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Research article

Uncertainty analysis of industrial energy conservation management in China's iron and steel industry

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ABSTRACT

There are remarkable uncertainty factors in the industrial sector that enhance the difficulties of setting energy conservation strategies, such as the macro economy, industrial structures, and technical uncertainties. However, current studies simply predict the possible trends or conduct scenario analyses, and neglect uncertainty factors in the management of industrial energy conservation. In response, this article considers China's iron and steel industry as an example and builds the Industrial Energy Conservation Uncertainty Analysis (IECUA) model to recognize and analyze the uncertainty factors via a 200-thousand-time Latin hypercube sampling. Then, we propose some management measures, including setting energy conservation targets and energy conservation strategies. The results show that energy conservation targets should be more flexible than just the predicted values, to enhance the feasibility of their realization. In addition, energy conservation strategies are set at industrial and technique levels. On the one hand, such key parameters as production output, the coke/steel ratio, and pig iron/steel ratio, should be strictly controlled to avoid non-compliance risks. On the other hand, energy conservation technologies can be considered under four quadrants depending on their sensitivity to energy conservation and economic efficiency. Finally, some differentiated technologies promotion suggestions are made, such as economic stimulation, market entry standards and technical application guidelines.

1. Introduction

With its rapid growth in recent decades, the industrial sector has sparked extensive concerns over energy conservation (Ouyang and Lin, 2015). Meanwhile, a variety of factors influence industrial production processes, creating significant uncertainties in energy consumption. First, changes in the macro economic situation may influence the price of energy and the industrial product, which introduces *external uncertainty* (Kinias et al., 2017). Second, there are fluctuations in industrial structure prediction, which causes *industrial uncertainty* (Wen et al., 2016). Third, that differences may occur between the simulation of technology systems attached to an industry and their actual performance, creates *technical parameter uncertainty* (Arens et al., 2012). Due to these three types of uncertainties, the energy consumption of the industrial sector is highly sensitive to a diversity of factors, making it difficult to forecast accurately.

A general definition of uncertainty is the departure from an ideal and completely determined system due to a lack of information or inherent variability (Walker et al., 2003). All sources of uncertainty present in the system significantly affect the final output after propagation in a specific way (Refsgaard et al., 2007). Therefore, uncertainty factors should be considered to ensure a comprehensive result — the distribution of the probability-weighted outputs rather than a single one (Baustert and Benetto, 2017). In the field of industrial energy conservation, it is very important to conduct uncertainty analyses to enhance the reliability of the chosen strategies.

Nevertheless, most current studies related to industrial energy conservation management neglect uncertainty factors. One traditional method is to predict the development trend of the industry (Schulze et al., 2016). These works forecast the energy conservation potential of a concrete industry and recognize the effective strategies used to improve energy efficiency. However, the key problem is that the result of a singular projection may not match reality because of the deep uncertainties involved, so the validity of the outcome cannot be

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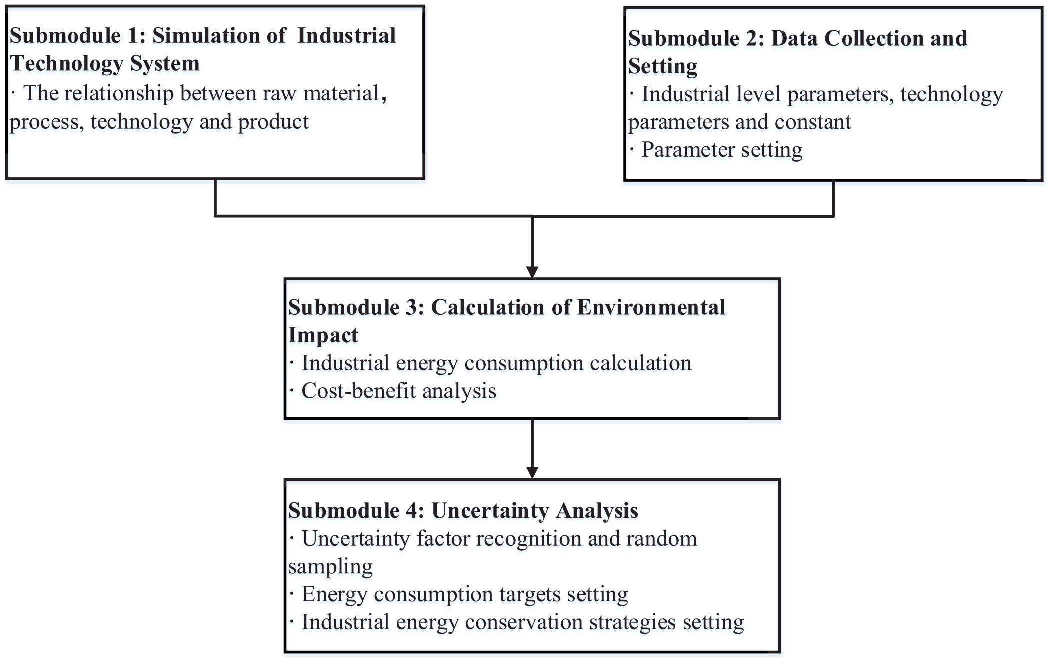

Fig. 1. Structure of the IECUA model.

guaranteed. A common approach to avoid this is called *scenario analysis* (DeCarolis et al., 2016), in which each scenario, based on some exogenous assumptions, corresponds to a specific way the future will unfold. In using this method, some studies (Huang et al., 2017; Lin and Xie, 2015; Murphy et al., 2015; Peng et al., 2015; Wen et al., 2015; Zhang et al., 2017) set a series of scenarios to forecast the possible trends of a specific industry, and propose different energy conservation strategies. However, regardless of the improvement from single prediction, scenario analysis also has some clear drawbacks. First, limited scenarios cannot contain the probabilities exhaustively, so the separated forecasts are insufficient, which is similar with single prediction. In addition, the process of setting the scenarios involves some subjectivity, which may cause inaccuracies in the forecast due to cognitive biases (Morgan and Keith, 2008). Therefore, the theoretical results of these studies may differ significantly from the actual situations, which undermines the targeted energy conservation strategies and enhances energy management risks.

Many present studies focus on uncertainty analysis in the field of energy conservation. However, most analyze the uncertainty of energy assessment models, such as the building energy model (Almeida et al., 2015; Gaetani et al., 2016; Kim, 2016; Sun et al., 2014; Tian, 2013), energy system planning model (Abdullah et al., 2015; Liu et al., 2014; Seljom and Tomasgard, 2015), and renewable energy application model (Maleki et al., 2016; Ritzenhofen and Spinler, 2016). In these researches, uncertainty analysis is conducted through random sampling to cover the full fluctuation range of the key uncertainty factors. However, these methods have rarely been used to energy conservation management in industrial sector.

Therefore, to fill the research gap, this article introduces uncertainty analysis into industrial energy conservation management via random sampling. We build an Industrial Energy Conservation Uncertainty Analysis (IECUA) model, which recognizes the main uncertainty factors and quantitatively assess their impact on industrial energy conservation. The results can provide references for industrial energy conservation management and planning to avoid the uncertainty risks.

Through rapid and steady development, the iron and steel industry has become a leader of China's industrial sector, with the production of crude steel reaching 803.8 million tons in 2015–91.8% higher than 2006 - making up 49.6% of the world's total output (CISA, 2016; World Steel Association, 2016). At the same time, the iron and steel industry is the country's primary energy consumer (Hasanbeigi et al., 2013), consuming 460 million tons of standard coal in 2015, or 10.7% of China's total energy consumption (NBSPRC, 2016). Though having decreased slightly, the demand for steel will be maintained at a high level over the next few years. In addition, such complex uncertainty factors as the fluctuation of industrial scale, raw materials, and products structure as well as technical applications, will significantly influence the industry's energy conservation strategies. Therefore, the iron and steel industry is selected as our case industry.

To date, China has unveiled a series of policies to strengthen the iron and steel industry's energy conservation. These policies can be divided into two aspects. The first is the setting of energy consumption targets, such as total energy consumption and energy intensity, while the second aspect is one of taking energy conservation measures, such as adjustments to raw material and product structures and promotion of technology (MIIT, 2011, 2016). These policies provide the main orientation of our research, where we utilize the model to analyze the uncertainty factors and make suggestions for energy conservation strategies in China's iron and steel industry.

This paper is divided into four sections. Following this introduction, Section 2 introduces the IECUA model, including technology simulation, data acquisition, and the basic uncertainty analysis method. Section 3 provides the results of the uncertainty analysis of China's iron and steel industry in terms of target setting and discusses the energy management path at both industrial and technical levels. Section 4 contains the conclusion of the research and some suggestions for improving energy management in the future.

2. Material and methods

2.1. Industrial Energy Conservation Uncertainty Analysis model

Fig. 1 illustrates the components of the IECUA model, consisting of four submodules: simulation of the industrial technology system, data collection and setting, environmental impact calculation, and uncertainty analysis.

Submodule 1 describes the relationships between the raw materials, process, products, and technologies to simulate the productive process