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Optimization Design of an Industrial Carbon Emission Intelligent Monitoring System for Carbon Neutrality

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ABSTRACT

This study aimed to optimize industrial carbon emission monitoring systems for enhanced accuracy and real-time responsiveness. It proposed an intelligent system that innovatively sinks multi-source carbon accumulation logic into the database layer (replacing traditional application-layer processing), integrated with dynamic factor version control and long short-term memory prediction models. These innovations yielded significant performance gains. Under thousands of concurrent users, key interface response time dropped from 7,465 ms to 40 ms (99.5% reduction), while carbon calculation error rates remained below 0.1%—far exceeding the International Standards Organization 14064 standard's 1% threshold. The proposed solution not only provides industry with efficient carbon management tools but also enables a paradigm shift from post-event statistics to real-time intelligent decision making, advancing global carbon neutrality goals.

KEYWORDS

Carbon Neutrality, Industrial Carbon Emissions, Energy Consumption Monitoring, Database Layer Computing, Dynamic Factor Version Control

INTRODUCTION

With increasingly severe global climate change, achieving carbon neutrality has become an urgent task for the international community (Dai et al., 2022; Huang et al., 2022; International Energy Agency, 2023; Wang et al., 2021). The industrial sector, as the main source of global carbon emissions, accounts for more than 37% of global total emissions (Wu et al., 2023), playing a key role in achieving carbon neutrality goals. However, existing industrial carbon emission monitoring systems face several technical bottlenecks, including coarse data collection granularity and the lack

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of subdivision at the equipment and process segment levels (Lin et al., 2023). Furthermore, carbon emission factor configuration relies on static models, which require manual code modification when policies are updated, leading to long response cycles (Cheng et al., 2025). This rigidity in business rules not only limits the flexibility and real-time performance of the system but also contradicts the requirements of modern information system modeling and business process management (Dumas et al., 2018; Weske, 2019). Therefore, developing a carbon emission monitoring system that can dynamically adapt to policy changes and industry needs is particularly important.

Specifically, the limitations of existing research are mainly reflected in three aspects: First, data collection is mostly at the factory level, lacking subdivision at the equipment and process segment levels (Lin et al., 2023). Second, carbon emission factor configuration relies on static models, requiring manual code modification when policies are updated, leading to long response cycles (Cheng et al., 2025). Third, although multi-source data have achieved physical storage integration, they lack deep fusion, resulting in high carbon emission accounting error rates and delayed strategy responses (Tang, 2021). These issues not only limit the efficiency of industrial enterprises in carbon emission management but also hinder the entire industrial sector from moving toward carbon neutrality.

The innovation of this study lies in proposing an optimized design of an intelligent monitoring system for industrial carbon emissions oriented toward carbon neutrality. This study aimed to achieve deep fusion of multi-source data at the equipment/process segment level, develop dynamic carbon emission calculation models, optimize strategy response mechanisms, and build a cross-industry adaptation framework. By integrating multi-source carbon emission accumulation logic into the database layer, combined with dynamic factor version control and long short-term memory (LSTM) prediction models, this study is expected to significantly improve accounting accuracy and real-time responsiveness. This not only provides industrial enterprises with high-precision, low-latency carbon management tools but also is expected to promote the paradigm shift of carbon emission monitoring from post-event statistics to real-time intelligent decision making (Fang, 2025), which is of great guiding significance for industrial enterprises in achieving carbon neutrality goals (Xu et al., 2022; Yu et al., 2020).

Innovation in Database Layer Computing Architecture

The database layer computing architecture proposed in this study, building on the multi-source data integration model by F. Zhang et al. (2021) and Sun et al. (2024), further realizes the deep integration of business rules (dynamic factors) and real-time data processing. By migrating the carbon emission calculation logic from the application layer to the database kernel layer, a three-level pipeline—namely, data aggregation, single-source calculation, and multi-source accumulation—is constructed. This architectural design is highly consistent with the model-driven computing sinking architecture proposed by Gao et al. (2022), whose core lies in reducing cross-layer interaction losses through the parallel computing capability of the database kernel. This is consistent with the research conclusion of Ding et al. (2024) on performance optimization of database-centric systems—that is, reducing data transmission between the application layer and the database can improve response efficiency by more than 90% in high-concurrency scenarios.

Connection With Information System Modeling Theory

The architectural design of this system follows the model-driven architecture theory (Li et al., 2022;), realizing the transformation from industrial carbon neutrality management requirements to information system functions through the three-level mapping of the computation-independent model, platform-independent model, and platform-specific model (Memari & Aljamous, 2023; Zhou, 2024). The mapping process refers to the method of applying business process model and notation modeling in manufacturing execution systems by Kharmoum et al. (2023) and the design methodology for flexible business process modeling by Ben Said et al. (2022), converting carbon management