Green Server Design: Beyond Operational Energy to Sustainability

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Overview

- We want to design sustainable servers

- Prior techniques measure sustainability but are not adequate for making architectural decisions

- We contribute an architecture-centric methodology for understanding and addressing sustainability

- We use this to evaluate energy-efficiency techniques from a sustainability perspective

Outline

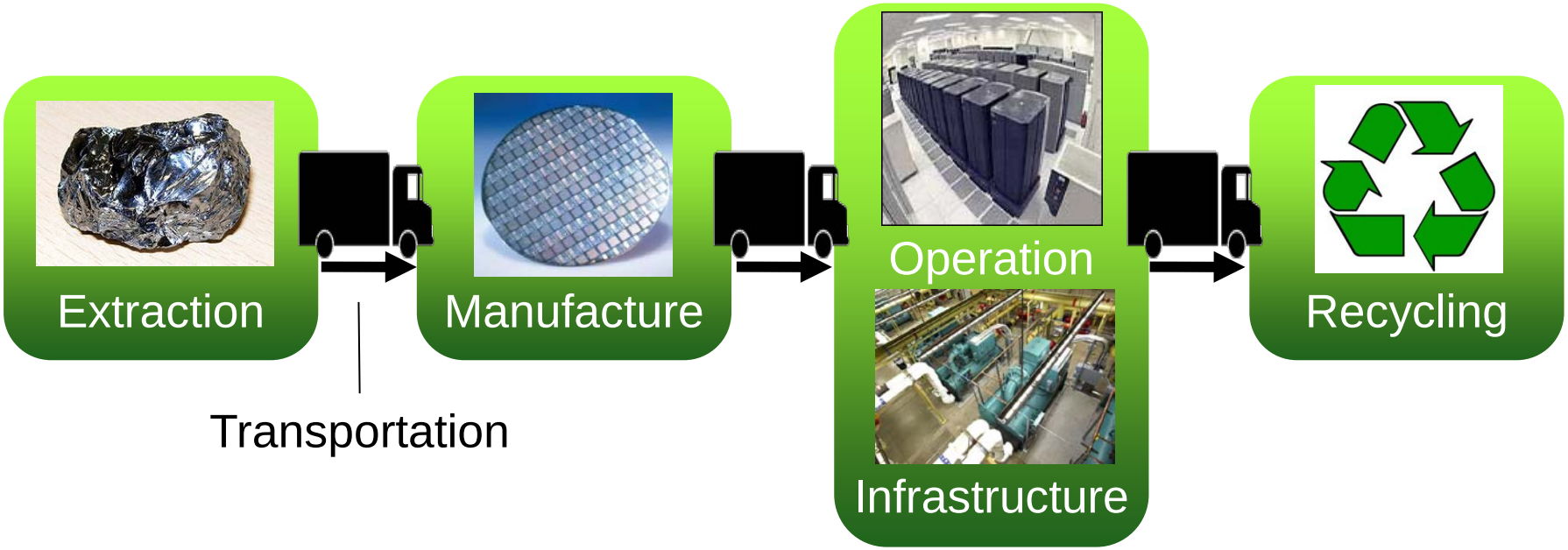
- Motivation
- Measuring Server Sustainability
- Understanding Server Sustainability Bottlenecks
- Energy-Efficiency vs. Sustainability
- Future Work
- Conclusions

Motivation

- Carbon footprint of IT is large (and growing)
  - Accounts for 2% of world (~ size of aviation industry)
  - Used to address other 98% (e.g., video conferencing)
- Businesses want to go green
  - 75% will consider sustainability in IT purchasing decisions
- Government regulation
  - Mandatory cap-and-trade policies in UK & US (proposed)

Measuring Sustainability

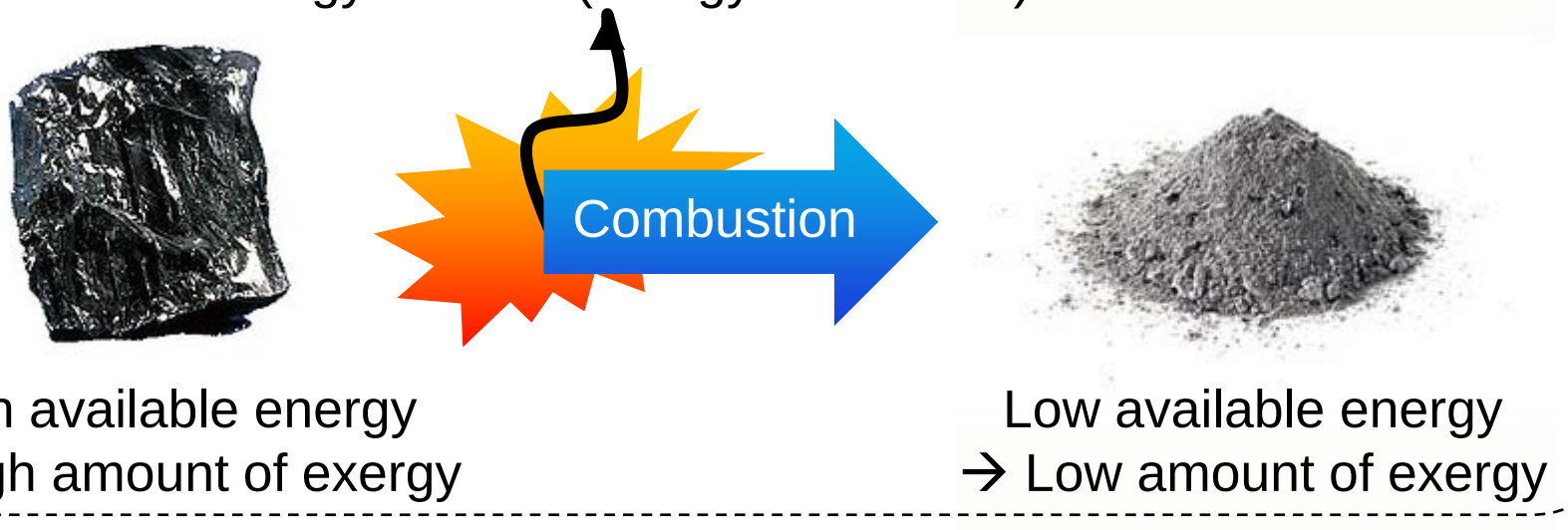
- No standardized method
- Prior sustainability work examined environmental impact across the lifecycle of a system:



- Used *exergy consumption* as a sustainability metric

Measuring Sustainability: Exergy

– Exergy is a thermodynamic metric that measures the amount of available energy in a system

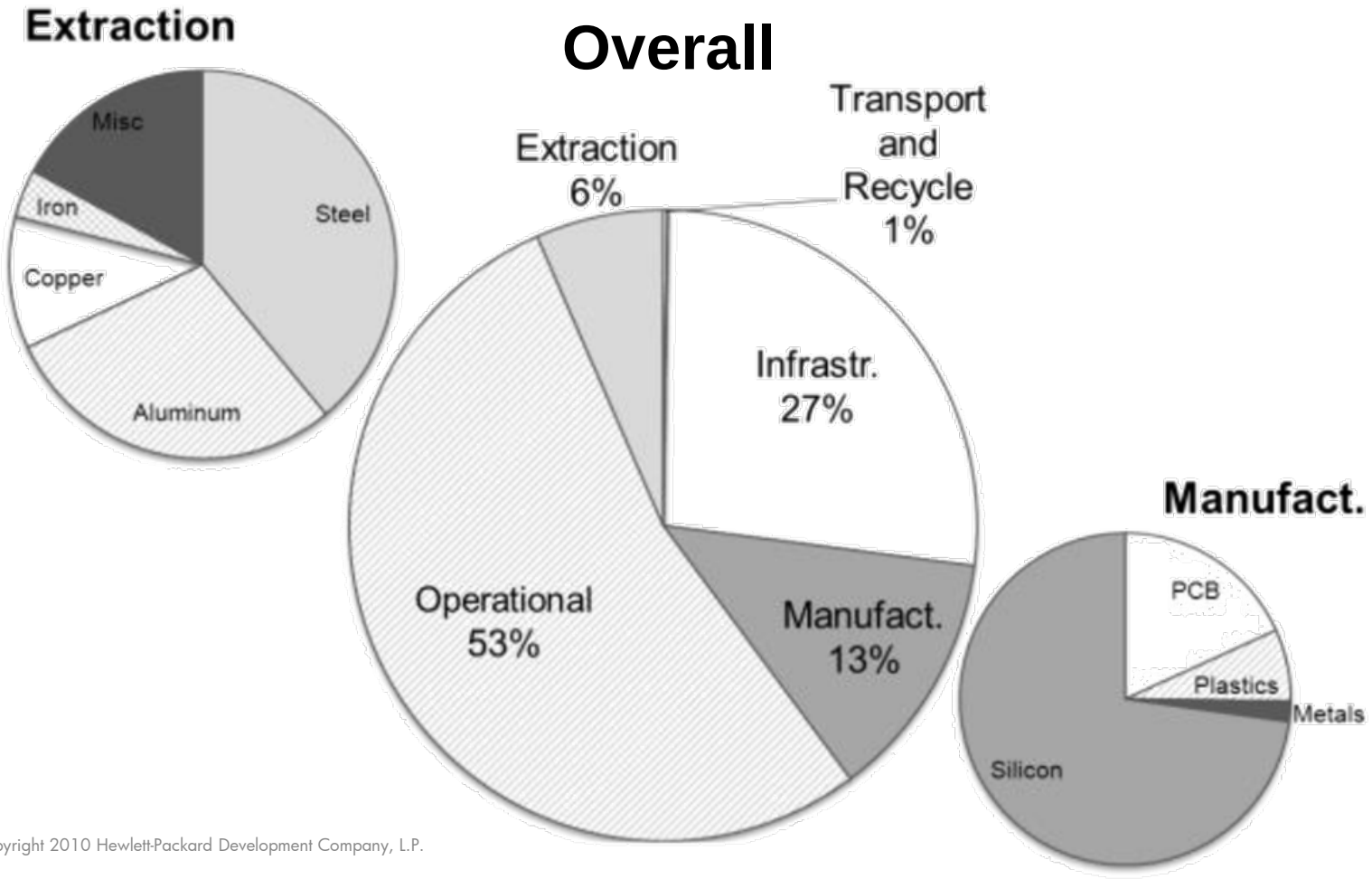


– Exergy consumption corresponds to the irreversibility of some processes (here, fossil fuel destruction)

– Sustainable solutions minimize exergy consumption

Prior Work: Measuring Server Sustainability

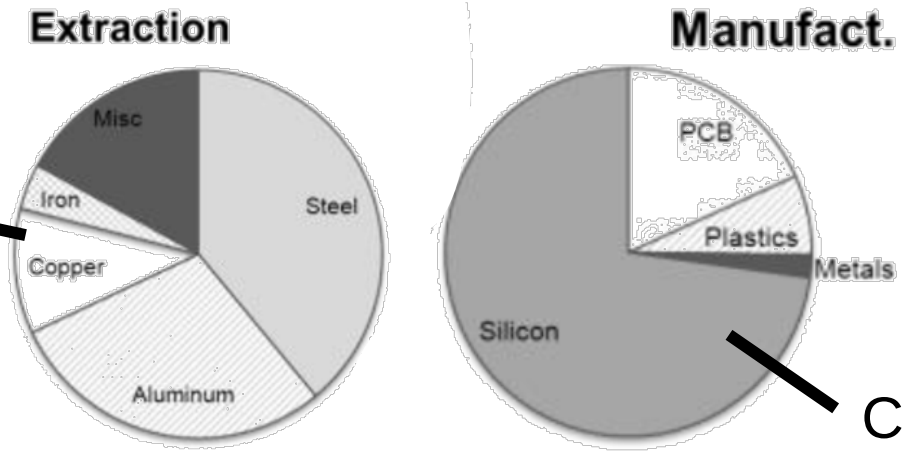
– Mapped server component mass to exergy consumption using a process-based approach



Prior Work: Measuring Server Sustainability

– Difficult to reason about architectural choices:
  - What component is the least sustainable?
  - What are the effects of, e.g., replacing hard disks with SSDs?

PCB traces or PSU transformer?



CPU or DRAM?

– Needed an architecture-centric approach to understand and address system sustainability

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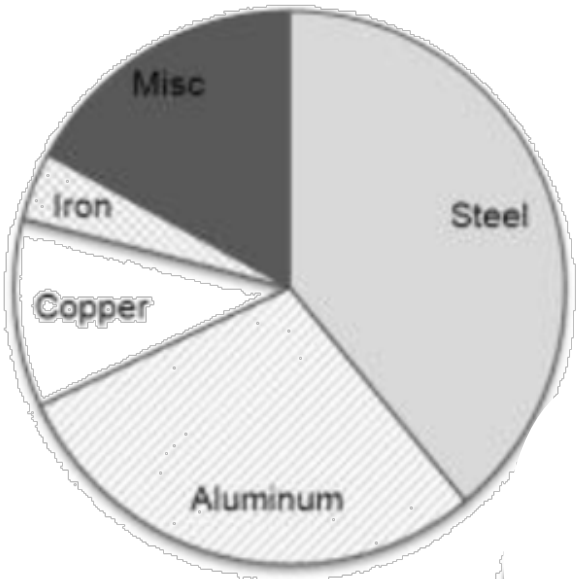
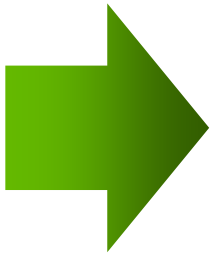
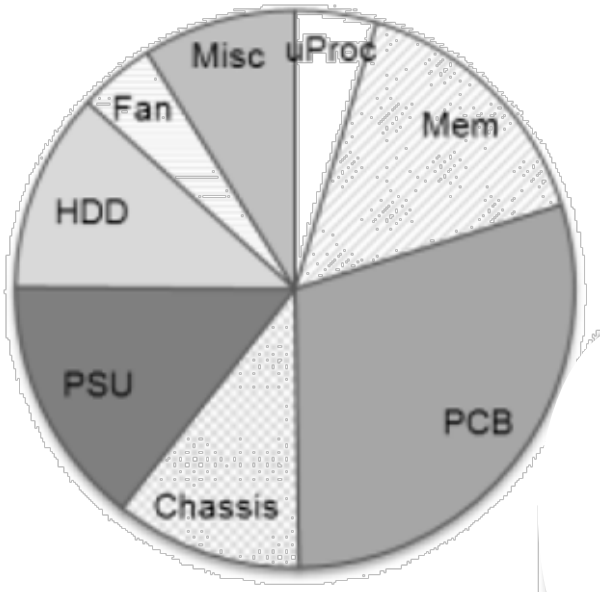
Our Work: Component-Based Approach

– We propose a component-based approach to measuring system sustainability



Prior Work
(Process-Based)

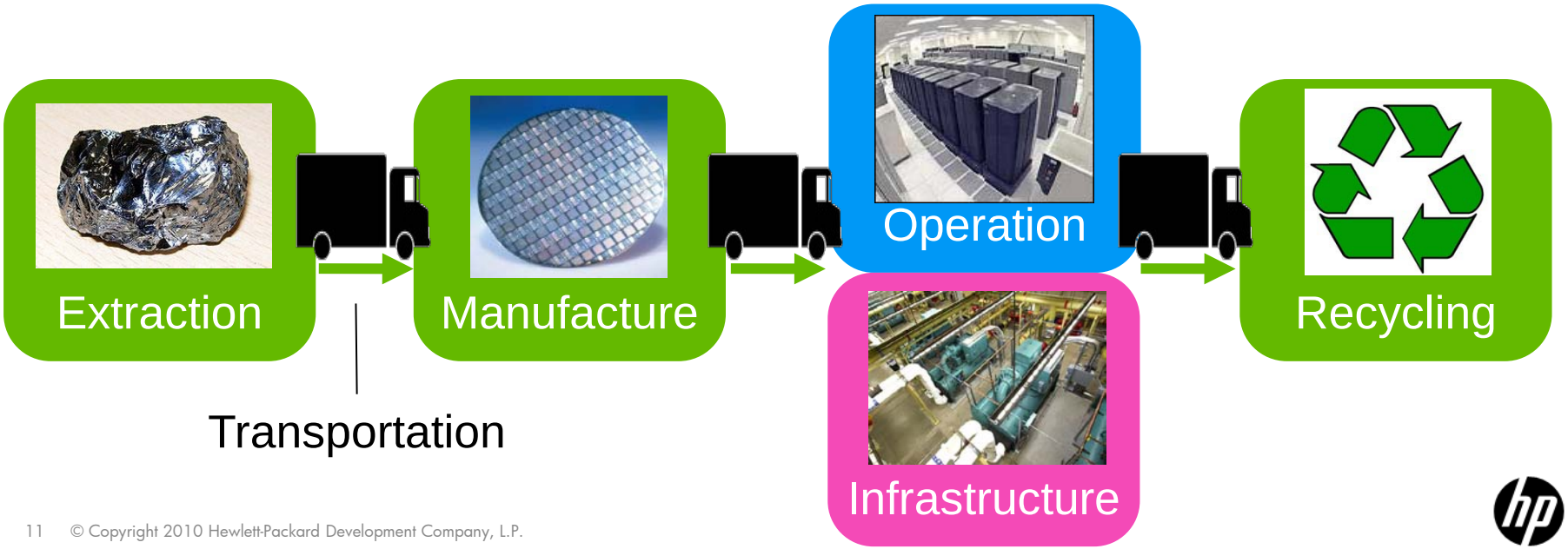




Our Work
(Component-Based)

Component-Based Approach

- We aggregate raw materials at component level
  - CPU, memory, disk, etc.
  - Intuitive mapping to system architecture building blocks
- Overall, we divide exergy into 3 categories: **Embedded**, **Operation**, and **Infrastructure**

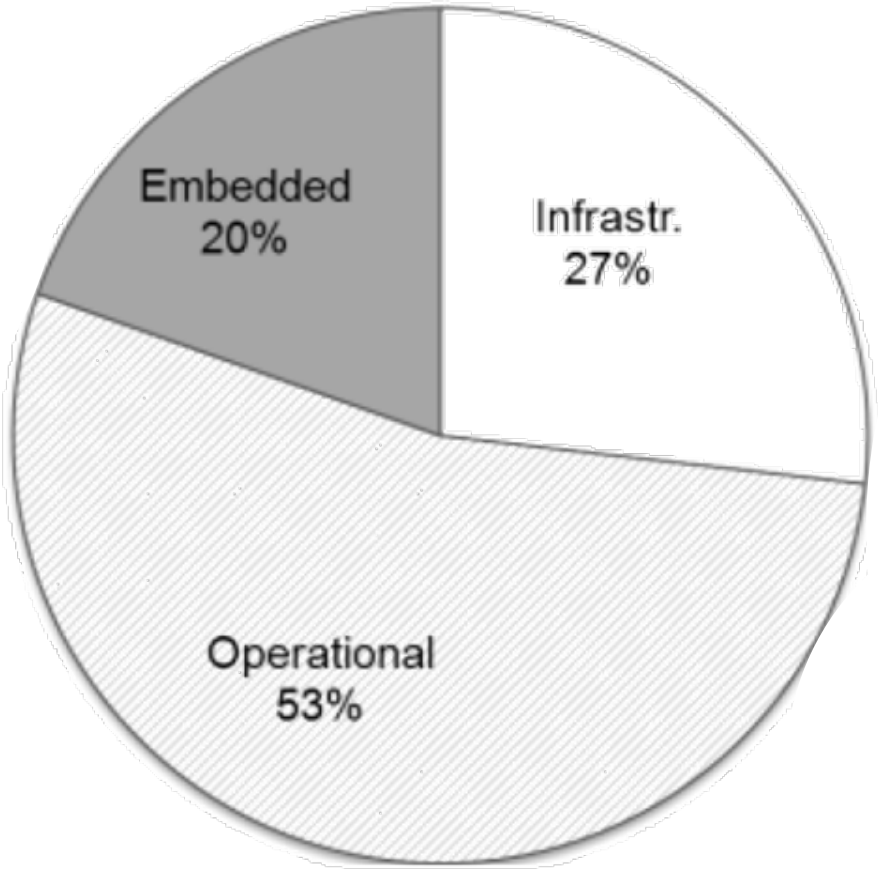


Server Sustainability Bottlenecks

- Applied our technique to a real server (HP ProLiant)
  - 2 Intel Xeon CPUs
  - 4 x 1GB DRAM DIMMs
  - 2 x 72GB hard disk drives
  - 2 gigabit NICs
  - 25% average utilization
  - 3 year operational lifetime
  - Cooling provisioned to handle maximum power ratings
    - *Power usage effectiveness* of 1.6 based on prior studies
  - Used supply chain information to calculate exergy consumption

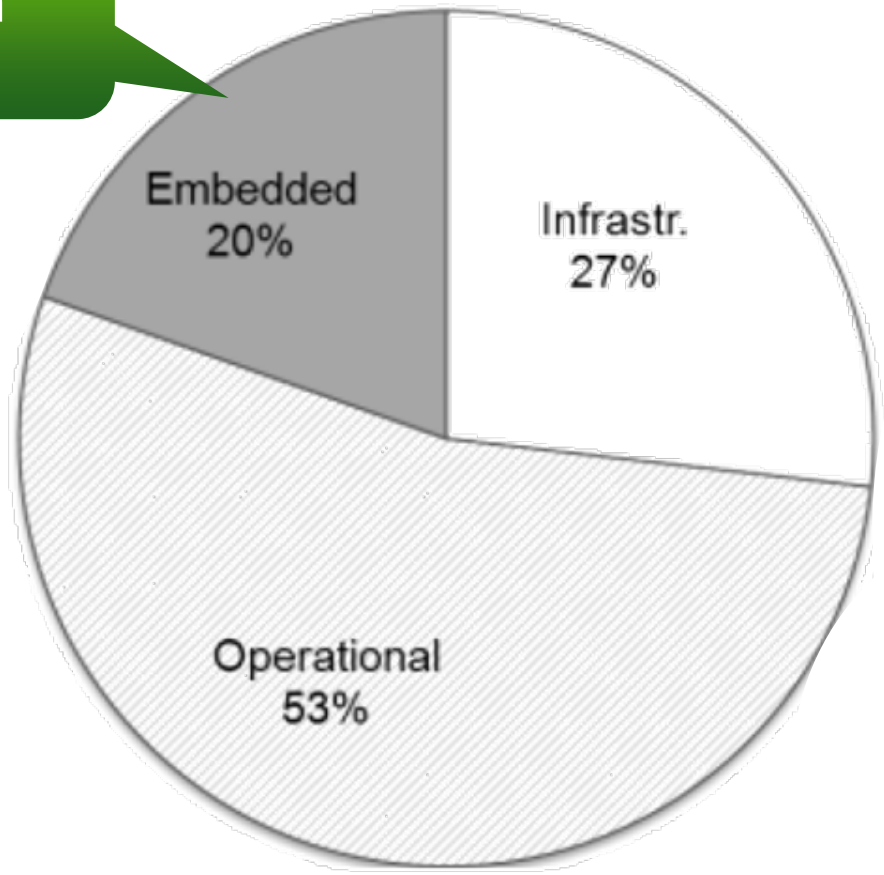
Server Sustainability Bottlenecks

– Total exergy consumed = 24 Giga Joules

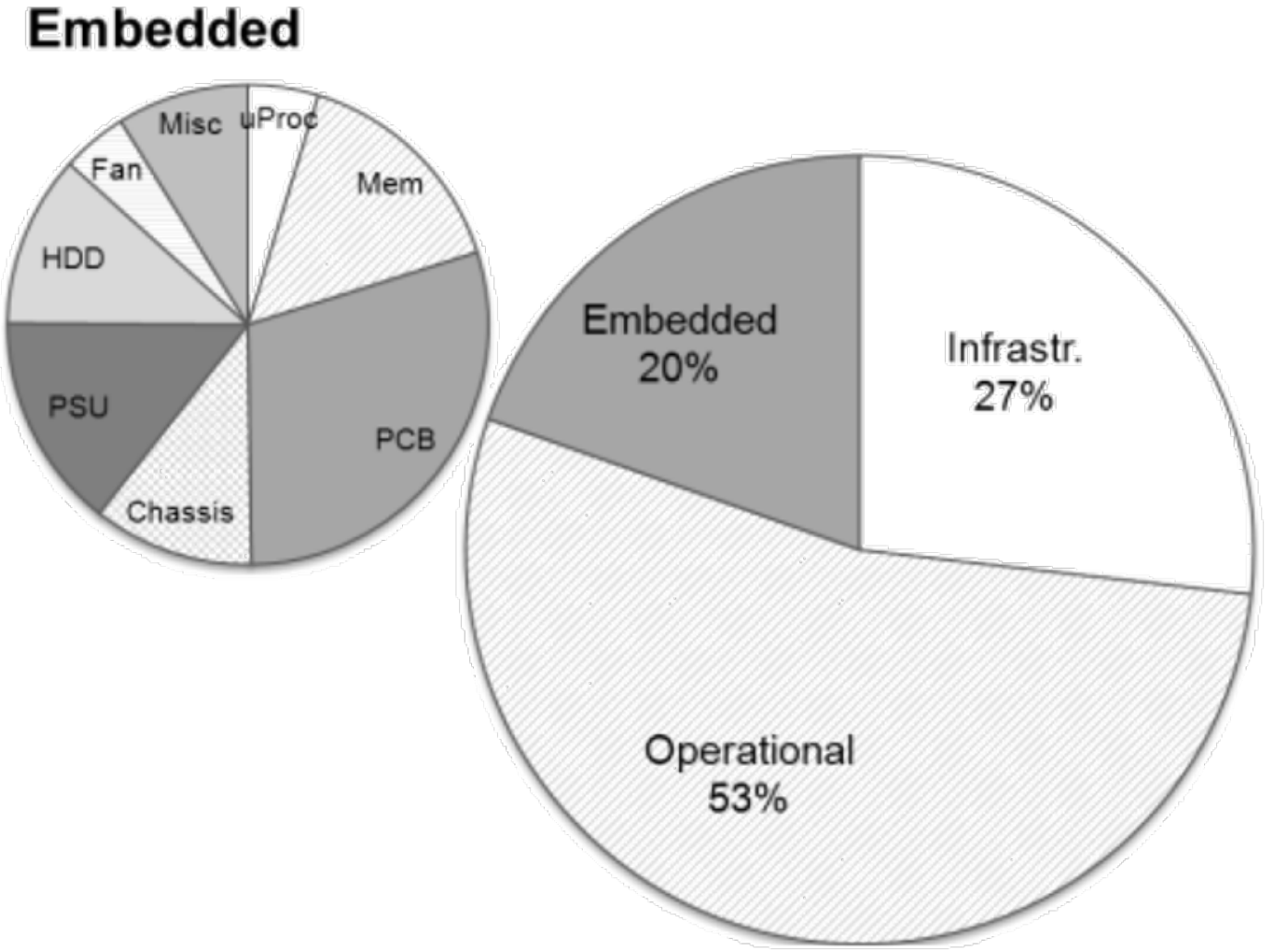


Server Sustainability Bottlenecks

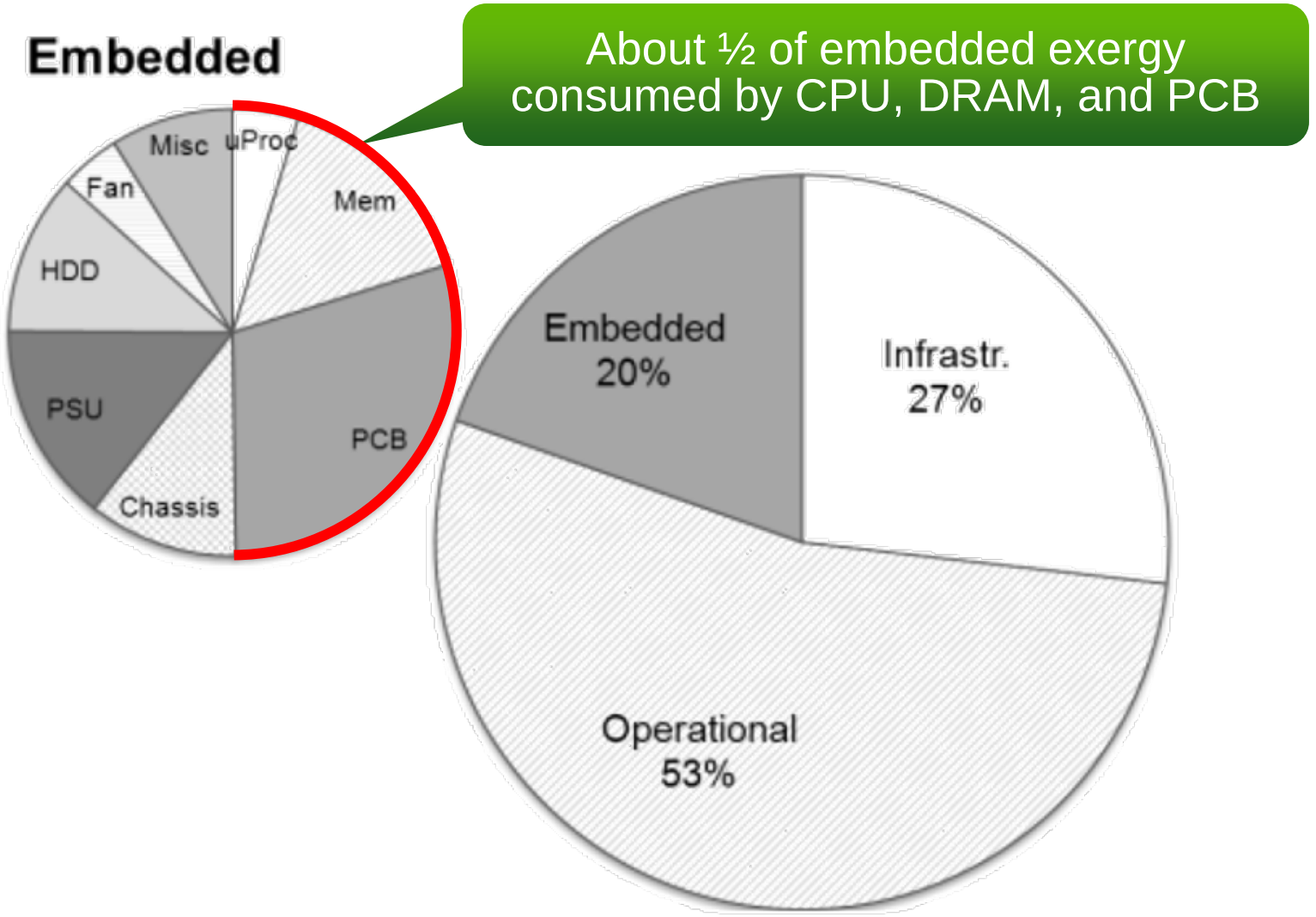
Embedded exergy consumption significant



Server Sustainability Bottlenecks



Server Sustainability Bottlenecks



Component-Based Approach

- Developed a methodology for system architecture community to evaluate sustainability
- Embedded exergy ("making" the component) contributes a significant amount to total exergy (20%)
- About half of this embedded exergy is from
  - Silicon-based processes such as CPU, DRAM
  - PCB processes
  - This is because these processes require chemicals which consume lots of exergy during their manufacture
- Operation still biggest contributor (> 50% of total)
  - How do energy-efficiency techniques affect sustainability?

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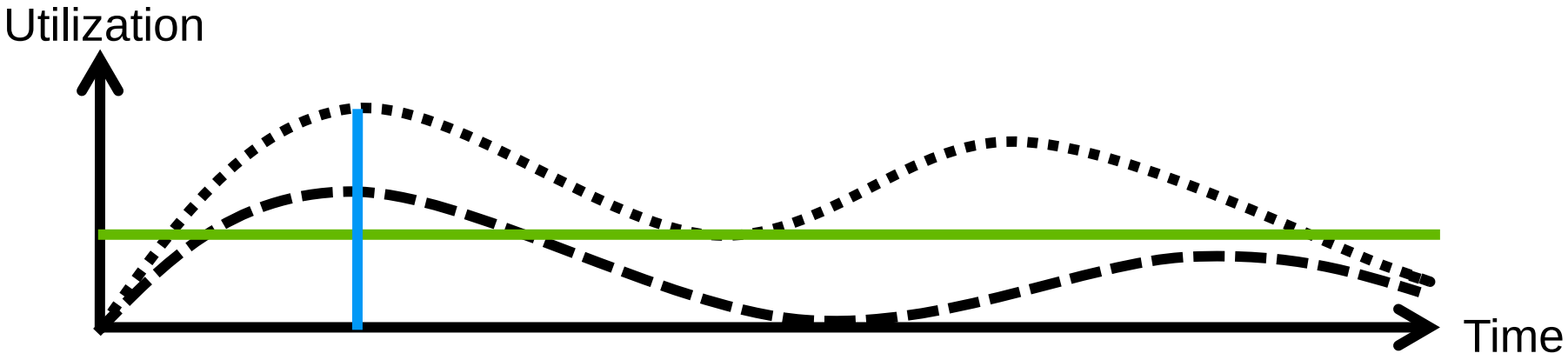
Energy-Efficiency vs. Sustainability

- We compared 3 energy-efficiency techniques across a parameterized workload space
  - Energy proportionality: Energy use proportional to utilization
  - Consolidation: Reduce # of system based on peak of workload
  - Low-power hardware: Energy-efficient embedded components
- Assumed ideal technique effectiveness

Energy-Efficiency vs. Sustainability

– Parameterized workload space as a function of
  - **Average utilization**
  - **Peak of sum (PoS) utilization**



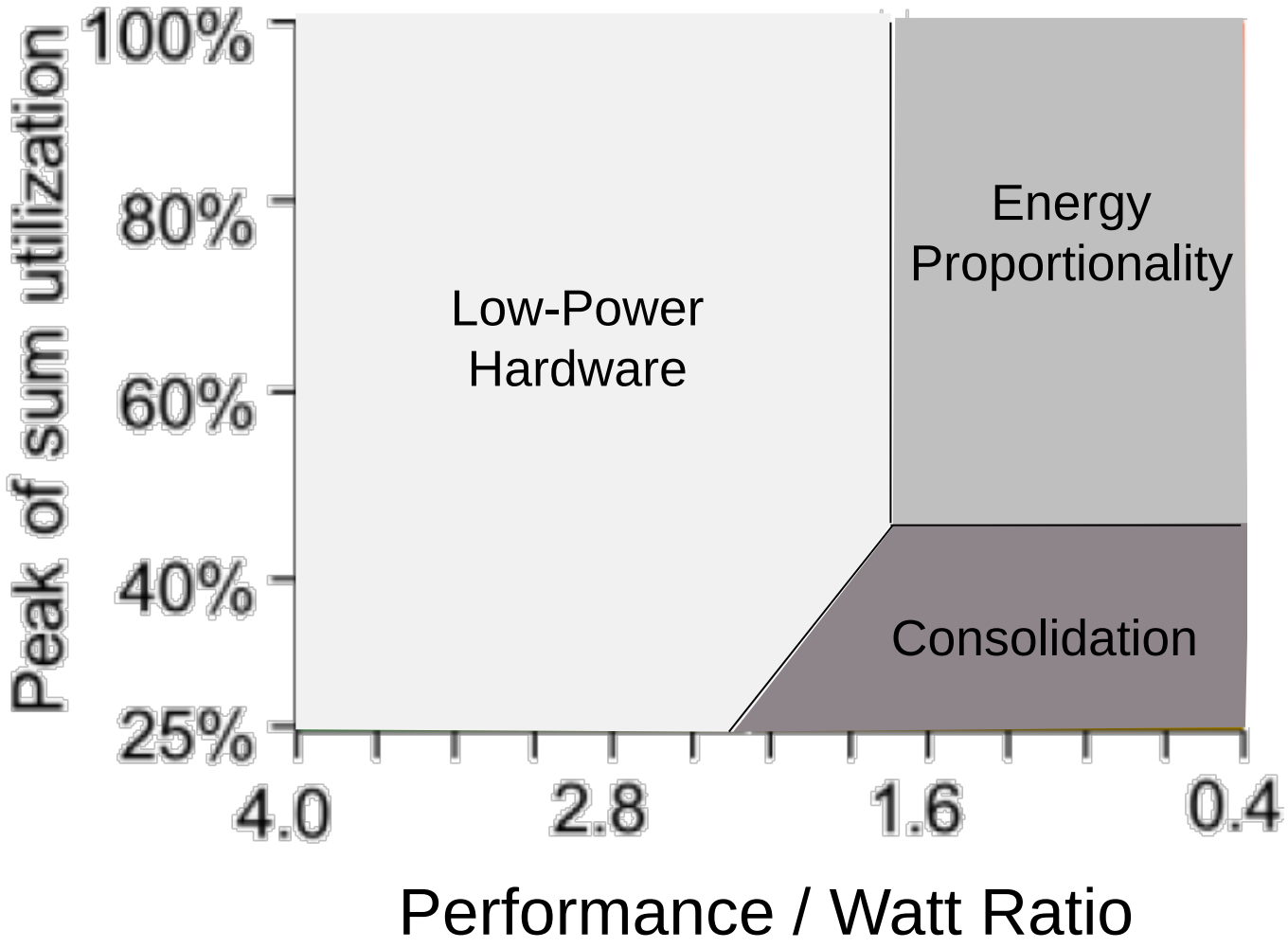
- **Performance/Watt ratio** of low-power to enterprise hardware

$$\frac{\frac{Perf_{low\text{-}power}}{Power_{low\text{-}power}}}{\frac{Perf_{enterprise}}{Power_{enterprise}}} =$$

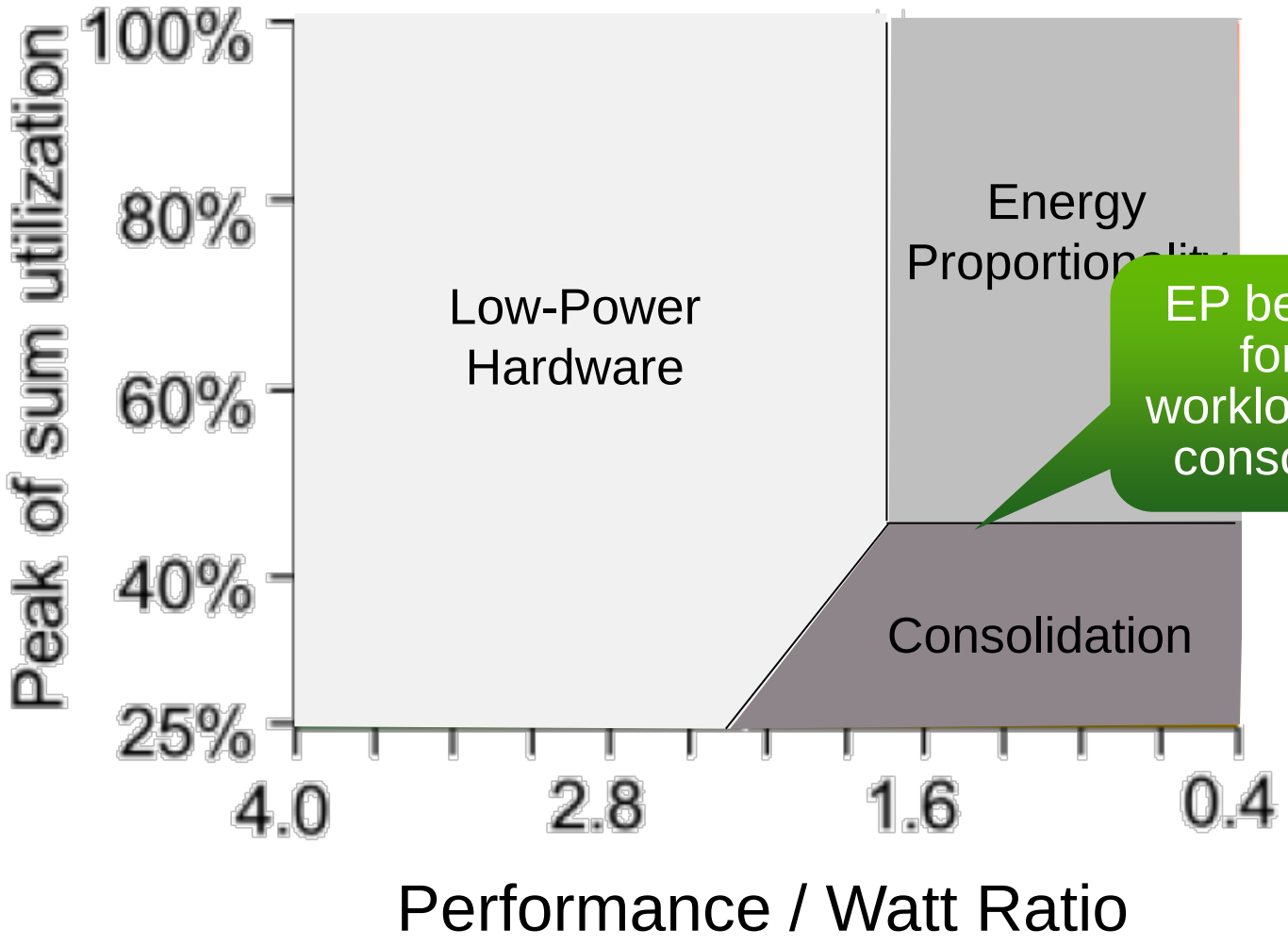
relative energy-efficiency improvement when running workload on low-power HW

Energy-Efficiency Techniques

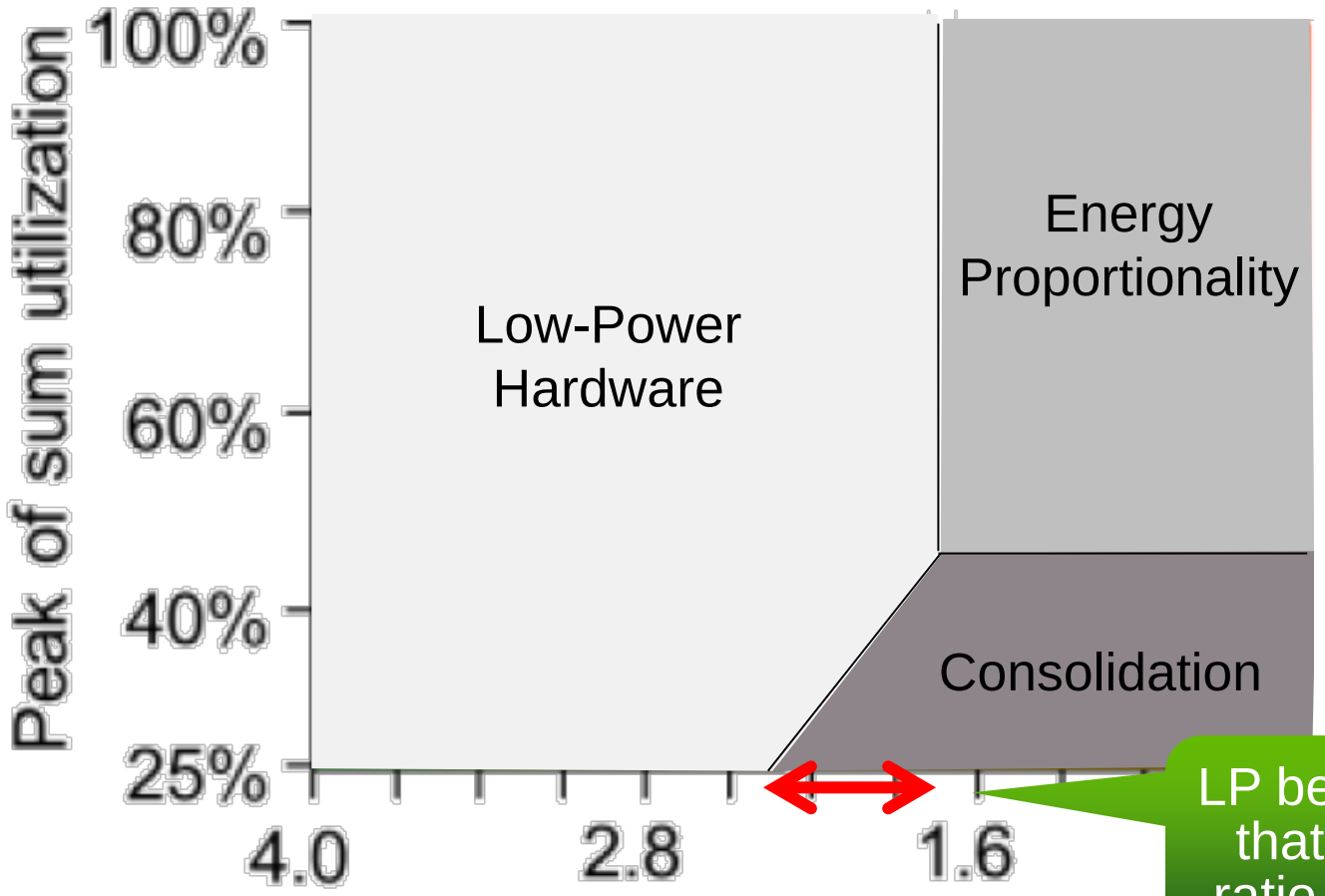
(Shaded regions denote the most sustainable technique)



Energy-Efficiency Techniques



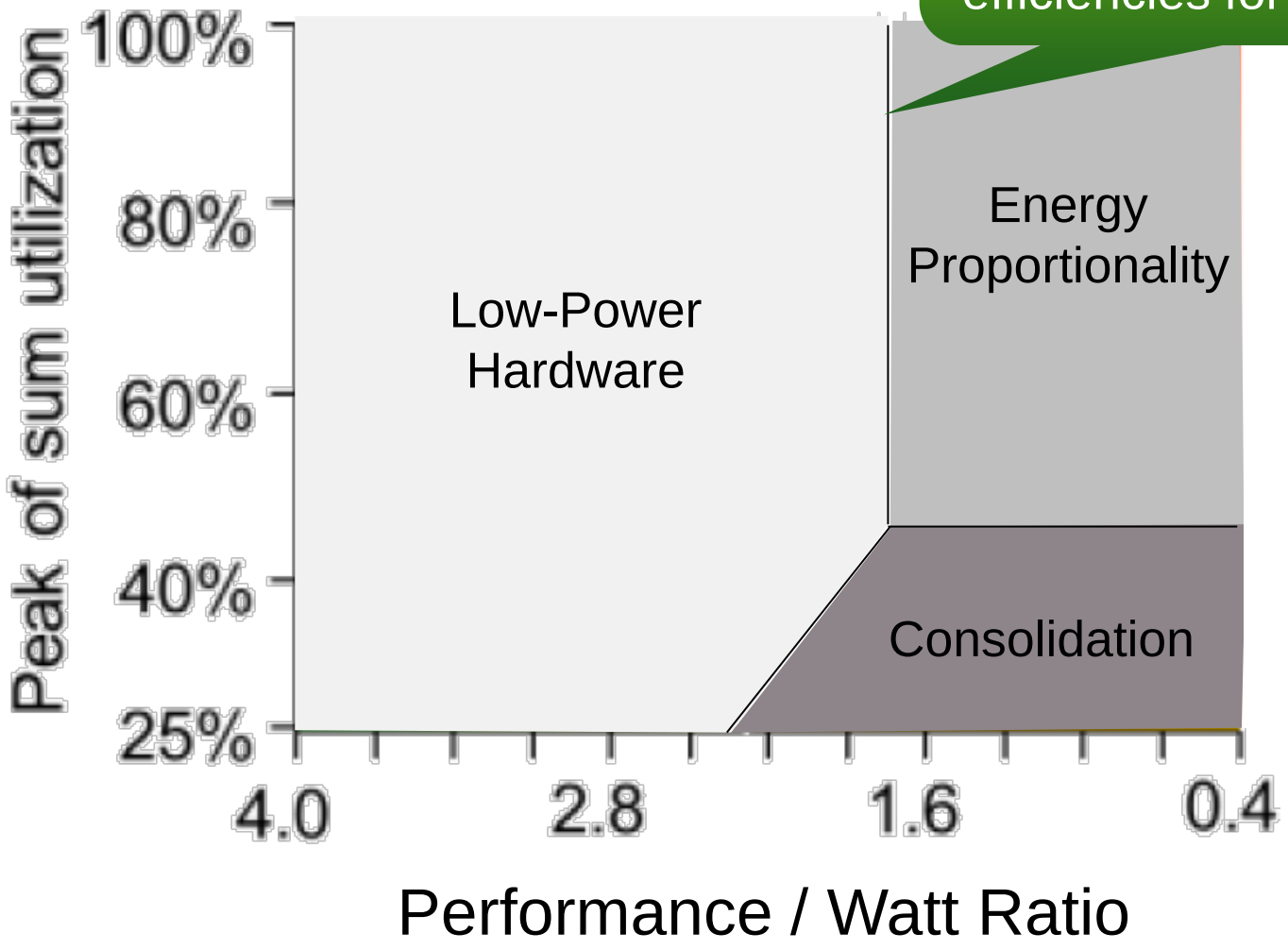
Energy-Efficiency Techniques



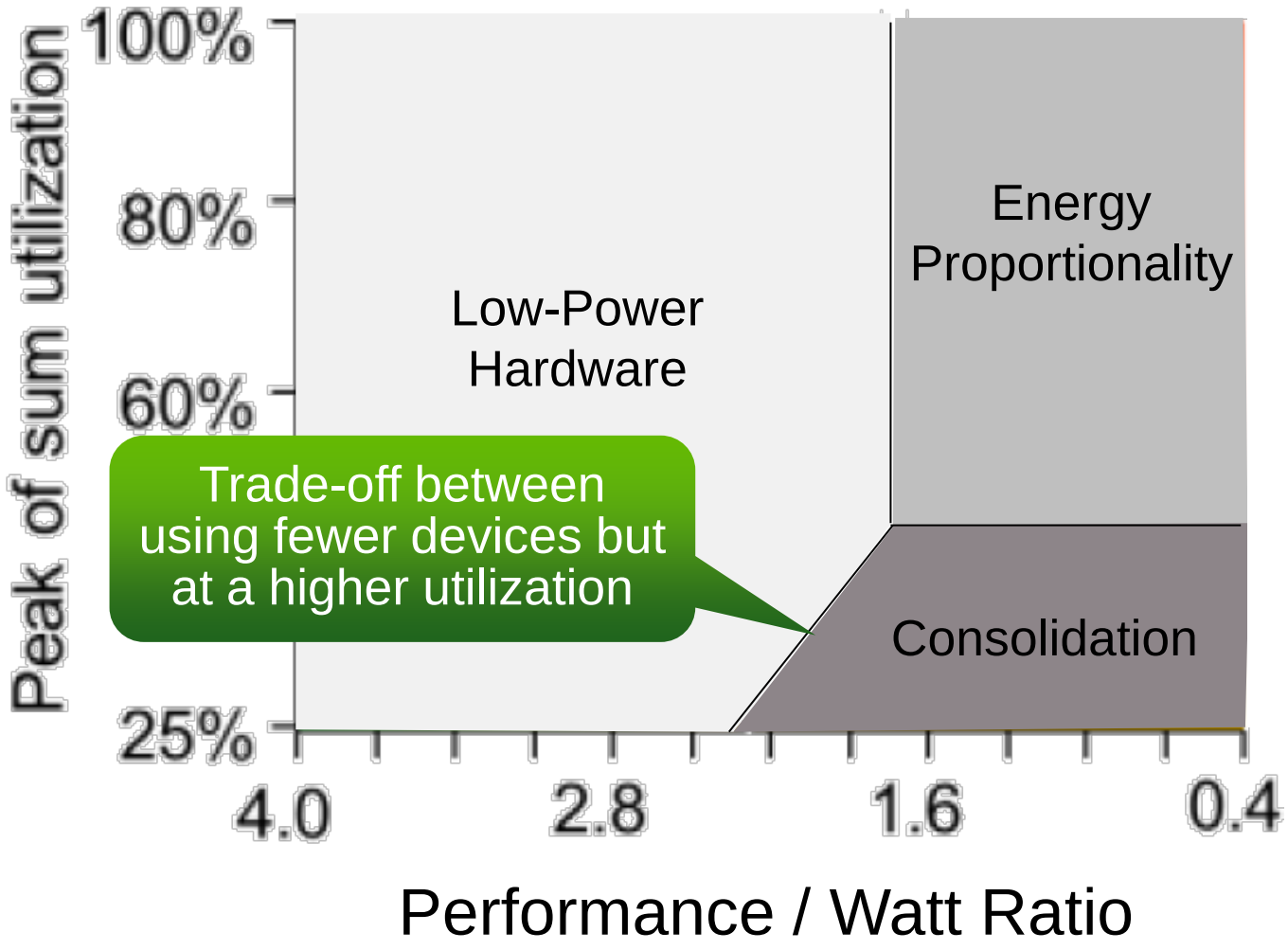
LP best for workloads that exhibit Perf/W ratio > 1.7-2.5 range

Energy-Efficiency Techniques

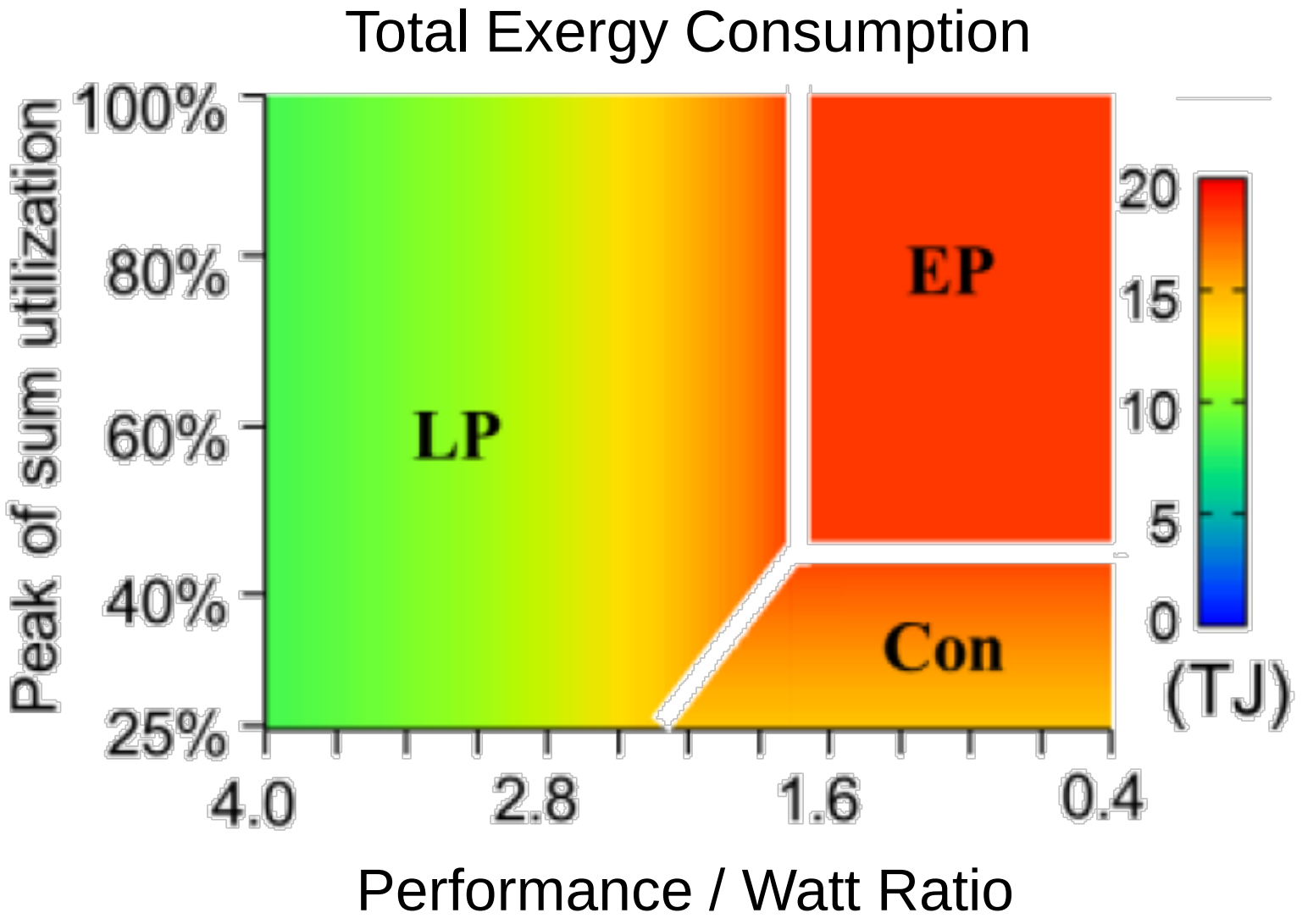
LP & EP are independent of PoS → break-even point depends on relative energy efficiencies for workload only



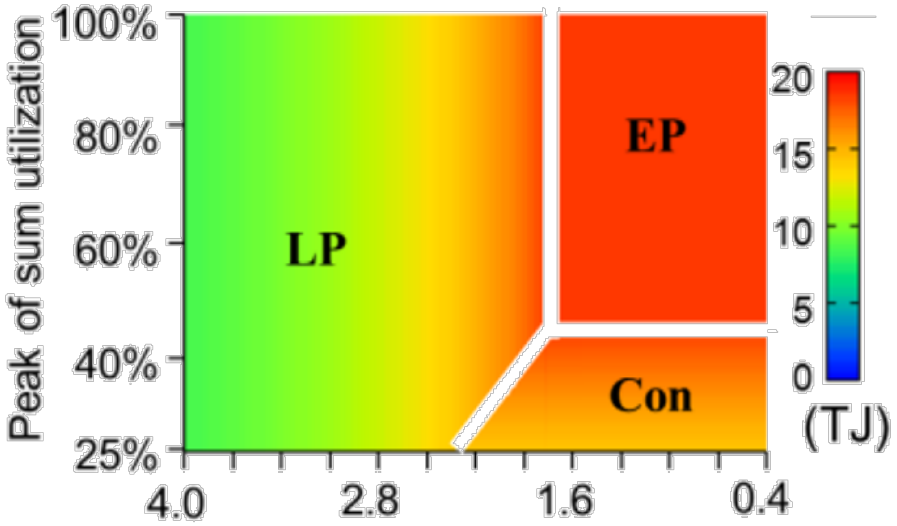
Energy-Efficiency Techniques



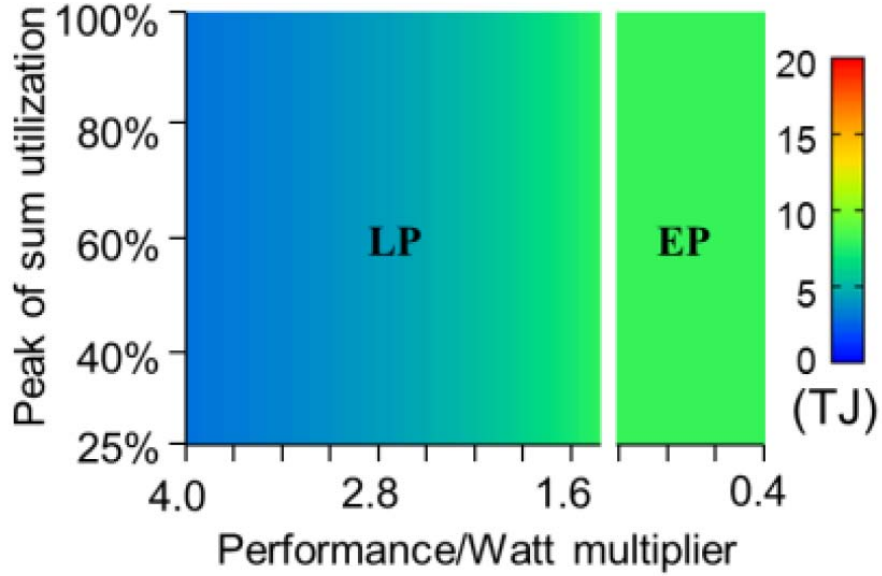
Energy-Efficiency Techniques



Energy-Efficiency vs. Sustainability

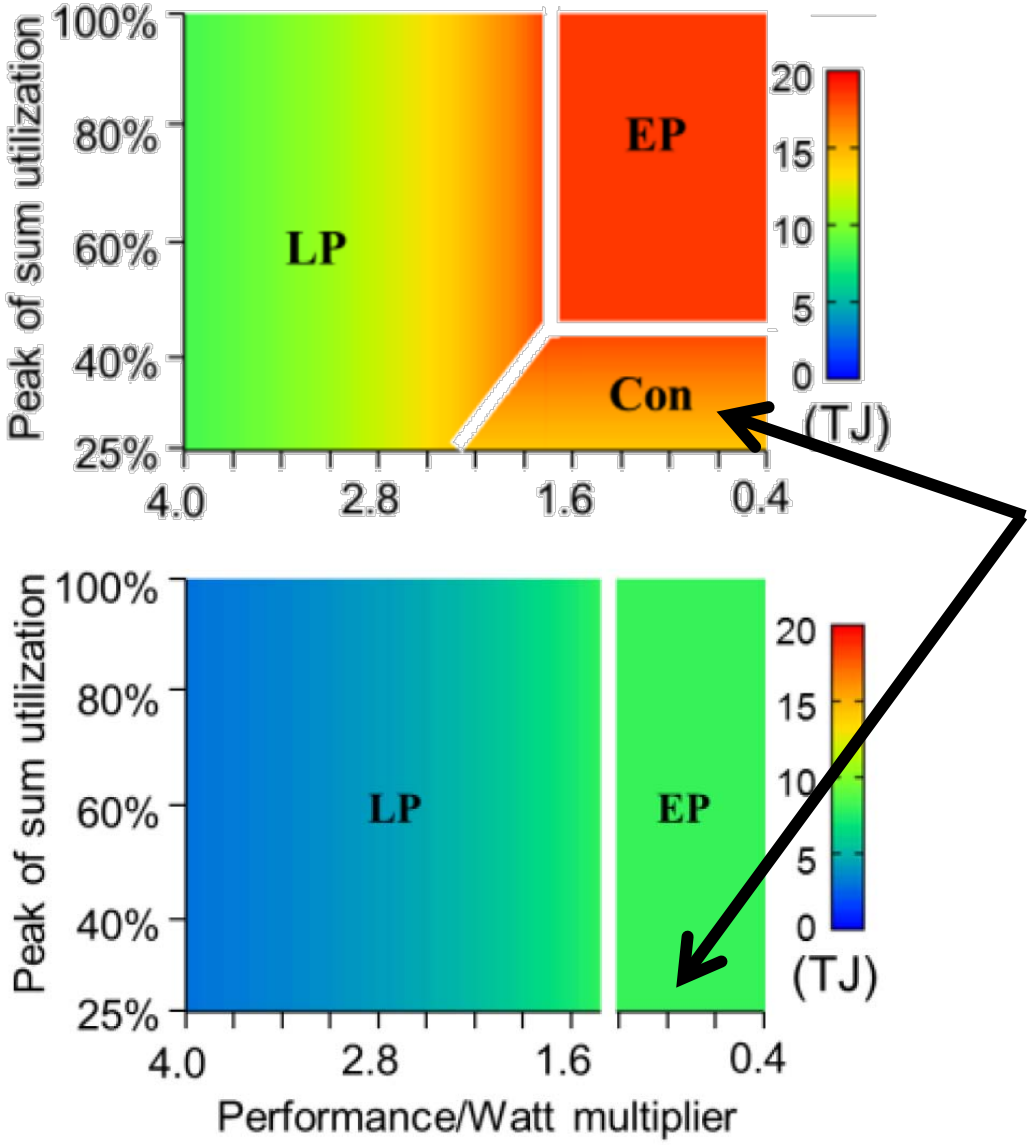


Sustainability focuses on total exergy consumption



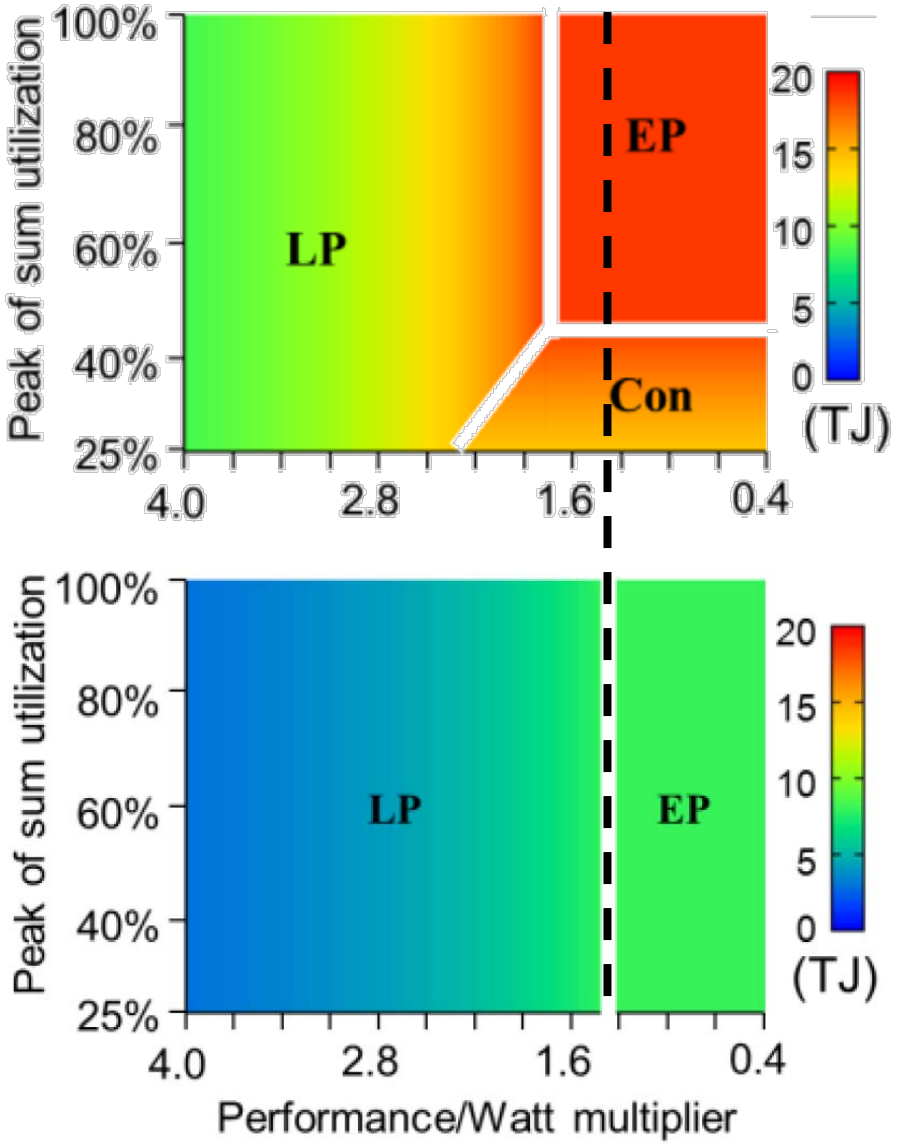
Energy-efficiency focuses on operational exergy consumption (note: op. exergy = op. energy if from non-renewable source)

Energy-Efficiency vs. Sustainability



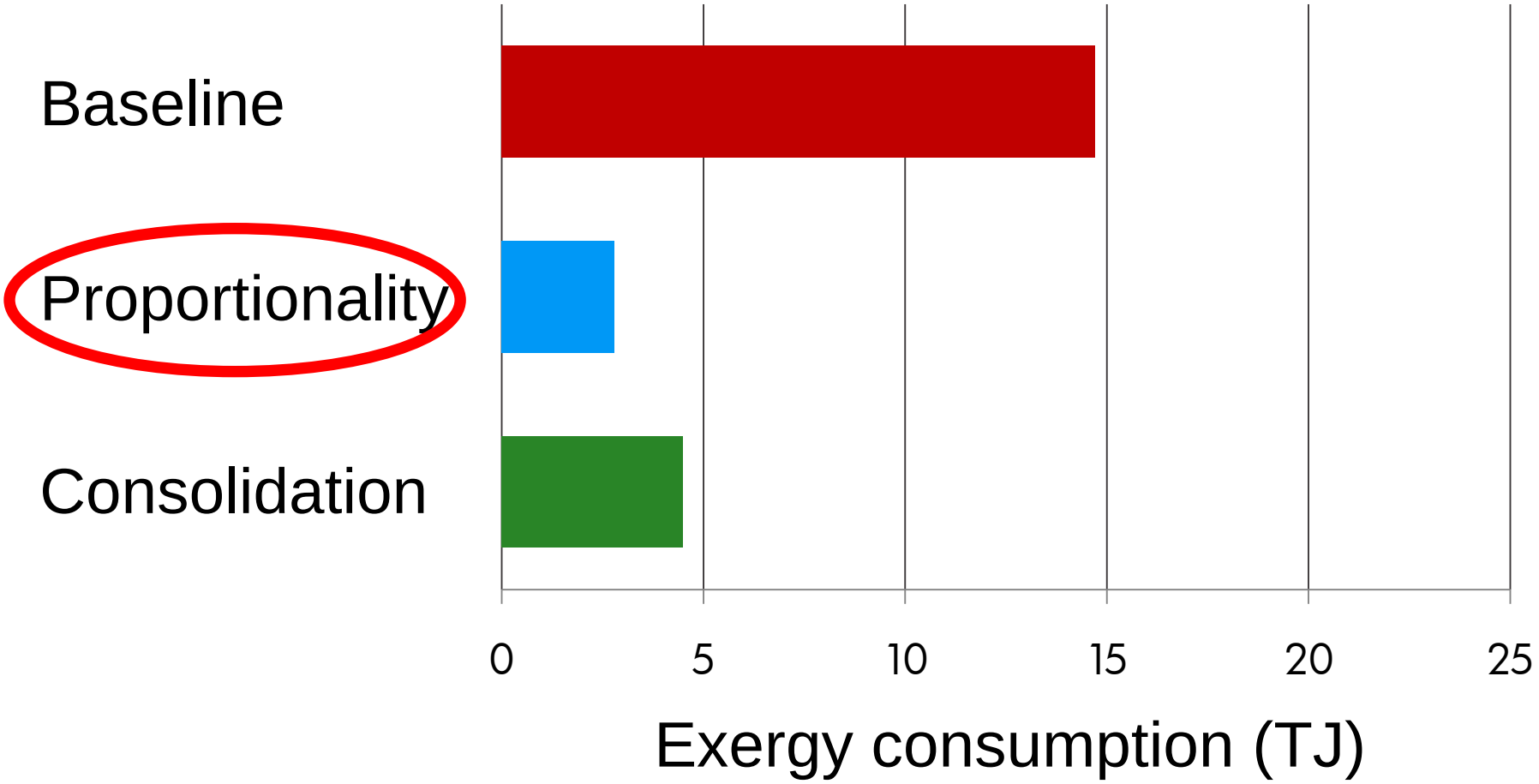
When considering sustainability, Con makes sense for some workloads because it reduces hardware (embedded) exergy consumption—this is not reflected in energy-efficiency

Energy-Efficiency vs. Sustainability

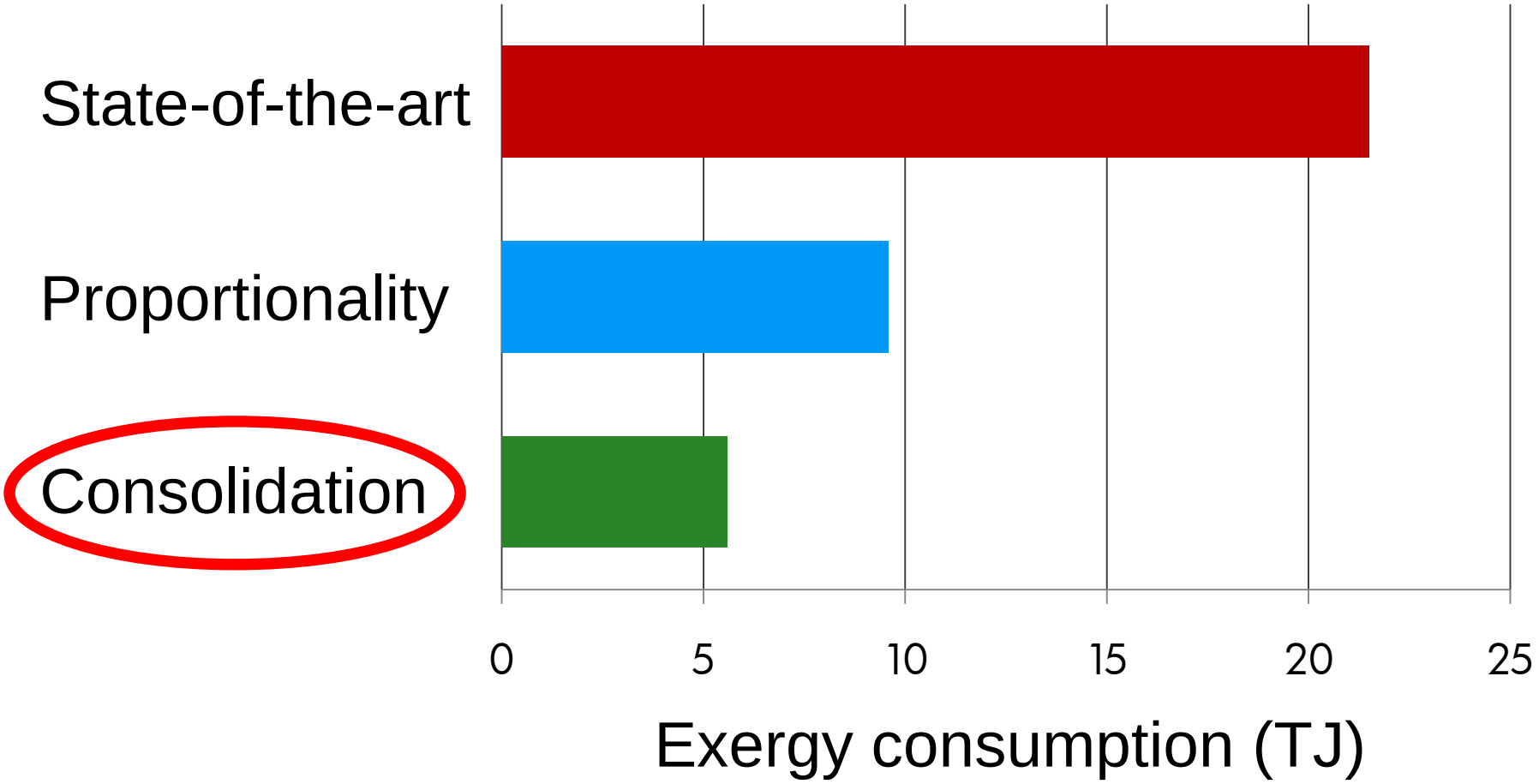


The break-even point for LP shifts. LP requires more hardware to achieve equivalent performance, this increase in embedded exergy consumption is not captured by energy-efficiency

Reducing Energy During Operation...



Not Same as Reducing Total Exergy!



Energy-Efficiency vs. Sustainability

Energy-Efficiency **Sustainability**

Workload	OP (% base)		Total (% base)	
	EP	Con	EP	Con
Ecommerce 1	18%	27%	36%	25%
Ecommerce 2	48%	66%	57%	63%
Dotcom	37%	52%	49%	49%
Pharmacy	10%	17%	31%	16%
SAP 1	39%	50%	51%	46%
SAP 2	53%	84%	61%	82%
Worldcup 1	27%	61%	42%	60%
Worldcup 2	21%	31%	38%	28%
Consolidation 1	62%	88%	68%	87%
Consolidation 2	59%	88%	66%	86%
Animation farm	98%	100%	98%	100%

Energy-Efficiency vs. Sustainability

EP always best when considering energy-efficiency, but…

Energy-Efficiency **Sustainability**

	OP (% base)		Total (% base)	
	EP	Con	EP	Con
Ecommerce 1	18%	27%	36%	25%
Ecommerce 2	48%	66%	57%	63%
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SAP 2	53%	84%	61%	82%
Worldcup 1	27%	61%	42%	60%
Worldcup 2	21%	31%	38%	28%
Consolidation 1	62%	88%	68%	87%
Consolidation 2	59%	88%	66%	86%
Animation farm	98%	100%	98%	100%

Energy-Efficiency vs. Su

…when considering sustainability, Con is best for almost ½ the workloads because it reduces embedded exergy consumption more than it increases operational

Energy-Efficiency **Sustainability**

Workload	OP (% base)		Total (% base)	
	EP	Con	EP	Con
Ecommerce 1	18%	27%	36%	25%
Ecommerce 2	48%	66%	57%	63%
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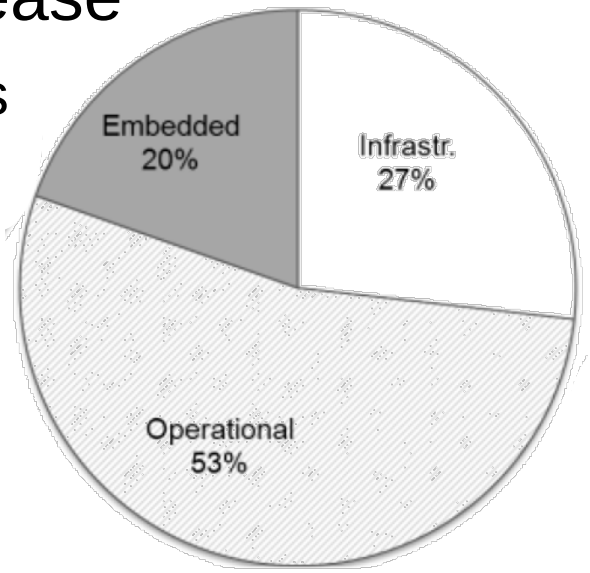
SAP 1	39%	50%	51%	46%
SAP 2	53%	84%	61%	82%
Worldcup 1	27%	61%	42%	60%
Worldcup 2	21%	31%	38%	28%
Consolidation 1	62%	88%	68%	87%
Consolidation 2	59%	88%	66%	86%
Animation farm	98%	100%	98%	100%

Energy-Efficiency vs. Sustainability Insights

- Energy-efficiency does not always = sustainability
- As energy-efficiency is more aggressively applied, embedded portion is expected to increase
  - Need sustainable techniques to address this
- Sustainability requires holistic design
  - Operational, infrastructure, and embedded exergy consumption are not independent
  - E.g., removing chassis may ↓ embedded but ↑ infrastructure



Future Work

- Develop methods to address embedded impact
  - Upcycling—reuse of components
    → Requires rethinking current designs for reuse
  - Dematerialized designs—use less material
    → Need to target highest-impact materials
- Ways to promote holistic system *co-design*
  - Working on thermal simulator for system architects
  - Enables quick feedback of how arch. choices affect cooling
- Examine the effects of renewable energy on datacenter sustainability

Conclusions

- Examined the sustainability of a server
  - Used lifecycle exergy consumption as metric for sustainability
- Developed an architecture-centric approach to understanding and addressing system sustainability
- Evaluated energy-efficiency techniques across workload space
  - Energy-efficiency does not necessarily = sustainability
  - Embedded exergy will become increasingly important
  - Holistic system design techniques are required

Questions?

Thank You!