and CO_2 mitigation potential analysis, Han and Hayashi (2008) concluded that the major potential for emissions reduction exists in inter-city passenger transport. Jifeng et al. (2008) used a system dynamics approach to evaluate urban transportation system performance in Dalian, China, concluding that Dalian should restrict the total number of vehicles to improve the sustainability of its transportation systems. Life cycle analysis (LCA) is also a new technique (Yan and Crookes, 2009) used to analyze the energy use and greenhouse gas emissions of road transportation fuels in China. Hence, borrowed quantitative techniques are significant for the analysis of transportation systems. Based on China's 2008 statistical transport data 2008, analyzed the trend of China's multimodal transport markets and provided some policy measures to optimize the operations of China's intercity transport network. A calculation model of transportation energy consumption based on vehicle driving was developed (Shunping et al., 2010) to calculate China's transportation energy consumption level, which was found to be rising. A non-radial SBM model (Chang et al., 2013) was used to analyze the environmental efficiency of China's transportation industry in 2009.

From these quantitative methods, we find that the method of data envelopment analysis (DEA) has been widely applied by many scholars to the assessment of transportation systems. Combined with the Charnes, Cooper, Rhodes (CCR) model and principal component analysis (PCA), DEA has been used to evaluate the performance of the transportation industry of China (Ding et al., 2011). Recently, a revised DEA method was proposed with sensitivity analysis of indexes to evaluate the performance of bus routes within a public transportation system in Beijing and put forward some improvement suggestions (Li et al., 2013). Based on the DEA model, a method of three-stage virtual frontier version was provided to evaluate the transportation energy efficiency in each region of China (Cui and Li, 2014). A non-radial DEA model was combined with multidirectional efficiency analysis (MEA) involving undesirable outputs to measure the energy and environmental efficiency of China's transportation system during the period 2006 to 2010 (Bi et al., 2014).

In addition to the studies mentioned, there is some research using a DEA approach to explore transportation systems in developed regions. The DEA model has been used to analyze the efficiency and partial productivity of European railway freight transportation in European countries during the period 1980–2003 (Hilmola, 2007). A novel slack-based measure network data envelopment analysis (SBM-NDEA) approach has been proposed to measure both the technical efficiency and service effectiveness of airlines (Tavassoli et al., 2014). In addition, the DEA Malmquist productivity index provided significant results when used to measure the productivity growth of transportation industries in the United States (Choi et al., 2015).

We combined the super-efficiency SBM model and the window DEA model to measure the environmental efficiency of highway transportation systems in 30 regions of China and the level of sustainable development in China's highway transportation system; then, we further analyzed the energy consumption and atmospheric pollution of highway transportation systems to provide scientific advice for the sustainable development of highway transportation systems in China. The SBM model can effectively solve the problem of undesirable outputs; further, it can distinguish the efficiency levels of efficient decision-making units (DMUs); the window DEA model can increase the quantity of DMUs and solve problems related to the efficiency evaluation of panel data effectively. We will explore these problems with a super-SBM-window combined model.

This research is different from prior work in four ways that reflect its unique contributions. First, this research focused on highway transportation systems rather than the whole transportation system. Recent research about the environmental efficiency of China's transportation system, like the work of Chang et al. (2013), has focused on China's whole transportation sector, including transport, storage, and post. Recently, the air pollution caused by motor vehicle emissions has become one of the most