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Energy saving analysis and management modeling based on index decomposition analysis integrated energy saving potential method: Application to complex chemical processes

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ABSTRACT

Energy saving and management of complex chemical processes play a crucial role in the sustainable development procedure. In order to analyze the effect of the technology, management level, and production structure having on energy efficiency and energy saving potential, this paper proposed a novel integrated framework that combines index decomposition analysis (IDA) with energy saving potential method. The IDA method can obtain the level of energy activity, energy hierarchy and energy intensity effectively based on data-drive to reflect the impact of energy usage. The energy saving potential method can verify the correctness of the improvement direction proposed by the IDA method. Meanwhile, energy efficiency improvement, energy consumption reduction and energy savings can be visually discovered by the proposed framework. The demonstration analysis of ethylene production has verified the practicality of the proposed method. Moreover, we can obtain the corresponding improvement for the ethylene production based on the demonstration analysis. The energy efficiency index and the energy saving potential of these worst months can be increased by 6.7% and 7.4%, respectively. And the carbon emissions can be reduced by 7.4–8.2%.

1. Introduction

Nowadays, environmental protection and energy-saving emission reduction has become the theme of society. The industrialization of a country is mainly affected by the chemical productivity, especially the ethylene productivity of complex chemical industries. The present demand for the ethylene production is over 155 million tons per year and is still growing [1,2]. In 2014, the ethylene production of China Petrochemical Corporation and China National Petroleum Corporation was 10,420 kt/a and 4976 kt/a, respectively. However, the average fuel and power consumption was 571.39 kg per ton of ethylene [3] and 616.7 kg per ton of ethylene [4], respectively. Thus the energy efficiency level of ethylene production is far lower than the international advanced level in chemical industry [5] or petroleum industry [6]. Moreover, more than 50% of the ethylene plants operating costs come from the cost of energy consumption of ethylene [7]. Therefore, energy saving analysis and management is an effective way to improve the productivity and energy efficiency of ethylene productivity. Meanwhile, reducing the carbon emissions of the ethylene industry has great significance to the energy saving and emission reduction of the whole society [8,9].

Therefore, we put forward an integrated framework which combines the IDA of energy performance with energy-saving potential analysis. The IDA method can obtain the level of energy activity, energy hierarchy and energy intensity effectively based on data-drive to reflect the impact of energy usage. The energy-saving potential method can verify the correctness of the improvement direction proposed by the IDA method. Meanwhile, energy efficiency improvement, energy consumption reduction and energy savings can be visually discovered by the proposed framework. In addition, this method is applied to analyze and manage energy-saving of the ethylene production process. The results of case study show the effectiveness and practicability of this method. In our experiment, the worst energy efficiency index can be increased by 6.7%, and the worst energy-saving potential can be increased by 7.4%.

Our recent work is shown as followed. Section 2 introduces the related work and Section 3 introduces the IDA method and the energy-saving potential method in detail. Then, Section 3 describes

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Symbols

SEC	synthesize energy consumption
IDA	index decomposition analysis
EEI	energy efficiency index
EPI	energy performance index
ES	energy saving
EH	energy hierarchy
P	energy saving potential
EEI_*avg*	energy efficiency index based on the average value of last year
EEI_*min*	energy efficiency index based on the minimum value of last year
EEI_*navg*	energy efficiency index based on the average value of the nearest months
EEI_*nmin*	energy efficiency index based on the minimum value of the nearest months
EEI_*assign*	energy efficiency index based on the assign value of the assign month
EPI_*avg*	energy performance index based on the average value of last year
EPI_*min*	energy performance index based on the minimum value of last year
EPI_*navg*	energy performance index based on the average value of the nearest months
EPI_*nmin*	energy performance index based on the minimum value of the nearest months
EPI_*assign*	energy performance index based on the assign value of the assign month
ES_*avg*	energy saving index based on the average value of last year
ES_*min*	energy saving index based on the minimum value of last year
ES_*navg*	energy saving index based on the average value of the nearest months
ES_*nmin*	energy saving index based on the minimum value of the nearest months
ES_*assign*	energy saving index based on the assign value of the assign month
EH_*avg*	energy hierarchy index based on the average value of last year
EH_*min*	energy hierarchy index based on the minimum value of last year
EH_*navg*	energy hierarchy index based on the average value of the nearest months
EH_*nmin*	energy hierarchy index based on the minimum value of the nearest months
EH_*assign*	energy hierarchy index based on the assign value of the assign month
P_*avg*	energy saving potential index based on the average value of last year
P_*min*	energy saving potential index based on the minimum value of last year
P_*navg*	energy saving potential index based on the average value of the nearest months
P_*nmin*	energy saving potential index based on the minimum value of the nearest months
P_*assign*	energy saving potential index based on the assign value of the assign month

the framework of the integrated method. Section 4 presents case study of energy optimization and analysis of ethylene production industry based on the proposed method that combining the IDA of energy performance with energy-saving potential analysis. Finally, the discussion and the conclusion are obtained in Sections 5 and 6, respectively.

2. Related work

There are many methods to analyze energy efficiency, such as the index method and the mean method [10]. But the energy saving knowledge cannot be applied to guide the energy efficiency analysis of actual situation. The data fusion method is much better to analyze the energy efficiency of ethylene plants. Zhou et al. propose a two stage data envelopment analysis (DEA) model to assess energy efficiency, which takes undesirable outputs into account and is able to recognize energy mix effect on energy congestion [10]. Geng et al. propose an extraction method based on data fusion for ethylene industry [11], and the hierarchical linear optimal fusion algorithm has been used for energy consumption indices acquisition [12]. But they do not consider the impact factors of energy consumption indicators. Kleemann et al. optimize the recovering method to save energy in chemical processes [13]. However, it does not take the economic cost of restructuring industrial plants into consideration. The DEA has been widely used for efficiency analysis of industrial production [14] and optimization process [15]. Geng et al. analyze the performance efficiency of China's ethylene plants using the DEA integrated analytic hierarchy process (AHP) [16] and DEA-cross model [17]. Han et al. proposed a fuzzy DEA cross-model to analyze energy efficiency of complex chemical processes [18]. Bi et al. investigates the relationship between fossil fuel consumption and environmental regulation of China's thermal power generation by the DEA model [19]. However, the efficiency discrimination of DEA will be very poor when more than a third of efficiency values are set to 1 [20,21]. Han et al. propose a method that combines DEA and artificial neural network (ANN) [22]. And Olanrewaju et al. integrated IDA-ANN-DEA to evaluate and optimize energy consumption in industrial sectors [23] and to assess energy potential in South African industry [24]. However, they did not take the local minimization problem, convergence rate and the structure of traditional ANN into account [25]. Also, these methods are used to evaluate the broad industry, but not ensure the specific production process and offer guidance to the process. The existing energy optimization and analysis methods in the complex chemical processes are insufficient. Thus the improving methods need to be pointed out.

The IDA is a popular tool for studying changes in energy consumption over time in a country or region [26–28]. Various studies have contributed to the use of the IDA [29], Unander et al. uses this method to decompose the IEA countries' energy-use [30]. In Brazil, the IDA has been used to decompose energy use [31]. Hatzigeorgiou et al. decomposes the CO_2 emissions in Greece during 1990–2002 into four factors: energy intensity effect, income effect, population effect fuel and share effect using the IDA, and concludes that the main element is income effect [32]. Hammond et al. uses decomposition analysis to separate the contributions of changes into five parts to the reduction in carbon emissions. And reduction in energy intensity is the primary reason [33]. Meanwhile, the IDA can quantify the contribution caused by the percentage change of individual attributes, such as the real energy intensity index and the structural change index [27].

Although the energy efficiency analysis of the IDA can obtain quantified energy-saving space, it is necessary to further distinguish the technological energy-saving potential and the structure