



The substitutability of non-fossil energy, potential carbon emission reduction and energy shadow prices in China



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ABSTRACT

The rapidly increasing consumption of energy and fossil fuel dominated energy structure have caused great pressure on energy security and carbon reduction policies in China, and the Chinese government has attempted to substitute fossil with non-fossil energy. To investigate the feasibility of replacing fossil energy with non-fossil energy in China, we apply an input distance function to estimate the substitutability of non-fossil energy for fossil energy and compare shadow prices. The result confirms the feasibility of substituting non-fossil energy for fossil energy. We then divide the non-fossil energy into nuclear energy and renewable energy and find that nuclear energy is more suitable than renewable energy to substitute for fossil energy. The shadow price ratio of non-fossil to fossil energy is 268.41 on average in the study period. The ratio experiences several fluctuations and shows a declining trend at the end of the study period, implying that improving energy structure in China is very promising.

1. Introduction

China has achieved remarkable progress in economic development since the reform and opening-up of the late 1970s. The total gross domestic product (GDP) in China, which is up to 5.88 trillion U.S. dollars, has surpassed that of Japan and ranks second in the world since 2010 (Liu and Raven, 2010; Xie and Wang, 2015a). However, energy consumption is simultaneously rising at an alarming rate. China has actually become the largest energy user and carbon dioxide (CO₂) emitter in recent years (Wang et al., 2016a; Wiedenhofer et al., 2017). As shown in Fig. 1, primary energy consumption had risen drastically from 0.6 billion in 1980 to 4.26 billion tons coal equivalent (tce) in 2014. China has become a net energy import country since 2007, as nearly 60% of crude oil needs are imported from abroad, which has posed a great threat to national energy security (Zhou et al., 2012; Zhang and Wei, 2015). More importantly, as shown in Fig. 2, China's energy structure has been dominated by fossil energy, which accounts for more than 90% of the total energy consumption for most of the last decades. Air pollution has become more and more serious in China because fossil energy produces a large number of environmental pollutants (e.g., carbon dioxide and sulfur dioxide) during combustion. The carbon emission in China is expected to be an astonishing third of the total amount of global carbon emission in recent years (Liu et al.,

2011). Because many countries have come to a consensus to reduce carbon emission in recent world conferences on the environment (e.g., the 15th United Nations Climate Change Conference in Copenhagen), China has been greatly pressured to achieve carbon emission reduction (Wang et al., 2011).

China's central government has long been concerned with issues of energy consumption and environmental pollution (Xie and Wang, 2015b). In 2009, China made a commitment to reduce carbon intensity, which promised that the amount of CO₂ emission per unit of GDP would be reduced by 40–45% from 2005 to 2020. In addition, the Chinese government made an ambitious plan to increase the share of non-fossil energy consumption in primary energy consumption to 15% by 2020 and to 20% by 2030. However, it seems rather difficult to achieve these goals because of the fossil fuel dominated energy structure and relatively low energy use efficiency (Li and Hu, 2012). Because it is difficult to improve energy use technology over a short time, increasing the share of non-fossil energy in energy structure may, therefore, be a better choice (Wu et al., 2006), and investigating whether it is feasible to substitute fossil energy with non-fossil energy is meaningful work to be performed.

Additionally, the price of energy can affect the status of energy allocation in production activities, thus affecting energy use efficiency (Zhang et al., 2016a). However, the price of energy had long been

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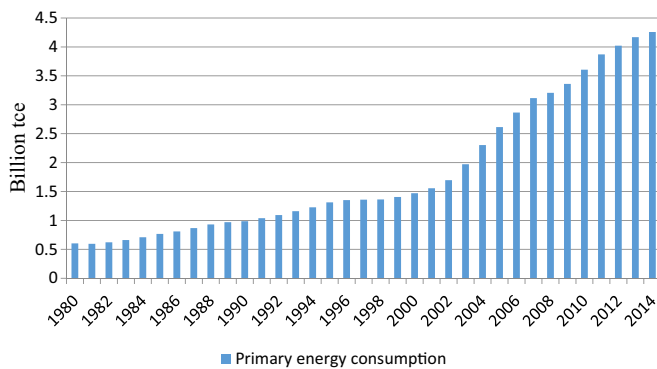


Fig. 1. Primary energy consumption in China, 1980–2014.

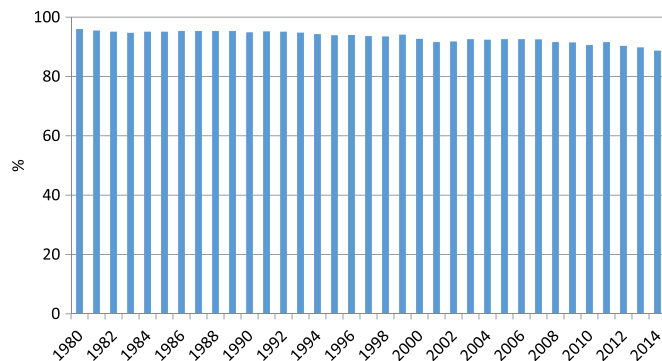


Fig. 2. The proportion of fossil energy consumption accounts for the total energy consumption in China, 1980–2014.

determined by the local governments and the governments tend to lower the price of energy for its own interests (e.g., attracting foreign enterprises), causing low energy use efficiency for a long time in China (Chen et al., 2016). The shadow price of energy can reflect the scarcity of energy, and is closely related to the energy utilization efficiency. More specifically, producers tend to use more energy when the market price of energy is much lower than shadow price of energy, leading to less incentive to raise energy use efficiency (Sheng and Yang, 2014). According to the conclusion of Kumbhakar and Bhattacharyya (1992), a reasonable pricing plays an important role in achieving sustainable energy use, whereas a distorted price would have a significantly negative impact on energy use efficiency. Therefore, calculating shadow price of energy would provide a good guide for determining a reasonable price of energy and raising energy use efficiency.

Based on a wide applied input distance function approach and relevant data, this study aims to calculate energy use efficiency and to explore the feasibility of substituting fossil with non-fossil energy by computing the indirect Morishima elasticity of substitution between fossil and non-fossil energy. Lastly, we calculate the shadow prices of fossil and non-fossil energy and compare their trends over the study period.

Therefore, the following questions are addressed in this study.

- (1) What is the overall status of energy use efficiency in China over the last three decades?
- (2) Is it feasible to substitute non-fossil for fossil energy? If so, is renewable energy or nuclear energy—both belonging to non-fossil energy—more suitable to replace fossil energy?
- (3) What is the overall status of shadow prices of non-fossil energy and fossil energy during the study period? Is the shadow price of non-fossil energy higher or lower than that of fossil energy? What is the trend of the shadow price ratio of non-fossil to fossil energy?

This paper is organized as follows: Section 3 presents the metho-

dology and data, Section 4 shows the empirical results and discussions, and Section 5 concludes with policy implications.

2. Background and literature review

The definition of non-fossil energy discussed in this paper is from the *China Energy Statistics Yearbook*, which clarifies that non-fossil energy consists of nuclear power and renewable power and that renewable power is mainly composed of hydropower, wind power, solar energy, biomass energy, etc. China's electricity consumption has been growing at an alarming rate. Electric power generated by fossil fuel accounts for nearly half of coal consumption and CO₂ emission from fossil fuel combustion in 2010, which shows an increasing trend in the near future (Zhang et al., 2014, 2016b). In contrast, renewable energy does not produce pollutants, and nuclear energy generates much fewer pollutants than fossil energy does (Lee and Jin, 2012). Thus, encouraging non-fossil energy consumption, especially in the power sector, would undoubtedly help reduce carbon emission and ensure energy security. In recent years, many policies aiming at encouraging the use of non-fossil energy consumption and substantially reducing the use of fossil energy have been introduced. Consequently, due to the strong support of the Chinese government, the proportion of non-fossil energy in primary energy consumption has risen from 4.17% in 1980 to approximately 11% in 2014, which indicates an obvious expansion of non-fossil energy consumption. There is hope to achieve this goal.

Today, non-fossil energy has played an important role in energy supply in China, especially in the electricity generation sector. The installed capacity and power generation of power plants using non-fossil energy are as high as 455.6 GW and 1417 billion kW h in 2014, respectively. The total power generation accounts for a quarter of national power generation in China.¹ In particular, power generated by hydropower accounts for more than half of the total power generated from non-fossil energy over the study period in China, and it is estimated that the totals of installed capacity and power generation are approximately 302 GW and 1064 billion kW h in 2014, respectively, and both of them rank first in the world. In contrast, the share of hydropower in non-fossil energy consumption shows a slight decrease in trends in recent years, which may be due to the vigorous development of nuclear and solar energy and some other types of non-fossil energy, e.g., wind and biomass energy. More importantly, some people doubted that the large-scale construction of hydropower stations is a major reason for the frequent earthquakes, especially in the western provinces of China (e.g., Sichuan and Hubei provinces). Additionally, hydropower stations seemed to be responsible for the reduction of water species and land desertification in surrounding areas (Chen et al., 2014). In contrast, nuclear power is gaining more popularity. More than 10 nuclear power plants have been put into operation in the past two decades due to strong support from the central government; the totals of installed capacity and power generating capacity are 19.9 GW and 132.5 billion kW h in 2014, respectively. In addition, some other types of non-fossil energy, such as wind, solar, biogas and biomass energy are also growing very fast as follows: the power generating capacities of these forms of renewable energy in 2014 are 153.4, 25.2, 91.2 and 41.7 billion kW h.

There are many studies to support the substitution of non-fossil for fossil energy. Zhou and Zhang (2010) showed that thermal power, which heavily relied on coal, had caused acid rain and haze weather in almost all of the provinces in China. The pollution problem has already posed a great threat to people's health; therefore, increasing the share of non-fossil energy consumption was undoubtedly a good counter-

¹ National Energy Administration of China, 2015. Handbook of renewable energy data. (Online). Available: <http://www.cnrec.org.cn/cbw/zh/2015-10-23-488.html> (in Chinese).

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