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Improving air pollution control policy in China—A perspective based on cost–benefit analysis

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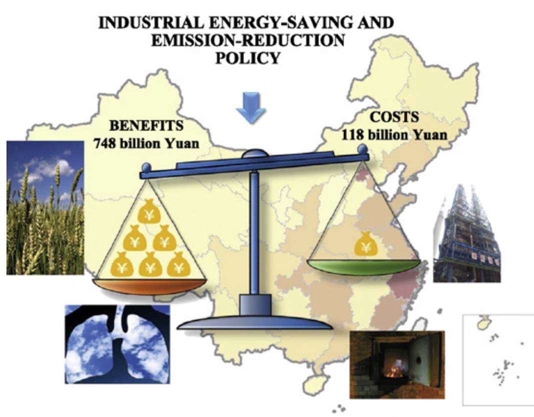
HIGHLIGHTS

- We conduct a cost-benefit analysis of the industrial energy-saving and emission-reduction policies.
- These policies are economically feasible and the estimated benefit-cost ratio is 6.32.
- The emission-reduction potential of energy-saving policy is greater than that of emission-reduction policy.
- There is a regional disparity of the benefit-cost ratios of implementing these policies.

GRAPHICAL ABSTRACT



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ABSTRACT

To mitigate serious air pollution, the State Council of China promulgated the *Air Pollution Prevention and Control Action Plan* in 2013. To verify the feasibility and validity of industrial energy-saving and emission-reduction policies in the action plan, we conducted a cost–benefit analysis of implementing these policies in 31 provinces for the period of 2013 to 2017. We also completed a scenario analysis in this study to assess the cost-effectiveness of different measures within the energy-saving and the emission-reduction policies individually. The data were derived from field surveys, statistical yearbooks, government documents, and published literatures. The results show that total cost and total benefit are 118.39 and 748.15 billion Yuan, respectively, and the estimated benefit–cost ratio is 6.32 in the S3 scenario. For all the scenarios, these policies are cost-effective and the eastern region has higher satisfactory values. Furthermore, the end-of-pipe scenario has greater emission reduction potential than energy-saving scenario. We also found that gross domestic product and population are significantly correlated with the benefit–cost ratio value through the regression analysis of selected possible influencing factors. The sensitivity analysis demonstrates that benefit–cost ratio value is more sensitive to unit emission-reduction cost, unit subsidy, growth rate of gross domestic product, and discount rate among all the parameters. Compared with other provinces, the benefit–cost ratios of Beijing and Tianjin are more sensitive to changes of unit subsidy

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than unit emission-reduction cost. These findings may have significant implications for improving China's air pollution prevention policy.

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1. Introduction

With decades of rapid economic growth, high energy consumption and high emission has been the characteristics of China's economic development and the development pattern has become unsustainable. Although the government has realized the problem and promulgated a series of energy-saving and emission-reduction policies with strict and explicit targets in the Five-Year plans (SEPA, 2002; SEPA, 2007; SEPA, 2011), the consequences are still barely of satisfactory or even worse. It has been reported that in the year of 2012, less than 1% of the 500 large cities in China reached World Health Organization's recommended air quality standards. Suspended particulate matter (especially PM_{10}) has become the primary air pollutant (Zhang and Crooks, 2012). In more than half of the cities, the concentration of suspended particulate matter has exceeded the national standards (SEPA, 2014).

To mitigate the intensive air pollution, the State Council promulgated the *Air Pollution Prevention and Control Action Plan* (hereinafter referred as the action plan) in 2013 (China State Council, 2013). Within the action plan, there are a host of important measures and targets in a 5-year period (2013–2017). The measures are mainly enhanced energy-saving and emission-reduction approaches, as energy conservation and emission mitigation are still the key aspect for China to address air pollution. Fulfilling these targets with relevant supporting policies is the core work of the central and local governments for the planned period. However, are these schemes cost-effective? Specifically, mitigating air pollution can results in the conservation of human health and crop yields, but is associated with additional costs. Hence, this study seeks to examine whether the implementation costs could be balanced with the social benefits of the energy-saving (ES) and emission-reduction (ER) policies in this action plan.

Different methodologies are available to evaluate air pollution prevention policies, such as: cost-effective analysis (CEA) (Atkinson and Lewis, 1974; Fronza and Melli, 1984; O'ryan, 1996), multi-objective nonlinear approach (Carnevale et al., 2012) and multi-criteria approach (Vlachokostas et al., 2011). These approaches are devoted to finding the most optimal and effective policy with the target, while they rarely evaluate the costs and benefits of these policies comprehensively. Compared with these methodologies, cost–benefit analysis (CBA) is a widespread tool to support decision-making that focuses on economic trade-offs by balancing the benefits of a policy against its direct implementation costs (Hanley and Spash, 1993).Since the 1970s, CBA of the environmental aspects of policy-making have received increasing attention (Hanley and Spash, 1993). Subsequently, some countries and organizations have begun to evaluate native air pollution prevention policies using CBA (USEPA, 2007; Congress, 1997; USEPA, 1999; Watkiss et al., 2005). These studies calculated the cost–benefit ratios to verify if policies were economically feasible without concerning the cost-effectiveness of specific measures within policies, which could not help policy-makers to improve the policies. Furthermore, some studies quantified the costs and benefits at the national level without consideration of regional disparities of the policy implementations. (Cao et al., 2009; Hongxiang et al., 2013).

Hence, we calculated the costs and the associated environmental and social gains of implementing the *Air Pollution Prevention and Control Action Plan* in China for 31 provinces, with consideration of the implementation of industrial ES and ER policies. We can both observe and interpret the disparity of costs and benefits in implementing the ES and ER policies and explore the opportunities of improving the cost-effectiveness of the ES and ER policies. Based on above, we quantified the benefit–cost ratios (BCRs) at the national level with the bottom-up concept, which helps us confirm whether the policy is economically feasible.

2. Methods and data

In this paper, the effects of two main policies within ES-ER policy were analyzed: energy-saving (ES) policy and emission-reduction (ER) policy. As shown in Table S1, ES policy aims to reduce the energy consumption so as to mitigate air emissions, while ER policy targets emission control by means of improving the end-of-pipe systems. ES policy involves the conservation of various types of energy i.e., coal, oil, natural gas and electricity. Since coal is primary energy consumed in industrial sector in China (Su et al., 2015), we quantified coal savings only in this study.

To reasonably assess the impact of the ES-ER policy, we used Price's approach to create a "counterfactual baseline" (Price et al., 2011), which can only be estimated in an absence of these policies. As a consequence, four scenarios were created: business as usual (BAU), energy-saving (ES), end-of-pipe treatment (EOP) and integrated policies (INP). In the BAU scenario, no additional ES policy and ER policy were considered. The economic structure, energy intensity, emission factors and technologies were assumed to remain constant (frozen) from the baseline year 2012. In the ES scenario, new energy saving targets and measures were posited, i.e., changes in coal burning and the elimination of small coal-fired boilers and backward productivity according to planned targets of the action plan, but without the application of the other new emission mitigation policies. In the EOP scenario, new emission-reduction targets and end-of-pipe technology improvements according to planned targets of the action plan were posited, without the application of the other new ES policy. In the INP scenario, integrated ES and ER policies were asserted, and it was assumed that all of the targets could be fulfilled after strictly applying those policies. For all the scenarios, we set 2012 as the baseline year.

Based on the policy analysis and scenarios assumptions above, we conducted a CBA of ER and ES policies. A decision support diagram is presented in Fig.1 to illustrate the methods in detail.

2.1. Cost–benefit analysis

In a CBA, all of the considered costs and effects are included in a monetized way. The annual flows of costs (C_t) and benefits (B_t) at a time t are discounted to their present values using a discount rate r over the period of time n during which the relevant effects of an investment become apparent. The core elements of a cost–benefit analysis are formulae (1) and (2), which provide the net present value (NPV) and the benefit–cost ratio (BCR) of a policy (Armstrong and Taylor, 2000; Hanley and Spash, 1993):

$$NPV = \sum_{t=0}^{n} B_t(1+r)^{-t} - \sum_{t=0}^{n} C_t(1+r)^{-t} \tag{1}$$

$$BCR = \sum_{t=0}^{n} B_t(1+r)^{-t} / \sum_{t=0}^{n} C_t(1+r)^{-t}. \tag{2}$$

The decision rule postulates that the investment is economically justified and the relevant policy should be effective if it provides a $NPV > 0$ or a $BCR > 1$ (Hanley et al., 2009). We used NPV to judge the feasibility of

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