Energy-saving and emission-abatement potential of Chinese coal-fired power enterprise: A non-parametric analysis

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A B S T R A C T
In the context of soaring demand for electricity, mitigating and controlling greenhouse gas emissions is a great challenge for China's power sector. Increasing attention has been placed on the evaluation of energy efficiency and CO2 abatement potential in the power sector. However, studies at the micro-level are relatively rare due to serious data limitations. This study uses the 2004 and 2008 Census data of Zhejiang province to construct a non-parametric frontier in order to assess the abatement space of energy and associated CO2 emission from China's coal-fired power enterprises. A Weighted Russell Directional Distance Function (WRDDF) is applied to construct an energy-saving potential index and a CO2 emission-abatement potential index. Both indicators depict the inefficiency level in terms of energy utilization and CO2 emissions of electric power plants. Our results show a substantial variation of energy-saving potential and CO2 abatement potential among enterprises. We find that large power enterprises are less efficient in 2004, but become more efficient than smaller enterprises in 2008. State-owned enterprises (SOE) are not significantly different in 2008 from 2004, but perform better than their non-SOE counterparts in 2008. This change in performance for large enterprises and SOE might be driven by the "top-1000 Enterprise Energy Conservation Action" that was implemented in 2006.

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1 These nine sectors include: iron and steel, chemical, electricity power generation, petroleum, construction materials, non-ferrous metals, coal mining, paper, textile.

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the top-1000 enterprises reached its target at the end of 2008. However, the cost-effectiveness of the program is unclear. There exists neither a bottom-up analysis nor an evaluation of energy-saving and emission-reduction potentials at the enterprise level in China (Price et al., 2011; WorldBank, 2009). Hence, the distribution of energy-savings and emission-abatement potential among large enterprises or SOEs is unknown.

Given this background, one question we are interested in is whether a large power enterprise has greater energy-saving potential and associated CO₂ abatement potential than a smaller enterprise. The existing literature does not provide a clear linkage between firm size and energy (inefficiency). On the one hand, large firms can benefit from economies of scale and the formalization of procedures, which allow them to gain superior performance relative to smaller ones. On the other hand, large firms might be characterized by complex hierarchical management structures, failure to minimize production costs and lack of competition, which lead to X-inefficiency (Leibenstein, 1975). Empirical studies are also equivocal. For example, some studies support a positive relationship between efficiency and firm size (Kalaitzandonakes et al., 1992; Lundvall and Battese, 2000; Pagano and Schivardi, 2003). Contrarily, Page (1984) finds little evidence of a systematic relationship between firm size and efficiency. Majumdar (1997) offers the opposite evidence and finds larger firms to be less productive than small ones.

As for ownership, the debate on relative efficiency of public versus private enterprises also has a long history in economics. The property rights view suggests that publicly owned enterprises perform less efficiently than privately owned enterprises since the public ownership attenuates property rights and reduces the manager’s incentive to minimize costs. Consequently, state-owned enterprises (SOE) perform less efficiently and hence have a higher abatement potential than private firms. However, the existing empirical evidence provides weak support for this hypothesis. For example, Atkinson and Halvorsen (1986) find no significant difference between publicly and privately owned electric utilities in the U.S.

Given the crucial role that the power sector plays in climate change mitigation and the debates on current practices, several important questions naturally arise: How large are coal-fired power enterprises’ reduction potential of energy usage and associated CO₂ emission in China? Are these potentials associated with enterprise scale and ownership? This paper attempts to respond to these questions by analyzing data from coal-fired power enterprises in China’s Zhejiang province of the years 2004 and 2008. Since the energy-saving regulation for these enterprises was implemented in 2006, this unique firm-level data also provides an opportunity to examine whether the energy reduction potential and its associated CO₂ abatement potential changed.

The non-parametric approach of data envelopment analysis (DEA) has been widely used in the literature. A key advantage of DEA over other approaches is that it does not need a specific pre-assumed functional form and can easily accommodate both multiple inputs and multiple outputs. This technique has been applied to evaluate, e.g., the relative energy and environmental efficiency of U.S. power plants (Färe et al., 1989, 2007; Pasurka, 2006; Tyteca, 1997). Zhou et al. (2008) and Zhang and Choi (2014) provide a comprehensive overview on the use of DEA model in energy and environmental studies. Recently, DEA has been used with increasing frequency in studies of the Chinese power sector: Choi et al. (2012) apply a non-radial slacks-based DEA model to estimate the energy efficiency and shadow price of energy-related CO₂ emissions at the province level for the period 2001 to 2010. Xie et al. (2012) use a two-stage network DEA model to evaluate the provincial environmental performance in China and explore the linkage between the environmental efficiency and generation forms. Yang and Pollitt (2009) apply three multiplicative DEA models to 582 Chinese coal-fired power plants in 2002 to gauge their environmental performance. They also employ an unbalanced panel of 796 power plants during 1996–2002 to calculate the Malmquist TFP indices (Yang and Pollitt, 2012). Using an output-oriented DEA technique, Zhao and Ma (2013) estimate the technical and scale efficiency score of 34 power plants during 1997–2010 and then examine the impact of deregulation on performance.

Apart from these previous studies, this paper applies the non-radial Weighted Russell directional distance function approach to measure the energy-saving potential index and CO₂ emission-abatement potential index for coal-fired power enterprises in 2004 and 2008. This approach is first developed by Chen et al. (2011) which mirrors the strategy employed by Chung et al. (1997) and extended the work of Fukuyama and Weber (2009). It recently has been applied for Japanese banks (Barros et al., 2012), Indian banks (Fuji et al., 2014) and Korean power plants (Zhang et al., 2013). One advantage of this methodology is that it provides the specific-factor efficiency (such as energy efficiency and CO₂ emission efficiency) in addition to the overall efficiency score in the radial directional distance function (DDF) model (Sueyoshi and Goto, 2011). Moreover, it can avoid the overestimation the efficiency value as it takes account the nonzero slacks, which are ignored in the

![Fig. 1. Power generation and installed capacity in Zhejiang (2002–2009).
Source: The power generation data is taken from the China Energy Statistical Yearbook (NBS, 2009); the installed capacity data is taken from the White Paper of Energy in Zhejiang (Zhejiang Province Economic and Information Commission and Zhejiang Provincial Bureau of Statistics, 2011).](image-url)
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