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Towards Resilient Data Centers

*Evaluating Policies for
Energy Efficiency*

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The environmental impact of data centers necessitates action to address the growing challenges posed by high energy consumption and carbon emissions Ultimately, a multifaceted approach that combines appropriate regulatory measures, financial incentives, consumer awareness, and innovation will enable data centers to meet the growing demand for digital services while minimizing their environmental footprint.



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Executive Summary

As data centers have become an essential part of the digital economy, their growing energy consumption has raised significant concerns. This report examines the factors that influence data center resilience and explores how governments can use this knowledge to improve the efficiency of publicly owned facilities or design procurement contracts that incentivize private data center contractors to adopt energy-efficient technologies.

The report also reviews global initiatives—including Sweden’s EcoDataCenter, Japan’s circular economy programs, the EU Code of Conduct, and U.S. federal efforts under the Data Center Optimization Initiative (DCOI). These case studies showcase innovations in cooling systems, alternative energy integration, and procurement reforms that align private incentives with public sustainability goals.

Despite these advances, resilient data centers continue to face several persistent challenges: high upfront costs of energy-efficient technologies, misaligned incentives between government objectives and contractor profitability, and limited transparency in energy usage and reporting.

To address some of these issues, the report employs economic modeling to evaluate two key contractual incentive mechanisms—Power Usage Effectiveness (PUE) requirement schemes and energy reduction target schemes—and assess their effectiveness in reducing energy consumption and promoting resilience. The analysis highlights counterintuitive results: while both mechanisms can improve efficiency, their effectiveness depends on the cost of upgrading algorithm efficiency. PUE requirements are most effective when upgrade costs are moderately high, encouraging stronger energy management without discouraging innovation. In contrast, energy reduction targets work best when upgrade costs are moderately low, providing direct financial incentives for efficiency improvements.



However, when upgrade costs are either very low or prohibitively high, neither policy proves effective, as intervention costs outweigh potential benefits.

The findings also reveal potential unintended consequences: stricter PUE requirements may inadvertently reduce algorithm efficiency, while energy reduction targets can lead to higher consumer prices. To address these complexities, the report recommends adopting alternative efficiency metrics—such as resource impact per job—that more accurately capture true energy savings; designing heterogeneous and phased incentive schemes tailored to different data center characteristics; allocating dedicated modernization funds or federal grants to help government-owned data centers overcome upfront investment barriers; and monitoring pricing strategies in contracted private data centers to protect consumers while ensuring service reliability.

Ultimately, achieving resilient data centers will require a strategic combination of efficiency measures, financial incentives, and technological innovation to balance sustainability goals with economic realities.

Introduction

The modern era has witnessed an exponential rise in data center deployment, driven by escalating demand for computational power and storage.¹

This surge, fueled by the widespread adoption of cloud computing and resource-intensive technologies such as Artificial Intelligence (AI), Machine Learning, and more recently, Generative AI, has amplified the global dependence on energy-intensive infrastructure. The expansion of data centers has, in turn, triggered a substantial increase in electricity use and associated carbon emissions, a trend further intensified by shifts such as the widespread adoption of remote work.

Governments, as both major operators and consumers of data center services, face unique challenges and opportunities in this evolving landscape. Federal agencies operate thousands of facilities while simultaneously contracting with private providers to host critical workloads. As a result, public policy plays a central role not only in regulating the efficiency of government-owned infrastructure but also in shaping the incentives that guide private contractors toward meeting federal sustainability and resiliency goals. Initiatives such as the DCOI illustrate how federal requirements establish performance benchmarks, while procurement contracts embed incentives to ensure contractors align with government standards.

Previous efforts in the data center sector have focused heavily on technological innovation, from advanced cooling systems to more efficient server utilization. However, technological advances alone cannot guarantee resilient and sustainable operations. Regulatory frameworks and procurement mechanisms are equally critical, as they determine how agencies allocate resources, evaluate performance, and reward efficiency. Bridging technical solutions with government policy is, therefore, pivotal for ensuring that data center operations advance both energy efficiency and resiliency objectives.

This report evaluates the effectiveness of performance-based incentive mechanisms in government procurement contracts designed to promote resilient and energy-efficient data centers. Specifically, it evaluates and compares two widely used performance criteria: (1) efficiency standards based on Power Usage Effectiveness (PUE), as mandated for federal data centers under the DCOI, and (2) the Energy Reduction Ratio. By examining these tools in the context of government-contracted facilities, the analysis provides insights into how federal policy can maximize resiliency gains while maintaining the availability and performance of critical digital services.

The report also considers the broader implications of these mechanisms for multiple stakeholders—including agencies, contractors, and end-users. Efficiency standards influence operational decisions in federal facilities, while incentive-based schemes shape investment choices among contractors. The interaction of these mechanisms with electricity prices, infrastructure characteristics, and demand for services highlights the trade-offs governments must navigate when pursuing resilience. Ultimately, the goal is to identify policy designs that both reduce energy consumption and maintain high levels of service reliability, ensuring that public-sector data centers set benchmarks for resilience and efficiency in the digital economy.

1. Arman Shehabi et al. *United States Data Center Energy Usage Report*. Tech. rep. LBNL-1005775. Lawrence Berkeley National Laboratory, 2016.

Background

This section provides an overview of the resource usage impacts of data centers, the factors influencing their energy efficiency, and the methods used to measure this efficiency.

Resource Usage Impacts of Data Centers

The operation and maintenance of data centers require substantial energy and generate large amounts of electronic waste (e-waste). This section explains these impacts and the areas for improvement.

Energy Consumption. Data centers rely heavily on the energy grid to power servers, storage systems, and networking equipment, with cooling systems necessary to maintain optimal operating conditions. The escalating demand for computing has resulted in data centers consuming an increasing share of electricity, now accounting for two percent of total electricity use in the United States.² As internet traffic, data generation, and high-performance computing applications continue to rise, this energy consumption is expected to grow. Without proper regulations, this figure is projected to rise to eight percent in the United States by 2030, further exacerbating environmental concerns.³

E-Waste. Data centers undergo frequent upgrading of hardware, servers, and other equipment. This fast-paced refresh cycle of technology leads to significant e-waste, much of which is not disposed of in a resilient manner. The complexity of electronic devices further complicates recycling and responsible disposal efforts. E-waste from data centers includes hazardous materials such as lead, mercury, and cadmium, which pose risks to human health when improperly managed.

Improvement Areas. Efforts to mitigate the resource impacts of data centers include innovations in energy-efficient hardware, advanced cooling techniques such as liquid cooling, and the integration of alternative energy sources. Energy-efficient hardware can lower power consumption by optimizing performance and reducing waste. Advanced cooling techniques, such as liquid cooling, can significantly decrease the energy required to maintain optimal temperatures. Additionally, integrating alternative energy sources like solar and wind power can help offset the reliance on traditional energy grids. Transitioning to alternative energy sources and adopting energy-efficient infrastructure are critical to gaining efficiencies in emissions. Improved recycling programs, modular designs for hardware, and policies promoting extended hardware lifespans could help address the growing issue of e-waste. However, widespread adoption of these solutions faces challenges, including high costs, technological limitations, and the need for incentives.

Factors Influencing Data Centers' Resource Usage Impact

Several factors influence how a data center affects resource availability, ranging from energy sourcing to cooling mechanisms. The energy sources and efficiency of a data center's operations, including the use of efficient hardware, power management techniques, and cooling solutions, directly impact energy consumption. Below are the key resource usage factors and technologies.

Energy Sources. Data centers rely heavily on the energy grid to power servers, storage systems, and networking equipment, with cooling systems necessary to maintain optimal operating conditions. The escalating demand for computing has resulted in data centers consuming an increasing share of electricity. The type of energy used is crucial to a data center's resource impact. Grid electricity, which is the primary energy source for most data centers,

2. U.S. Department of Energy. *Data Centers and Servers*. <https://www.energy.gov/eere/buildings/data-centers-and-servers>. 2024.

3. Caroline O'Donovan Evan Halper. *AI is Exhausting the Power Grid. Tech Firms are Seeking a Miracle Solution*. <https://www.washingtonpost.com/business/2024/06/21/artificial-intelligence-nuclear-fusion-climate/>. 2024.

can include a mixture of fossil fuels (e.g., coal, natural gas, and oil) and alternative energy sources (e.g., solar, wind, and hydroelectric). The specific mix varies depending on the geographic location of the data center and the energy policies of the region. Electricity powered by fossil fuels has low efficiency in emissions. In contrast, alternative energy sources have high efficiency in emissions. Common alternative energy sources include on-site solar panels, wind farms, and hydroelectric power.

Increasingly, many data centers are transitioning to using alternative energy to power their operations to meet resiliency goals. Many large companies are committing to running their data centers on 100 percent alternative energy. For example, Google aims to operate its data centers on a 100 percent alternative energy basis, sourcing power from wind, solar, and hydropower, and is continuously working to reduce the resource usage footprint of its infrastructure by 2030.⁴ AWS is using 100 percent alternative energy, including sources like solar, wind, and hydropower.⁵ IBM has also made significant strides in this area. In 2023, 74 percent of the electricity consumed by IBM's data centers came from alternative sources. This was an increase from 66 percent in 2022. IBM's efforts to boost energy efficiency include upgrades in information technology (IT) equipment, retrofitting lighting systems, and improving cooling efficiency.⁶

Cooling Systems. The type of cooling system used in data centers can significantly affect their resource usage impact. Traditional air conditioning systems are energy-intensive. Alternative cooling methods, such as free cooling (which uses outside air in colder climates), liquid cooling (which uses water to conduct heat away), geothermal cooling (which takes advantage of the earth's heat regulation), and AI-driven cooling systems (which leverage artificial intelligence technologies to optimize and enhance cooling performance), can significantly reduce energy consumption.

Many data centers use water for cooling, such as in cooling towers. This can place significant strain on local water resources, especially in drought-prone regions. Additionally, the discharge of heated water into local bodies can harm aquatic ecosystems. Technologies like closed-loop cooling systems, which minimize water usage, or water-free methods like direct liquid cooling can help mitigate these issues. Some data centers repurpose waste heat for district heating, providing warmth to local communities or industries. This practice lowers overall energy demand.

IT Technology. The adoption of low-power processors, advanced power supplies, and solid-state drives reduces overall energy consumption. Server and infrastructure optimization ensures hardware is operating at peak efficiency. Additionally, server virtualization and cloud computing allow data centers to maximize the use of physical hardware, reducing the number of physical servers needed and minimizing energy consumption. By consolidating workloads on fewer servers, data centers can reduce power usage and cooling requirements. Data centers often implement elastic scaling, which allows for more efficient resource utilization by ensuring that computing power is only used when necessary.

4. Google. *24/7 Carbon-Free Energy by 2030*. <https://www.google.com/about/data-centers/cleanenergy/>. 2024.

5. Amazon. *AWS Cloud*. <https://sustainability.aboutamazon.com/products-services/aws-cloud>. 2025.

6. Matthew Gooding. "IBM Claims its Data Centers Run on 74 Percent Renewable Energy". *Data Center Dynamics* (2024). <https://www.datacenterdynamics.com/en/news/ibm-claims-its-data-centers-run-on-74-percent-renewable-energy/>.

Measuring Energy Efficiency in Data Centers

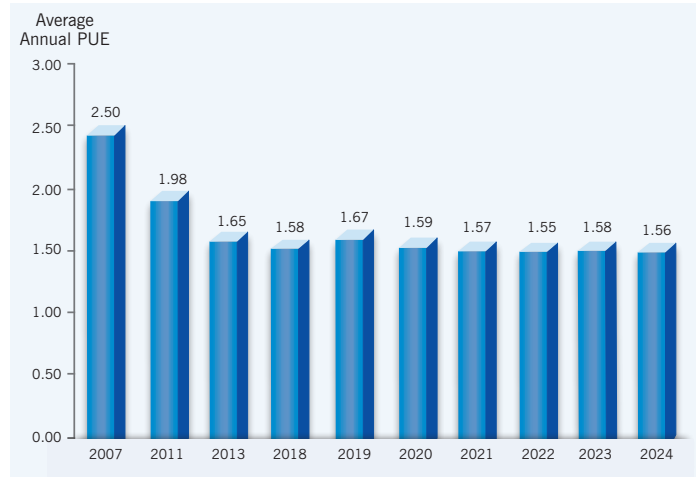
PUE—a key metric used to measure the energy efficiency of data centers—is defined as the ratio of the total amount of energy used by a data center to the energy used by its IT equipment:

$$PUE = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}$$

Total facility energy is the total energy consumed by the data center, including all systems required for its operation (e.g., cooling, lighting, power infrastructure, etc.). IT equipment energy refers to the power consumed exclusively by the IT equipment (e.g., servers, storage, networking hardware, etc). A PUE value of 1 indicates perfect efficiency, meaning the IT equipment uses all the energy. Values greater than 1 indicate that some energy is used for non-IT purposes, such as cooling and lighting. PUE is crucial because it helps data center operators understand how efficiently their facilities use energy and identify areas for improvement. Lowering PUE can lead to significant cost savings.

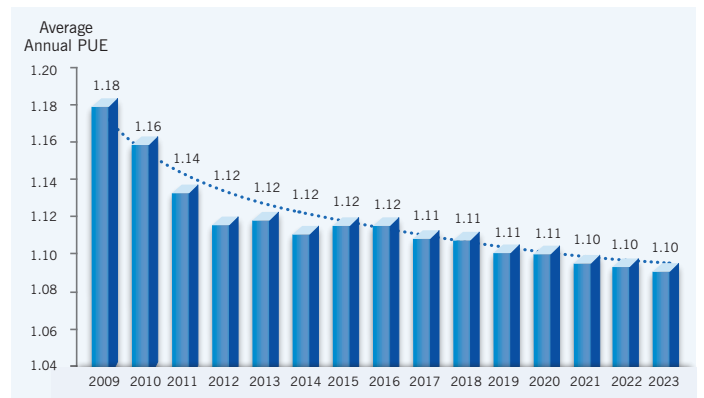
The global average annual PUE has shown significant improvement over the years, as shown in Figure 1. In 2007, the average PUE was 2.50, indicating that data centers were consuming 2.5 times the energy needed for their IT equipment. By 2024, this figure was projected to decrease to 1.56, reflecting advancements in energy-efficient technologies and practices.

Figure 1: Average Annual PUE



This global trend towards improved energy efficiency is further exemplified by the performance of Google’s data centers, highlighted here as it serves as a benchmark for the industry. According to Figure 2, since 2009, Google’s quarterly PUE values have consistently remained close to 1.1, showcasing commitment to energy efficiency and implementing advanced energy management practices.

Figure 2: Google’s Average Annual PUE of All Data Centers⁷



7. ?

Table 1 illustrates the distribution and energy efficiency of data centers across various countries.^{8,9,10} The United States stands out with the highest number of data centers, reflecting its significant role in global data center infrastructure. In contrast, Australia demonstrates remarkable energy efficiency with the lowest average PUE, indicating advanced energy management practices. European countries like Germany and the United Kingdom show moderate energy efficiency while emerging tech hubs such as China and Canada are also making strides in optimizing their data center operations. This data underscores the diverse approaches and advancements in data center energy efficiency worldwide.

Data centers can adopt several strategies to improve their PUE, such as optimizing cooling systems by implementing advanced cooling technologies like liquid cooling, which can significantly reduce energy consumption. Additionally, integrating alternative energy sources, such as solar or wind power, can help lower PUE. Efficient power distribution is another key strategy, involving the upgrading of power distribution systems to minimize energy losses during transmission. By understanding and improving PUE, data centers can enhance their energy efficiency, reduce costs, and contribute to a more resilient future.

Table 1: Data Centers and Average PUE by Country

| Country | Number of Data Centers | Avg. PUE (last reported year) |
|----------------|------------------------|-------------------------------|
| United States | 5,381 | 1.58 (2023) |
| Germany | 521 | 1.70 (2023) |
| United Kingdom | 514 | 1.65 (2023) |
| China | 487 | 1.60 (2024) |
| Canada | 450 | 1.57 (2024) |
| France | 410 | 1.55 (2024) |
| Australia | 306 | 1.48 (2022) |
| Netherlands | 299 | 1.55 (2021) |
| Russia | 255 | 1.70 (2023) |
| Japan | 218 | 1.60 (2024) |

8. Statista. *Number of Data Centers and Average PUE by Country*. 2023. <https://www.statista.com>.

9. Uptime Institute. *Data Center Efficiency and Performance Metrics*. 2023. <https://www.uptimeinstitute.com>.

10. Cushman & Wakefield. *Global Data Center Trends and Statistics*. 2023. <https://www.cushmanwakefield.com>.

Global Approaches to Data Center Efficiency

Governments worldwide are implementing frameworks to ensure that data centers—whether publicly operated or privately contracted—meet stringent standards for energy efficiency and resilience. At the same time, a number of initiatives and programs have emerged as industry-leading examples, showcasing innovative technologies and best practices designed to reduce energy consumption and strengthen operational resilience.

The following subsections highlight notable efforts by organizations and governments that are setting the pace in building more efficient and resilient data centers.

Sweden: EcoDataCenter Initiative

The Swedish government has taken a significant step in promoting resiliency by building a highly efficient data center that operates entirely on 100 percent alternative energy. EcoDataCenter stands as a leading example of this initiative. One of the key features of this data center is its use of free cooling. Free cooling takes advantage of the naturally cool outdoor temperatures, especially in colder climates, to cool the facility without the need for energy-intensive mechanical refrigeration systems. By filtering and humidifying cooler outdoor air and converting it into a water circuit through a heat exchanger for use inside the data center, the facility significantly reduces its electricity consumption.

In addition to energy-efficient cooling, the data center incorporates an innovative approach to waste heat reuse. The excess heat generated by the servers and other equipment is captured and repurposed to warm nearby buildings. This heat recovery system helps to maximize the overall energy efficiency of the facility, reducing the need for external heating sources, such as natural gas, and further contributing to the facility's resilient operation.

The success of this data center is evident in its PUE of 1.22.¹¹ In contrast, the industry average PUE is typically around 1.56 in 2024, according to Figure 1, highlighting the substantial energy savings and operational efficiency of the Swedish facility. The low PUE signifies that the data center is using energy efficiently, with minimal waste in cooling and other supporting functions.

European Union: Code of Conduct for Data Centers

The European Commission has established the Code of Conduct for Energy Efficiency in Data Centers, a voluntary framework that sets efficiency targets and best practices for public-sector facilities.¹² Government agencies in the EU are encouraged to adopt measures such as energy-efficient cooling, renewable integration, and workload consolidation. Although voluntary, the program is widely adopted across member states and serves as a baseline for procurement, with agencies frequently requiring contractors to demonstrate compliance.

11. EcoDataCenter. <https://ecodatacenter.tech/>. 2025.

12. European Commission Joint Research Centre. *European Code of Conduct for Energy Efficiency in Data Centres*. 2022. https://joint-research-centre.ec.europa.eu/scientific-activities-z/energy-efficiency/energy-efficiencyproducts/code-conduct-ict/european-code-conduct-energy-efficiency-data-centres_en.

Japan: Circular Economy Data Center Initiative,

Japan's Ministry of Environment has launched initiatives aimed at promoting a circular and ecological economy, reflecting the country's strong commitment to sustainability.¹³ This initiative also encourages data center operators to adopt practices that minimize waste and maximize the reuse, recycling, and re-manufacturing of IT equipment and infrastructure components.

In particular, the circular principle implies that data centers integrate practices such as repairing and refurbishing IT hardware, reusing server components, and recycling electronic waste. By reducing the need for new raw materials and keeping obsolete equipment out of landfills, these centers can significantly reduce their resource usage impact while maintaining high operational standards. This aligns with the broader goals of the circular economy, where products and materials are kept in use for as long as possible to extract maximum value and minimize waste.

Japan's program and the example of this innovative data center showcase how the combination of energy-efficient technologies and circular economy principles can lead to the creation of data centers that are highly effective. As such, these models provide valuable insights for other nations and organizations that are looking to implement more efficient data infrastructure, paving the way for a more resilient digital future.

Singapore and Australia: Green Mark and NABERS

Singapore's Green Mark for Data Centers certification¹⁴ sets mandatory requirements for public-sector facilities and strongly incentivizes private operators working with government clients to meet resiliency thresholds. Other Asia-Pacific governments are moving in similar directions. For example, in Australia, starting July 2025, any data center hosting federal workloads must attain a minimum

five-star NABERS Energy rating—or otherwise demonstrate operational optimization—under the Net Zero in Government Operations strategy.¹⁵ These policies reflect a regional emphasis on using government demand to accelerate resilient practices across the industry.

United States: Resilient Federal Data Centers

The U.S. government is actively leading the charge in promoting resiliency by piloting a series of comprehensive measures at its federal data centers. These initiatives are designed to drastically reduce the resource impact of government-operated data center infrastructure while ensuring high performance and efficiency. The government's pilot programs focus on integrating a wide range of cutting-edge technologies and strategies, all aimed at making federal data centers more energy-efficient and resilient.

The U.S. government has been leading resiliency efforts through the DCOI.¹⁶ One of the central aspects of this resiliency effort is energy efficiency. Federal data centers are being optimized to reduce energy consumption by adopting energy-saving technologies such as advanced cooling systems, energy-efficient IT equipment, and the integration of smart power management systems. These measures are designed to lower the overall electricity demand of the facilities and decreasing operational costs over time. One significant pilot project is the U.S. Army's use of liquid cooling technology in its data centers.¹⁷ By adopting direct-to-chip liquid cooling, the data centers have greatly reduced the need for energy-intensive cooling systems while improving overall system performance. Furthermore, AI-driven cooling systems leverage AI algorithms to analyze data such as temperature, airflow, and equipment efficiency, optimizing cooling output and leading to reduced energy consumption and cost savings.

13. Japan Ministry of the Environment. *Circular and Ecological Economy*. <https://www.env.go.jp/en/policy/cee/>. 2012.

14. Infocomm Media Development Authority. *BCA-IMDA Green Mark for Data Centres*. <https://www.imda.gov.sg/how-we-can-help/bca-imda-green-mark-for-data-centres-scheme>. 2024.

15. Michael Wilson. *Australian Government Sets New Standards for Data Centre Efficiency*. <https://www.nlyte.com/blog/australian-government-sets-new-standards-for-data-centre-efficiency/>. Accessed: 2025-08-22. 2024.

16. Center of Expertise for Energy Efficiency in Data Centers. *Data Center Optimization Initiative (DCOI)*. <https://datacenters.lbl.gov/data-center-optimization-initiative-dcoi>.

17. Penny Jones. *Asetek Takes Liquid Cooling in to US Military Data Centers*. <https://www.datacenterdynamics.com/en/news/asetek-takes-liquid-cooling-in-to-us-military-data-centers/>. 2012.

In addition to enhancing energy efficiency, the adoption of alternative energy is crucial to meeting the rising electricity demand. Solar and wind energy are identified as two of the most scalable and cost-effective solutions to support the growing electricity needs of data centers. This shift towards alternative energy not only reduces reliance on fossil fuels but also further lowers the resource usage impact of data centers.

Another key feature of these resiliency measures is wastewater recycling. Federal data centers are incorporating advanced systems to recycle and reuse wastewater, such as that generated by cooling processes or from the facility's daily operations. The National Security Agency data center in Fort Meade, Maryland, uses recycled wastewater to cool and power the facility. By reprocessing this water for non-potable uses, such as cooling or landscaping, the data centers can reduce their overall water consumption, minimizing strain on local water resources. This resilient water management approach aligns with growing concerns about water scarcity, particularly in areas experiencing droughts or other water-related challenges.

Incorporating energy monitoring tools, such as those offered through Data Center Infrastructure Management (DCIM) technology, can significantly enhance energy conservation efforts. DCIM enables data managers to automatically track data center assets and measure key factors like energy usage, cooling, virtualization, server utilization, and facility performance. The insights gathered from this data allow operators to optimize data center construction and operations, reduce costs, and improve energy efficiency, ultimately leading to more informed and strategic decision-making.

The U.S. government's ambitious resiliency measures at federal data centers set an important example for the private sector and other government entities around the world. By demonstrating the feasibility of implementing such comprehensive resiliency practices, these projects are paving the way for a future where data centers can operate in an effective way, helping to meet the growing demand for digital services without compromising the resources of the planet.



Challenges in Achieving Resilient Data Centers

While successful resilient data center initiatives have shown the potential to reduce energy consumption and resource impact through innovations in IT technology, alternative energy adoption, and advanced cooling methods, significant challenges remain in promoting widespread effective practices.

Improving energy efficiency in data centers is a multifaceted challenge, involving multiple key issues. From the high upfront costs associated with upgrading infrastructure and adopting advanced technologies to the misalignment of incentives between government policies and data center companies, and the need for greater transparency in energy usage and resource usage reporting, each of these factors plays a critical role in shaping the path towards more resilient data center operations. This section delves into these challenges, exploring the complexities and potential solutions for making data centers more energy efficient.

High Upfront Costs of Energy Efficiency Improvements

For government-owned data centers, budget constraints and multi-year procurement cycles can delay infrastructure upgrades. Even when agencies recognize the long-term savings of advanced cooling systems or alternative integration, capital expenditures must compete with other priorities in the federal appropriations process. For private contractors, especially smaller firms, the challenge is different: limited access to financing or risk-averse investors can hinder adoption of energy-efficient technologies. When government agencies procure services from contractors, they may need to incorporate subsidies, accelerated depreciation allowances, or favorable contract terms to offset these initial costs.

Beyond these differences, both types of facilities face steep costs for upgrading to efficient servers, liquid or free-air cooling systems, and on-site alternative power. For federal facilities, retrofitting older government buildings often requires navigating complex compliance processes (e.g., federal building codes and General Services Administration (GSA) standards, which are guidelines from the GSA that set requirements for federal building design, construction, and operation), adding time and cost. For contractors, obtaining third-party certifications, such as LEED (Leadership in Energy and Environmental Design), can be a financial burden but may be incentivized through procurement scoring. Thus, while the upfront cost issue is universal, its root causes and remedies differ between government-owned and contracted centers.

Incentives Misalignment Issue

Government agencies aim to promote long-term resiliency, reduced resource impact, and compliance with federal initiatives such as the DCOI. Private contractors, however, are driven primarily by profitability and may not prioritize energy efficiency unless the contract structure makes it financially worthwhile. This misalignment often leads to suboptimal outcomes unless contracts are carefully designed.

For government-owned facilities, the misalignment is internal: even if managers identify opportunities for cost savings through efficiency improvements, they may not be allowed to reinvest those savings directly into further upgrades. Instead, savings are absorbed into general agency budgets, reducing the motivation to pursue additional projects.

For contractor-operated facilities, the misalignment is external: unless the contract explicitly rewards efficiency, the contractor's profitability depends more on pricing and service volume than on energy performance. One way to close this gap is through performance-based contracting, where payments are tied to outcomes. For example, contracts can reward contractors for achieving lower PUE values, reducing total energy consumption, or implementing alternative integration, and penalize them for falling short of agreed benchmarks. Such mechanisms create a direct financial incentive for contractors to align with government efficiency and resiliency objectives.

In short, while the government seeks to optimize long-term resilience, both government-owned and contractor-operated centers face barriers: the former due to rigid budget rules, and the latter due to weak incentives in traditional procurement structures. Aligning these incentives through contract design and budget flexibility is essential to bridging the gap.

Lack of Transparency

Transparency in energy usage and reporting is a persistent challenge, but it takes different forms for government-owned and contractor-operated data centers. Government-owned facilities often have internal mandates to report performance, such as those under the DCOI. However, enforcement is inconsistent across agencies, and reporting formats are not always standardized, which makes it difficult to compare performance or track progress at a national level.

For contractor-operated data centers, the issue is more acute. Contractors may choose to highlight selective achievements (such as alternative adoption) for marketing purposes while withholding full operational data. Without a standardized reporting framework written into contracts, agencies have limited ability to verify actual energy performance. Contractors may also resist full disclosure, citing competitive or proprietary concerns.

To address this, governments could require uniform, standardized reporting frameworks across both government-owned and contractor-operated facilities, backed by independent third-party verification. For example, procurement contracts could mandate that contractors disclose PUE, alternative energy usage, and cooling efficiency metrics in a consistent format. Agencies could then use these disclosures to compare providers, track progress, and identify best practices.

In short, government-owned centers struggle with uneven enforcement, while contractors often lack standardized requirements altogether. Robust and enforceable reporting obligations—combined with independent verification—are essential for policymakers to assess performance, build accountability, and drive continuous improvement in resiliency.

Across all three challenges—high upfront costs, misaligned incentives, and lack of transparency—government-owned and contractor-operated data centers face overlapping but distinct barriers. Federal facilities struggle primarily with rigid budget cycles, compliance requirements, and uneven enforcement, while private contractors face financing constraints, profit-driven trade-offs, and limited reporting obligations. Addressing these differences requires tailored strategies: budget flexibility and dedicated funding streams for government-owned centers, and procurement reforms that embed efficiency requirements, financial incentives, and standardized reporting for contractor-operated centers. Only by recognizing and addressing these distinct challenges can policymakers create a unified path toward resilient and energy-efficient government data infrastructure.

Government Regulation and Procurement for Resilient Data Centers

The government plays a dual role in the data center ecosystem: it operates thousands of federal data centers across agencies and is also a major customer of private-sector facilities through procurement contracts.

As such, energy-efficiency policies must focus both on direct regulation of federal data centers and on incentive structures embedded in government contracts. Rather than relying solely on broad-based taxes or subsidies aimed at private companies, federal initiatives target operational improvements in government-owned facilities while aligning contractor incentives with federal resiliency goals.

Grants and Federal Modernization Programs

Federal agencies receive targeted funding to upgrade their own data centers. Programs such as the DOE's Federal Energy Management Program (FEMP)¹⁸ and the GSA's modernization initiatives¹⁹ provide technical assistance and capital for implementing advanced cooling, alternative energy integration, and AI-driven monitoring systems. These grants and programs allow agencies to overcome budget-cycle barriers and accelerate compliance with federal efficiency mandates. By funding internal modernization, the government demonstrates leadership in resilient operations and establishes benchmarks for the private sector.

PUE Requirement Under the DCOI

The DCOI mandates that agencies achieve specific targets for PUE, data center consolidation, server utilization, and reporting transparency. Each agency must track and report progress toward these metrics, with GSA and the Office of Management and Budget (OMB) overseeing compliance. This requirement ensures that federal facilities consistently adopt industry best practices in energy efficiency. Importantly, federal agencies also extend similar expectations to contractors: procurement solicitations often require that private data centers hosting government workloads meet or exceed the same PUE thresholds applied to federal facilities, ensuring alignment between public and contracted operations.

Under the DCOI, federal agencies were required to ensure existing tiered data centers achieve and maintain a PUE of 1.5 or lower, while new tiered data centers must be designed to maintain a PUE of 1.4 or lower—with best-in-class designs encouraged to target a PUE near 1.2.²⁰ These thresholds were intended to standardize efficiency across government-operated infrastructure and establish a benchmark for private contractors managing federal workloads.

However, this metric may not always result in improved environmental outcomes, as more efficient algorithms could reduce IT energy consumption while leaving cooling energy unchanged, inadvertently increasing PUE, despite an overall improvement in data center efficiency. Hence, a focus on PUE may not always lead to superior environmental outcomes.

18. U.S. Department of Energy. *Home Federal Energy Management Program*. <https://www.energy.gov/femp/federal-energy-management-program>.

19. U.S. General Services Administration. *IT modernization*. <https://www.gsa.gov/policy-regulations/policy/information-technology-policy/it-modernization>.

20. Patrick Donovan. *DCOI Compliance: A Guide to Improving PUE in U.S. Federal Data Centers*. <https://www.apc.com/us/en/support/resources-tools/white-papers/dcoi-compliance-a-guide-to-improving-pue-in-us-federal-data-centers.jsp>.

Under the OMB, agencies are still required to measure and report PUE, but they are no longer held to fixed thresholds as the sole measure of performance. Instead, OMB places greater emphasis on data center availability, consolidation, and server utilization, recognizing that PUE can be influenced by factors such as geography, redundancy requirements, and workload type.²¹

In practice, this means that while PUE remains an important metric for benchmarking and contract compliance, agencies now evaluate it alongside a broader set of criteria. Many procurement contracts continue to embed PUE requirements—often referencing the original 1.5/1.4 thresholds—as baseline expectations, while also rewarding contractors who exceed these standards through performance-based clauses. This dual approach maintains accountability for efficiency while giving agencies and contractors flexibility to balance energy performance with resiliency and availability needs.

Tax Incentive for Energy Reduction

Another avenue for the government to influence resiliency more broadly is via tax mechanisms. Specifically, tax incentives could be offered to data centers, including those contracted by the government, that meet specified energy reduction targets. The energy reduction ratio calculates the ratio of energy use after implementing energy-saving measures to the energy use before. This ratio is key for evaluating the effectiveness of energy conservation initiatives and tracking progress toward resiliency goals. For example, if a data center implements new cooling systems or more energy-efficient hardware, the energy reduction ratio can show the success of these changes.

In the United States, there are several federal and state incentives aimed at promoting energy-efficient data centers. Federally, the Investment Tax Credit (ITC) allows data centers to qualify for tax credits when they invest in energy-efficient technologies. Additionally, accelerated depreciation is

available for energy-efficient equipment, which helps reduce taxable income. At the state level, Maryland offers sales and use tax exemptions for data center equipment and electricity used by data centers. North Carolina provides similar sales tax exemptions on electricity and equipment, and Loudoun County in Virginia offers sales and use tax reductions for data centers.

In Europe, France provides tax relief through the Energy Investment Allowance (EIA) for investments in energy-saving technologies. Sweden offers an energy tax reduction for data centers that meet certain efficiency criteria, making it financially beneficial for data centers to adopt more resilient practices.

Other regions also have incentives in place. In Australia, the Energy Savings Scheme offers incentives for data centers that implement energy-efficient measures. In Canada, the Accelerated Capital Cost Allowance (ACCA) allows for faster depreciation of energy-efficient equipment, reducing the financial burden of such investments.

Beyond incentives, there are also specific tax structures that have been proposed and implemented to incentivize resilient practices, including resilient computing. A popular example is the “carbon tax,” which is a tax levied based on the amount of CO₂ (or equivalent) usage due to the consumption of fossil fuels in an industry. Such a tax has been implemented, for example, in British Columbia, Canada, since 2008.²² Such taxes are also common in Europe, with Finland introducing a carbon tax as early as 1990.²³

21. Sebastian Moss. “Lawmakers criticize OMB’s overhaul of Data Center Optimization Initiative”. *Data Center Dynamics* (2019). <https://www.datacenterdynamics.com/en/analysis/lawmakers-criticize-ombs-overhaul-data-center-optimization-initiative/>.

22. Akio Yamazaki. “Jobs and climate policy: Evidence from British Columbia’s revenue-neutral carbon tax”. *Journal of Environmental Economics and Management* 83 (2017), pp. 197–216.

23. Alex Mengden. Carbon Taxes in Europe, 2024. <https://taxfoundation.org/data/all/eu/carbon-taxes-europe-2024>. 2024.

As shown in Table 2, various countries have implemented different carbon tax rates to incentivize the reduction of carbon. These rates vary significantly, with Uruguay having the highest rate at \$167 per metric ton of CO₂, while Japan has the lowest at \$3 per metric ton. Such variations highlight the diverse approaches taken by countries to address carbon usage through taxation.

Table 2: Carbon Tax Rates by Country²⁴

| Country | USD/metric ton of CO ₂ Uruguay |
|-------------|---|
| Uruguay | \$167 |
| Sweden | \$137 |
| Switzerland | \$101 |
| Finland | \$100 |
| Norway | \$69 |
| France | \$56 |
| Japan | \$3 |

While such incentives could spur effective technologies, the impact on consumer spending is uncertain. While energy efficiency improvements could benefit consumers through faster services, data centers might raise prices to maintain profitability, potentially offsetting these consumer benefits.

Governments face the challenge of regulating data centers without stifling technological innovation. Strict policies may hinder the growth of emerging technologies such as AI, cloud computing, and big data analytics, which heavily depend on data centers. Policymakers must strike a balance between fostering innovation and ensuring resiliency, which can be difficult given the fast-paced evolution of the tech industry.

Contractual Models for Energy Efficiency

Beyond regulating its own facilities, the government leverages its purchasing power to shape contractor behavior. Many federal agencies finance energy efficiency projects in data centers through performance-based contracting models such as Energy Savings Performance Contracts (ESPCs). Under these agreements, contractors or Energy Service Companies (ESCOs) fund and implement upgrades—such as advanced cooling systems or alternative energy integration—and are repaid through the verified energy savings generated over time. Other incentive structures, including cost-plus-incentive-fee contracts and shared-savings arrangements, allow contractors to receive additional compensation or retain part of the cost reductions when efficiency targets are exceeded. Specifically, the cost-plus-incentive-fee contract covers expenses related to government services. If the contractor meets certain performance goals—such as maintaining a PUE level below a specified threshold or achieving energy reduction targets during the contract period—they are eligible for an additional incentive bonus. These contractual mechanisms realign profitability with federal resilience goals, ensuring that private partners have a direct financial interest in achieving measurable improvements in data center efficiency and resiliency.²⁵

Taken together, these approaches illustrate how the federal government advances data center resiliency through both direct regulation of its own infrastructure and procurement mechanisms that influence private operators. Modernization grants and programs provide agencies with resources to lead by example, the DCOI establishes consistent efficiency benchmarks while adapting to operational realities, and contractual models ensure that private partners share in the responsibility—and benefits—of meeting federal resilience goals. By integrating regulation, funding, and procurement incentives, the government not only strengthens its own data center operations but also steers the broader market toward higher standards of energy efficiency and resiliency.

25. Schneider Electric. *Consolidating Federal Data Centers Through Energy Savings Performance Contracts*. <https://blog.se.com/datacenter/2014/08/05/consolidating-federal-data-centers-energy-savings-performance-contracts/>. 2014.

24. ?

Economic Modeling and Analysis of Different Incentive Schemes

While the impact of straightforward regulations on government-owned data centers is relatively easy to predict, the effects of incentives related to meeting PUE requirements and energy reduction targets during the procurement of data services from private contracts are more complex.

To gain deeper insight into the impact of these incentives, an economic model is employed that focuses on these two incentive schemes.

Economic modeling is the process of creating abstract mathematical models to simulate and predict the behavior of economic systems, as well as to understand, explain, and forecast economic outcomes. By simplifying complex economic realities, these models focus on the key variables and relationships that drive economic decisions and interactions. Economic modeling helps the government, businesses, and researchers assess the effects of various contracts and predict future trends.

This model analyzes a scenario involving three key entities:

1. **Government** agencies
2. **Private contractor** (i.e., private data center companies)
3. **Customers** or **users** of the data centers.

The decisions made by each entity are outlined below.

Government. In the economic model, the government adopts cost-plus-incentive-fee contracts for procurement: covering the data center's variable resource costs while offering additional incentives to improve efficiency. Specifically, the government's objective is to select an optimal incentive scheme among the two options below that minimizes the total monetary budget (the sum of the incen-

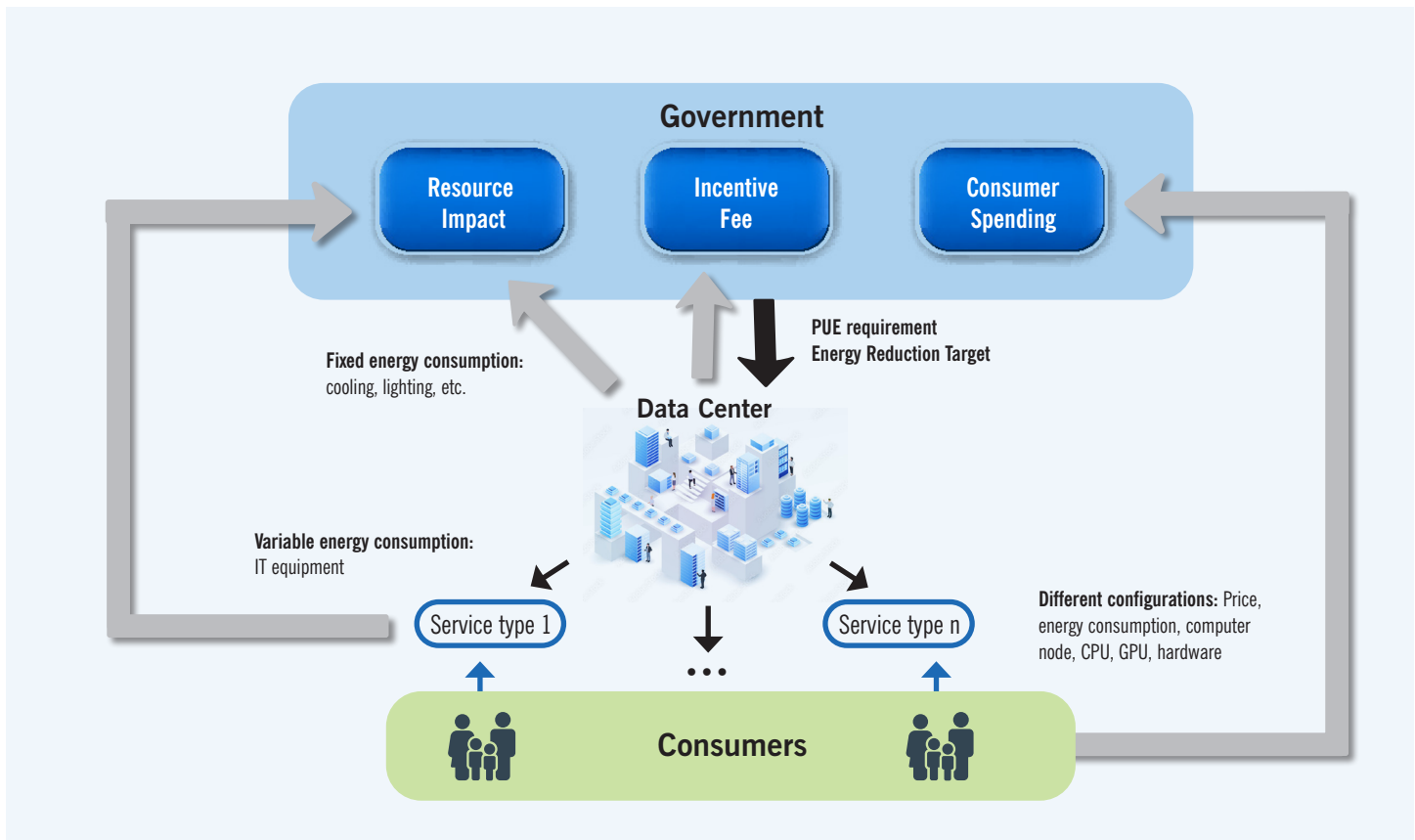
tive fee and the data center's variable costs for contracted services) plus resource impact, and minus consumer spending (as depicted in Figure 3). Under each incentive scheme, the government determines specific incentive parameters:

- **PUE Requirement.** The government establishes a maximum PUE threshold that data centers must meet in order to qualify for an incentive fee, and determines the corresponding fee amount. PUE is defined as the ratio of the total energy consumed (including energy consumed by IT equipment, as well as non-IT infrastructure such as cooling, power delivery, and lighting) to the energy used solely by IT equipment.
- **Energy Reduction Target.** The government sets energy reduction targets for data centers to qualify for an incentive fee and determines the corresponding fee amount.

Data center. The data center will adjust algorithm efficiency, cooling methods, as well as its pricing to consumers, to maximize profits while reacting to the relevant incentives (as depicted in Figure 3). The data center's profit is calculated as the payment from the government, plus revenue from consumers, minus both the variable electricity costs (for IT equipment) and the fixed electricity costs (for cooling and lighting). The following steps outline the process in analyzing how each incentive scheme impacts decision-making:

- **No incentive scheme in effect:** The government only covers the variable costs incurred by the data center for its services. In this case, since the data center does not earn revenue from the government, it makes decisions based on profit-maximizing strategies, considering the cost of technology, the cost of electricity and consumer demand.
- **PUE requirement:** The data center evaluates whether to maintain a PUE below the threshold to qualify for the incentive fee. It compares the profit from optimal decisions without the incentive fee to the profit from meeting the PUE requirement and receiving the incentive fee.

Figure 3: Economic Modeling Framework



- **Energy reduction target:** The data center evaluates whether to reduce energy consumption sufficiently to qualify for the incentive fee. It compares the profit from optimal decisions without the incentive fee to the profit after meeting the energy reduction target and receiving the incentive fee.

Customers or users. Customers make their service choices based on factors such as service speed, sensitivity to service speed, and price. These choices determine the demand.

The analysis of the incentive schemes highlights several key potential impacts and reveals the complex interplay between these schemes, efficiency improvements, profitability, and the resource usage impact of data centers.

The Impact of Resilient Technologies

Resilient technologies, such as more efficient algorithms that reduce IT energy consumption per task or advanced cooling methods that lower cooling energy usage, often come with additional costs but have the potential to enhance overall societal benefits. The analysis shows that while improved cooling technology consistently reduces energy consumption and lowers PUE, the effects of a more efficient algorithm can be more complex.

On one hand, the faster service speed enabled by the algorithm reduces IT energy consumption per job, which lowers overall IT energy consumption but paradoxically increases the PUE. This is because PUE is a ratio of total facility energy to IT equipment energy, and a reduction in IT energy without a corresponding proportional reduction in total energy can lead to a higher PUE. On the other hand, increased service speed may attract more customers, boosting consumer spending and, consequently, raising IT energy consumption.

This higher IT equipment consumption could lead to a lower PUE, as PUE is the ratio of total facility energy to IT equipment energy. The growing demand can enhance data center profitability, which might then be reinvested into further efficiency improvements, ultimately reducing the PUE.

Given the mixed effects of resilient technologies on PUE and other metrics, it is uncertain whether a PUE-based incentive would always result in benefits. While improved cooling technologies have a clear and direct impact on reducing energy consumption and PUE, the benefits of more efficient algorithms are more nuanced. They can lead to both positive and negative outcomes depending on how they influence overall energy dynamics within the data center. Therefore, the government must account for these complexities when designing incentive-based contracts aimed at enhancing resilience in data centers. Striking a balance between the direct and indirect effects of these technologies is essential to ensure that the incentives result in genuine resource benefits.

The Impact of PUE Requirement Incentive Scheme

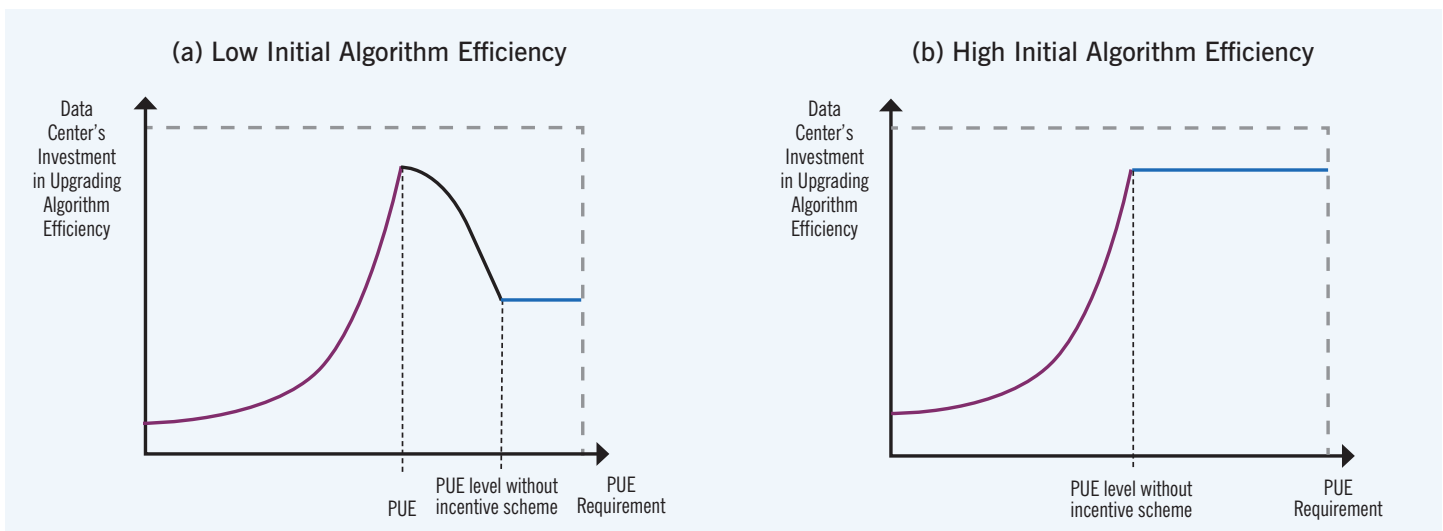
The implementation of incentive contracts tied to PUE requirements can significantly impact data center operations, energy consumption, and consumer spending. However, these impacts can be complex and context-dependent, influenced by factors such as existing technology adoption, cost structure, algorithm efficiency, and other conditions. Below are the key potential effects:

Cooling Technology. A stricter PUE requirement in the incentive contract typically encourages data centers to adopt more efficient cooling technologies, which reduces the energy required for cooling—a major contributor to overall energy consumption. While this lowers both energy consumption and PUE, the adoption of such technologies often involves high upfront costs, which may result in reduced profitability for data centers due to these additional expenses.

As such, the government must offer substantial incentive fees to data centers to offset high upfront costs and encourage the adoption of more efficient cooling technologies. At the same time, to offset the higher costs associated with implementing resilient technologies, data centers may ultimately raise prices to maintain profitability. Such price increases could harm consumers and reduce overall consumer spending.

Algorithm Efficiency. Suppose the incentive fee is sufficient to motivate the data center to meet the PUE requirement. Our analysis indicates that the effectiveness of the PUE requirement incentive scheme depends on the efficiency of the data center's algorithms.

Figure 4: Impact of PUE Requirement Incentive Scheme on Algorithm Efficiency



- Low Algorithm Efficiency:** If the data center's algorithm efficiency is low (as shown by the black curve in Figure 4(a)), implementing a stricter PUE threshold could push the data center towards resilient improvements. In such cases, existing technologies can be adopted at a relatively low cost, and the data center may focus on reducing IT energy consumption per job through better algorithm optimization. This could lead to faster service speeds, attracting more consumers. At the same time, to increase the share of energy consumed by IT equipment, the data center would lower prices to further expand demand, ultimately benefiting consumer spending. However, the increased demand leads to a higher number of jobs, thereby increasing total energy consumption. Since maintaining a lower PUE is more costly for the data center, the minimum incentive fee required from the government increases accordingly, thereby raising the overall budget, despite a reduction in cost coverage due to decreased energy consumption for procurement.
- High Algorithm Efficiency:** Conversely, if the data center's algorithms are already highly efficient (see, e.g., the purple curves in Figure 4(a) and Figure 4(b)), further improvements may require significant investment in research and development, which can be prohibitively expensive. In this case, data centers may respond to stricter PUE thresholds by increasing IT energy consumption, both by raising energy use per job and by increasing the number of jobs. To achieve this, the data center would reduce algorithm efficiency and lower prices. While this may boost consumer spending, it could also result in slower service speeds, higher overall energy consumption, increased procurement costs, and ultimately undermine the intended resource benefits. Similar to the case of low algorithmic efficiency, the government must offer a higher incentive fee and allocate a larger budget to motivate the data center to meet more stringent PUE thresholds.

Conditions for Effective PUE Requirement Incentive Scheme Adoption. Further analysis suggests that the optimal PUE requirement incentive scheme should be adopted when the cost of improving algorithm efficiency is moderate. If the cost is too low and the data center's algorithm efficiency is already high, meeting the PUE threshold could inadvertently prompt a reduction in algorithmic efficiency to increase IT energy consumption, leading to higher overall energy usage, and ultimately undermining the government's objectives. Conversely, if the cost of improving algorithm efficiency is high (e.g., for smaller companies that cannot afford technological upgrades), data centers may find it prohibitively expensive to make improvements and may instead focus on increasing demand to meet the PUE threshold. This would lead to a significant increase in energy consumption, ultimately diminishing the value of the government's objective.

The Impact of Energy Reduction Target Incentive Scheme

Below are the key potential effects of the energy reduction target incentive scheme.

Cooling Technology. A stricter energy reduction threshold would directly lead to lower total energy consumption. To achieve this, data centers would need to improve their cooling technologies. However, data centers may turn to demand management as a solution. This would involve adjusting their energy consumption by raising prices to reduce demand, which in turn reduces consumer spending. Although complying with the energy reduction threshold might require data centers to make suboptimal decisions for their profitability, leading to reduced profits, they would only choose to meet the target if it makes them better off overall. Therefore, under the energy reduction target incentive scheme, a data center's overall earnings (profit plus incentive fee) would not be adversely affected. To offset data center costs, the minimum government incentive fee rises accordingly, increasing the overall budget.

Algorithm Efficiency. A stricter energy reduction threshold has a mixed effect on algorithm efficiency. To meet a higher energy reduction target, data centers must reduce variable energy consumption. This can be achieved either by improving algorithm efficiency to reduce per-unit energy consumption or by reducing demand through higher prices or lower algorithm efficiency. These two potential responses have opposing effects.

- **Low Algorithm Efficiency:** When a data center operates with relatively low energy efficiency (i.e., when energy consumption is high), the implementation of the incentive scheme or stricter energy reduction thresholds can incentivize improvements in energy efficiency. In such cases, the cost of enhancing IT technology is relatively low, making it cost-effective for data centers to improve algorithm efficiency, thereby reducing IT energy consumption per job and overall energy consumption. Despite a reduction in cost coverage due to decreased energy consumption for procurement, the incentive fee required from the government increases accordingly because improving IT technology is more costly for the data center, thereby raising the overall budget. At the same time, the data center could lower energy consumption by reducing demand through higher prices. The impact on consumer spending is uncertain. While higher algorithm efficiency benefits consumers, a higher price may, in turn, negatively affect consumer spending.
- **High Algorithm Efficiency:** However, if a data center's algorithm efficiency is already high and energy consumption is already low, the cost of further improving algorithm efficiency becomes prohibitive. In this case, to reduce energy consumption, data centers may opt to decrease demand by lowering algorithm efficiency and increasing prices. Although energy consumption can be reduced, this often comes at the expense of slower service speeds, increased government budget due to higher incentive fees and cost coverage, reduced demand, and lower consumer spending under stricter energy reduction thresholds.

Conditions for Effective Energy Reduction Target Incentive Scheme Adoption. The analysis further indicates that the optimal energy reduction target is effective in improving the government's objective value when the cost of enhancing energy efficiency is moderate. In other words, the incentive scheme does not lead to a better outcome when the cost of improving algorithm efficiency is either too low or too high. If the cost is too low, data centers have already implemented the highest level of efficiency achievable without the incentive scheme, making further improvements unfeasible. Conversely, if the cost is too high, even with initially low algorithm efficiency, data centers would find the improvements too costly to pursue. As a result, they would likely focus on reducing demand to meet energy reduction targets, which would ultimately increase budget, lower consumer spending, and harm overall value.

Comparison of PUE Requirement and Energy Reduction Target Incentive Scheme

Figure 5 illustrates how the effectiveness of the PUE requirement and energy reduction target incentive schemes in improving the government's objective value varies depending on the cost of improving algorithm efficiency and unit electricity cost of computing services. Each incentive scheme has a distinct region where it is more effective, which we explain below.

When is the PUE Requirement Incentive Scheme More Effective?

When the cost of upgrading algorithm efficiency is moderately high, the PUE requirement incentive scheme becomes optimal. It focuses on improving energy usage effectiveness, which yields better outcomes compared to other incentive schemes in this cost range.

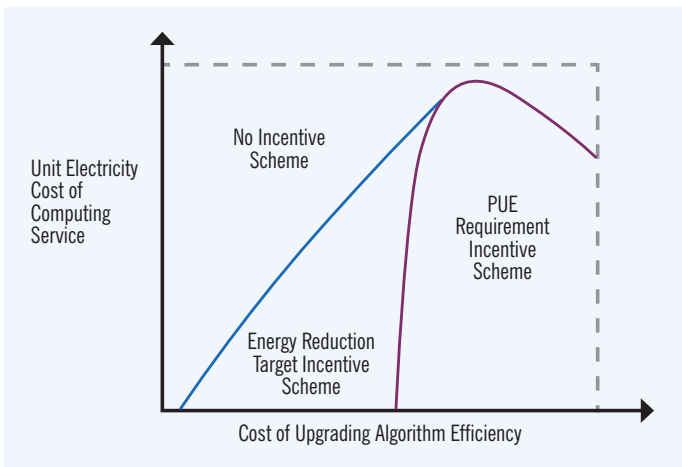
When is the Energy Reduction Target Incentive Scheme More Effective?

When the cost of upgrading algorithm efficiency is moderately low, the energy reduction target incentive scheme is optimal. It provides direct incentives for improving algorithm efficiency, making it cost-effective for service providers to invest in upgrades.

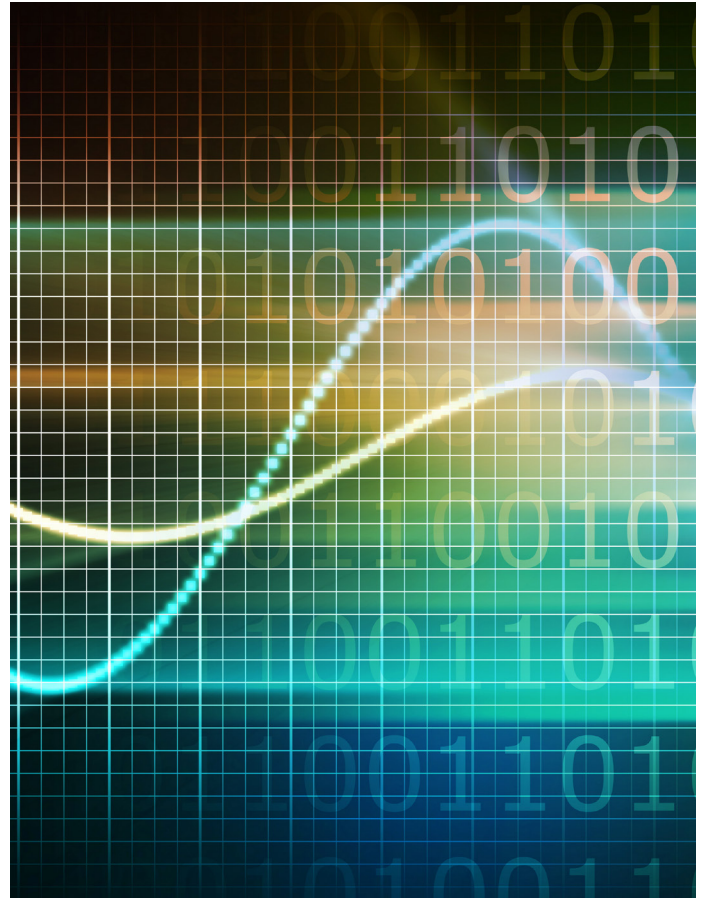
When are None of the Incentive Schemes Effective?

When the cost of upgrading algorithm efficiency is too low or too high (the “No Incentive Scheme” region in Figure 5), neither the energy reduction target nor the PUE requirement is effective. Here, neither of the incentive schemes would result in positive outcomes as the cost of interventions outweighs the benefits of efficiency improvements. As discussed earlier, if the cost of upgrading algorithm efficiency is too low, then the efficiency level without intervention is already high, these policies could unintentionally reduce algorithm efficiency, which may increase energy consumption, leading to reducing total value. On the other hand, if the cost of upgrading the algorithm efficiency is too high, data centers may find improvements too costly and focus on increasing demand to meet energy targets, leading to higher energy consumption and lower government’s objective value.

Figure 5: When is Each Incentive Scheme More Effective in Improving the Government Objective Value?



In summary, while both incentive schemes are effective when the cost of improving algorithm efficiency is moderate, a comparison of total revenue reveals that the PUE requirement incentive scheme leads to better outcomes when the cost of improving algorithm efficiency is moderately high. However, when the cost of improving service speed is moderately low, the energy reduction target incentive scheme results in a more favorable overall outcome.



Recommendations

In summary, the impact of incentive schemes in government procurement contracts—such as PUE requirements and energy reduction targets—on technology adoption, energy consumption, data center profitability, and consumer spending is complex. To achieve the desired resource and economic outcomes, the government must carefully weigh these trade-offs.

Alternative Metrics and Policy Considerations

The PUE measure, while commonly used, does not always accurately reflect energy efficiency. The analysis highlights that improvements in IT equipment efficiency could lead to higher PUE values, which may mislead the government and disincentivize data centers from adopting better algorithms. Moreover, a more stringent PUE requirement may not always drive improvements in algorithm efficiency, especially when PUE is already low and algorithmic efficiency is high. Therefore, a more comprehensive metric that consistently correlates with energy efficiency is needed.

Resource impact per job is a potentially better metric. This measure consistently correlates with the adoption of better cooling technologies and algorithms, making it a more reliable indicator of energy efficiency and resilience.

Encouraging Service Speed Alongside Energy Savings

Incentive schemes should encourage both data centers to improve service speed while reducing energy consumption. One effective approach is to structure procurement contracts that include financial assistance for infrastructure upgrades aimed at enhancing performance and efficiency. This support could take the form of dedicated modernization funds or federal grants to help overcome the significant upfront investment barriers. By reducing the financial risks associated with adopting advanced, energy-efficient technologies, these incentives can facilitate modernization without compromising service quality or profitability.

Monitoring Price Adjustments

A potential downside of incentive schemes in procurement contracts is that data centers may raise prices to meet PUE or energy reduction thresholds, potentially impacting consumers. To mitigate this risk, the government should consider implementing price ceilings or requiring data centers to justify any price increases as necessary to cover operational costs during the contract period.

Conditions for Policy Implementation

The analysis suggests that the government should carefully evaluate when and to what extent each policy and its parameters should be applied. Incentive schemes—such as energy reduction targets or PUE requirements—should be incorporated into procurement contracts with data centers where the cost of improving algorithmic efficiency is moderate. In such cases, these incentives can promote cost-effective IT upgrades, enabling energy reductions without compromising service quality or increasing consumer costs.

Heterogeneous Policies

In procurement contracts or when managing government-owned data centers, governments should consider applying differentiated PUE requirements and aligning incentives with data center characteristics—particularly their current level of algorithmic efficiency. A tiered incentive structure can ensure that data centers with already high efficiency are not penalized or disincentivized. For instance, less stringent PUE requirements or higher incentive levels can be offered to data centers that have already made substantial improvements in algorithm efficiency. This approach encourages continued investment in efficiency without pressuring operators to degrade algorithm performance or pass costs on to consumers.

A similar consideration applies to energy reduction target incentive scheme. Without proper design, highly efficient data centers might seek to meet energy reduction targets by intentionally lowering algorithm efficiency—reducing performance to appear more energy-efficient. To avoid this, energy reduction target should scale with actual improvements in energy performance, offering meaningful incentives even for facilities already operating at high efficiency. This can be achieved through tiered incentive fee levels or less aggressive reduction targets, ensuring continued participation and discouraging counterproductive behavior.

Smaller or emerging data centers—whether government-owned or under government contract—often face higher financial barriers to adopting energy-efficient technologies. To support them, governments should offer targeted modernization funds, or low-interest loans specifically for efficiency upgrades. These financial tools can prevent smaller operators from resorting to cost-cutting measures that compromise algorithm efficiency or service quality.

Balancing Efficiency and Stakeholder Outcomes

The findings reveal that while efficiency improvements can reduce resource impacts, they may have unintended consequences for data center profitability, consumer spending, and energy consumption. For example, reducing PUE may lead to lower profits, higher prices, or even higher energy consumption in some scenarios. The government should regularly assess the trade-offs between resource goals (e.g., energy consumption reduction) and economic outcomes (e.g., data center profitability and consumer spending) to avoid disproportionately harming consumers.

Promoting Transparency

Governments should require contracted private data centers to clearly disclose how their resource usage policies impact key factors such as service quality, pricing, energy consumption, and the adoption of technologies. This would not only ensure compliance with the incentive scheme but also help consumers make informed choices, fostering competition among data centers to maintain service speed and affordability while achieving energy efficiency targets.

Clear guidelines for compliance with PUE and energy reduction targets should be established. These guidelines would provide a road map for data centers to improve efficiency resiliently, making it easier for them to plan and implement necessary changes.

Encouraging Innovation in Technologies

The government could reduce technology costs by offering research and development grants focused on creating cost-effective cooling technologies that lower energy consumption without raising expenses. Additionally, fostering collaborations between data centers, technology firms, and universities can promote breakthroughs in cooling solutions that meet PUE targets more affordably.

Incentivizing Alternative Energy Adoption

Governments can encourage contracted private data centers to adopt alternative energy sources by including a range of financial incentive schemes in procurement contracts, such as tax credits for investments in alternative energy technologies like solar, wind, and other resilient energy solutions. These incentives would help offset the initial investment costs of transitioning to alternative energy, making it more financially feasible for data centers to make the switch.

The increased adoption of alternative energy sources can, in turn, stimulate innovation in alternative energy technologies, foster the growth of energy markets, and help data centers meet their resiliency goals more effectively.

Encourage AI Integration

Governments can encourage data centers to adopt AI and machine learning solutions that enable real-time monitoring and optimization of energy consumption.

Conclusion

The resource usage impact of data centers necessitates urgent action to address the growing challenges posed by high energy consumption.

Recent technological innovations, such as advanced cooling systems, resilient IT infrastructure, and alter-native energy integration, have made significant progress in improving data center efficiency. Our review of global initiatives further highlights how governments and organizations are addressing these challenges through diverse strategies: Sweden's EcoDataCenter and Japan's circular economy programs showcase technological and resource reuse innovations; the EU's Code of Conduct provides a voluntary but widely adopted framework; Singapore and Australia demonstrate how public procurement can set binding efficiency standards; and the U.S. federal government has piloted comprehensive resiliency programs under the DCOI. Together, these case studies underscore the importance of combining regulation, procurement, and innovation to shape sustainable practices.

At the same time, structural challenges remain. Misaligned incentives, significant upfront costs for adopting resilient practices, and lack of transparency and standardized metrics limit the effectiveness of these approaches and hinder accountability among stakeholders.

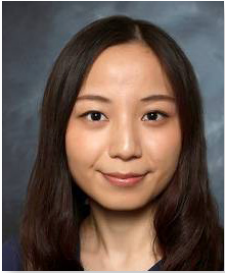
The economic modeling in this report demonstrates that no single policy tool is universally effective. While efficiency measures such as PUE thresholds and energy reduction targets in procurement contracts have the potential to drive resilience, their effectiveness depends on data center characteristics and upgrade costs. PUE requirements can drive improvements when efficiency upgrade costs are moderately high, but they risk discouraging innovation when costs are too low or too high. Energy reduction targets are more effective when efficiency upgrades are moderately affordable, but they can unintentionally reduce service speed or raise consumer prices. Alternative metrics, like resource impact per job, could provide more accurate assessments of efficiency and resilience.

Innovation and collaboration are pivotal. Governments should promote technological advances such as AI-driven energy optimization and renewable energy integration, while ensuring transparent and standardized reporting frameworks that strengthen accountability. At the same time, dedicated financial support mechanisms are needed to overcome upfront investment barriers, particularly for smaller operators. Embedding well-calibrated, incentive-based mechanisms in procurement contracts can further align private incentives with public sustainability goals.

Ultimately, a multifaceted approach that combines regulatory measures, financial incentives, and innovation will enable both federal data centers and private data center contractors to meet the growing demand for digital services while minimizing their resource footprint. By acting decisively and collaboratively, we can ensure a resilient digital future.



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Towards Sustainable Data Centers

*Evaluating Policies for Energy Efficiency and
Environmental Responsibility*

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