A System Dynamics Perspective on Applying a New Energy Efficiency Metric for Data Centers

System Dynamics Conference

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Problem Context (1)

1.5 % **Of US Electricity is consumed by data centers**

60 Billion kwh/year

1 data center can consume 100x electricity of an office building

12 % **Estimated growth rate**

Government & Industry reduction mandates and benchmarks

the green grid™

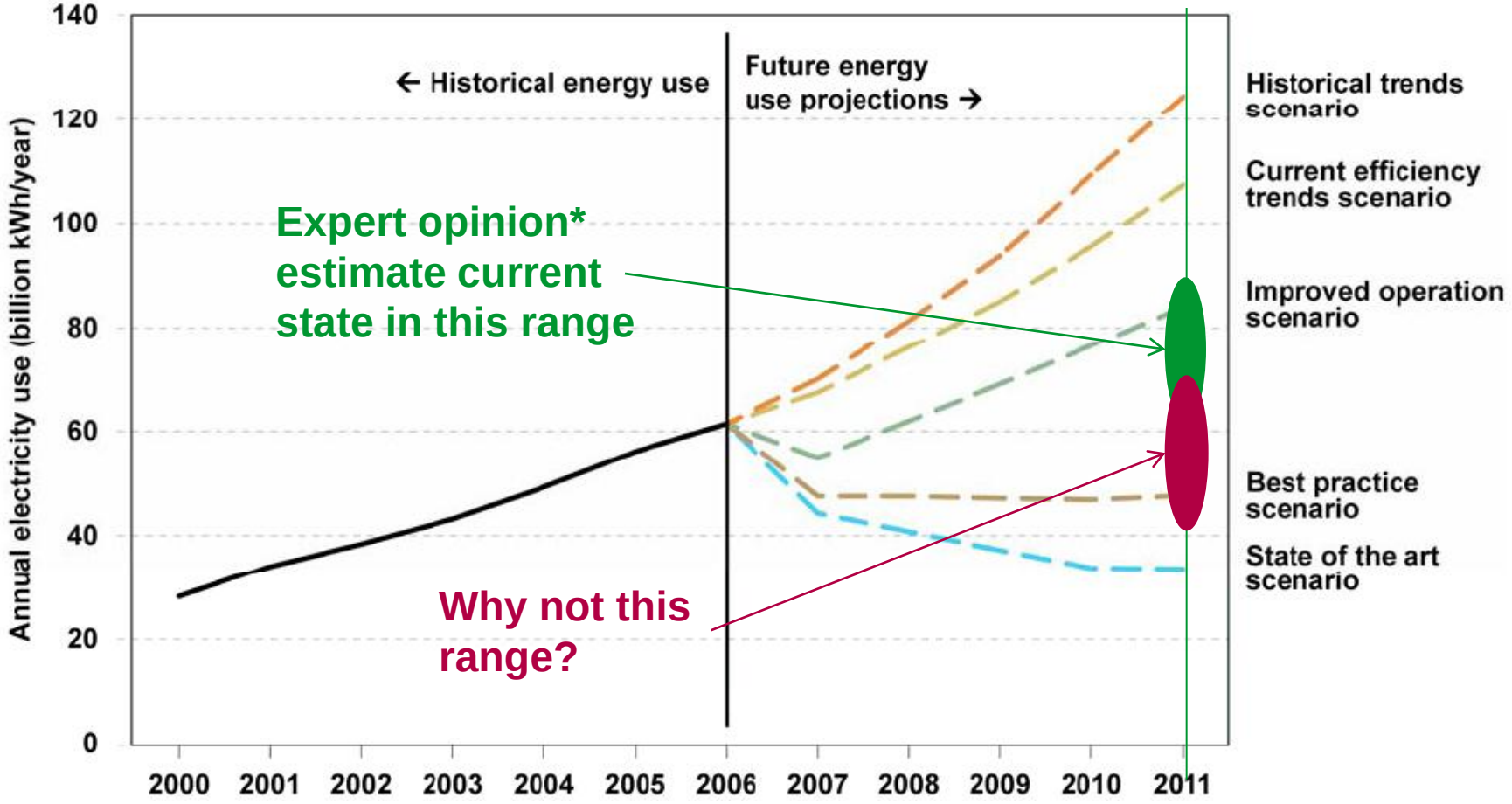
energy

Institute for Energy

Problem Context (2)

Today

EPA. (2007). *Report to Congress on Server and Data Center Energy Efficiency.*



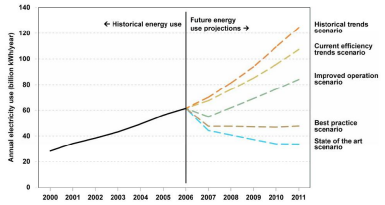
Question posed: What could be the dynamics surrounding underperformance in efficiency progress

*** New DOE study to be started soon**

Approach – inside out

Industry wide

Energy Dynamics

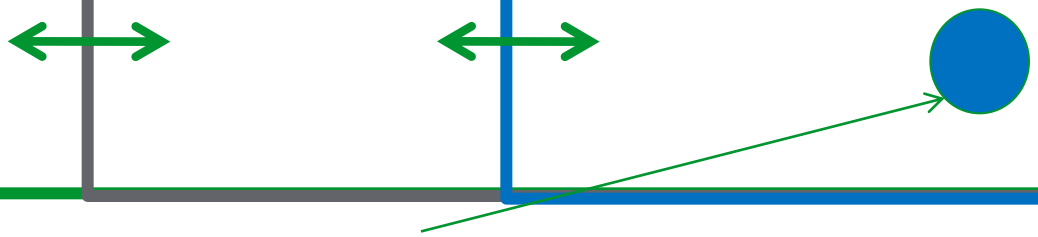


Single data center

Energy dynamics

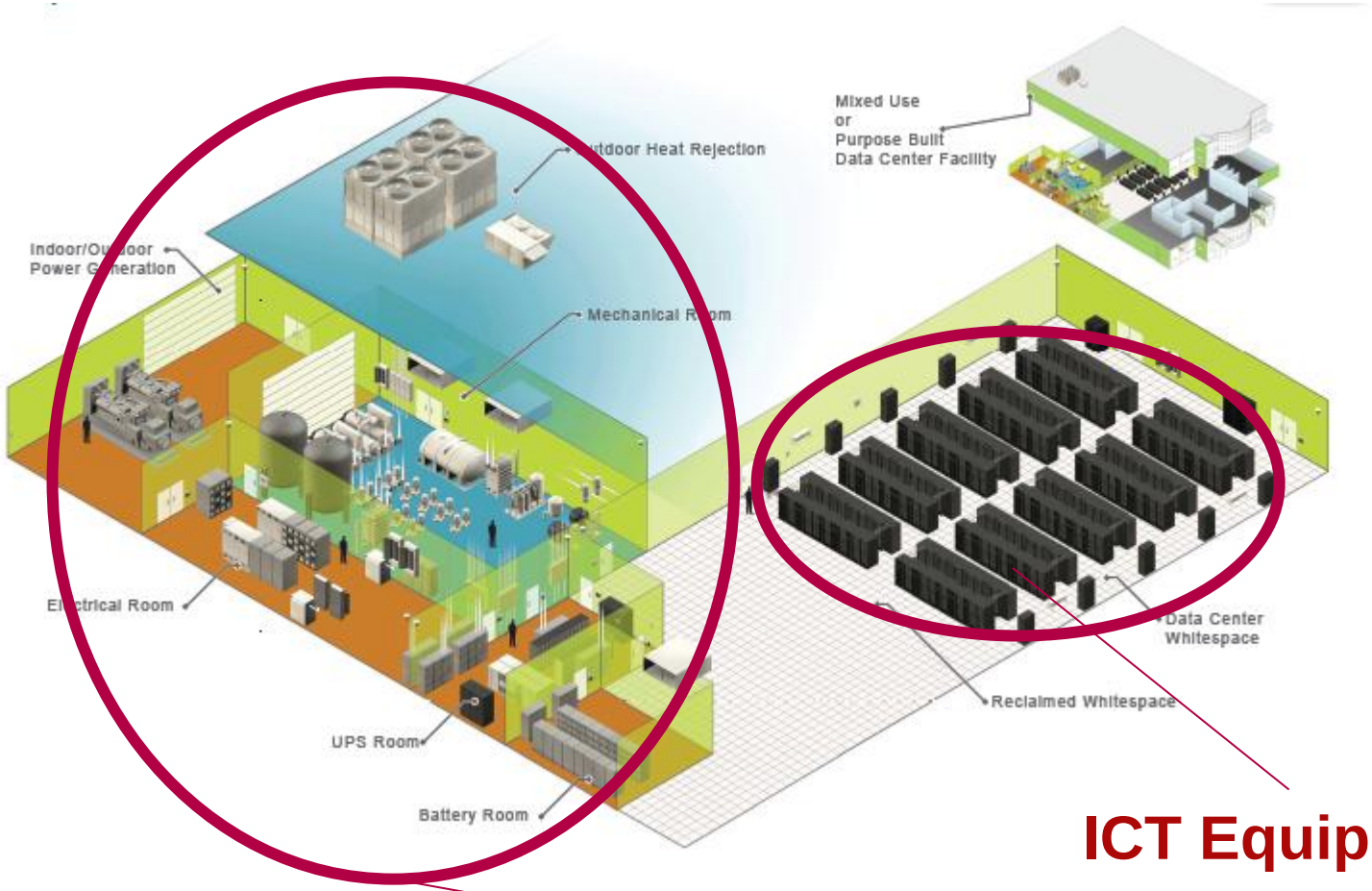
Management stake-holders

Decision dynamics



This paper reviews one decision structure that is prevalent in every data center…it's an anchoring starting point

Data Center Anatomy



ICT Equipment

Infrastructure needed to power and cool the data center

Leading benchmark metric

The simple story

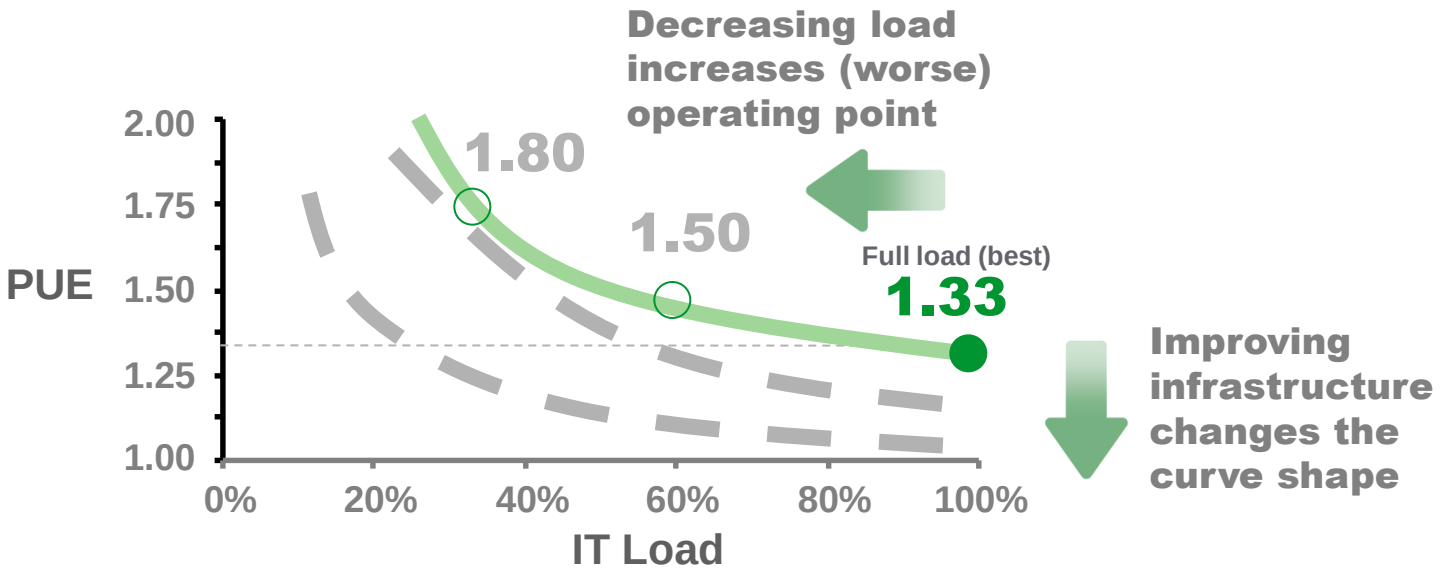
PUE = Power Usage Effectiveness

$$\text{PUE} = \frac{\text{Total data center input power}}{\text{IT load power}}$$

PUE represents how much EXTRA power ("electrical losses") you consume to power, cool, and protect the IT load

LOWER is better, 1 is perfect

The detail story



Leading benchmark metric

Improving PUE does not always improve electric bill

$$PUE = \frac{\text{IT load power} + \text{Infrastructure losses}}{\text{IT load power}}$$

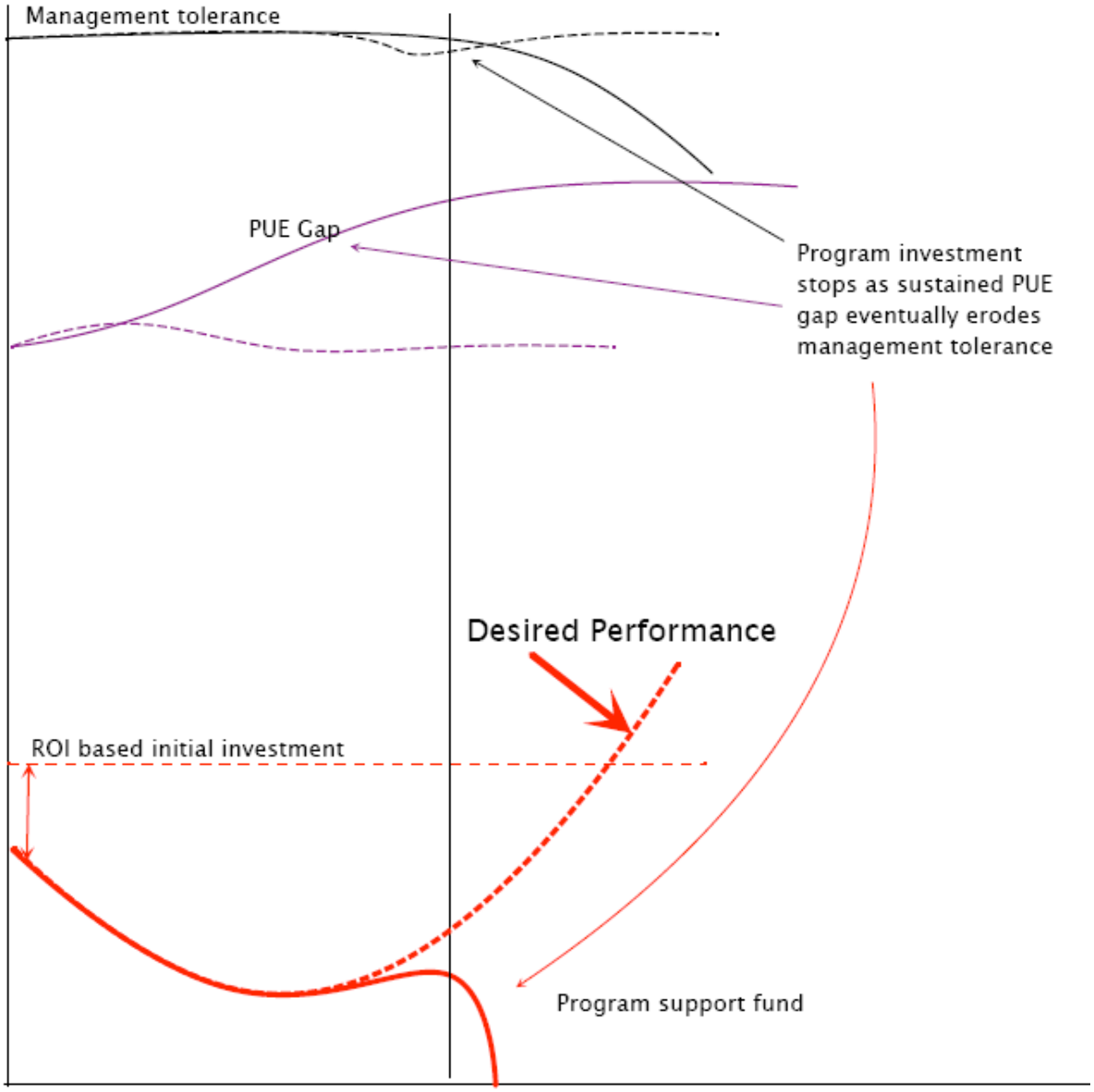
Data center design upgrade example	Electric bill	PUE
Virtualization / consolidation (Reduce ICT Load)	**BETTER** (lower) *Because of optimized use of server capacity*	**WORSE** (higher) *Unless power and cooling are downsized to align with lower IT load* *
Higher room temperature (Reduce INF losses)	**WORSE** (higher) *If increased server fan power exceeds cooling system savings*	**BETTER** (lower) *Because of higher efficiency of cooling system*
Install more eff. UPS (Reduce INF losses)	**BETTER** (lower) *Because of lower electrical infrastructure losses*	**BETTER** (lower) *Because of higher efficiency of power system*

3 management approaches for data center energy reduction

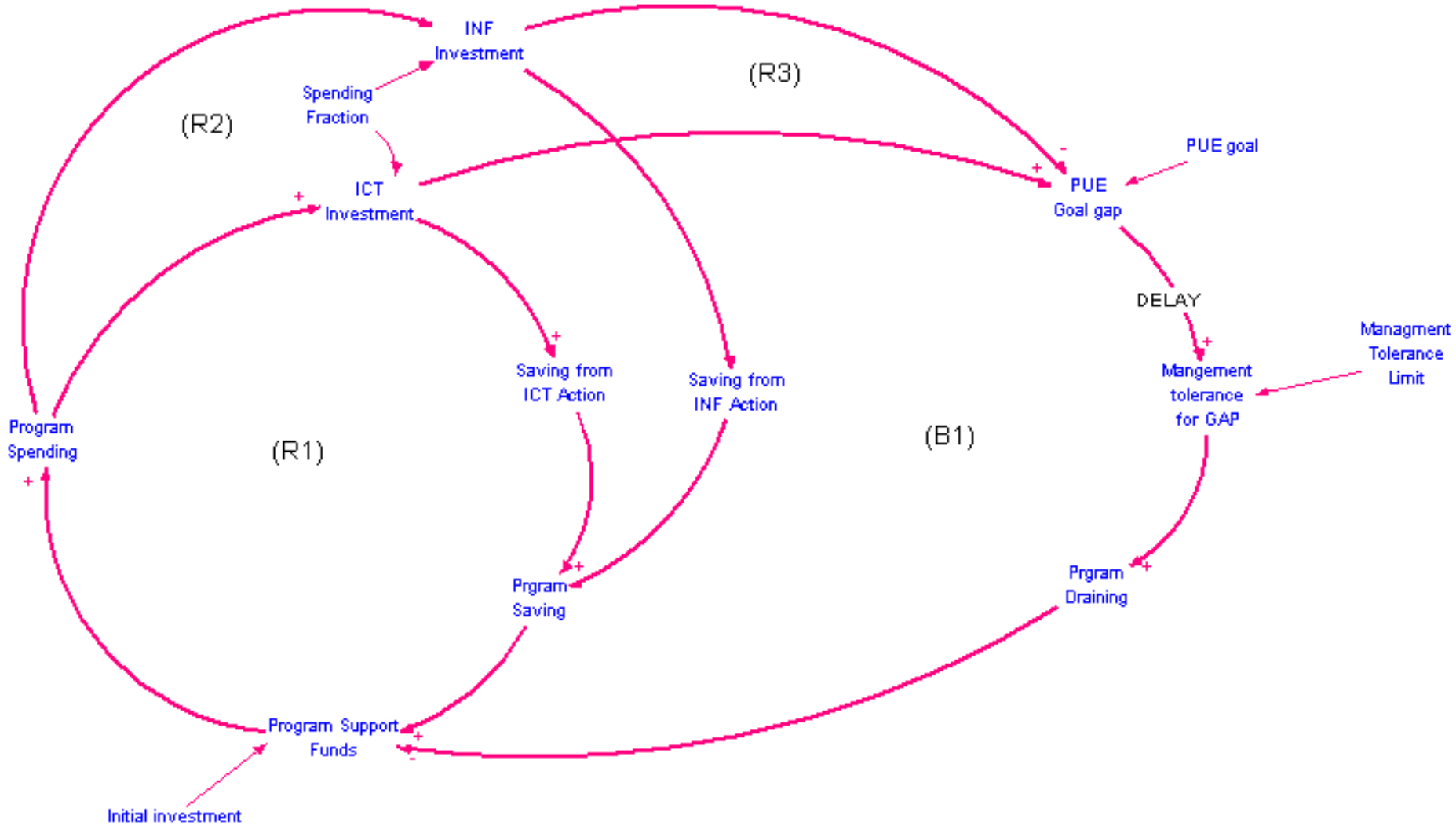
Approach	Characteristic
1. Open Loop	Reduction program is funded **once** and return on investment alternatives scenarios are investigated and best alternative is chosen for implementation
2. Re-enforcing loop with savings focus only	Reduction program is seeded with initial funds and time frame. Savings are allowed to be **re-invested** to continue program until savings goal is achieved
3. Re-enforcing loop with savings focus and PUE metric focus	Same as "2" above but management additionally sets (explicitly or implicitly) a **target for PUE**

Approach “3” reference mode

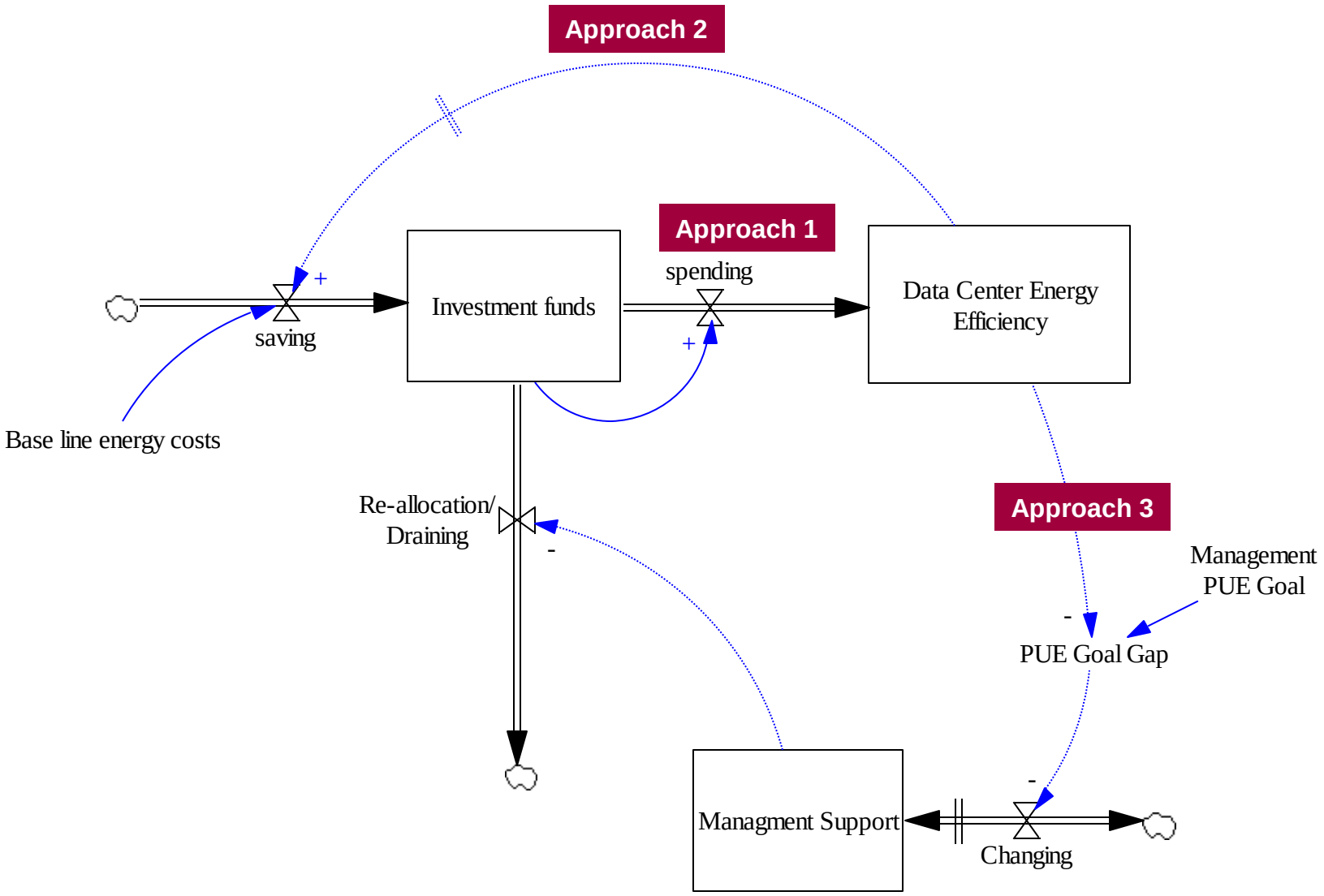
ICT energy improvement focus only example



Approach “3” generalized causal loop



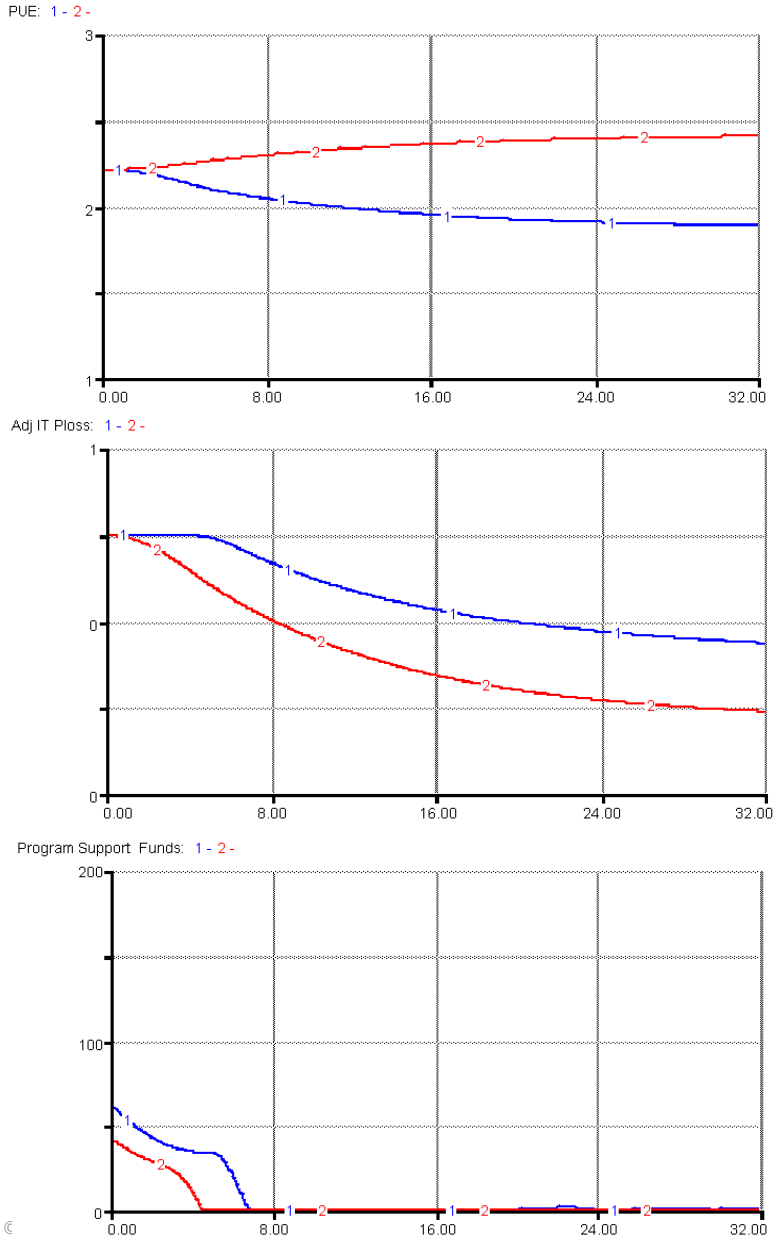
Dynamic Hypothesis (all approaches)



3 research questions are explored for each approach

	Question
1.	What is the impact of investing in infrastructure activities versus ICT activities?
2.	What are the implications changing the initial investment?
3.	What are the implications of investment sequence when a limiting loop exists?

“Path” matters to program success



Sequence 1: Invest exclusively in infrastructure reduction for 4 months followed by investment in ICT.

- ICT load does not initially reduce, (INF losses decrease)
- PUE initially improves (decreases)
- Program funds “naturally” drain because management sees metric move in right direction

Sequence 2: Invest exclusively in ICT reduction for four months followed by investment in INF reduction.

- ICT load initially reduces
- PUE initially degrades (increases)
- Program funds are removed by management after delay as PUE metric goal-gap increases

Insight table

	Management Approach		
	Open Loop	**Reinforcing loop**	**Limits to growth**
Question 1: What is the impact of investing in infrastructure activities versus ICT activities?	An investment profile that maximizes energy loss opportunity will not minimize PUE	Same as Open Loop PLUS because funds are directed back into the energy reduction fund, the time for the investment to return the initial investment is shortened	Same as Reinforcing loop
Question 2: What are the implications changing the initial investment?	The lower the initial investment, the lower the gains.	Because of the reinforcing loop structure any initial investment will lead to a fully funded program due to the reinvestment of savings.	Same as Reinforcing loop
Question 3: What are the implications of investment sequence when a limiting loop exists?	NA	NA	Because of the limit to growth structure, path of investment is important in ensuring the limiting action is never reached and the program will support full energy reduction efforts.

Conclusions

This paper yielded the following insights for implementing energy reduction efforts for data centers:

Allow energy savings to re-invest in a reduction program

- Debate/delay around initial size of investment can be minimized
- Full savings can be reached

When a PUE metric is added, order of investment is a key consideration for program success

- A plan starting with infrastructure investments followed by ICT investments is less likely to be impacted by a “limits to growth” loop

System dynamics modeling assists in quantifying time and savings profiles

- Break-even time and percent INF v ICT investment profiles are readily modeled
- PUE behavior over time visibility enables clear expectations to be communicated to management

Next steps

- *Package model in a tool that allows management/implementers to run scenarios based on their own projects.*

- *Expand inside out model based on field data*

- *Explore outside-in approach and calibrate on industry data and trends*

- *Strengthen links and lessons to/from other domains with similar behavior and structure*

I am actively seeking research collaborators with interests in these types of problems

Questions?