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Not Just How Much, But When: Projecting AI-Driven Data Center Electricity Demand and Its Temporal Carbon Impacts in Korea

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Extended Abstract

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Abstract Summary

The rapid expansion of artificial intelligence (AI) is driving a new wave of electricity demand through the growth of data centers. However, understanding how this demand evolves and interacts with power systems remains challenging, particularly in data-constrained contexts. This study develops a bottom-up framework to project data center electricity demand in Korea through 2040 using limited but widely available information, including contracted power capacity, electricity consumption, and commissioning year. By integrating these data with literature-based parameters on power usage effectiveness (PUE), operating rates, and server density, we reconstruct a historical time series of server stock and derive future electricity demand under alternative scenarios.

We construct two scenarios: a baseline scenario reflecting planned policy support for AI development, and a high-growth scenario assuming accelerated deployment of data center infrastructure. Results show that data center electricity demand could increase by 6.8 to 15.2 times by 2040 relative to current levels, with even the baseline scenario exceeding widely cited global benchmarks. To assess system implications, we combine projected demand with observed hourly load patterns to simulate 8,760-hour load profiles, and estimate associated carbon emissions using time-varying emission factors based on Korea's projected generation mix.

The results highlight the importance of temporal dynamics. While peak data center demand partially aligns with solar generation, mitigating overall emissions, persistently high demand during late afternoon and evening hours may increase carbon intensity. These findings suggest that managing the timing of electricity consumption is critical for mitigating the environmental impact of AI-driven demand. The proposed framework provides a scalable approach for analyzing data center electricity demand and its temporal carbon implications in data-limited settings.

Presenting Author Biography

Jihyo Kim is an Associate Professor at KAIST's Graduate School of Green Growth and Sustainability. Her research lies at the intersection of energy economics, policy, and data analytics, with a focus on electricity market design, demand-side flexibility, and the evolving energy implications of digital technologies such as AI and data centers.