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Options for European Data Center Energy Supply under Climate and Market Uncertainty

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The rapid expansion of digital infrastructure has elevated data centres to a position of strategic importance within European electricity systems. Recent analyses indicate that, despite advances in facility engineering, power supply remains the leading cause of impactful outages, while rapidly increasing AI-driven computational demand further heightens exposure to reliability and geopolitical risks (BusinessWire 2025). At the same time, climate resilience remains underrepresented in many operational studies, which often omit realistic climate scenarios, robust optimisation comparisons, or explicit temperature-dependent performance effects (Khalili et al. 2025). Integration with local electricity markets is frequently constrained by fragmented regulation, scalability limitations, and incomplete physical grid modelling. Even advanced technical work on cooling architectures, workload forecasting, and power electronics does not consistently couple renewable integration, climate-aware sizing, and economic–environmental trade-off (Zhou et al. 2025; Koot and Wijnhoven 2021). Together, these gaps motivate the need for an integrated data-centre energy-system model that is outage-aware, climate-informed, market-coupled, and technology-diverse

This work introduces the first model for the techno-economic assessment of data centres in Europe, designed to be transparent, tractable, and extensible. Facility electricity demand is decomposed into the workload-driven IT load, a temperature-coupled cooling load, and auxiliary electrical needs. Cooling demand is expressed as a deterministic function of ambient temperature, allowing spatial and temporal climatic variability to influence both hourly operations and technology sizing. This climate-aware formulation captures region-specific effects such as elevated cooling requirements in southern Europe or seasonal load compression in northern regions, which are often abstracted away in stylised analyses.

A simplified yet physics-consistent representation of on-site energy assets is integrated into the model. The resource portfolio includes battery energy storage systems (with standard state-of-charge dynamics), gas turbines, small modular reactors, and variable renewable resources such as wind and photovoltaic generation. Each technology is characterized by its feasible operating envelope, availability constraints, efficiency assumptions, and capacity limits, enabling the evaluation of energy shifting, emergency backup capability, renewable integration, and grid-service provision. Optional security-of-supply constraints allow the model to enforce outage tolerance or “n–1”-type reliability requirements. The modular structure also supports future extensions, including probabilistic outage modelling, advanced cooling-system control strategies, and explicit network-flow formulations.

Real-world electricity prices and tariffs from Eurostat non-household price bands, DESNZ non-domestic UK statistics, and public utility-rate databases are embedded to compute operational costs under diverse pricing structures, including energy charges, demand charges, dynamic tariffs, and carbon costs. Hourly renewable resource profiles and temperature data provide environmental drivers for both cooling requirements and on-site renewable yields. These datasets form a data-to-model pipeline capable of generating realistic and synthetic IT-demand trajectories for scenario analysis across European locations.

First results highlight the dominant influence of climate on cooling demand, the cost and reliability trade-offs across on-site supply configurations, and the potential advantages of hybrid portfolios combining storage, renewables, and firm generation. This model establishes a consistent baseline for more detailed thermal, economic, and grid-integrated analyses, offering actionable insights for operators and policymakers seeking to support resilient and sustainable data-center growth in Europe.

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