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Li Ni & Venus Khim-Sen Liew

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Carbon emission price forecasting in China using a novel secondary decomposition hybrid model of CEEMD-SE-VMD-LSTM

Li Ni[a,b] and Venus Khim-Sen Liew[a]

[a]Faculty of Economics and Business, Universiti Malaysia Sarawak, Kota Samarahan, Malaysia; [b]School of Finance and Taxation, Anhui Economics & Management College, Hefei, People's Republic of China

ABSTRACT

Effective forecasting of carbon prices helps investors to judge carbon market conditions and promotes the environment and economic sustainability. The contribution of this paper is constructing a novel secondary decomposition hybrid carbon price forecasting model, namely CEEMD-SE-VMD-LSTM. It is noteworthy that the sample entropy is introduced to identify the highly complex signals rather than empirically determined in previous studies. Specifically, the complementary ensemble empirical mode decomposition (CEEMD) model is used to decompose the original price signals. The sample entropy (SE) and variational mode decomposition (VMD) are conducted to recognize and secondary decompose the highly complex components, while the long short-term memory (LSTM) model is employed to forecast the carbon price by summing up the predicted intrinsic mode function (IMF) components. The conclusion shows the proposed model has the smallest forecasting errors with the values of RMSE, MAE and MAPE are 0.2640, 0.1984 and 0.0044, respectively, the secondary decomposition models are better than other primary decomposition models and the forecasting performances of LSTM-type models are better than those of other GRU-type models. Further evidence convinces us that short-term forecasting accuracy is superior to long-term forecasting. Those conclusions and model innovation can provide a valuable reference for investors to make trading decisions.

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KEYWORDS
Carbon price forecasting; secondary decomposition; CEEMD; sample entropy; VMD; LSTM

1. Introduction

The rapid economic development has promoted a huge increase in energy consumption and carbon emissions. To solve the environmental issues, the Chinese government officially implemented the 'Carbon peak, Carbon neutrality' strategy in September 2020. The construction of a carbon market has become a specific measure for China to deal with environmental constraints. The price mechanism is the core of the carbon market (Huang et al., 2019). Therefore, revealing the carbon premium mechanism and forecasting the complex carbon price effectively are the keys to reducing carbon emissions.

The empirical mode decomposition (EMD) technology was the mainstream carbon price forecasting method in previous studies (Wang, Cheng, et al., 2022; Zhu et al., 2015). The obvious advantages of EMD-type models are decomposing the nonlinear and non-stationary price series into different intrinsic mode functions (IMFs) for capturing the time–frequency multi-scale price characteristics (Yang et al., 2020). Huang et al. (2021) found that the hybrid models based on the variational mode decomposition (VMD), generalized autoregressive conditional heteroskedasticity (GARCH) and long short-term memory (LSTM) model were able to effectively forecast the European carbon price, while the EMD-VMD-LSTM models acquired better forecasting accuracy in China carbon market (Sun & Huang, 2020; Wang et al., 2021). Broke through the point forecasting defects of traditional EMD-type models, Ji et al. (2022) developed a three-stage vertical interval model based on the improved complementary ensemble empirical mode decomposition (ICEEMD) to enhance the forecasting reliability. To reduce the reconstruction error, Zhou et al.(2022) proposed a complementary ensemble empirical mode decomposition with an adaptive noise (CEEMDAN) hybrid model for forecasting Guangzhou carbon price. Furthermore, the CEEMDAN-LSTM model is suitable for short-term carbon price forecasting (Yun et al., 2023). Using the complementary ensemble empirical mode decomposition (CEEMD) and VMD technologies to secondary decompose the carbon price conducted the support vector machine (SVM), back propagation neural network (BP)

CONTACT Li Ni 21010257@siswa.unimas.my

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