**International Journal of Grid and High Performance Computing**
Volume 18 • Issue 1 • January-December 2026

# Deep Learning Power System Carbon Emission Regulation and Intelligent Modeling of Elastic Load

Xu Zhao
*Yunnan Power Dispatching and Control Center, China*

Yang Wu
*Yunnan Power Dispatching and Control Center, China*

Wentao Zou
http://orcid.org/0009-0005-1452-9479
*Beijing Tsintergy Technology Co., Ltd., China*

Xuhui Wang
*Yunnan Power Dispatching and Control Center, China*

**Received:** January 21st, 2026 | **Accepted:** March 30th, 2026

## ABSTRACT

Against the background of China's double-carbon strategy, the authors put forward a double-loop Transformer–Bi-directional (Bi)–long short-term memory–actor–critic framework that realizes the closed-loop coordination of carbon emission prediction and load control through carbon-load coupling loss and a self-calibration feedback mechanism. The experimental results, which are based on the 15-min resolution dispatching data from six provinces in East China, showed that the carbon emission mean squared error of the framework was 0.038 total carbon dioxide (tCO2), the peak–valley load difference was reduced by 8.7%, and the peak-shaving benefit was increased by 5.4%. In addition, the sensitivity analysis results showed that when the carbon emission weight exceeded 0.6 the system will give priority to reducing carbon emissions. The framework successfully realizes the end-to-end collaborative modeling of carbon emissions and elastic loads and provides an extensible solution for low-carbon scheduling and demand side management.

## KEYWORDS

Deep Learning, Power Gird, Carbon Emission, Carbon-Load Coupling, Dual-Loop Framework

## INTRODUCTION

With the continuous advancement of the dual carbon strategy, the high proportion of renewable energy connected to the grid has gradually become an important structural feature of of the new power system in China (Jiang & Raza, 2023; Stephanie & Karl, 2020). However, the inherent randomness, volatility, and intermittency of wind power and photovoltaic output significantly enhance the multidimensional coupling complexity among source, load, and storage, making it difficult for the scheduling model with traditional economic optimization as the core to meet the dual needs of carbon emission constraints and fine-load regulation at the same time (Fahim et al., 2023; Zang et al., 2024).

DOI: 10.4018/IJGHPC.408425

At the regional power grid scale, carbon emission intensity and electricity load show obvious nonlinear, time-varying, and two-way feedback characteristics. On the one hand, the dynamic adjustment of the output structure of generation side units will directly change the carbon emission factor per unit of electricity (Jia et al., 2024; Yanzhe & Ullah, 2025). On the other hand, the response behavior of demand-side flexible resources (e.g., interruptible load and peak-shifting load) affects the time series shape of the system carbon emission curve in the opposite direction (Bistline et al., 2021). However, the existing research often regards carbon emission prediction and load control as independent serial tasks, and modern research methods lack the ability to unify the modeling of the interactive evolution mechanism of the two. This limitation makes the system prone to problems in complex scenarios such as extreme weather, holidays, or power grid disturbances. Problems such as accumulation of prediction bias, a lag in control response, and even strategy conflicts seriously restrict the real-time nature and robustness of low-carbon scheduling (Hawker et al., 2024; Prieto-Godino et al., 2025).

From the perspective of technical paths, current mainstream methods mainly rely on a single model (e.g., sequence-to-sequence [Seq2Seq], a temporal convolutional network [TCN], or light gradient boosting machine [LightGBM]) to independently predict carbon emissions or loads and then generate scheduling instructions through postprocessing modules (Gong et al., 2025; Howlader, 2025; Misiurek et al., 2025). Although this type of method has a certain degree of effectiveness under relatively smooth operating conditions, its limitations have become increasingly prominent in the context of high-penetration renewable energy access: First, ignoring the coupling feedback relationship between carbon emissions and loads makes it difficult to achieve online correction of prediction errors, which can easily lead to a chain effect of step-by-step error amplification. Second, the model structure has an insufficient collaborative perception ability of multisource heterogeneous information (e.g., supervisory control and data acquisition [SCADA], advanced metering infrastructure [AMI], meteorological data, and social events), and it is difficult to cope with multitarget conflicts under sudden disturbance conditions (Elghaish et al., 2026; Tian et al., 2025). Third, regulation strategies are usually based on static weight setting, which lacks the ability to dynamically trade off carbon emission reduction, economic cost, and user comfort (Hoummadi et al., 2024; Sarker et al., 2021).

In light of these shortcomings, we propose a dual-loop prediction control framework. For the first time, a carbon-load coupling equation that covers the three-layer topology of power generation, transmission and distribution, and users is constructed under a unified modeling system. The millisecond-level closed-loop mechanism, combined with the outer data loop and the inner control loop, realizes the homogeneous correction of prediction error and regulation behavior. This framework not only breaks through the limitation of the traditional serial prediction-control paradigm in methodology but also verifies the feasibility of multi-objective collaborative scheduling in engineering practice.

The verification results, based on a total of 840 million units of data, collected every 15-min from six provinces in East China, showed that the model reduced the carbon emission intensity error (CIE) to 0.045 total carbon dioxide ($tCO_2$), which is 36.6% lower than the baseline method, while achieving a 17.5% peak–valley difference reduction rate, and restored system stability within 20 min under extreme disturbance conditions. Furthermore, by introducing β-warmup joint loss function and an actor–critic decision-making architecture, when $\beta = 0.6$, the system achieved Pareto optimization among carbon emissions, economy, and user comfort, which provides a quantifiable and deployable technical path for the implementation of the provincial power grid. The goal of 3% annual carbon reduction provided a quantifiable and deployable technical path, marking an important transformation of low-carbon dispatching from single-objective optimization to multidimensional collaborative evolution (Kathirgamanathan et al., 2021; Rolando et al., 2025).

In sum, the following are the main contributions of this research:

## Related Content

Road Traffic Parameters Estimation by Dynamic Scene Analysis: A Systematic Review

H. S. Mohanaand M. Ashwathakumar (2012). *Evolving Developments in Grid and Cloud Computing: Advancing Research (pp. 223-238).*