SUSTAINABLE DATA CENTERS ROADMAP

Findings and Recommendations

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ICEF
Innovation for Cool Earth Forum

FINDINGS AND RECOMMENDATIONS

Finding 1

With a data center construction boom underway globally, the months and years ahead will be a critical time for data center sustainability. Many decisions with respect to the construction and operation of data centers will have lasting impacts on natural resources and the environment.

Recommendations

1-1. *Data center owners and operators should integrate energy and environmental concerns centrally into the planning for new data centers and operations of existing data centers.*

1-2. *Governments should require disclosure of energy and environmental impacts in connection with data center construction and operations, using standardized metrics. (See Recommendation 11-1.)*

1-3. *Governments should require data centers to meet minimum energy and environmental standards. These standards should address topics such as operational energy efficiency, water use efficiency, low-carbon power and greenhouse gas emissions. (The standards could focus on data centers in particular or be part of broader standards applicable to multiple sectors.)*

Finding 2

Attitudes about data centers vary greatly from place to place and within jurisdictions. Many governments are eager to attract new data centers, typically for a combination of economic and strategic reasons. However, local communities around the world are expressing growing concerns and, in some cases, strong opposition to new data centers.

Recommendations

2-1. Data center owners and operators should engage collaboratively with local communities throughout the life-cycle of a project, from site selection to post-construction operations. This engagement should include communication of both the expected benefits to the community from the data center and potential risks (including those related to grid strain, water resources and local air pollution).

2-2. Data center owners and operators should work collaboratively with local communities in areas near data centers to implement measures that protect residential quality of life.

Finding 3

The energy and environmental impacts of data centers vary dramatically depending on their siting, design, management and other factors.

Well-located and well-managed data centers can help accelerate deployment of low-carbon power by serving as anchor customers for innovative clean energy technologies, de-risking investments in renewables projects and enabling grid flexibility.

Poorly-located and poorly-managed data centers can have serious negative energy and environmental impacts, including greenhouse gas emissions, local air pollution and water stress in surrounding areas.

Recommendations

3-1. Data center owners and operators should make energy and environmental factors a priority in data center siting and management decisions. Governments should make *energy and environmental factors a key factor in data center permitting decisions.*

3-2. *Utilities, regulators and data center operators should support accessible impact analyses on grid, environment, water and electricity pricing to enable informed local community decisions.*

Finding 4

Smart siting is key to minimizing environmental impacts of data centers. Locations with the potential for additional low-carbon electricity and ample water resources are especially important. When economic and strategic factors lead to data centers being sited in locations that are suboptimal from a sustainability standpoint, a range of technology options and management practices can partly reduce adverse environmental impacts.

Recommendations

4-1. *Data center owners and operators should prioritize current and future availability of low-carbon electricity, freshwater and other resources in data center siting decisions.*

4-2. *Data center owners and operators should select technologies and adopt management practices that minimize adverse environmental impact.*

4-3. *Governments should fast-track approvals for well-located, well-designed and well-managed data centers. Priority factors should include availability of low-carbon power and ample water supplies, as well as the potential for power flexibility. Rating agencies and other stakeholders should recognize and credit the energy and environmental performance of such data centers.*

Finding 5

In 2024, data centers used roughly 1.5% of electricity globally. The figure was much higher in some countries and regions, including roughly 4-5% in the United States, 3% in the European Union, 22% in Ireland and 25% in Northern Virginia. Some new data centers in planning and under construction will use extraordinary amounts of electricity (thousands of megawatts and more), straining electric grids.

Finding 6

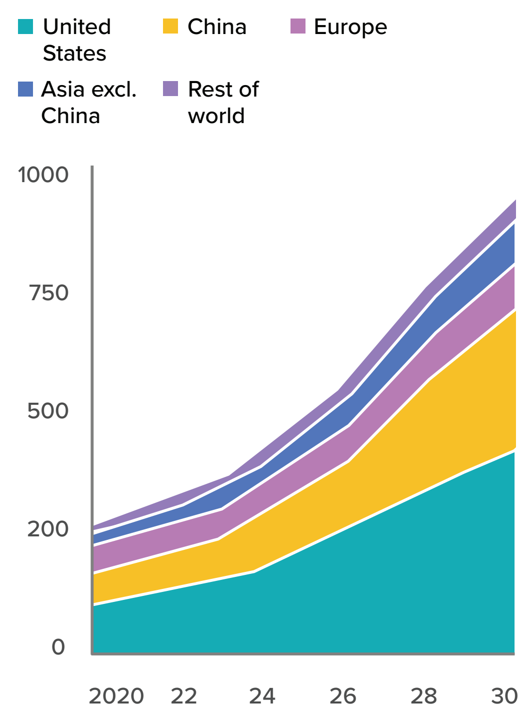
Scenarios of future power demand for data centers vary widely and depend on assumptions related to market growth, technological progress, adoption of efficiency measures and future policies. Recent International Energy Agency (IEA) scenarios suggest that global power demand for data centers could reach 1.8-3.4% of total power demand by 2030. In the United States (home to roughly 45% of global data center capacity), similar scenarios suggest that power demand for data centers could reach 6.7-12% of total power demand by 2028.

Recommendations

6-1. Data center operators should prioritize energy efficiency, including the use of advanced cooling, other highly-efficient equipment and highly-efficient algorithms whenever possible.

6-2. Governments, research institutions and philanthropies should support efforts to develop and disseminate best practices for modeling data center energy use, including inter-model comparisons and open models.

Global data center electricity consumption (TWh) by world region



Source: IEA, Energy and AI (April 2025)

Finding 7

In 2024, data centers were responsible for roughly 0.3% of global greenhouse gas emissions. This figure is likely to increase in the years ahead. The rate of increase will depend on several factors, including in particular the extent to which new data centers use low-carbon power.

Recommendations

7-1. Data center operators should include grid carbon intensity as a key siting consideration and site data centers in the lowest-emitting grid regions as much as possible.

7-2. Data center operators and utilities should work together to identify a mix of new low-carbon power generation technologies to add to the grid to meet rising data center load. This should include renewable power, nuclear power and retrofits of existing fossil fuel power plants with carbon capture and storage.

7-3. Data center operators and utilities should prioritize measures that enhance data center load flexibility when determining the amount of new generation required in connection with new data centers.

7-4. Governments should require disclosure of data centers' life-cycle greenhouse emissions, aligned with standardized protocols. Data center operators should transition to low-global-warming-potential refrigerants, procure carbon-free electricity and set targets for embodied carbon reduction in building materials and equipment. Industry and policymakers should collaborate on marginal emissions accounting to ensure real-world reductions.

Finding 8

The scale of data center growth creates opportunities to bring innovative clean energy technologies to market. Advanced market commitments and direct investments from large data center operators offer an important opportunity to de-risk first-of-a-kind technologies and accelerate deployment of low-carbon power.

Recommendations

8-1. Electricity regulators should enable advanced market commitments that allow multi-buyer participation, recognize hourly matching and credit verifiable flexible-load performance.

8-2. Data center owners and operators should seek additional opportunities for catalytic investments and advanced market commitments that accelerate production of clean power, clean goods and environmental services (such as water reclamation and CO_2 removal).

8-3. Data center owners and operators should pay close attention to immediate local environmental impacts at facilities where advance market commitments offer the potential for longer-term, global clean energy benefits.

Finding 9

Many data centers have traditionally been inflexible loads on electric grids. If this continues, it will create significant stress on many grids, causing reliability problems and increasing greenhouse gas emissions. However, many data centers have significant opportunities to manage their loads with more flexibility, which could improve reliability. Data center load flexibility can also reduce future emissions by minimizing or avoiding construction of new fossil-based generation capacity and enabling better renewables integration.

Recommendations

9-1. Utilities and independent power producers should deploy advanced control tools to accelerate interconnection and grid studies and to operate flexible portfolios. These tools include model-predictive control, enhanced forecasting and, where appropriate, artificial intelligence (AI).

9-2. Data centers should employ power flexibility technologies (including software and energy storage) to reduce impacts on the power grid, especially during periods of high demand and grid stress.

Finding 10

Data center water use is tiny globally in relation to other sectors but can be very significant locally.

Global agriculture water use is roughly 12,000 times greater than global data center water use. The process of producing one hamburger consumes roughly the same amount of water as 19,000 ChatGPT-3 queries.

However, large data centers can have significant impacts on water availability and quality in some regions. Operators can mitigate adverse water impacts from data centers through site selection, choice of cooling technologies, reclaiming water and other measures.

High-quality data on water use at data centers are extremely limited.

Recommendations

10-1. Data center owners and operators should share site-specific water use and consumption data proactively and invite third-party review. If necessary, governments should require disclosure of this information.

10-2. Before siting data centers, data center owners and operators should assess likely water impacts, including in particular by consulting with local stakeholders. In water-scarce regions, companies should consider several steps to reduce likely water impacts, including advanced cooling technologies that require little to no water, water reclamation and reuse, maximizing non-thermal power supplies, and buying building materials and chips with low-water footprints.

Finding 11

Data concerning data centers' environmental impacts are poor, including in particular data concerning greenhouse gas emissions and water use. Absence of data hampers understanding of the sector's impacts, modeling of its potential trajectories and good decision-making. Facility-level disclosures provide significantly more benefit than company-level disclosures. The IEA Energy and AI Observatory is an important repository for information related to data centers.

Recommendations

11-1. Research institutions, standards bodies, non-governmental organizations (NGOs), government agencies, data center operators and equipment manufacturers should converge on common metrics for disclosing data center energy use, water use and emissions.

11-2. Governments should establish dedicated units to monitor data center energy and water impacts. International collaborations, such as the IEA's Energy and AI Observatory and the Clean Energy Ministerial (CEM), should expand their work on data centers, supported by sustained funding.

11-3. Research institutions, governments and NGOs should establish knowledge sharing platforms for developing and sharing best practice datasets, energy models and scenario frameworks to rapidly improve the rigor and accuracy of data center energy models.

Finding 12

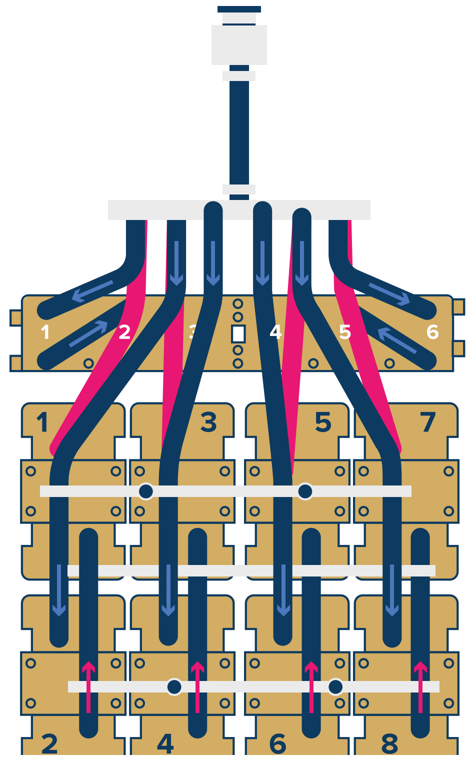
Roughly 95% of data centers today predominantly use air-based cooling. However high-performance computing (HPC) and graphics processing unit (GPU)-heavy workloads are driving adoption of liquid cooling methods, as well as intelligent thermal management. These liquid cooling methods use substantially less water and often significantly less energy per kilowatt of information technology (IT) load than air-based cooling methods, which rely heavily on evaporation and high fan power.

Recommendations

12-1. Data center developers and operators should (1) select locations that enable use of free cooling, heat reuse or access to non-potable water and renewable energy, (2) install climate-appropriate cooling systems and (3) establish facility-level energy and water performance targets and publish sustainability metrics annually.

12-2. National policymakers should establish the market conditions and regulatory frameworks necessary for broad adoption of energy- and water-efficient cooling technologies.

12-3. Standards organizations, such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the International Standards Organization (ISO) and the Open Compute Project (OCP), should establish uniform testing protocols and certification pathways to validate performance of new data center cooling technologies—especially liquid cooling, rear-door heat exchangers and high-efficiency refrigerants.



Direct-to-chip cold plate liquid cooling for high-heat-density data centers.

Finding 13

For data center waste heat to be useful, data centers must be located near heat hosts, such as district heating systems. Opportunities for beneficial use of data center waste heat are greatest in cold climates. Other than in those regions, data center waste heat is unlikely to be used beneficially at a significant scale.

Recommendations

13-1. Data center operators should adopt high-temperature liquid-cooling systems—such as direct-chip or immersion cooling—that achieve exit temperatures of 45-70 °C, enabling effective heat reuse in applications, such as district heating.

13-2. National and subnational governments should require feasibility studies for heat reuse when permitting large new data centers and offer incentives to deploy heat reuse systems. National and subnational governments should consider 10-20% heat reuse mandates for new data centers.

13-3. Heat host industries (e.g., district heating utilities, hospitals, laundries, greenhouses and industrial processes) should actively engage with data-center operators to explore using waste heat for 24/7 applications.

Finding 14

Governments have a wide range of policies to address the energy and environmental impacts of data centers, including regulatory standards, fiscal incentives and disclosure requirements. Power usage effectiveness (PUE) is the most common metric used by governments in data center energy and environmental policies. PUE is an important but narrow metric that only measures one aspect of a data center's energy use. Other metrics, such as carbon usage effectiveness (CUE), water usage effectiveness (WUE) and energy reuse effectiveness (ERE), are important to fully reflect data centers' energy and environmental impacts. Economy-wide policies (not focused on data centers) play an important role in data centers' energy use and environmental impacts.

Recommendations

14-1. Governments should collect and share data on data centers' energy use and environmental impacts.

14-2. Governments should use a broad set of metrics when regulating data centers' energy use and environmental impacts, not just PUE.

14-3. When governments procure data center services, they should require vendors of data center services to disclose their energy use, water use and greenhouse gas emissions.

14-4. IEA Member governments should expand the IEA's Energy and AI Observatory, devoting additional resources to monitoring and reporting on data centers' energy use and environmental impacts, as well as policy trends with respect to data centers around the world. The Clean Energy Ministerial (CEM) should expand its work on data centers under its power sector and AI initiatives.

Finding 15

Data centers produce a small fraction of global e-waste, but the amount of such waste will increase as data center capacity grows in the years ahead. If not handled correctly, hazardous materials in e-waste can leach into soil and water and pose serious environmental and health risks. Recycling and reuse programs can help significantly in managing e-waste challenges. However, data privacy and security concerns, as well as a lack of standardization and transparency, lead to the destruction of many data center components that could be repurposed.

Recommendations

15-1. Governments should implement and harmonize standards for reuse, refurbishment and recycling of e-waste, including safe sanitization of data-bearing IT equipment, and should strengthen extended producer responsibility rules.

15-2. Data center operators should refurbish, resell or donate retired equipment through certified recyclers, reduce equipment turnover with preventative maintenance, and optimize infrastructure using virtualization, cloud computing or shared systems.

15-3 Manufacturers should design modular, repairable and recyclable equipment; provide spare-part support and clear recyclability labeling; and minimize use of hazardous materials.