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Modeling a hybrid methodology for evaluating and forecasting regional energy efficiency in China

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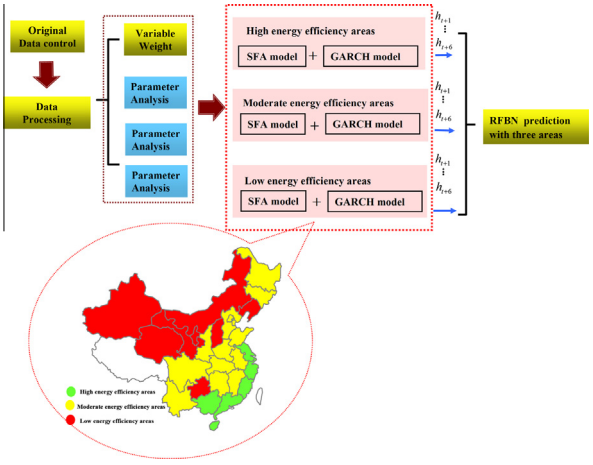
HIGHLIGHTS

- A new hybrid methodology consists of SFA-GARCH model and RBFN model is structured.
- Regional energy efficiency in China is measured during 2003–2014.
- Short-term forecast is examined without manual intervention from 2016 to 2020.
- The hybrid methodology avoids the superposition of errors of the individual forecasts.
- The 30 regions in China are clustered into high, moderate and low efficiency areas.

GRAPHICAL ABSTRACT



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ABSTRACT

This study proposes a new hybrid methodology for short-term prediction of energy efficiency. This new method consists of the stochastic frontier analysis-generalised autoregressive conditional heteroskedasticity (SFA-GARCH) model and the radial basis function neural (RBFN) model. The study finds that 30 regions (provinces and municipalities) in China have cluster-hetergeneity, and the different levels of industry structure, technology content and energy resources in the different regions lead to dissimilar energy saving quotas. In addition, through fair comparison between the traditional GARCH model and the new hybrid model, it is proved that the new hybrid model shows good performance and the results are reasonable. The energy efficiency indicators predicted by the hybrid model appear to be more reliable than the summation of the individual forecasts because it avoids the superposition of errors.

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1. Introduction

1.1. Background

Due to the environmental pressure, energy efficiency and energy saving are becoming increasingly significant to government policy in China in response to a range of challenges including energy resource scarcity, shortage of energy supply and high energy price. Many of the high energy-consuming fixed asset investments have become enterprises in energy-intensive industries. Chinese energy consumption per unit output value is 2.3 times of the world average, and the energy efficiency is 10% less than the world average [1]. Continually increasing energy consumption and energy intensity have not only caused the alarm for Chinese energy security but also led to carbon emission

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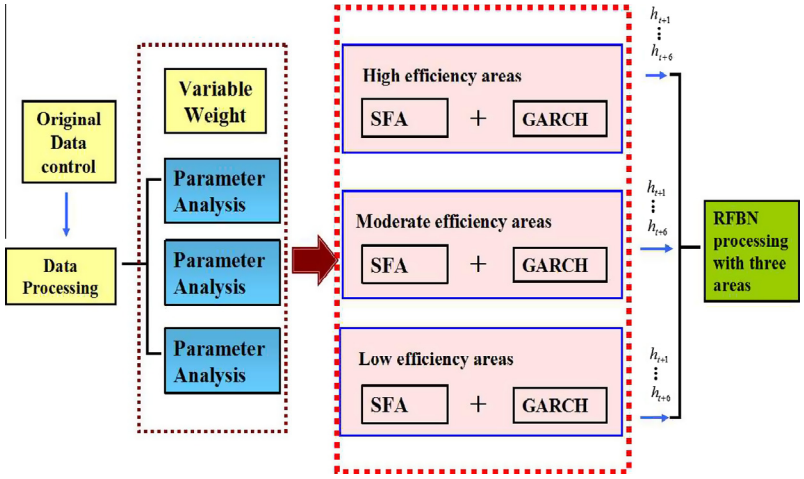

Fig. 1. Flowchart of the proposed methodology.

pressure in the post Kyoto-protocol era [2]. Therefore, to improve energy efficiency has become a rigorous matter in China. It is of great significance to investigate regional energy efficiency and analyse the influencing factors, because it can impact the strategy of scientific and technological development and the transformation of the mode of economic growth. Moreover, accurate forecasting of regional energy efficiency is vital for politic decision.

1.2. Previous studies of energy efficiency evaluation and prediction

There are mainly four types of models closely related to energy efficiency evaluation. First is the stochastic frontier analysis (SFA) model. It is mainly adopted to deal with the linear regression of energy efficiency. Boyd [3] and Boyd et al. [4] adopted the SFA model to investigate energy performance index. Then, the index data analysis (IDA) model is further extended based upon the SFA model. The SFA model can be used to investigate how the linear change of industrial structure impacts the total energy intensity. For example, Newell et al. [5] adopted it to analyse the relation between technical change and energy saving. Lin and Du [6] adopted the SFA model to estimate energy efficiency in 30 provinces, and they argued that the deficiency of this linear approach is ignoring the technology gaps across variable groups. Furthermore, the data envelopment analysis (DEA) model has been applied to overcome the disadvantage of the SFA model basically. Scholars employed the DEA model because they believed that energy efficiency should be put together with wide independent factors in order to evaluate outputs [1]. Wang et al. [7] applied the DEA model to do multi-directional efficiency analysis. Wang and Feng [8] adopted this model to evaluate the performance of environmental efficiency in China. They figured out that the tendency of environmental efficiency has begun to have an ascending path because of improved technologies. Recently, the DEA model has been implemented to examine the energy efficiency of coal-fired power units by Song et al. [9]. The obvious causal relationship could be obtained thanks to the linear characteristics of the DEA model. The DEA model can be easily applied to a multiple input–output black-box framework for estimating different indexes, especially for the decision making units of industries. However, the DEA model has some limitations. It does not overcome the summation of measurement errors, and evaluation of this method is easy to be influenced by its extreme value. Fourth, some studies employed the generalised autoregressive conditional heteroskedasticity (GARCH) models to estimate the volatility of assets, and they showed the short-run performance based upon in-sample forecasts [10]. The GARCH model mainly focuses on volatility analysis of time series data, without examining the underlying physical process. Ji and Guo [11] recently analysed the oil price volatility and its related issues via adopting the GARCH model for figuring out the reason of global financial crisis. Li et al. [12] further employed the GARCH model to examine the detailed causality relationship among different variables in thermal power plants, and then to figure out the most influential factors through non-manual intervention methodology.

On the other hand, the radial basis function neural (RBFN) model is a successful application for seasonal and time series forecast. It is able to structure frameworks for modeling a broad range of nonlinear issues. It can structure any type of relations with a high degree of accuracy. The most obvious advantage is that the RBFN model can universally approximate a large number of data, and no prior model needs to be built within the process. This power comes from the computation progress of the information from the data. Wedding and Cios [13] used the RBFN model and the Box–Jenkins model to generate certainty factors with normal output. Ginzburg and Horn [14] also employed a neural network to analyse time series prediction.

Recently, due to the limitation of each single model, hybrid methodology has become an important methodology to analyse comprehensive nonlinear systems. Conejo et al. [15] proposed a hybrid method based on the auto-regressive integrated moving average (ARIMA) models and the wavelet transform (WT) models to forecast day-ahead energy price of Spanish market. A hybrid model has been constructed by Li et al. [12] combining time series methods (WT model + RBFN model) and an adaptive evolutionary algorithm for day-ahead price. However, all the above methods ignore the effect of measurement errors and other statistical noises that may lead to the result errors.

There are many papers that focus on particular sectors of Chinese energy system but few studies pay attention on prediction of energy efficiency in medium-term (i.e., to 2020). The objective of this paper is to address this gap, by quantifying energy efficiency factors at a function level and by adopting the hybrid model. The new hybrid model will overcome the limitation of single model, and it combines the SFA-GARCH model and the RBFN model, for evaluating influencing factors and forecasting regional energy efficiency. The advantage of this method can be described as follows. When the amount of data is large, the RBFN model is presenting that the data match a training pattern with a high degree of accuracy and the results are reliable. When the amount of data is low, there are few training patterns and the forecast will be obtained in favour of the GARCH model. Therefore, the new hybrid model is more accurate than adopting RBFN model or GARCH model alone.

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