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Impact analysis of the implementation of cleaner production for achieving the low-carbon transition for SMEs in the Inner Mongolian coal industry

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ABSTRACT

At present, carbon emissions produced by coal consumption have raised concerns around the world, but the carbon emissions associated with coal production should also be considered. As China's second-largest province for coal production, it is of extreme importance around the whole country for small and medium-sized coal enterprises in Inner Mongolia to achieve low-carbon transition.

In this paper, we apply the IPAT equation to analyze the relationships among environmental impact, population, affluence and technology. The results of the analysis show that technological innovation can make an environmental impact or can cause pollutant emissions of a unit GDP to decline. Technological innovation is viewed as an avenue for environmental improvement, and corporate entities are key players in the environmental improvement. This equation can also be used indirectly on the micro-scale, for example, to determine the directions of development of enterprises and encourage the enterprises to achieve low-carbon transition as soon as possible. Selecting the example of a surface coal mine in Inner Mongolia (China) under the framework of cleaner production and the theory of inventive problem solving (TRIZ), cleaner production options helping to reduce carbon emissions were proposed and implemented. Through the implementation of the options, carbon emissions of the coal mine were reduced by approximately 4%. Contributing cleaner production options for reducing carbon emissions mainly include increasing the efficiency of energy usage, substitution of environmentally friendly materials, optimization of process controls and changing process technologies. The results obtained in this paper can not only provide a decision-making foundation for the local governments when they invest in carbon reduction projects but also play an exemplary role for other similar enterprises to reduce carbon emissions.

1. Introduction

Global Warming Potential (GWP) for carbon dioxide (CO_2) is lower than the GWP corresponding to other greenhouse gases (GHGs). However, due to large emissions and many emission sources, CO_2 has the greatest impact on global climate change (Kyoto Protocol, 1997). Because of the pressures of climate change, the Chinese government has required that from 2014 to 2015, carbon dioxide emissions of the unit GDP drop more than 4% and 3.5%, respectively, each year (Action Plan on Energy Conservation, Emissions Reduction and Low Carbon Development for 2014–2015, 2014). Cleaner production has been a bridge connecting industrialization and sustainability, and cleaner production has also been a technology promoter (Geiser, 2001).

Cleaner production is one of the main means of achieving energy savings and emissions reduction, and cleaner production audit is an important prerequisite for the implementation of cleaner production. Cleaner production can reduce industrial waste and emissions by increasing the efficiency of the use of materials and energy (Fresner et al., 2010). At present, most Chinese coal enterprises focus on the reduction of sulfur dioxide and dust, excluding carbon dioxide because carbon dioxide has not been listed as one of the assessment projects for total pollutant emissions and routine monitoring.

At present, carbon emissions produced by coal consumption have raised concerns around the world, but the carbon emissions

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associated with coal production should also be considered. Five mining areas in China were assessed for their drainage gas and ventilation air characteristics, and the amount of methane being emitted from the mine sites was quantified (Su et al., 2011). According to the analysis of the energy consumption structure and the by-product emissions associated with coal mining, a calculation formula for the coal production enterprises was proposed (Zhu et al., 2012). Carbon and ecological footprints were used as tools for determining the relative importance of ventilation mine air emissions on overall coal mining activity (Díaz et al., 2012). Applying the whole life cycle analysis method, carbon emissions for the coal and power industry chain were calculated in China (Liu and Wang, 2013). On the basis of comprehensively analyzing the constitution of the GHGs emitted at a surface coal mine, the corresponding calculation model of carbon emissions was established (Cai and Liu, 2012; Liu and Cai, 2012). Taking the typically large-scale surface coal mines of China as an example, the carbon emission level of different mining technologies was analyzed (Zhang, 2013). A new method of estimating fugitive gas emissions from surface coal mining was proposed (Saghafi, 2012; Ju et al., 2016). The research on carbon emissions from coal mines mostly focused on the construction of calculation models and methods.

According to the statistics associated with coal in 2014, for underground coal mines, the large-size enterprises accounted for 10%, and small and medium-sized enterprises (SMEs) accounted for 90%. For surface coal mines, the large-size enterprises accounted for 8%, and small and medium-sized enterprises (SMEs) accounted for 92% in China. As the second-largest province of China for coal production, it is extremely important around the whole country that small and medium-sized coal enterprises of Inner Mongolia achieve low-carbon transition.

To achieve the low-carbon transformation of coal enterprises, it is necessary to investigate influencing factors, causes, and control methods for carbon emissions associated with the production process. In this study, on the basis of the IPAT equation, the relationships among environmental impact, population, affluence and technology were analyzed on the macro-scale. Considering that the level of management of many SMEs is usually not high in the Inner Mongolian coal industry, surface coal mines are one of the major contributors to carbon emissions in the area of coal production, and a surface coal mine was selected for a case study. Under the framework of the strategies of cleaner production and the theory of inventive problem solving (TRIZ), cleaner production options for helping to reduce carbon emissions were proposed and implemented. Meanwhile, the amount of carbon emissions before and after implementing the options was compared. Finally, contributing options for reducing carbon emissions were screened. The research framework is shown in Fig. 1.

2. The strategies of cleaner production and its theoretical basis

2.1. The IPAT equation

In the early 1970s, Ehrlich and Holdren first proposed the use of the IPAT equation. This equation represents environmental impact (I) as the product of three variables: (1) population, (P); (2) affluence, (A); and (3) technology, (T). The equation can be expressed as follows (Chertow, 2000):

$$I = PAT \tag{1}$$

In Eq. (1), "I" indicates environmental impact, "P" indicates population, "A" indicates affluence, and "T" indicates technology. Among the three variables of Eq. (1), the third term, "technology", is the greatest hope for achieving sustainable development, and changing this term is the central tenet in industrial ecology (Graedel and Allenby, 1995). In practice, technological variables often seem easier to manage than human behavior (Chertow, 2000).

Industrial ecology adopted an IPAT variant as its "master equation" (Graedel and Allenby, 1995):

$$\text{Environmental impact} = \text{Population} \times \frac{\text{GDP}}{\text{Person}} \times \frac{\text{Environmental impact}}{\text{unit of per capita GDP}} \tag{2}$$

Eq. (2) can also be expressed as:

$$I = P \cdot \frac{GDP}{P} \cdot \frac{I}{GDP} \tag{3}$$

In Eq. (3), $\frac{GDP}{P}$ indicates gross domestic product (GDP) per person, and $\frac{I}{GDP}$ indicates environmental impact per unit of GDP.

The driving force of environmental impact by the IPAT equation is clear at a glance. The IPAT equation can provide a theoretical reference for improving the ecological environment and reducing the environmental load. Environmental impact (mainly including resource consumption and environmental pollution) is concerned not only with the population but also with social wealth and technological development. Environmental impact increases as the population, affluence or technology increases, or if one factor increases faster than another one declines. In many cases, population and affluence can be balanced by improvements to the environment offered by technological systems (Chertow, 2000). The more science and technology develop, material consumption and pollution emissions per unit of economic output can be reduced, and the smaller the environmental impacts are.

The IPAT equation is used in research related to climate change, generally in energy-related carbon emission studies (Chertow, 2000). Eq. (3) can also be expressed as seen below:

$$CO_2 \text{ emissions} = P \cdot \frac{GDP}{P} \cdot \frac{CO_2}{GDP} \tag{4}$$

This equation is the basis for calculations, projections, and scenarios of greenhouse gases, and in this way, IPAT has played a prominent role in the Intergovernmental Panel on Climate Change (1996) (Chertow, 2000; Nakićenović, 2004). Liang Chen et al. designed four scenarios of CO_2 emissions for forecasting and analyzing the variation in CO_2 emissions in China from 2008 to 2020 based on a modified IPAT model. The paper then gives four paths for low-carbon transformation in China: technological innovation, industrial structure optimization, energy structure optimization and policy guidance.

The IPAT equation is suitable for macro-scale assessment. Regional and local scale assessments generally highlight other drivers for environmental changes such as policy, institutions, and complexity of social factors (Turner, 1996).

The coordinated development among the economy, environment and society is the main goal of sustainable development. Accompanied by economic and social development, a low environmental impact should be produced. Based on this target, the following two scenarios have been set.

Scenario 1: The target is that environmental impact (I) remains constant, assuming that the population (P) and per capita GDP increase, which will cause the unit environmental impact (T) to decline (Table 1).

Scenario 2: The target is that environmental impact (I) decreases, assuming that the population (P) and per capita GDP