



Green IT: Reducing the Energy Use and Carbon Footprint of Institutional Computing Infrastructure – A Case Study of a Mid-Size Campus Data Centre

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Abstract: Rapid digitalization has made computing one of the fastest-growing sources of electricity demand in institutions, yet most server rooms and computer labs run far below their efficient operating point. This study applies operations research (OR) techniques – energy and utilization analysis, bin-packing optimization, a linear power model and scenario simulation – to (i) analyze the energy and carbon footprint of a representative mid-size campus IT facility, (ii) test Green IT interventions, and (iii) propose an optimal combination of measures. Using a synthetic but realistic dataset of 120 servers, 400 desktop computers and supporting network and cooling equipment, we show that server consolidation, cooling optimization and PC power management can reduce annual electricity use by about 62% and, with a 25% solar offset, cut carbon emissions by about 71%.

1. INTRODUCTION

Background

Green IT refers to the environmentally sustainable design, use and disposal of computing resources [1]. Data centres, networks and end-user devices together account for a significant and growing share of global electricity demand, and the rise of cloud services, analytics and artificial intelligence is accelerating that trend [2][6]. In India, institutions such as universities, hospitals and mid-size enterprises operate their own server rooms and computer labs, often with legacy hardware, one application per server and limited power management. At the same time, electricity prices and sustainability reporting requirements are rising, making energy efficiency both a cost and a compliance issue.

Problems

- **Low server utilization:** dedicated, lightly loaded servers draw most of their peak power even when idle [3].
- **Inefficient cooling and power delivery:** a high Power Usage Effectiveness (PUE) means a large share of electricity never reaches IT equipment [4].
- **Unmanaged end-user devices:** desktops left powered on around the clock in labs and offices.
- **Electronic waste:** short refresh cycles and low formal recycling rates [5].
- **Carbon-intensive electricity supply:** most grid power in India is still coal-based.

Objectives

1. Quantify the current energy consumption and carbon footprint of the facility.
2. Model power and capacity behaviour using OR methods.
3. Propose optimized interventions (consolidation, cooling, power management, renewables).
4. Evaluate the benefits through scenario simulation.

2. LITERATURE REVIEW

Defining Green IT. Murugesan [1] framed Green IT around four paths: green use, green disposal, green design and green manufacturing. Most institutional levers fall under green use and green disposal.

Energy proportionality and utilization. Barroso and Hölzle [3] observed that servers typically operate at 10–50% of peak utilization while consuming more than half of peak power when idle, and argued for energy-proportional design. This justifies consolidating workloads onto fewer, busier machines.

Data-centre efficiency metrics. The Green Grid introduced PUE, the ratio of total facility energy to IT equipment energy [4]. Masanet et al. [2] showed that efficiency gains kept global data-centre energy growth far below the growth



in computing output between 2010 and 2018.

Optimization of workload placement. Beloglazov et al. [7] treated virtual-machine placement as a bin-packing problem and proposed energy-aware heuristics such as modified best-fit decreasing. First-fit decreasing (FFD) is a standard OR heuristic with well-known performance guarantees.

Computing and carbon. Strubell et al. [6] highlighted the carbon cost of compute-intensive AI workloads, and Forti et al. [5] documented the global e-waste problem, where only a minority of discarded equipment is formally collected and recycled.

Gap. Few studies combine utilization, cooling, end-user devices and carbon accounting in one quantitative model for a mid-size Indian institution; this paper addresses that gap.

3. METHODOLOGY

3.1 Study Area

The case study considers a hypothetical mid-size campus IT facility with three components: (a) a server room hosting administrative, academic and web applications; (b) shared network and storage equipment; and (c) computer labs and offices with desktop PCs. Cooling and power delivery losses for the server room are captured through PUE. The analysis period is one full year (8,760 hours).

3.2 Data Collection

- **Server inventory and utilization:** number of physical servers, average CPU utilization sampled every 5 minutes over several weeks.
- **Power measurement:** idle and peak power of representative servers, from metered rack PDUs.
- **Facility metrics:** total facility energy and IT energy to compute PUE; cooling set-points and airflow layout.
- **End-user devices:** number of PCs, average power draw and daily operating hours.
- **Asset lifecycle:** age of equipment, refresh cycles and disposal route (optional).
- **Emission factor:** grid emission factor for the region.

3.3 OR Techniques Applied

- **Linear power model:** server power $P(u) = P_{\text{idle}} + (P_{\text{peak}} - P_{\text{idle}}) \times u$, where u is CPU utilization [3].
- **Bin-packing optimization:** assign workloads (items) to physical hosts (bins) with a utilization ceiling to minimize the number of active hosts, using the FFD heuristic [7].
- **Facility model:** total energy = IT energy $\times$ PUE; carbon = energy $\times$ emission factor.
- **Scenario simulation:** compare baseline against combined interventions on energy, cost proxy and CO_2 .

4. DATA

Table 1 summarizes the synthetic baseline dataset. Server demands were generated from a log-normal distribution (random seed 42) to reproduce the typical pattern of many lightly loaded workloads with a few heavy ones. The average utilization of the 120 servers is 11%.

Segment	Units	Avg. utilization	Avg. power per unit (W)	Hours per year	Annual IT energy (MWh)
Physical servers	120	11%	226	8,760	237.5
Network and storage	—	—	4000 (total)	8,760	35.0
Desktop PCs (labs/offices)	400	—	85	8,760 (always on)	297.8

Table 1: Baseline infrastructure inventory (synthetic)

- Server power parameters: $P_{\text{idle}} = 210$ W, $P_{\text{peak}} = 350$ W (idle is 60% of peak).
- Baseline PUE of the server room = 2.0 (cooling and power losses equal the IT load).
- Assumed grid emission factor = 0.71 kg CO_2/kWh (approximate national average; replace with the current official value for real studies).



5. ANALYSIS

5.1 Power and Utilization Model

At the baseline utilization of 11%, each server draws $P = 210 + 140 \times 0.11 = 226$ W, i.e. 65% of peak power to deliver only 11% of capacity. The 120 servers draw 27.1 kW, and with network and storage the IT load is 31.1 kW. At PUE 2.0, the server room draws 62.2 kW, or 545 MWh per year. The desktop fleet adds 298 MWh, giving a facility baseline of 843 MWh and 598 tonnes of CO₂ per year.

5.2 Consolidation as a Bin-Packing Problem

The total workload equals 13.6 server-equivalents. With a utilization ceiling of 70% per host, the theoretical lower bound is ceiling(13.6/0.7) = 20 hosts. The FFD heuristic packs the workloads onto 20 hosts. Adding 20% headroom for failover and growth gives 24 hosts, a reduction of 80% in physical servers. Average utilization rises to 57%, and power per host rises to 290 W, but total server power falls from 27.1 kW to 6.9 kW (74% lower). The key insight is that the large fixed idle-power share makes fewer, busier machines far more efficient.

5.3 Scenario Simulation

Four scenarios were evaluated:

- **Baseline:** current configuration.
- **Scenario A:** virtualization and server consolidation (24 hosts); PUE held at 2.0 (conservative).
- **Scenario B:** Scenario A plus cooling optimization (hot/cold aisle containment, higher supply-air set-point) to reach PUE 1.5, and a PC power-management policy (sleep after inactivity, shutdown after hours) assumed to cut desktop energy by 40%.
- **Scenario C:** Scenario B plus 25% of electricity supplied by on-site solar or a renewable power purchase agreement.

Scenario	Annual energy (MWh)	Energy reduction	Annual CO ₂ (t)	CO ₂ reduction
Baseline	843	—	598	—
A: Consolidation	490	42%	348	42%
B: A + cooling + PC policy	323	62%	229	62%
C: B + 25% solar	323	62%	172	71%

Table 2: Scenario results (synthetic data)

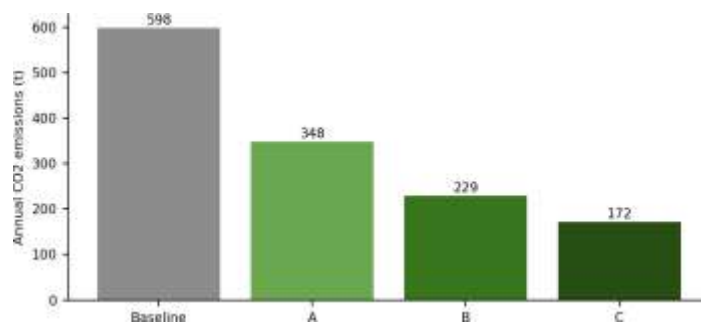


Figure 1: Annual CO₂ emissions by scenario

Consolidation alone saves 42% of energy. Adding cooling optimization and PC power management raises savings to 62%, and the solar offset brings emission reduction to 71%. At an assumed tariff of INR 8 per kWh, Scenario B saves roughly INR 42 lakh per year in electricity alone.

6. PROPOSED INTERVENTIONS

Based on the analysis, the following interventions offer the greatest benefit, ordered by priority:

1. Server Consolidation and Virtualization

- Virtualize lightly loaded servers using FFD-style placement with a 70% utilization ceiling.
- Retire or decommission idle “zombie” servers identified through utilization monitoring.
- Move suitable workloads to energy-efficient cloud or shared services.

2. Cooling and Power Efficiency

- Hot/cold aisle containment, blanking panels and cable management.



- Raise supply-air temperature within equipment guidelines; adopt free or economizer cooling where feasible.
- Replace old UPS units with high-efficiency models; track PUE continuously.
- 3. End-User Device Management**
 - Enforce sleep, hibernate and after-hours shutdown policies centrally.
 - Replace aging PCs with low-power thin clients or laptops where suitable.
- 4. Renewable Energy**
 - Install rooftop solar to offset daytime load.
 - Evaluate renewable power purchase or green tariff options.
- 5. Lifecycle and E-Waste Policy**
 - Extend equipment life through upgrades and refurbishment.
 - Dispose of equipment only through authorized e-waste recyclers and keep an asset register.
 - Include energy efficiency criteria in procurement.
- 6. Monitoring and Governance**
 - Deploy power metering and dashboards; report energy and CO₂ annually.
 - Appoint a Green IT coordinator and set measurable targets.

7. LIMITATIONS

- The data are synthetic and hypothetical; real workloads have time-varying peaks, memory, storage and network constraints that a single-dimension CPU bin-packing model ignores.
- PUE improvement and PC energy savings are assumed values, not measured outcomes; PUE may worsen at low IT load unless cooling is right-sized.
- Capital cost, payback period, migration effort, licensing and risk of service disruption are not modelled.
- Embodied carbon of new hardware and solar panels, and indirect effects such as rebound in demand, are not included.
- The emission factor is an assumption and varies by region and year.

8. CONCLUSION

- OR techniques show that the current infrastructure is inefficient: average server utilization of 11% means most of the electricity is spent on idle capacity.
- Bin-packing based consolidation reduced the server count from 120 to 24 and delivered 42% energy savings on its own.
- Combined measures (consolidation, cooling, PC policy) cut energy use by about 62%, and with a 25% renewable share reduce carbon emissions by about 71%.
- Technical measures work best when combined with procurement, e-waste and governance policy. Future work should validate the model with measured data and add cost and payback analysis.

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