



# Towards Resilient Data Centers

Evaluating Policies for Energy Efficiency and  
Environmental Responsibility

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# Outline

- The Problem
- Global Landscape
- Barriers to Progress
- Policy Instruments
- Economic Analysis
- Recommendations



SECTION 1

# The Problem

*Why data center energy consumption is a federal priority*

# The Scale of the Challenge

DATA

## 2%

**Current U.S. Share**

of national electricity consumption

## 8%

**Projected by 2030**

without regulatory intervention

## 5,381

**U.S. Data Centers**

largest concentration globally (2023)

AI, ML, and Generative AI workloads are the primary growth driver, with compute demand doubling every 2–3 years.

Federal agencies operate thousands of facilities while simultaneously contracting with private providers for critical workloads.

The shift to remote work and expanded cloud adoption has further accelerated electricity demand across the sector.

E-waste from rapid hardware refresh cycles contains hazardous materials (lead, mercury, cadmium) posing public health risks.

Water consumption for cooling strains local resources, particularly in drought-prone regions.

The U.S. government is uniquely positioned to drive systemic change as both operator and largest single buyer of data services.

SECTION 2

# Global Landscape

*What leading governments are doing — and what works*

# What Makes a Data Center Resilient?

## Energy Sources

- Fossil fuels
- Alternative energy: solar, wind, hydroelectric

## Operational Efficiency

- Cooling systems
  - Free, liquid, water, closed-loop, liquid
  - Infrastructure optimization
- Advanced power supplies

## Computational Efficiency

- Low-power processors, solid-state
- Algorithm optimization, server virtualization, cloud computing, elastic scaling, workload consolidation



# Understanding Power Usage Effectiveness (PUE)

## PUE

Total Facility Energy

IT Equipment Energy

Non-IT Energy + IT Equipment Energy

IT Equipment Energy

*Lower is better · PUE = 1.0 is theoretical perfection*

1.0

Theoretical perfect efficiency

1.2

Best-in-class (Google, EcoDataCenter)

1.4

DCOI target — new federal data centers

1.5

DCOI target — existing federal data centers

1.56

Global industry average (2024)

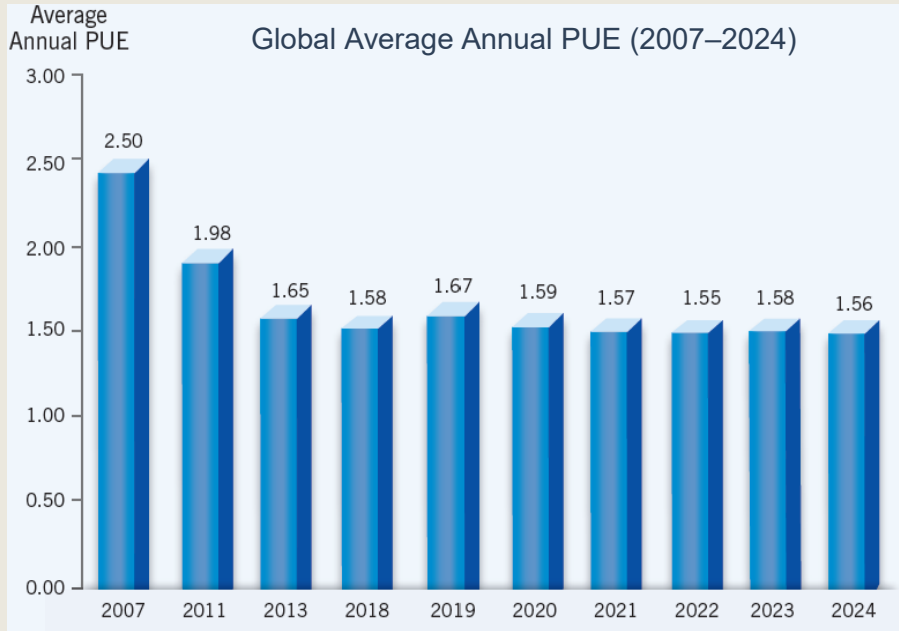
1.7

Germany & Russia average — well below standard

2.50

Global average in 2007 — where the industry started

# Global PUE Progress & International Comparison



Source: Statista / Uptime Institute / Cushman & Wakefield (2021–2024)

## PUE by Country (Most Recent)

Australia	1.48
France	1.55
Canada	1.57
USA	1.58
China	1.60
Japan	1.60
UK	1.65
Germany	1.70
Russia	1.70

# International Policy Approaches: Five Models

## TECHNOLOGY-LED

### Sweden — EcoDataCenter Initiative

100% alternative energy + free cooling + waste heat reuse for district heating

▶ **PUE: 1.22 vs. industry avg. 1.56**

## STANDARDS-BASED

### European Union — Code of Conduct for Data Centres

Voluntary efficiency targets for cooling, renewable integration & workload consolidation; embedded in procurement

▶ **Widely adopted across member states**

## CIRCULAR ECONOMY

### Japan — Circular Economy Initiative

Hardware reuse, refurbishment, and e-waste recycling; keeps materials in use longer

▶ **Reduces e-waste and resource extraction**

## PROCUREMENT-DRIVEN

### Singapore & Australia — Green Mark & NABERS

Mandatory certifications for public-sector; Australia requires 5-star NABERS for all federal workloads from July 2025

▶ **Binding procurement conditions**

## REGULATORY

### United States — DCOI / Federal Pilots

Liquid cooling, AI-driven optimization, wastewater recycling, DCIM monitoring across federal facilities

▶ **PUE 1.4/1.5 federal thresholds**

SECTION 3

# Barriers to Progress

*Structural challenges that undermine current policy effectiveness*

# Three Structural Barriers to Resilient Data Centers

01

## High Upfront Investment Costs

GOVT.

Multi-year budget cycles delay infrastructure upgrades; capital expenditures compete with other federal priorities; GSA/building code compliance adds cost and time for retrofits.

PRIVATE

Limited financing access for smaller contractors; risk-averse investors; LEED/third-party certification costs create financial burden.

02

## Misaligned Incentives

GOVT.

Internal efficiency savings are absorbed into agency general funds — managers cannot reinvest savings, reducing motivation for further improvements.

PRIVATE

Profitability driven by pricing and volume, not energy performance. Without explicit contract rewards, contractors have no financial reason to improve.

03

## Lack of Transparency & Standardization

GOVT.

DCOI reporting mandates are inconsistently enforced; formats not standardized across agencies; progress hard to track at national level.

PRIVATE

Selective disclosure of favorable metrics; no universal framework in procurement contracts; contractors cite proprietary concerns to resist full disclosure.

SECTION 4

# Government Policy Instruments

*The tools available — and how they work in practice*

# Federal Policy Instruments: A Toolkit



## Grants & Modernization Funds

DOE FEMP and GSA programs fund advanced cooling, renewable integration, and AI monitoring. Overcome budget-cycle barriers and allow agencies to lead by example.

*Example: Federal Energy Management Program (FEMP)*



## PUE Requirements (DCOI)

Existing centers  $\leq 1.5$  PUE; new centers  $\leq 1.4$ ; best-in-class  $\leq 1.2$ .  
Extended to private contractors via procurement solicitations.

*Mandate: Data Center Optimization Initiative*



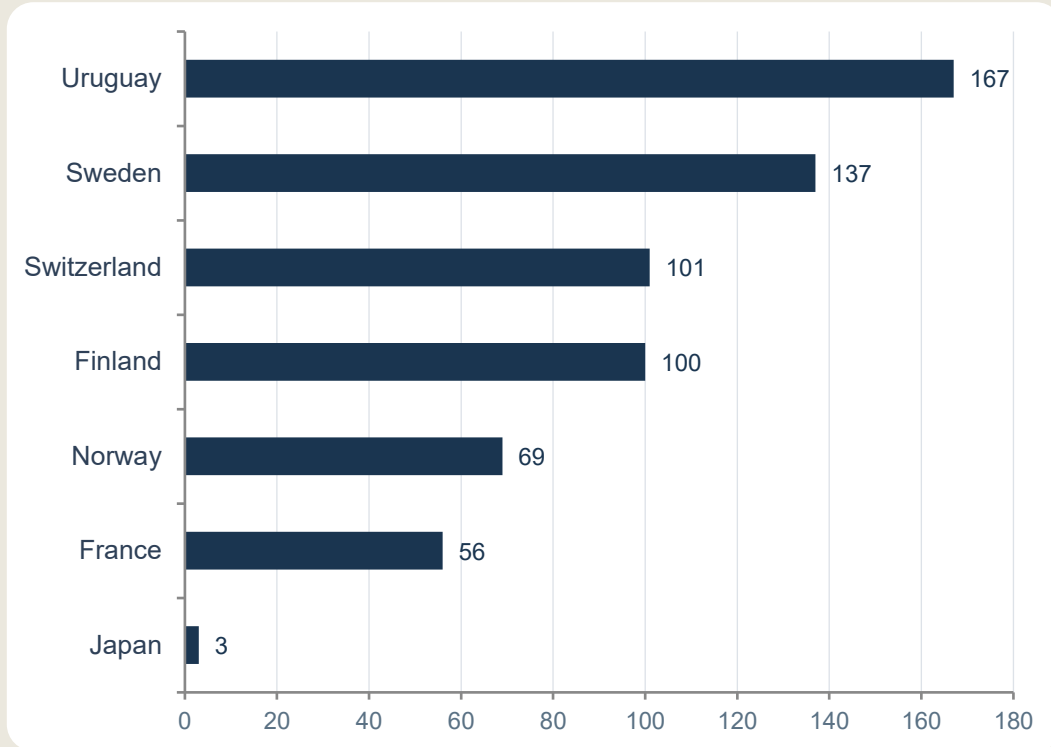
## Tax Incentives & Carbon Pricing

Investment Tax Credit, accelerated depreciation for efficient equipment. State-level exemptions (MD, NC, VA). Carbon taxes range from \$3/tonne (Japan) to \$167/tonne (Uruguay).

*Example: EU Energy Investment Allowance; BC Carbon Tax*

# Carbon Tax Rates: International Comparison

*Tax rates per metric ton of CO<sub>2</sub> (USD equivalent)*



Sources: Tax Foundation (2024), OECD Carbon Pricing Dashboard

# Federal Policy Instruments: A Toolkit



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*Example: EU Energy Investment Allowance; BC Carbon Tax*



## Performance-Based Contracting

ESPCs: contractors fund upgrades, repaid through verified savings. Cost-plus-incentive-fee: bonus payments for meeting PUE/energy targets. Shared-savings arrangements.

*Model: Energy Savings Performance Contracts (ESPCs)*

DISCUSSION  
BREAK

## Which government policy tool do you think is most effective at improving data center energy efficiency?

### A Grants & Modernization Funds

Direct capital to overcome upfront cost barriers

### B PUE Requirements (DCOI)

Regulatory mandate with clear efficiency benchmarks

### C Tax Incentives & Carbon Pricing

Financial signals that shift cost-benefit calculations

### D Performance-Based Contracting

Aligning contractor profit with public efficiency goals

**Follow-up:** Do you think the same tool works equally well for **government-owned facilities** and **private contractors**, or should they be treated differently?

*The economic analysis coming up next will show that the answer may surprise you and depends critically on context.*

SECTION 5

# Economic Analysis

*Modelling how incentive schemes actually affect data center behavior*

# Economic Modeling Framework

A three-stakeholder game-theoretic model of government procurement contracts under two competing incentive schemes

## GOVERNMENT

Objective: Minimize budget + resource impact – consumer spending

*Decisions: PUE threshold · Energy reduction target · Incentive fee*



## DATA CENTER

Objective: Maximize profit = gov. payment + consumer revenue – electricity costs – upgrading cost

*Decisions: Algorithm efficiency · Cooling technology · Consumer pricing*



## CONSUMERS

Choose services by speed & price → determines demand & data center revenue

## Scheme A — PUE Requirement

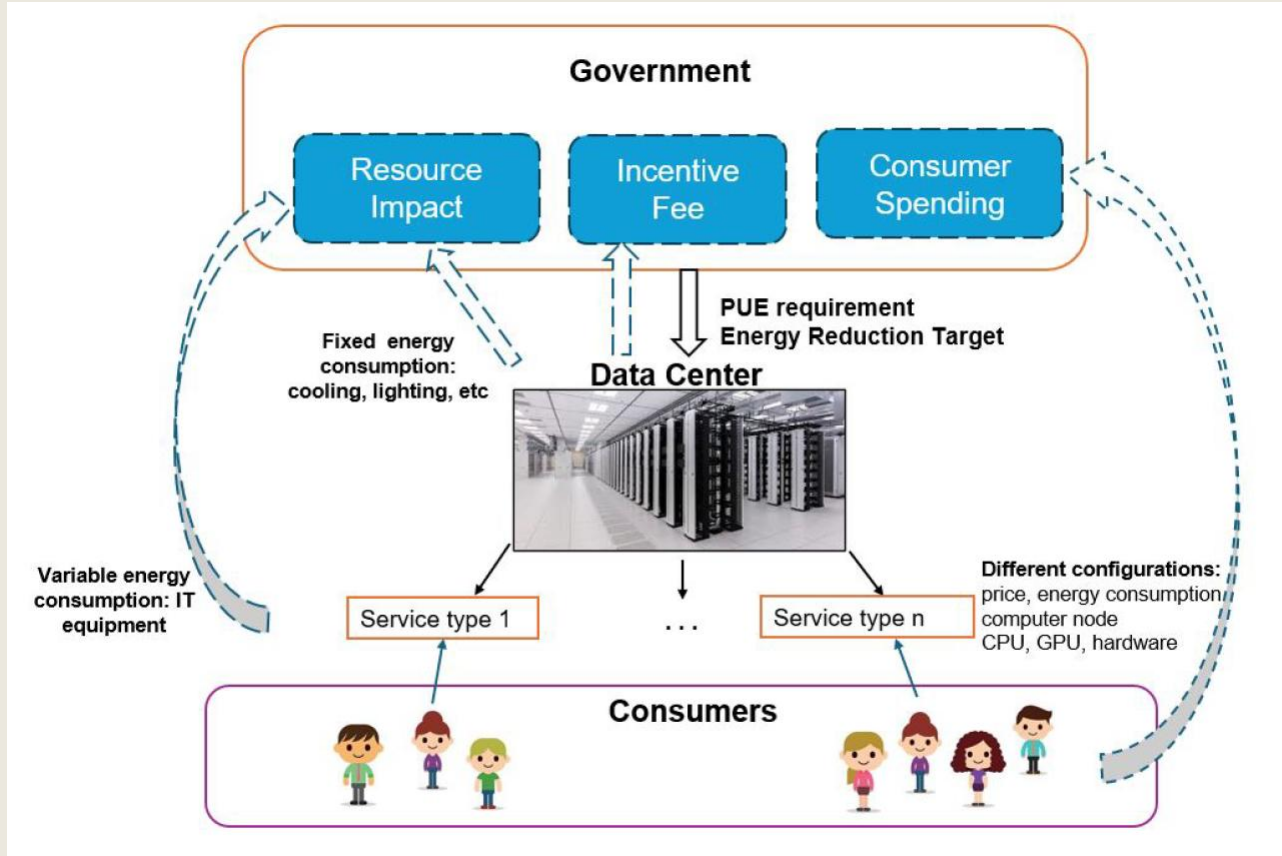
- Government sets maximum PUE threshold the data center must achieve
- Incentive fee paid only when PUE falls at or below the threshold
- Data center may adjust algorithm efficiency, cooling, or price to hit target

## Scheme B — Energy Reduction Target

- Government sets absolute % reduction in total energy consumption
- Incentive fee paid when reduction target is achieved vs. baseline
- Data center may reduce energy via efficiency, cooling, or demand cuts

**Key question: Which scheme delivers better outcomes — and when?**

# Economic Modeling Framework



# PUE Requirement: Effects on Cooling Technology

METRIC

## PUE

Total Facility Energy

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IT Equipment Energy

Non-IT Energy + IT Equipment Energy

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IT Equipment Energy

## When PUE Threshold Is Stricter

### MECHANISM

Stricter PUE requirements → upgrading cooling technologies  
→ less non-IT energy consumption → lower PUE

### RISK / OUTCOME

BUT: Higher service speed attract more customers, raises IT energy consumption. Government must pay more in incentive fees.

# Effects of Algorithm Efficiency on PUE

## PUE

Total Facility Energy

IT Equipment Energy

Non-IT Energy + IT Equipment Energy

IT Equipment Energy

## IT Equipment Energy

Energy Consumption per Job x Demand

### DEMAND EFFECT

- ↑ Faster service attracts more customers
- ↑ Total number of jobs rises
- ↑ Total IT energy rises with demand
- ↓ PUE may fall — but total energy is now higher

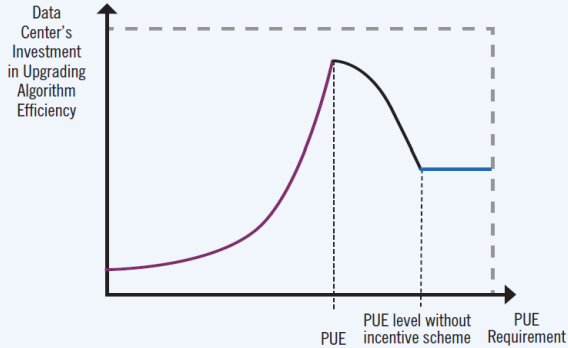
### DIRECT EFFECT

- ↓ IT energy consumed per job
- Cooling energy unchanged (fixed costs)
- IT energy falls, non-IT energy stays roughly similar
- ↑ PUE rises — ratio gets worse even though efficiency improved

**Policy implication: A PUE target alone does not guarantee lower total energy consumption or better algorithm performance**

# PUE Requirement: Effects on Algorithm Efficiency

(a) Low Initial Algorithm Efficiency



## When Algorithm Costs Are LOW

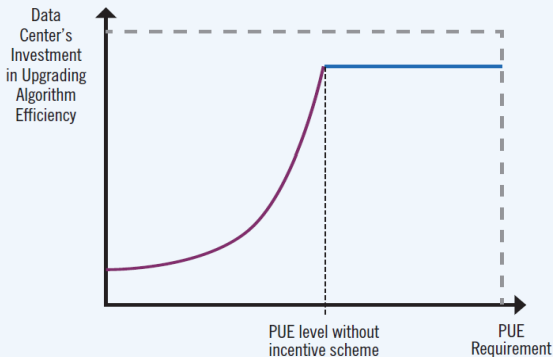
### MECHANISM

Stricter PUE requirements → algorithm optimization → faster service → higher demand → higher IT energy consumption → lower PUE

### RISK / OUTCOME

Higher demand may offset some energy savings. Government must pay more in incentive fees.

(b) High Initial Algorithm Efficiency



## When Algorithm Costs Are HIGH

### MECHANISM

Operators may seek alternative ways to satisfy PUE requirements:

- 1) Lower price → boost demand → higher IT energy consumption → lower PUE
- 2) Reduce algorithm efficiency → higher IT energy consumption → lower PUE

### RISK / OUTCOME

RESULT: Lower service efficiency, higher energy consumption, and higher procurement costs.

# Energy Reduction Target: Effects on Cooling Technology

METRIC

## Energy Consumption

Energy Consumption per Job x Demand+ Non-IT Energy

## Energy Reduction Ratio

Energy Consumption After Implementation

Energy Consumption Before Implementation

### When Energy Reduction Target is Stricter

#### MECHANISM

Data centers can meet energy-reduction targets through two mechanisms:

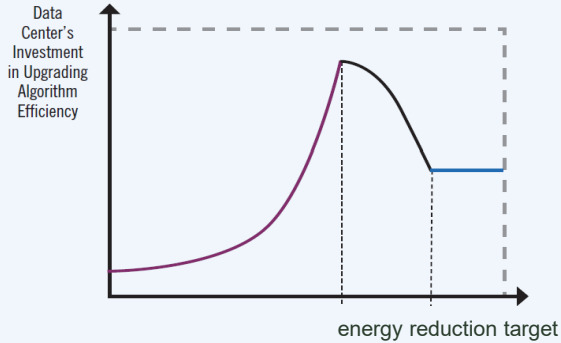
- 1) Improving cooling → less non-IT energy consumption → lower energy consumption → lower energy reduction ratio
- 2) Increasing price → lower demand → lower IT consumption → lower energy consumption → lower energy reduction ratio

#### RISK / OUTCOME

While both approaches reduce energy consumption, demand-reduction strategies can increase prices and reduce consumer welfare. Government pays higher incentive fees.

# Energy Reduction Target: Effects on Algorithm Efficiency

(a) Low Initial Algorithm Efficiency



## When Algorithm Costs Are LOW

### MECHANISM

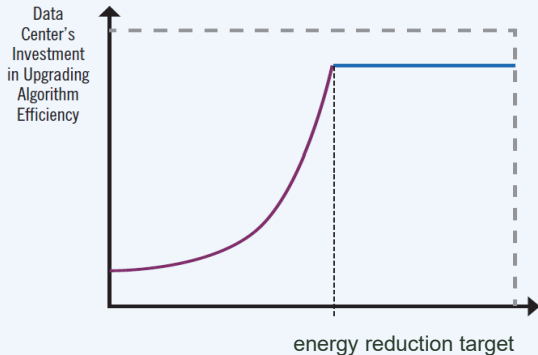
Lower energy reduction target → increase algorithm efficiency → higher service speed

- 1) → energy consumption falls;
- 2) → higher demand → higher price → energy consumption falls

### RISK / OUTCOME

Data center may raise prices to curb demand further — consumer spending impact is uncertain. Government pays higher incentive fees.

(b) High Initial Algorithm Efficiency



## When Algorithm Costs Are HIGH

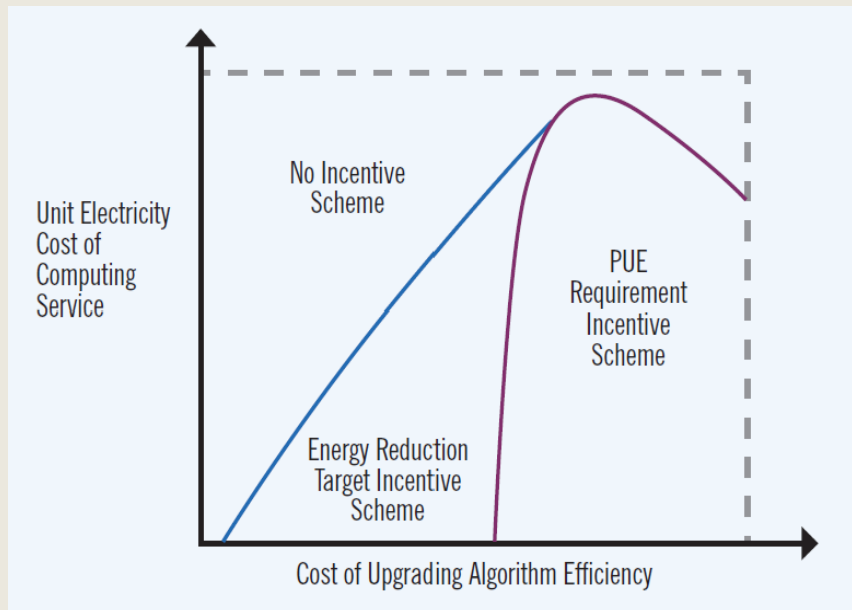
### MECHANISM

Lower energy reduction target → higher price → lower demand → lower IT energy consumption and consumer spending → lower energy reduction ratio

### RISK / OUTCOME

Lower consumer spending. Government pays higher incentive fees.

# Which Policy Instrument, When? A Decision Framework



Condition	PUE	Energy Red.	Action
Very low costs (already efficient)	×	×	Monitor only
Mod-low costs	△ Costly	✓ Effective	Use Energy Red.
Mod-high costs	✓ Effective	△ Costly	Use PUE
Very high costs (unaffordable)	×	×	Fund first

SECTION 6

# Policy Recommendations

*Eight actions to achieve resilient, energy-efficient government data infrastructure*

# Policy Recommendations (1-4)

## 1 Adopt Alternative Metric

Replace or supplement PUE with a metric that measures energy consumed per computational task completed. This consistently rewards both cooling improvements and algorithm efficiency, eliminating perverse incentive effects.

## 2 Allocate Dedicated Modernization Funds

Establish dedicated appropriations and federal grant programs specifically for data center efficiency upgrades. Include low-interest loan facilities for smaller private contractors and government-owned facilities facing budget rigidity.

## 3 Implement Consumer Price Monitoring

Require contracted data centers to disclose and justify any price changes during incentive periods. Consider price ceilings in procurement contracts to prevent efficiency costs from being passed to end-users or agencies.

## 4 Condition Incentives

Assess each facility's upgrade cost profile before applying incentive schemes. Use grants first to bring high-cost-barrier facilities into the moderate range. Apply PUE or energy reduction targets only once feasible adoption conditions exist.

# Policy Recommendations (5–8)

## 5 Design Heterogeneous, Tiered Incentive Structures

Differentiate PUE thresholds and incentive fee levels based on each data center's current efficiency profile. Less stringent requirements for already-efficient centers; more support for those in the moderate upgrade cost range.

## 6 Mandate Standardized, Verified Reporting

Require all contracted and government-owned data centers to disclose PUE, energy consumption, pricing, and alternative energy usage in a uniform format. Independent third-party verification should be mandatory, not optional.

## 7 Evaluate Tradeoffs Across Multiple Stakeholders

Efficiency policies should be evaluated not only on energy outcomes, but also on their effects on consumer welfare, provider incentives, and overall system performance.

## 8 Incentivize Alternative Energy & AI-Driven Optimization

Embed tax credits for solar/wind adoption in federal procurement contracts. Fund R&D grants for AI-driven cooling and workload optimization. Foster university-industry collaborations to lower technology costs.

## The Path to Resilient Data Infrastructure

- ▶ Data center energy demand is growing rapidly, making efficiency and sustainability increasingly important public policy concerns.
- ▶ No single policy instrument is universally effective. The success of PUE requirements and energy-reduction incentives depends on the technological and economic conditions facing individual facilities.
- ▶ Policymakers should anticipate behavioral responses from operators and consumers, not just technological changes.
- ▶ The government is uniquely positioned to drive change through its dual role as both a data center operator and a major purchaser of cloud services.
- ▶ A multifaceted strategy combining targeted funding, performance-based incentives, standardized reporting, and technology-neutral efficiency metrics offers the most promising path toward resilient data infrastructure.

# About the Research Team

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# Questions & Discussion

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