

Energy-Water-Land Frameworks for Data Center Siting and Operations

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Focal Area: Energy-Water-Land Intersections

Existing Challenge: Data centers are rapidly deploying across the country, and the pace is expected to increase [1]. Despite the great diversity of facility types, sizes, and configurations that have been deployed, all data centers have intersections with energy, water, and land resources and infrastructure [2]. Data centers require energy for operations, many require water for cooling systems, and the infrastructure also requires land. Trade-offs of system designs and configurations, especially cooling systems, can have an impact on the total energy needs, resulting water requirements, and land footprint [3]. Beyond on-site intersections with local resources, the energy requirements from the facility will often have off-site impacts. There can be off-site water implications associated with electricity procured from the grid, and there could be additional land impacts depending on the need for and potential location of new generating facilities [2].

Even with early data center development in the United States, there have been reports of negative impacts on water and land resources, including agricultural lands [4, 5]. In this rapidly evolving field, there is growing uncertainty regarding the scale, location, and configuration of data centers and to what extent these facilities may impact or be constrained by water and land resources. There is a need for a relevant and standardized approach for analytical frameworks to robustly inform data center siting and operations while considering the various energy, water, and land trade-offs in the broader context of other energy and economic considerations. Prior DOE investments in data and models, described below, can be leveraged to address some components of this complex multi-sector challenge, but further advancements are needed.

Near-Term Opportunities: The following near-term opportunities represent a collection of interdependent work streams needed to achieve a coherent energy-water-land analytical framework. We frame these opportunities as Impacts, Constraints, Synergies, and Outreach.

Impacts: Characterizing energy, water, and land trade-offs and impacts for different data center configurations and designs: There is substantial uncertainty over the water and land use of different data center types and configurations; a rapidly evolving and expanding industry motivates the need to be able to quantify potential impacts of existing and planned facilities [3].

- *Standardized metrics and factors for water and land use:* Developing robust water use and land use factors for different data center types, energy supplies, and configurations
- will be essential to adequately assess the magnitude of potential impacts. These factors could also consider water quality, land use type, and other more granular impacts beyond water consumption and water withdrawal quantities.
- *Estimates of energy trade-offs of different configurations:* Understanding and quantifying the energy implications of different cooling systems and overall system configurations

will enable an improved assessment of on-site and off-site energy and water usage as well as local land use impacts [6].

- *On-site vs. off-site impacts:* Delineating water and land impacts geospatially through the explicit consideration and differentiation of on-site vs. off-site impacts, along with associated mitigation measures, will be essential due to the site-specific nature of both water and land resources. Off-site impacts will largely be determined by local and regional electric grid infrastructure, which can vary greatly.
- *Contextualizing water and land impacts geospatially:* Characterizing impacts on local water and land resources must use site-specific geospatial datasets at relevant spatial and temporal scales. Estimates of water consumption, water quality, and land use transformation need to be placed in context of local watershed conditions, individual and cumulative water use impacts, competing water demands, prior and surrounding land use, and regional grid infrastructure conditions. This geospatial contextualization is necessarily for assessing both on-site and off-site impacts.
- *Other impacts:* Other topics to consider related to land and water resources include the impacts of data center siting and proximity on property values, visual and lighting externalities that affect landowners, and long-term land use transformation implications.

Constraints: Standardizing approaches to evaluate water- and land-related constraints for

future data center development: A key strategic question to address is to what extent can water availability and land availability serve as constraints to future infrastructure development along with the relevant cost implications.

- *Water availability and scarcity metrics:* Standardizing water availability, water source characteristics (e.g., water quality), and water scarcity metrics, along with methods to assess water quality impacts, will be essential to effectively assess potential water constraints. Water availability and scarcity metrics are complicated by varying water rights regimes that define legal water availability, intra-annual and inter-annual changes in physical water availability, future projections of water demand of other sectors, and future projections of water supplies [7].
- *Economic analysis of water acquisition:* Estimating costs of water acquisition, procurement, treatment, and discharge of industrial water uses can be challenging, with many regional and site-specific factors leading to uncertainty [8]. Improving these capabilities would enable more effective integration with data center siting models.
- *Land availability metrics:* Standardizing land availability and local land use restrictions will be essential to understanding areas where land constraints could hinder data center deployment. Specifically, county-level land use regulations can greatly influence the deployment of energy and industrial infrastructure, and there is a need to better characterize these local restrictions [9]. These must be placed in the context of other land use planning activities happening at the state, county, and local levels.

Synergies: Identifying and evaluating energy-water-land synergies associated with data center

siting: In contrast to considering only impacts and constraints, there are opportunities for water and land resources to provide synergies with data center development.

- *Utilization of alternative water resources:* Instead of fresh water, on-site data center water needs could be met by alternative water resources such as brackish groundwater, municipal wastewater, and industrial wastewater. Using alternative water resources will likely come with an energy and cost penalty, and future research is needed to optimize procurement, transport, treatment, and utilization of these resources [10].
- *On-site energy generation and storage:* To avoid off-site land and water impacts and energy grid perturbations and irregularities, energy for facilities could be produced and stored on-site. There are many distributed energy technologies that could be deployed alongside data center infrastructure, which would localize both land and water impacts while potentially avoiding grid-related challenges.
- *Complete asset life cycle management:* To better understand the holistic impacts of data centers, documenting the costs and impacts of all phases of the data center development process is recommended—from site origination and permitting through construction, commissioning, operations, and long-term asset resource requirements and performance. This could require the establishment of new methods.
- *Integration with other industrial facilities:* Through novel industrial symbiotic arrangements, data centers could be co-located with other industrial facilities to make use of waste heat and available process water while potentially minimizing impacts on land resources. Identifying specific integration points across a variety of industrial sectors would clarify feasibility, cost, and technical potential of these options.

Outreach: Developing a comprehensive clearinghouse of relevant data and an open-source analytical platform: A consolidated, comprehensive data repository and open-source tool would enable the data produced to be widely disseminated and utilized. The clearinghouse would need to have a user-friendly design, updated data, an active user base willing to contribute data, and be trusted by stakeholders. The analytical framework must be robust yet flexible to accommodate novel and emerging configurations, while also providing data at relevant spatial and temporal resolutions.

Success Measure for 3–5-Year Pilot Targets: A variety of metrics could demonstrate the impact that an improved energy-water-land framework for data center siting could have:

- **Design and implementation of cooling system types and configurations** across new data center builds would indicate the relevance of water and/or land constraints.
- **Permitting timelines for data center siting decisions** could be tracked and analyzed to identify the extent to which water and land impacts affect siting.
- **Measured water consumption and watershed-level impacts** data would show site-level impacts and trends of existing and newer facilities.
- **Contributions to clearinghouse** of data would indicate the general traction of the resource for practitioners.
- **Downloads and verified users of the tool** would indicate widespread utilization.

Other metrics could be developed through a more stakeholder-driven process involving industry; local and state governments; and other energy, water, and land managers.

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