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# Powering the Sustainable AI Future: Frugal Intelligence, Sustainable Energy, and Lifecycle Accounting at the Energy–Water Nexus

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## Abstract

The rapid expansion of artificial intelligence is creating a complex energy–water nexus, with interconnected demands arising from computation to cooling in the data center, electricity generation, semiconductor manufacturing, and the wider infrastructure and supply chains supporting AI systems. This work examines how AI can reduce both electricity and water use while maintaining performance and reliability. The framework covers ways to reduce demand through efficient AI models, algorithms, hardware, data center operations, cooling, water use, green and clean electricity, and smart workload placement. The framework considers energy and water use, carbon emissions, and water scarcity separately, recognizing that improving one may not always improve the others. Computational efficiency can reduce electricity demand and associated cooling requirements, but its water benefits depend on cooling technology, operating conditions and electricity supply. Dry cooling can reduce direct evaporation while increasing electricity-related impacts; alternative water sources can reduce potable water demand without necessarily reducing overall consumption. The use of low-carbon energy resources is essential for developing sustainable AI data centers, but their effectiveness depends on resource availability, additionality, temporal matching, and local grid conditions. A quality-constrained assessment is proposed using facility- and task-level indicators, geographically resolved water accounting, lifecycle boundaries and demand-rebound analysis. Sustainable AI is framed as the coordinated reduction of energy and water demands and their environmental consequences, rather than optimization of isolated efficiency ratios. Ultimately, sustainable AI requires a systems-level approach that combines frugal intelligence, efficient infrastructure, sustainable energy, and lifecycle accountability to deliver high-quality AI services with lower energy, carbon, water and environmental impacts.

**Keywords:** *AI cooling systems; artificial intelligence; data center; frugal AI; sustainable AI; sustainable energy*