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Exploring the effects of influencing factors on energy efficiency in industrial sector using cluster analysis and panel regression model

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ABSTRACT

The various industrial sub-sectors in China should require differentiated policy measures on energy conservation and emission reduction. The existing literature lack comprehensive and in-depth investigation on the influencing factors of energy efficiency at the level of industrial sub-sectors. We aim to examine the disparities in energy efficiency and the driving factors of the energy efficiency among industrial sub-sectors. Using super-SBM, cluster analysis and panel regression model, we explore the effects of influencing factors on energy efficiency across the industrial sub-sectors, and examines the entity effects and dynamic evolving characteristics of energy efficiency in various sub-sectors in China from 2005 to 2011. The results indicate that, there indeed exist significant disparities in energy efficiency across the sub-sectors. In the entire industry, technological progress, energy consumption structure and enterprise scale are the determining factors, but marketization degree and labor productivity do not have significant effects. Meanwhile, obvious variations are found in the effects of influencing factors across sub-sectors with different energy efficiency levels. The entity effects and evolving characteristics of energy efficiency across the industrial sub-sectors, and the dynamic effects of the influencing factors on energy efficiency all have distinct variances. Diverse policy implications are presented to the industrial sub-sectors with different energy efficiency.

1. Introduction

Global warming attributed to the use of fossil fuels is regarded by many observers as a real threat to the environment [1]. Clearly, industrial energy efficiency stands out as one of the most important ways of reducing this threat, given that industry represents the highest energy-consuming sector in the world [2]. Seeking out improvements in energy efficiency is widely regarded as one of the most important and cost-effective ways of reducing final energy consumption, improving industrial competitiveness, mitigating climate change and ultimately achieving sustainable development [3]. In 2004, the Development Research Centre of the State Council in China laid out the major priorities for all future energy policy in China, which included placing greater emphasis on energy conversation and energy efficiency, particularly in the industrial sector. Despite the fact that there have been general improvements in energy efficiency through these years, energy efficiency is still much lower than that of the developed countries. Hence, there is considerable room for improvement in industrial energy efficiency [4]. Since the industrial sector is the largest energy consumer and produces more than 70% of all CO_2 emissions, improving industrial energy efficiency plays a significant role for enhancing overall energy security and promoting low-carbon development in China [5]. It would therefore be meaningful to analyze the industrial energy efficiency in China, since this could provide empirical information for the policymakers to lay down effective policy measures to improve the industrial energy efficiency [6].

Given that improvements in energy efficiency are considered to be the basic principle in realizing energy conservation and emission reductions, the analysis of the factors influencing industrial energy efficiency could lead to an industrial system with low level of energy consumption, emissions and pollution [7]. In order to better measure industrial total factor energy efficiency, data envelopment analysis [8] and stochastic frontier analysis [9] have been widely used. Moreover, econometric models including tobit model [10], multivariate regression [11], spatial econometric model [12] and

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logit model [13], and the methods based on index decomposition analysis [14], have been used to quantitatively analyze the influencing factors of industrial energy efficiency. However, those studies only stays at the level of energy efficiency measurement and influencing factors analysis, none of the existing studies excavated the inherent differences and time evolution characteristics in energy efficiency within the industrial sector, as well as the current effect and long-term effect of the influencing factors on energy efficiency.

There are huge variations in the influencing factors, and the industrial energy efficiency may vary significantly across industrial sub-sectors. The huge disparities among different industrial sub-sectors in China require differentiated policy measures on energy conservation and emission reduction. Thus, it is of great significance to evaluate the energy efficiency and analyze the determinants in China industry at the sub-sectors level. Feng et al. [15] have taken the industrial heterogeneity into consideration, however, no studies have been done to explore the energy efficiency heterogeneities among industrial sub-sectors. To fill this research gap, the cluster analysis, thus allowing us to explore energy efficiency heterogeneities in industrial sub-sectors. Wang et al. [16] have divided 35 sub-industrial sectors in Beijing(China) into three categories through the system clustering analysis, and the results indicated that the energy efficiency among three categories is significantly different, but there are no further analysis on each category with different energy efficiency level.

With these above issues in mind, this study combine cluster analysis and panel regression model to explore China's industrial energy efficiency and its influencing factors at sub-sectors level. Our extensions to the existing studies include the following items. (i) We evaluate the industrial energy efficiency by two stage super-SBM which could discriminate the efficient DMUs. (ii) We classify industrial sub-sectors into different categories according to the level of energy efficiency, and furthermore, we investigate the influencing factors of energy efficiency in each category. (iii) We employ the entity and time fixed effects model to analyze the effects of the influencing factors, which could not only find out the detailed entity effects across different sub-sectors and time effects at different time points, but also obtain the dynamic effects of influencing factors on energy efficiency in different stages.

The rest of the paper is organized as follows. The literature review is presented in Section 2. In Section 3, we describe the relevant methods, and proposed the procedure for the analyzing the industrial energy efficiency and influencing factors. In Section 4, we obtain the empirical results. Section 5 concludes the paper and put forwards some policy recommendations. Because this paper involves many abbreviations, we here summarize them in nomenclature section.

Nomenclature

EE	energy efficiency	PRM	panel regression model
DMU	decision making unit	LTP	level of technological progress
DEA	data envelopment analysis	MD	marketization degree
SFA	stochastic frontier analysis	LP	labor productivity
SBM	slack-based model	ECS	energy consumption structure
IDA	index decomposition analysis	ES	enterprise scale
TFEE	total-factor energy efficiency	MII	mining industry
R&D	research and development	MAI	manufacturing industry
FCM	fuzzy c-means clustering	EGWI	electricity, gas and water industry

2. Literature review

In economic management field, as for measuring total-factor energy efficiency (TFEE), two methods have been usually used in industry sector, which include parametric method represented by stochastic frontier analysis (SFA) [17] and non-parametric method represented by data envelopment analysis (DEA) [18]. As a non-parametric method, DEA is regarded as a more effective method for measuring energy efficiency and has been widely used. For example, Wang and Wei [8] applied DEA to evaluate regional energy and emissions efficiency within the industrial sectors of 30 major Chinese cities between 2006 and 2010, and further assess the potential for energy saving and emission reductions. Shi et al. [18] used DEA to measure industrial energy efficiency and investigate the energy-saving potential in 28 administrative provinces in China. Wu et al. [19] constructed both static and dynamic energy efficiency performance indices to measure industrial energy efficiency performance using environmental DEA models. Zhao et al. [20] used DEA to study the changes of total factor energy efficiency at both sector and provincial levels in China. Han et al. [21] presented fuzzy DEA cross-model to analyze the energy efficiency status of ethylene production plants in chemical industry. Ozkara and Atak [22] investigated the TFEE scores of the manufacturing industry in 26 regions of Turkey using DEA models. Moon and Min [23] employed two-stage DEA model to evaluate economy efficiency and pure energy efficiency, and gave suggestions to improve the energy efficiency.

Furthermore, the research on exploring the influencing factors of industrial energy efficiency could be divided into three aspects that are comprised of econometric models, index decomposition analysis and qualitative policy analysis. As the measuring values of TFEE are in the range [0,1], the tobit models are often been used to analyze the influencing factors. Pan et al. [10] analyzed the determinants of provincial industrial energy efficiency in China by random effects tobit regressions. Li and Shi [24] estimated the energy efficiency of various industrial sectors in China, and used tobit regression model to explore the influencing factors of energy efficiency. Wu [25] examined the TFEE of industrial sector in Shandong using SFA, and applied tobit model to examine the factors influencing energy efficiency within this sector. Except of the tobit model, multivariate regression, spatial econometric model and logit model are also been used to analyze the influencing factors of industrial energy efficiency. Peng et al. [11] conducted quantitative analysis of the influencing factors of energy efficiency by multivariate regression in the chemical fiber industry of China textile industry. Xu and Lin [26] employed data-driven nonparametric additive regression model to investigate the relationships between new energy industry and the driving factors. Liu et al. [12] used spatial econometric model to study the impact of industrial agglomeration on energy efficiency. Hochman and Timilsina [13] adopted logit model to quantify the economic, behavioral, and institutional barriers that impede the deployment of energy-efficient technologies.

Index decomposition analysis (IDA) has also been used to investigate the influencing factors of industrial energy efficiency. Ang and Xu [14] proposed intensity refactorization and activity revaluation approaches to investigate the trends in industrial energy efficiency based upon IDA. Wu and Huo [27] adopted logarithmic mean divisia index (LMDI) decomposition techniques to investigate the effectiveness of policies targeting energy conservation in the energy-intensive manufacturing and transportation sectors. Norman [28] utilized the approach of activity refactorization to measure the energy efficiency enhancement of industrial