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A hybrid model for explaining the short-term dynamics of energy efficiency of China's thermal power plants

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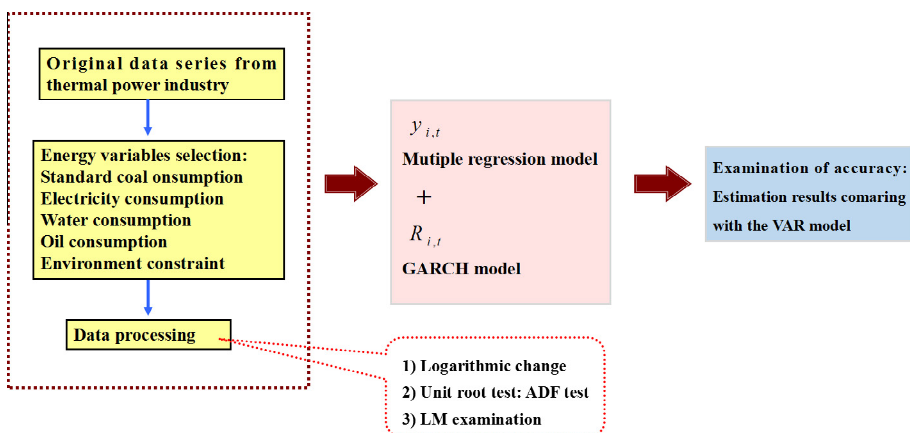
HIGHLIGHTS

- The new hybrid method consists of a multiple regression model and the GARCH model.
- The hybrid model is an improved benchmarking methodology.
- The method analyses the energy efficiency index of thermal power plants without artificial intervention.
- The volatility degree between determinants and energy efficiency index can be evaluated.
- Environment constraints of thermal power plants are considered.

GRAPHICAL ABSTRACT



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ABSTRACT

A new hybrid methodology is introduced which is a combination of multiple regression model and generalised autoregressive conditional heteroskedasticity (GARCH) model. Comparing the new approach and the vector auto-regression (VAR) model, this paper analyses the short-term dynamics of the energy efficiency index (EEI) in response to change in the five indicator variables for thermal power plants in China. The result indicates that: (i) The new hybrid model can directly calculate the EEIs of thermal power plants without artificial intervention. (ii) It can eliminate the disturbance of residual superposition. (iii) The new method will offer more direct information on the degree of volatility among determinants and operating inefficiency.

1. Introduction

1.1. Background

In this decade, there is an increasing number of studies paid more attention to evaluating, analysing energy efficiency around the world. The global warming is one of the world's most significant problems and global warming is primarily attributed to the emission of carbon dioxide (CO_2). China has become the second-largest economy entity in the world since the implementation of China's economic reform in 1978. However, this achievement has led to the inefficient natural resource utilisation, rising of emission of carbon dioxide and large energy consummation as well. Today, China is the world's second largest installed electricity generation nation. China's CO_2 emission is close to 10 billion tons in 2013, and

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Nomenclature

Δy_t	constant variance
$y_{i,t}$	energy efficiency indicators of item i at the end of period t
$x_{i,t}$	independent variables
R_t	energy efficiency
M_i	impact variable of the event i
h_t	conditional variance of R_t
υ_t	result of VAR model
a	constant
b	constant

Greek symbols

α	parameter
β	parameter
γ	coefficient of correlation
Γ	matrix valued polynomial
ε_t	residual error
υ	data series
μ_t	squared distribution

Subscripts

t	time index
0–1	state point
i	time-varying changes of impact variables
n	number of variables
q	the number of lags
c	point
k	point

coal-fired power generations contribute more than 80%. Thermal power generation is a procedure in which thermal energy obtained by the consumption of coal, gas and other fuels in transformed into electricity. Therefore, thermal energy is the main source of energy consumption and pollution in electricity generation industry.

To improve energy utilisation efficiency, protect the environment and implement sustainable development, various series of energy policies have been published by the Chinese government in order to establish a sufficient regulatory of energy use in different industries. A target has also been presented that the CO_2 emissions per unit gross domestic production (GDP) should be reduced by 40–45% by 2020 compared with the level in 2005. Government highly focuses on energy efficiency evaluation of high energy-consuming industries, especially thermal power industry. Therefore, evaluating and measuring the energy efficiency of thermal power industry with the consideration of environment constraint indicator is very vital for plants to reduce energy consumption and monitor environment pollution. The paper will adopt five variables of thermal power plants. They are namely: (i) standard coal consumption per unit product of power (hereinafter to be referred as SCC); (ii) the rate of electricity consumption of power plant (hereinafter to be referred as EC); (iii) the total water consumption per unit product of power generation (hereinafter to be referred as WC); (iv) the total oil consumption per year (hereinafter to be referred as OC); (v) the investment rate of desulfurization system (hereinafter to be referred as RDS) which is treated as an environmental constraint indicator of each thermal power plant.

1.2. Previous studies for evaluating utility performance

The importance of energy efficiency evaluating on one hand, and its complexity on the other hand, has motivated many studies in this area. There are several popular methodologies for energy efficiency evaluation. The first methods are linear approach and stochastic frontier analysis, which are the primal studies in evaluating utility efficiency. Farrell [1] contributed the linear regression approaches to measuring utility production efficiency based upon the foundation work of Knight [2] and Debreu [3]. The new linear regression approaches provided a distance function to evaluate efficiency in a primal system. The improvement work by Shephard [4] developed a mutual relationship between costs, production and benefits. Filippini and Hunt [5] examined a stochastic frontier approach to calculate the difference of energy efficiency among OECD countries. They adopted energy price to be an independent variable, which is in order to measure how well do the actions of consumers respond to the energy efficiency with the policy variables change. Zhou et al. [6] employed a parametric frontier approach to evaluate economic wide energy efficiency indicators. The methodology is the basis of index decomposition analysis, which can be applied to indicate a change in energy consumption. However, linear approaches can only indicate a single relation from input variables to outputs. It does not demonstrate the interconnection between variables. The behaviour of the changes of energy efficiency may not be completely captured by the linear techniques. Moreover, this method does not take into account random errors. Estimated results will be influenced by the residual superposition.

To solve this problem, the second approaches have been further developed. The multiple regression models are extended to explain the influences of many variables. Denholm et al. [7] adopted the model to assess the technological and environmental performance of wind power plants. They found that the energy efficiency of wind power plants will be at least five times greater than that of fossil combustion technology by improving capacity efficiency. Bernard and Cote [8] used principal component analysis (PCA), one type of multiple regression models, to calculate the energy efficiency of manufacturing. They treated environmental factor as an important determinant in system simulation. Besides that, they concluded that only regression approaches are unable to demonstrate the particular patterns of energy efficiency. It cannot provide a fair benchmarking of energy efficiency performance among different objectives. Based upon above mentioned, some studies further extended the data envelopment analysis (DEA) approach to involve more determinants. The DEA model is a nonparametric "black-box" multiple regression model. There are huge amounts of scholars applied the DEA model to evaluate the overall energy efficiency index (EEI) through involving different types of inputs. Examples of such studies include Song et al. [9], Khoshnevisan et al. [10], Bianchi et al. [11] and Mousavi-Avval et al. [12]. The drawback is that most models are invariant with respect to the decision making units (DMUs), and these models mainly focus on less input or higher output for better overall energy efficiency. This methodology simply includes all DMUs in one analysis while does not provides a mechanism for incorporating useful information such as volatility of interrelation into the analysis.

Instead of solving these methodological issues in an ordinary least squares regression, the generalised autoregressive conditional heteroskedasticity (GARCH) models were established. The earliest fundamental work of ARCH models was pioneered by Engle in 1982 [13], and the GARCH methodology was introduced by