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Powering Data Centers in an Uncertain World - A Decision-Driven Model for Energy System Optimization

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Extended Abstract

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Abstract Summary

The rapid expansion of artificial intelligence (AI) and digital services is driving a significant increase in electricity demand from data centers, elevating their importance within electricity systems worldwide. While data centers currently represent a modest share of total electricity consumption, their highly concentrated and rapidly growing load creates substantial local challenges for power systems. In several major hubs, including Dublin and Amsterdam, grid congestion and limited connection capacity have already delayed new developments and constrained further expansion (IEA 2025). These challenges have prompted increasing interest in alternative infrastructure concepts, particularly the co-location of data centers with dedicated power generation and energy storage assets to reduce grid dependency, improve reliability, and enable participation in electricity markets (IEA 2025; Davenport et al. 2024).

At the same time, the economic performance of these supply strategies remains uncertain. Existing studies reach divergent conclusions regarding the relative attractiveness of renewable energy, storage, natural gas, and nuclear options, largely due to differences in assumptions about technology costs, market conditions, and reliability requirements (Uranbold and Lima 2025; Soto Gonzalez et al. 2024). Moreover, important modelling gaps persist. Many approaches represent data-center demand as static and do not capture hourly variability or the sensitivity of cooling demand to ambient temperature, thereby overlooking critical climate effects and their interaction with renewable generation (Soto Gonzalez et al. 2024; Figini and Paolone 2025; Khalil et al. 2025). In addition, electricity market interactions, carbon pricing, and supply reliability are often treated in a simplified or implicit manner (Böse et al. 2024; Patel et al. 2025).

These limitations motivate the development of an integrated modelling framework that jointly captures climate effects, market dynamics, technology choices, and reliability

constraints in the assessment of data-center energy supply systems.