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Integrated Data Center Architecture for Carbon-Aware Operations and Lifecycle Sustainability

Global data center capacity is projected to more than triple by the end of 2030 and nearly double in power consumption, studies say. This is mainly attributed to the rapid growth of Artificial Intelligence and the increasing demand for massive amounts of data on a daily basis. With advancements in cloud computing, this surge is exponential. Existing data centers are being hyper-scaled, with centers exceeding 50 MW energy capacity to meet the ever-growing demand for data. They are optimized for performance and cost but often overlook carbon signals. As the number of data centers increases, their energy usage grows, leading to higher carbon emissions, often quantified in terms of carbon intensity per unit of power consumed. Numerous state-of-the-art techniques have been proposed, such as DVFS, carbon-aware data transfer, etc. However, these methods often address only a single aspect of the data center, neglecting the joint optimization of all its components. In this paper, we propose an integrated data center architecture that minimizes both operational and embodied emissions.To our knowledge, this is the first framework that jointly optimizes energy, cooling, workload scheduling, and lifecycle emissions within a single architecture. The framework combines energy-proportional hardware, intelligent cooling with waste-heat reuse, carbon-aware scheduling, and onsite renewables with microgrid management. Lifecycle assessment and circular design principles ensure long hardware lifetimes and transparent carbon accounting across the supply chain. We discuss the expected benefits of this unified approach and outline how it can enable substantial reductions in operational and embodied emissions compared to existing siloed methods. This unified architectural framework not only holistically integrates sustainability strategies across data centers, reducing total CO_2 emissions, but also maintains performance and service-level agreements. Together, these strategies shift the focus from reducing watts to minimizing kilograms of CO_2e per job, advancing sustainable data center operations.

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