Measuring and Modeling the Energy Consumption of ICT Distributed Systems

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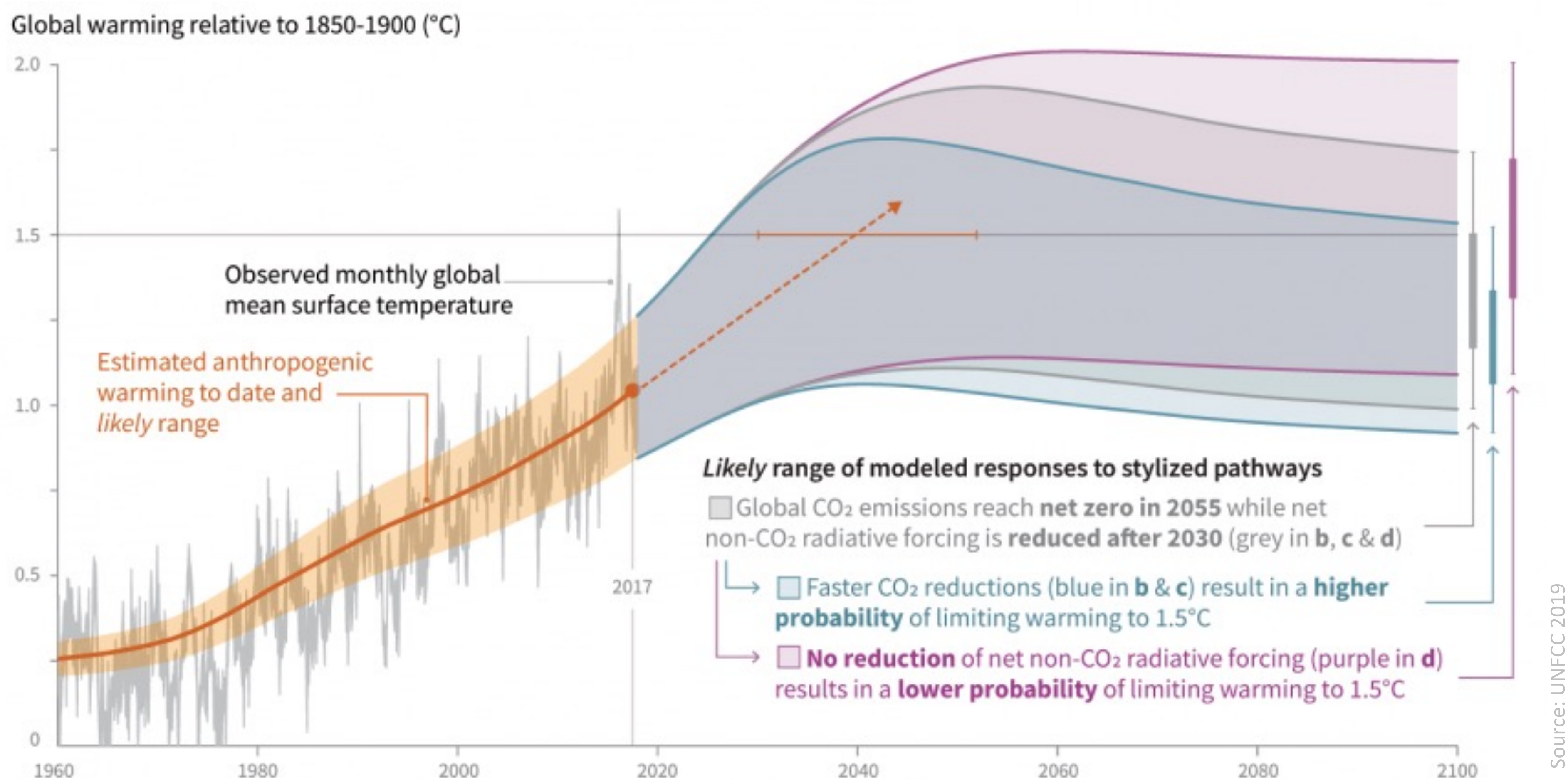
ACML Workshop on power efficient deep learning
17th November 2021

Outline

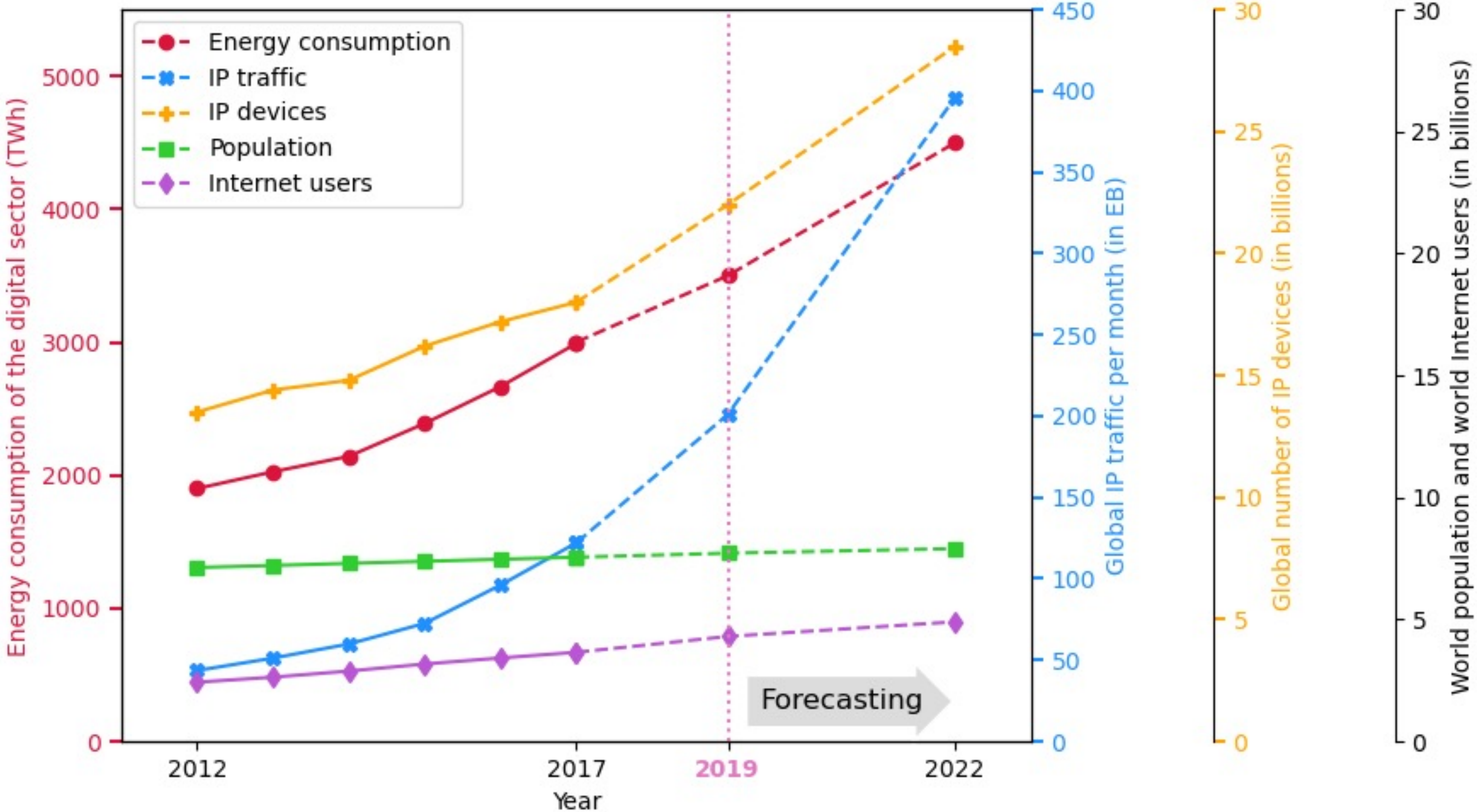
- Context
- Understanding the energy consumption of distributed systems
- Measuring accurately the energy consumption of distributed systems
- Modeling energy consumption of Cloud infrastructures
- Concluding broader remarks

Paris Agreement: 1.5° C



Objective: reducing global greenhouse gas emissions by **8%** each year

ICT energy consumption

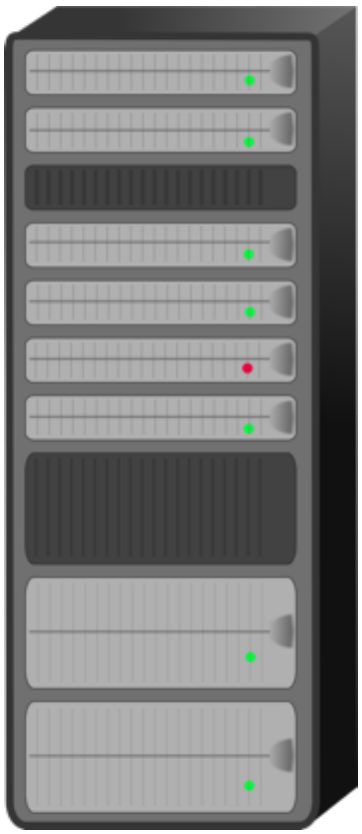


ICT energy consumption grows by **9%** each year.

[HDR 2020]

My scientific context

- Energy consumption
- Large-scale distributed sytems
- Computing and networking parts
- Use phase



Started with Grid computing some years ago…

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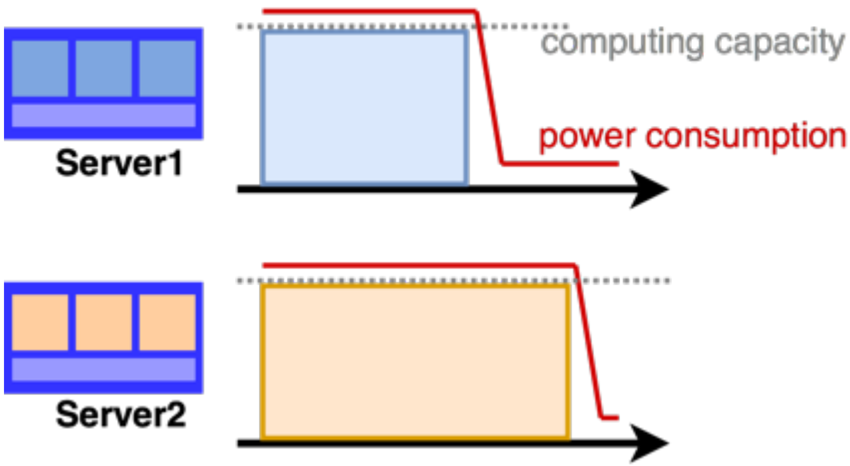
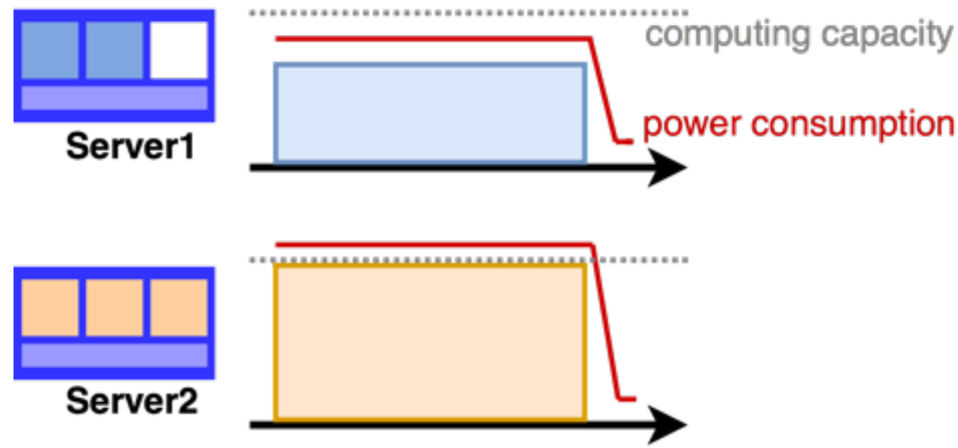
Energy efficiency: business as usual?

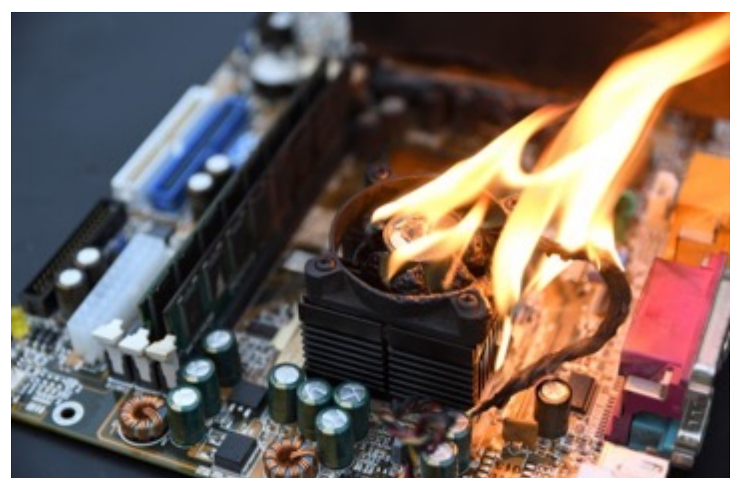
Computing faster?



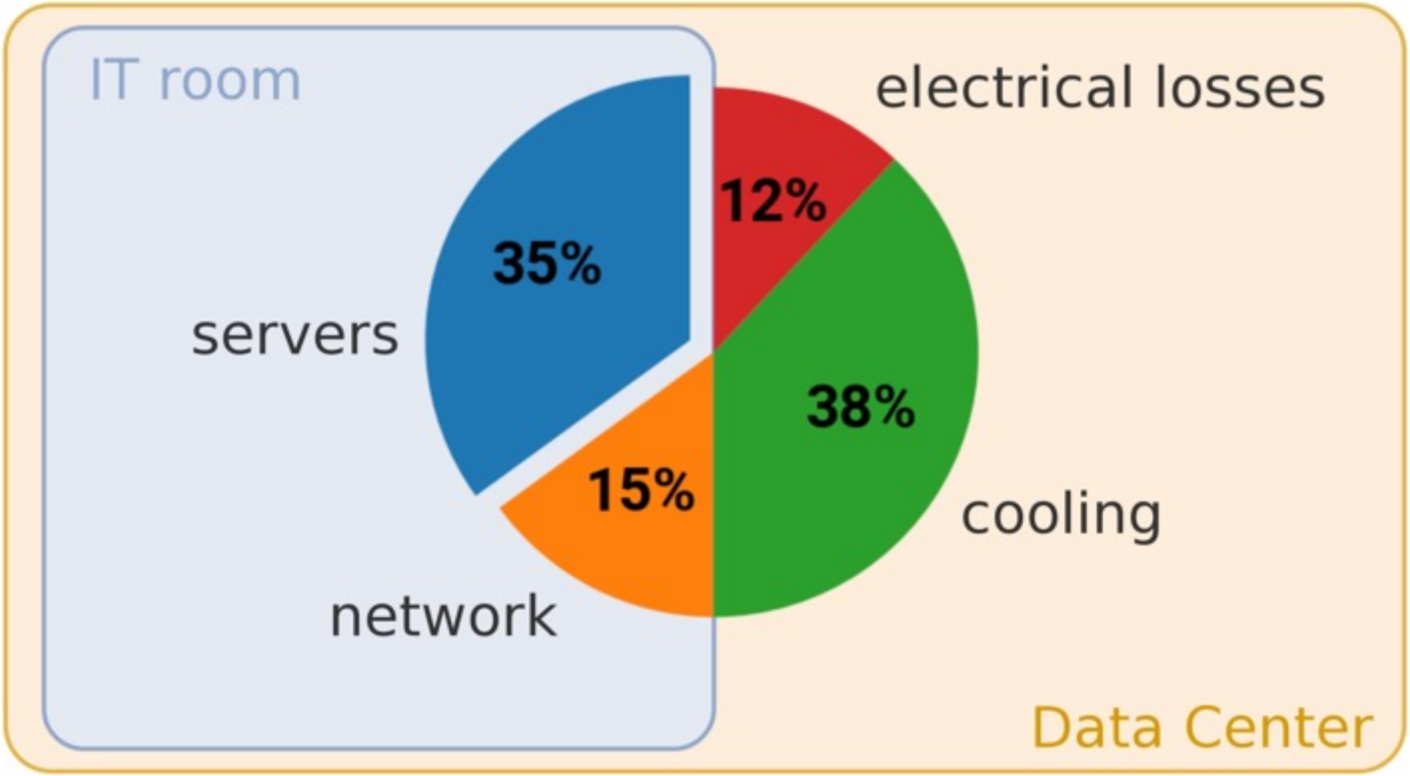
Computing slower?



Temperature matters.



How to measure energy efficiency in DCs?



PUE: Power usage effectiveness

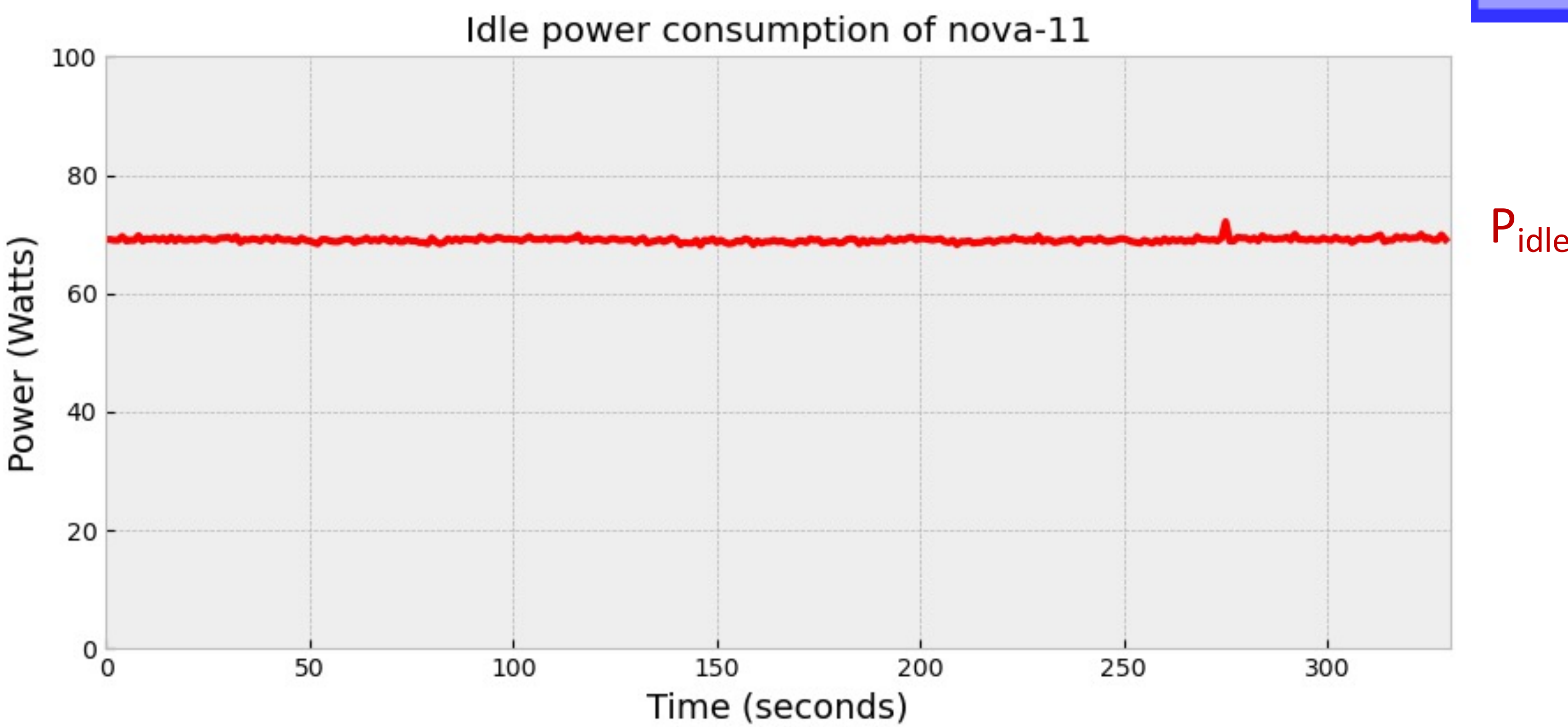
$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

the green grid™

"*Green Grid Data Center Power Efficiency Metrics: PUE and DCIE*", Green Grid White Paper, 2008.

Wrong idea #1

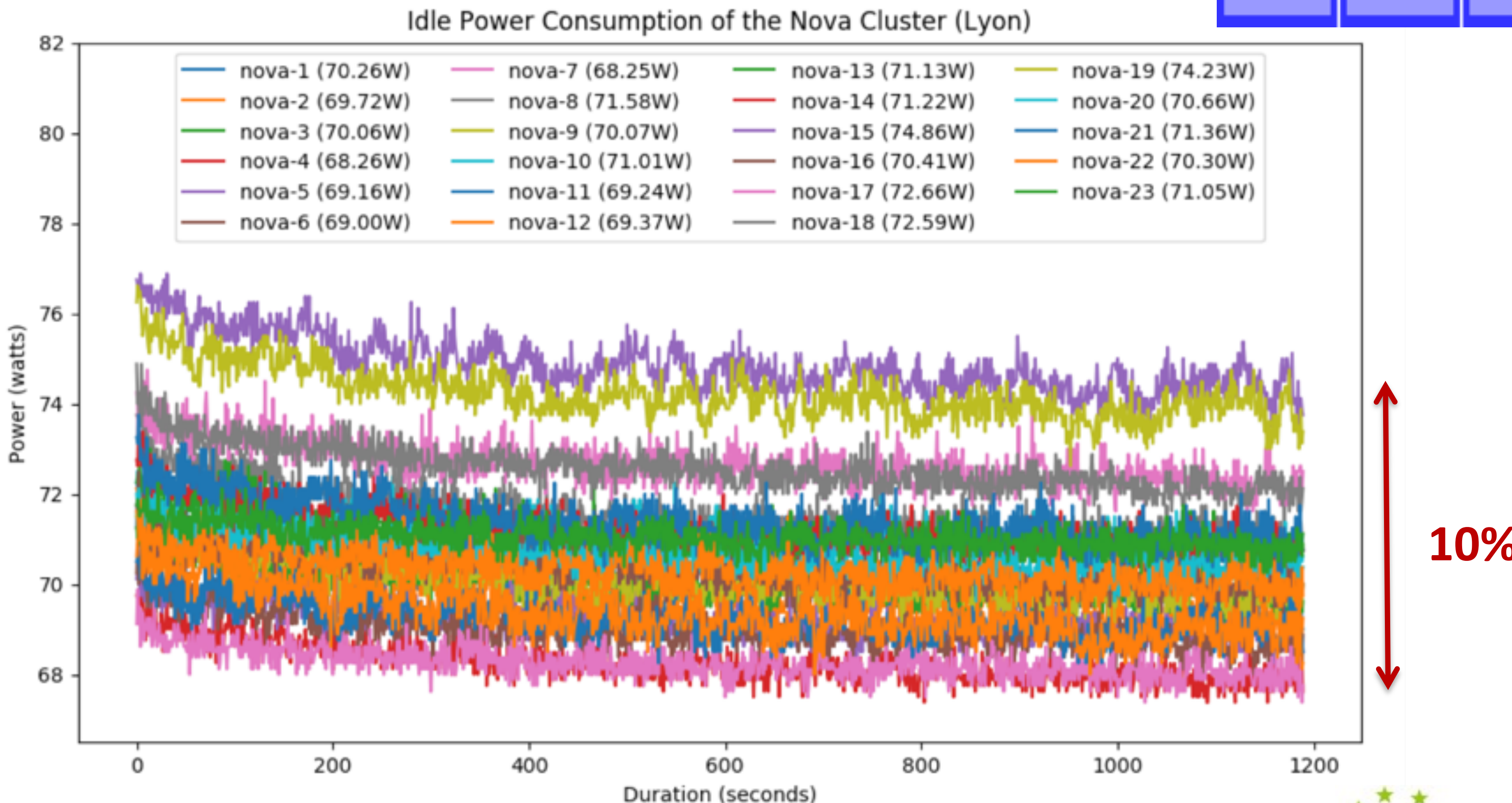
Idle server consumes nothing or little.



Nova node: 2 x Intel Xeon E5-2620 v4, 8 cores/CPU, 64 GiB RAM, 598 GB HDD (2016)

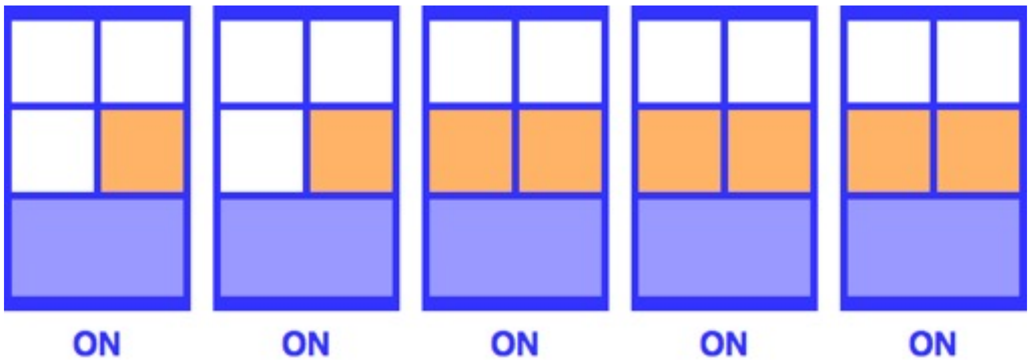
Wrong idea #2

This server model consumes that amount of power.



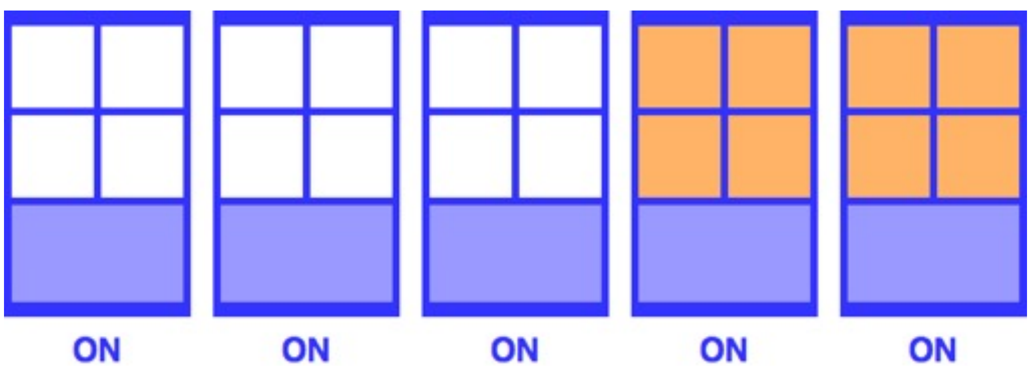
10% difference in idle and more at maximal consumption.

No chance for naive modeling



Naive model:

$5 \times P_{idle} + 8 \times P_{process} = X$ Watts



$5 \times P_{idle} + 8 \times P_{process} = X$ Watts

Best configuration for power consumption ?

It depends.

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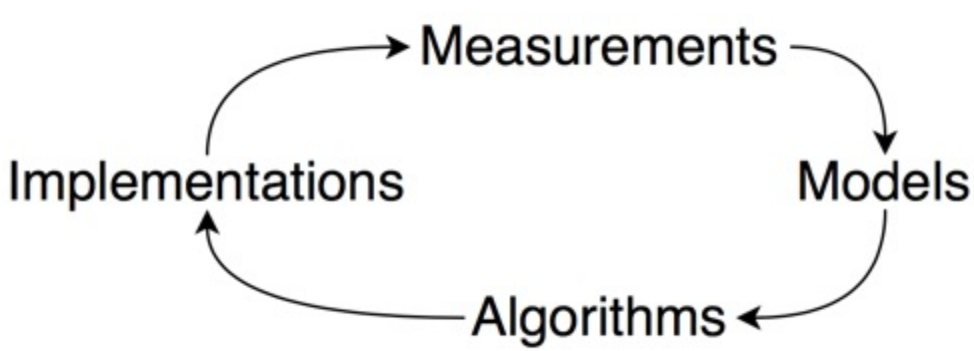
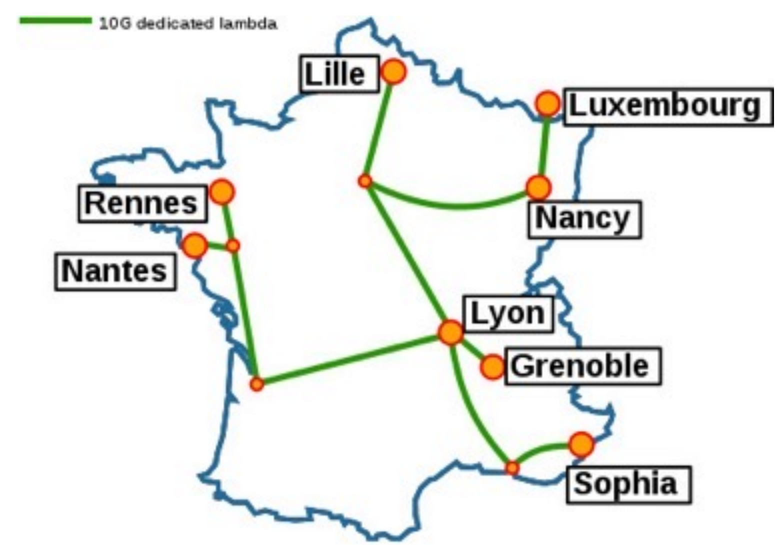
Energy consumption: a complex phenomenon

Need for **wattmeters** and sound experimental campaigns

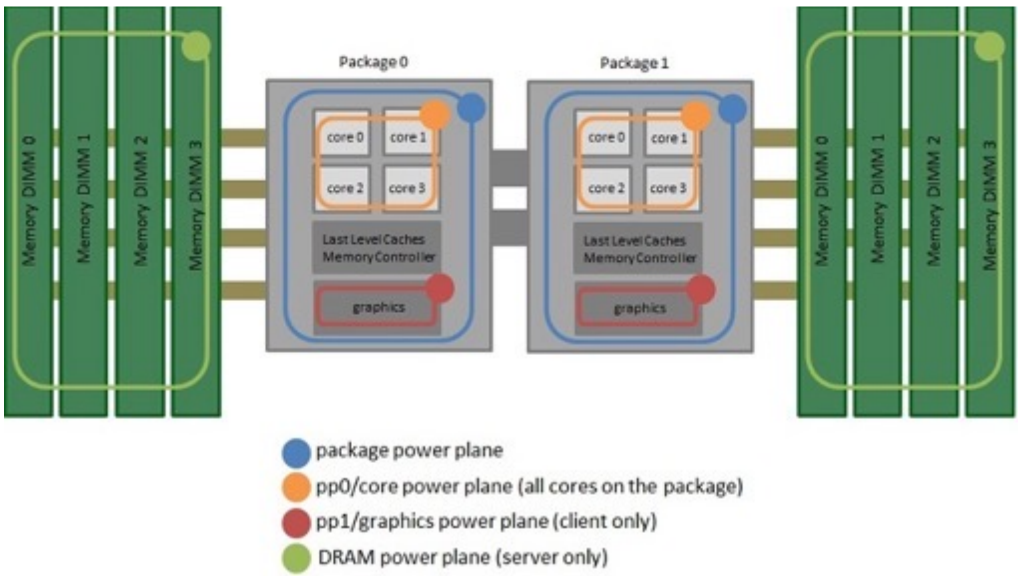
- To understand
- To build robust models
- To get solid instantiations
- To obtain realistic algorithms





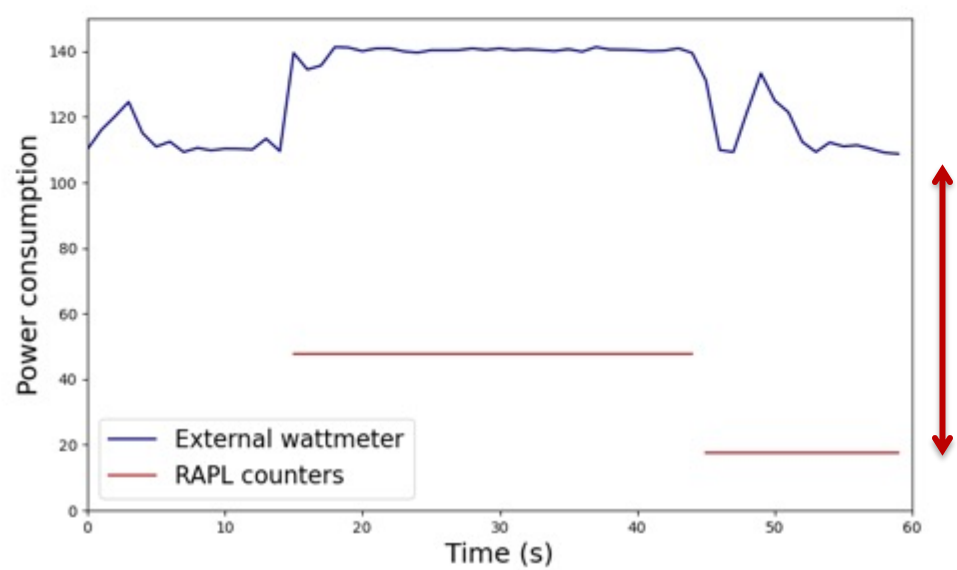
Performing measurements

Intel's RAPL (Running Average Power Limit) interface

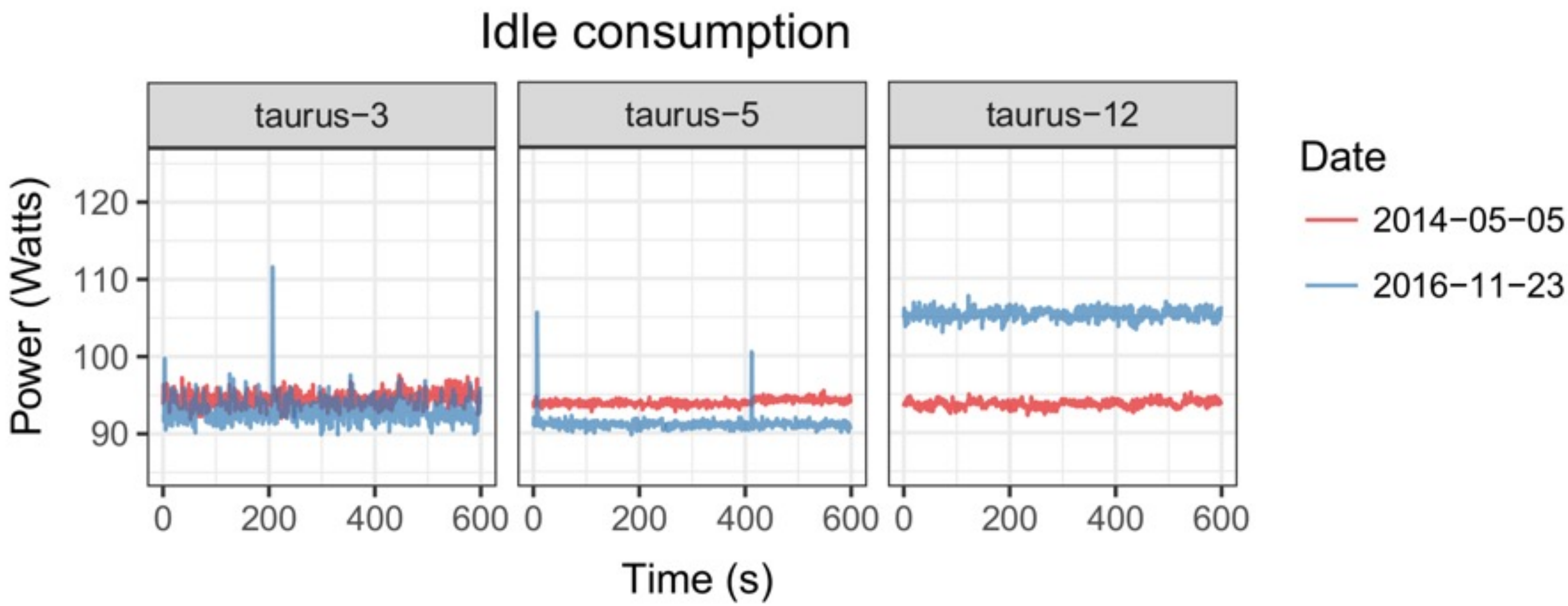



```
Energy measurements:
PACKAGE_ENERGY:PACKAGE0    176.450363J    (Average Power 42.9W)
PACKAGE_ENERGY:PACKAGE1     75.812454J    (Average Power 18.4W)
DRAM_ENERGY:PACKAGE0        11.899246J    (Average Power 2.9W)
DRAM_ENERGY:PACKAGE1         8.341141J    (Average Power 2.0W)
PP0_ENERGY:PACKAGE0        118.029236J    (Average Power 28.7W)
PP0_ENERGY:PACKAGE1         16.759064J    (Average Power 4.1W)
```

Warning: RAPL counters ignore a **large part** of the power consumption of servers.



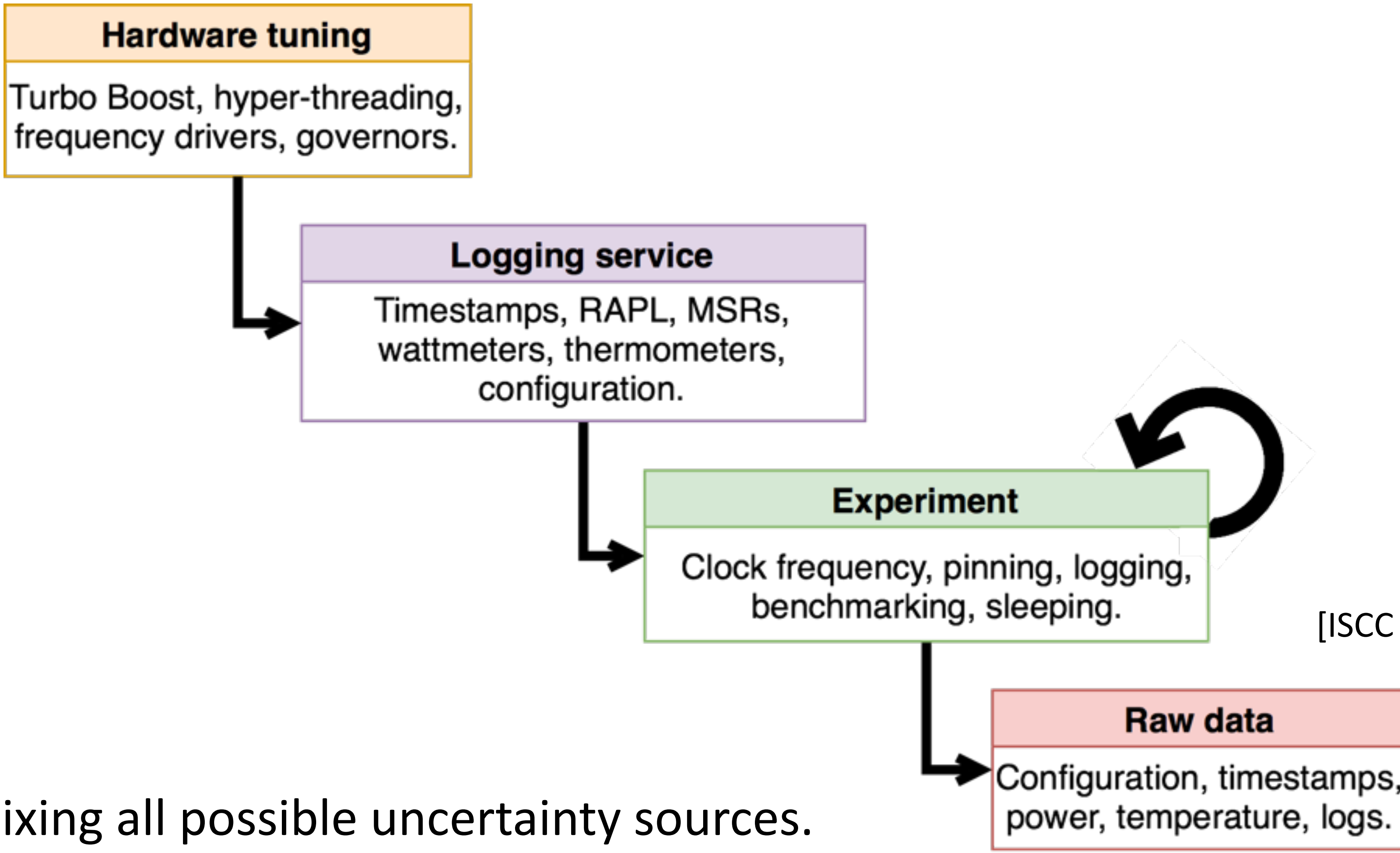
Reproducibility?



[Cluster 2017]

Idle power consumption varies over time.

Methodology for measuring server consumption

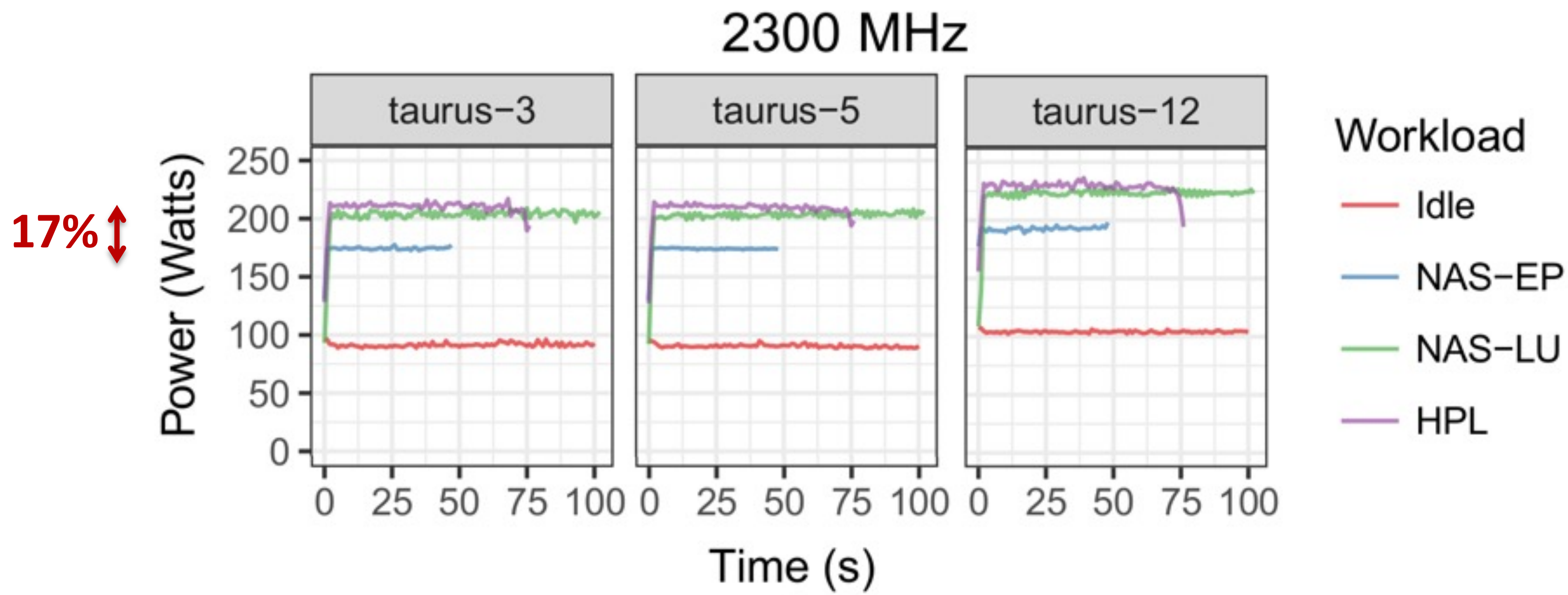


[ISCC 2021]

Fixing all possible uncertainty sources.

Wrong idea #3

The relation between power and CPU load is linear/quadratic/cubic.

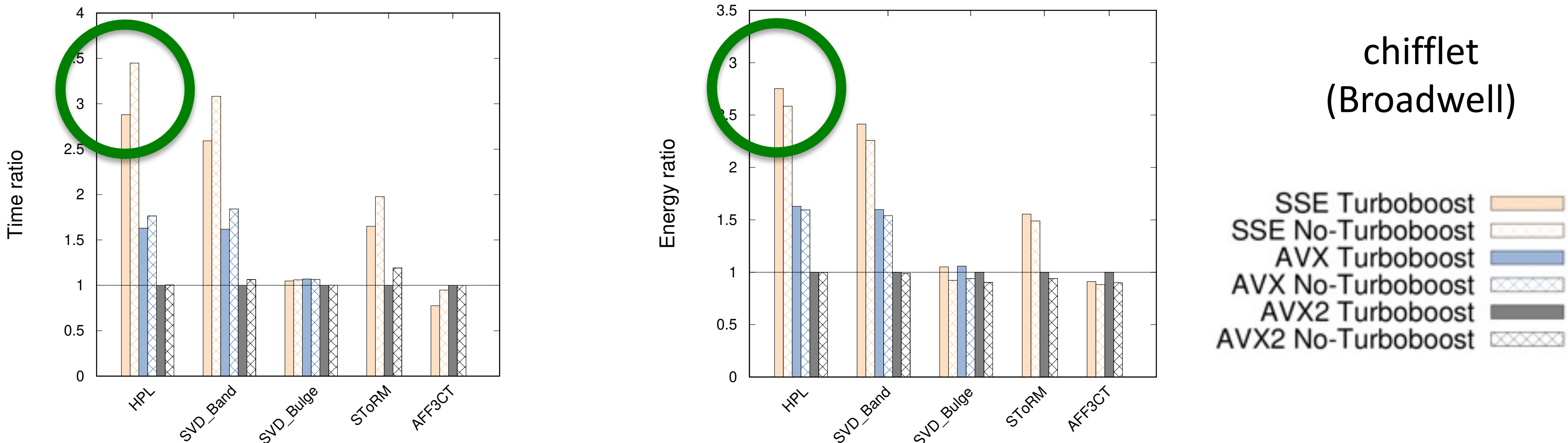


[Cluster 2017]

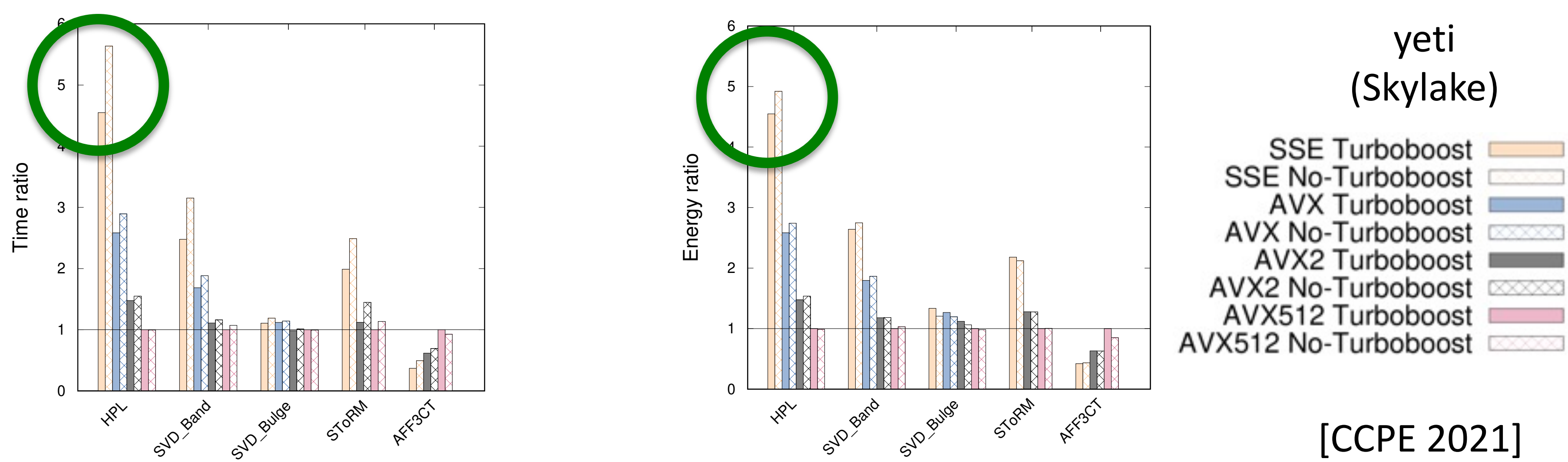
17% difference in consumption for applications fully loading the server.

Wrong idea #4

For a given application, there is a least consuming configuration.



Faster with Turboboost, but consuming more energy.

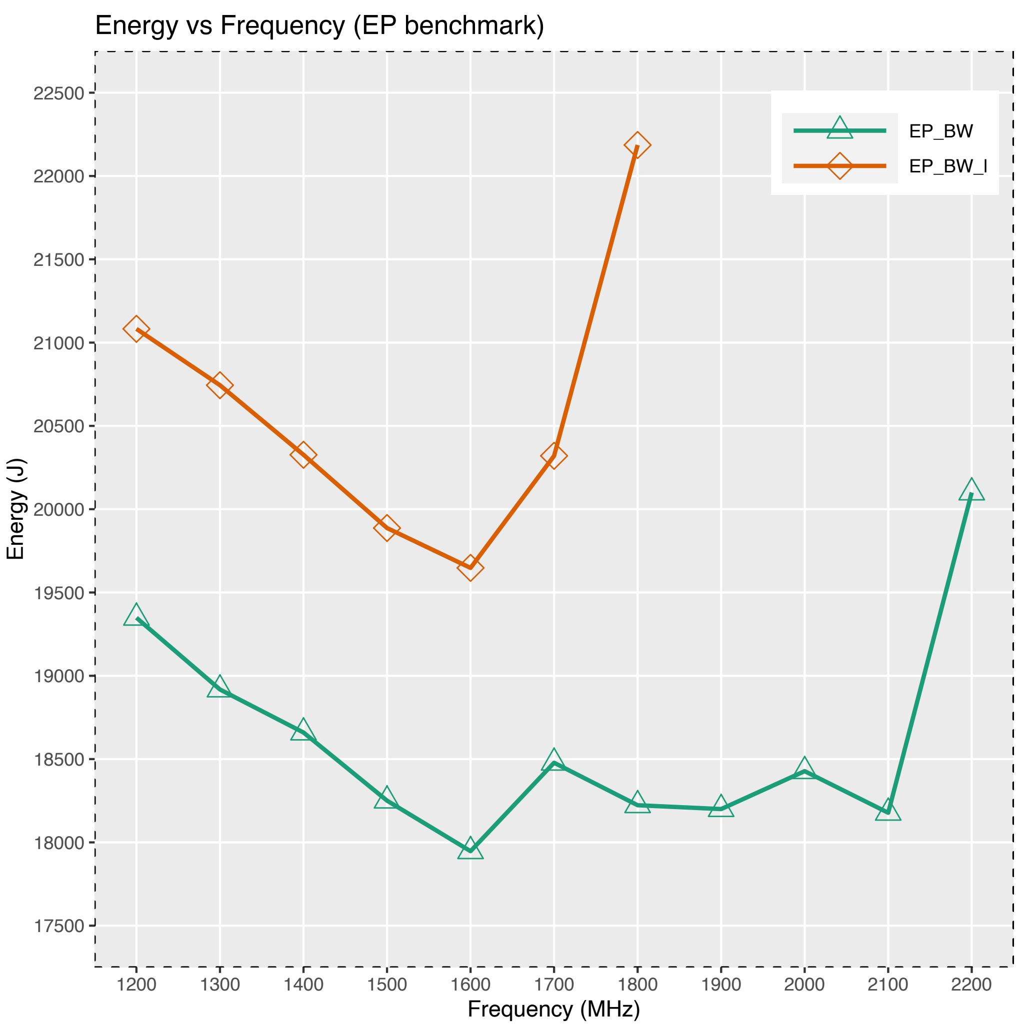


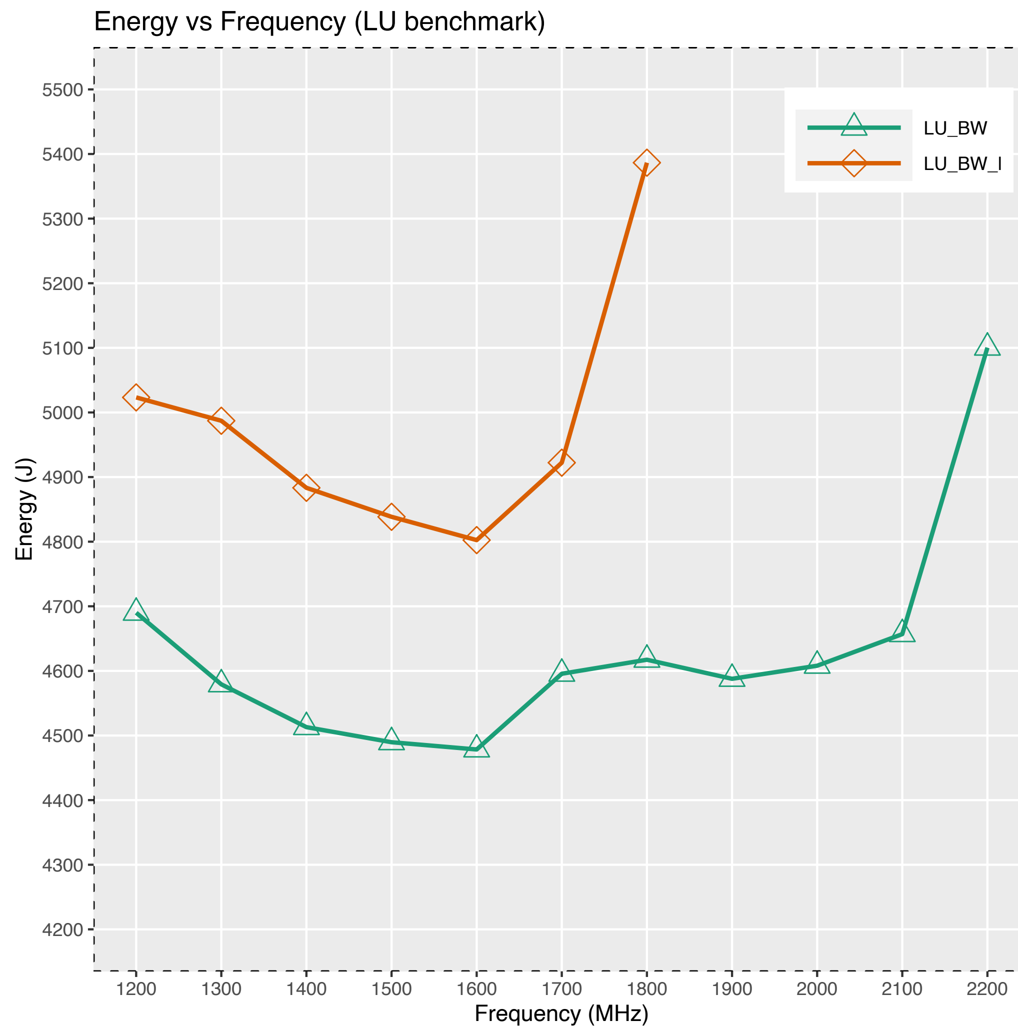
[CCPE 2021]

Faster with Turboboost, and comsuming less energy.

Wrong idea #5

Low power processors consume less energy.

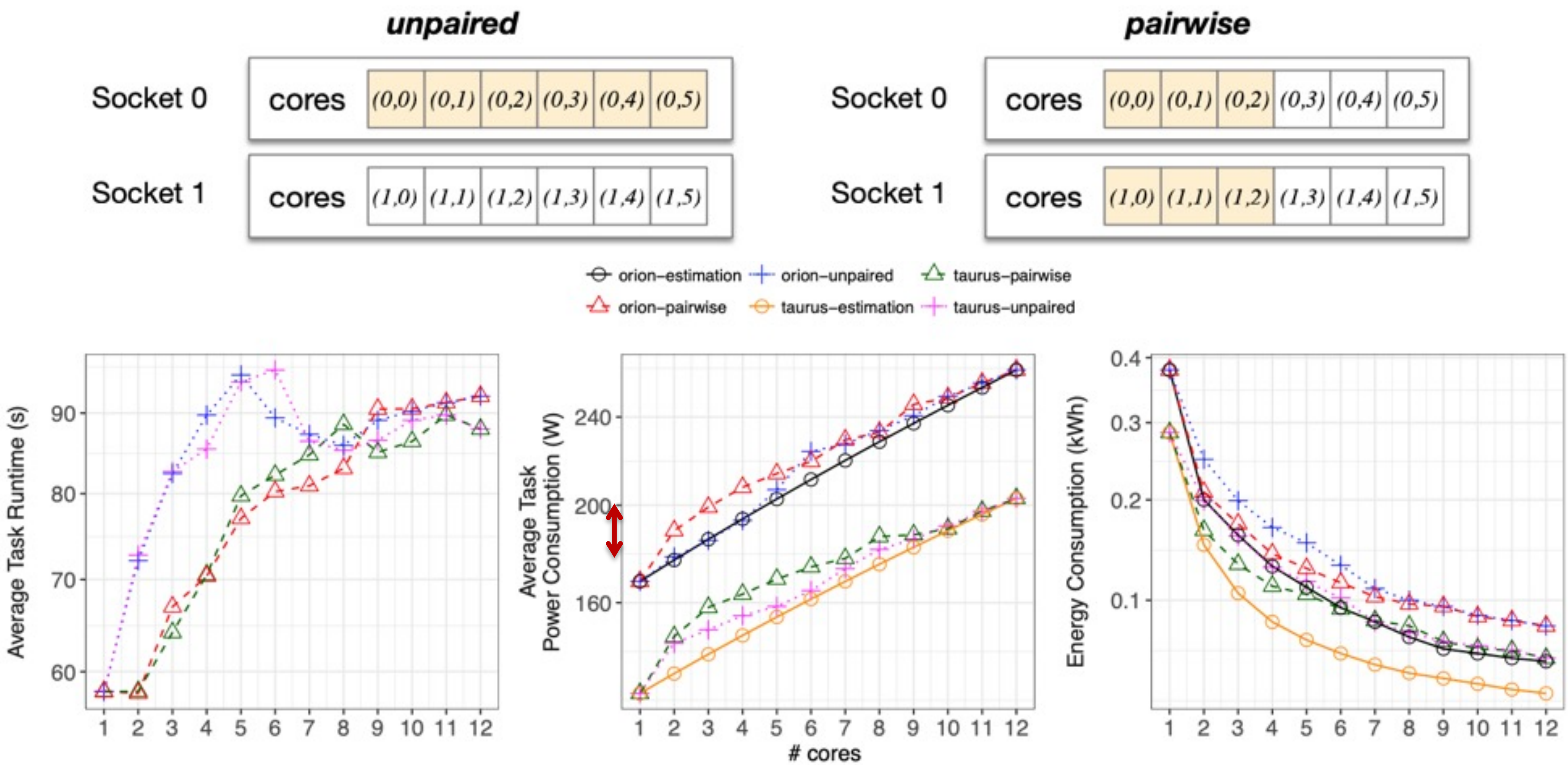




BW_l: Xeon E5-2630L v4 (Broadwell) -> low power processor (orange)
BW: Xeon E5-2630 v4 (Broadwell) (green)

[ISCC 2021]

Process placement onto cores



[JOCS 2020]

Up to **8%** difference in average power consumption between unpaired and pairwise.

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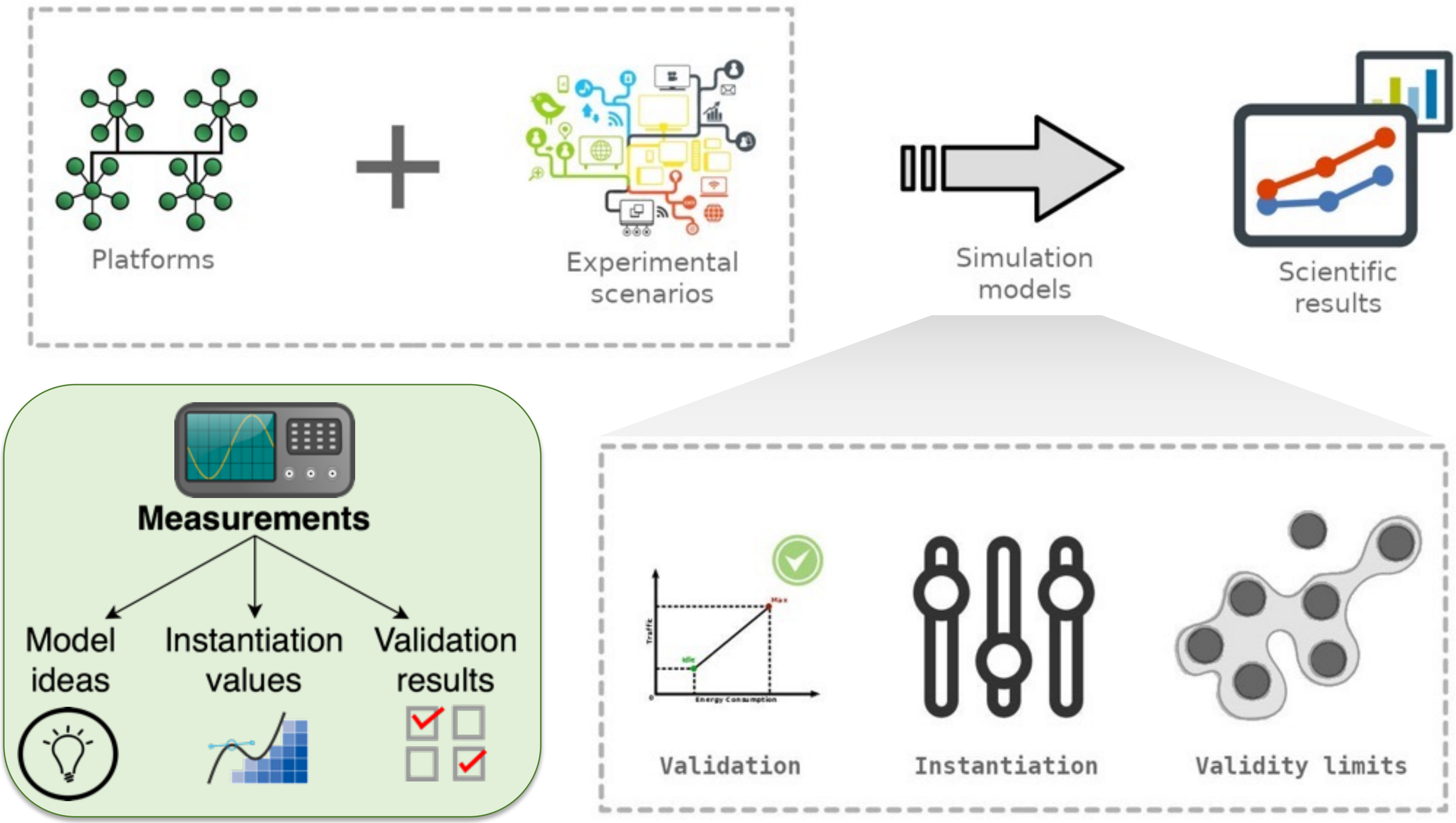
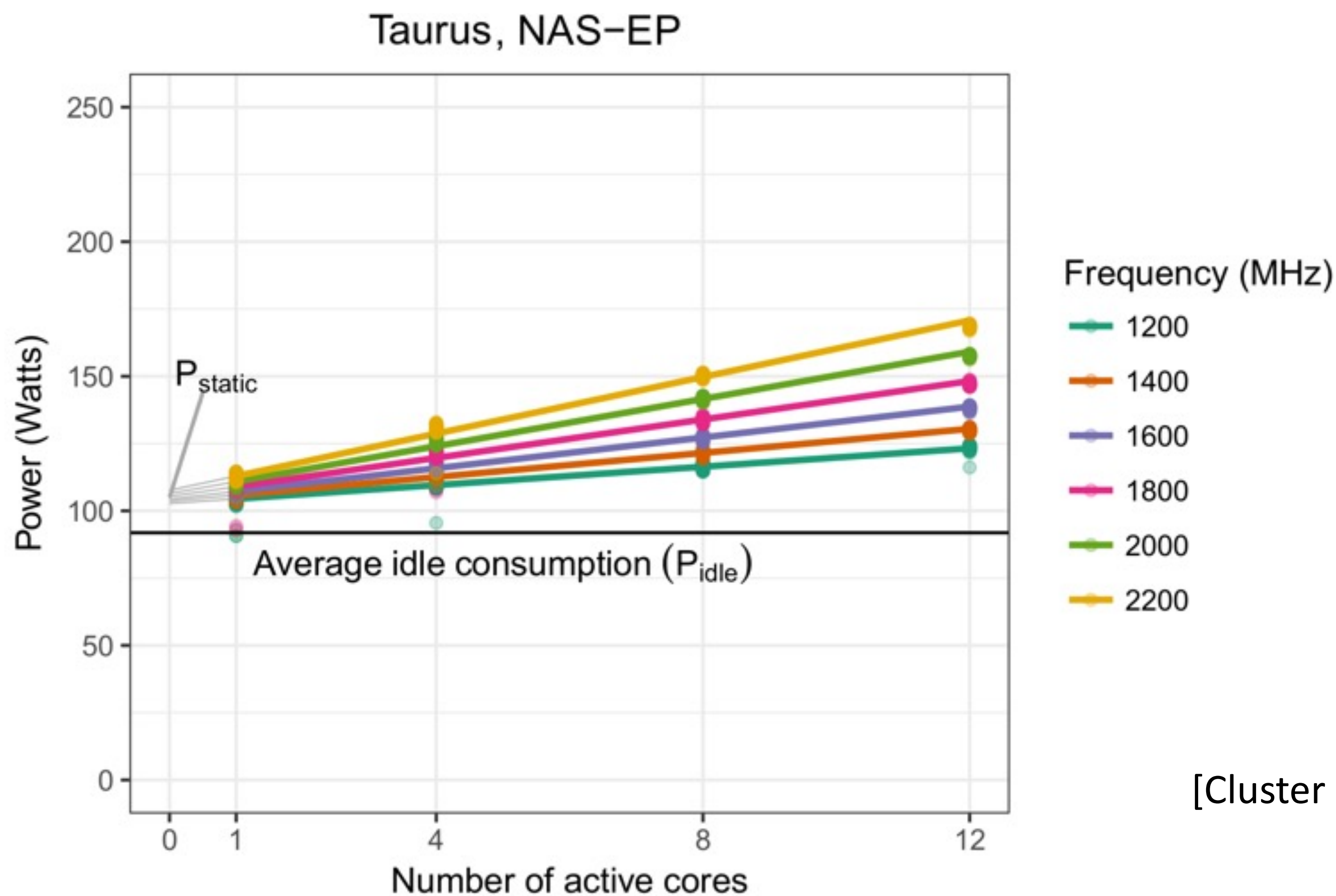
Simulating energy consumption



Server profiling



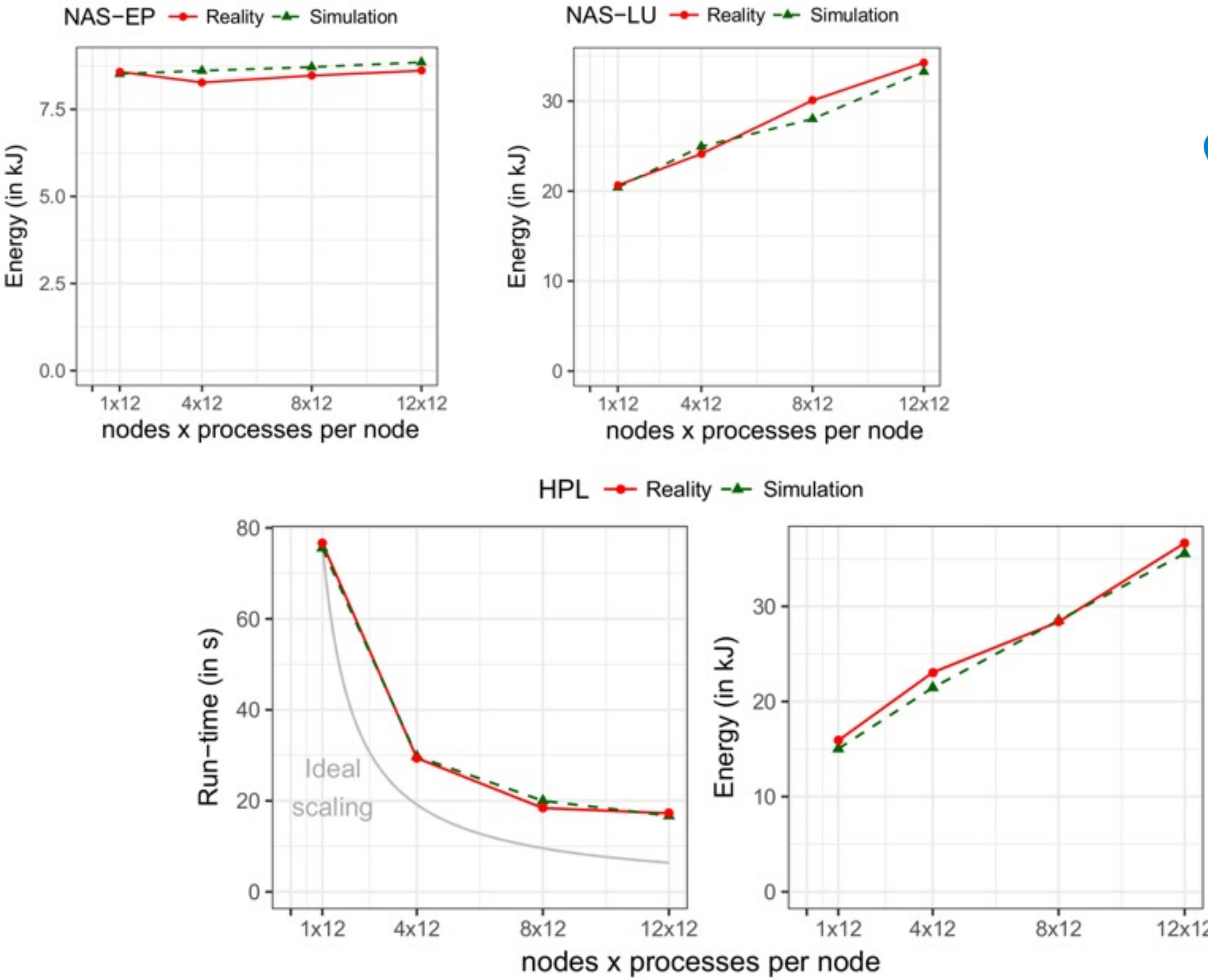
[Cluster 2017]

To do for each computing kernel.

At each frequency.

And each time we want to compare the model to real life.

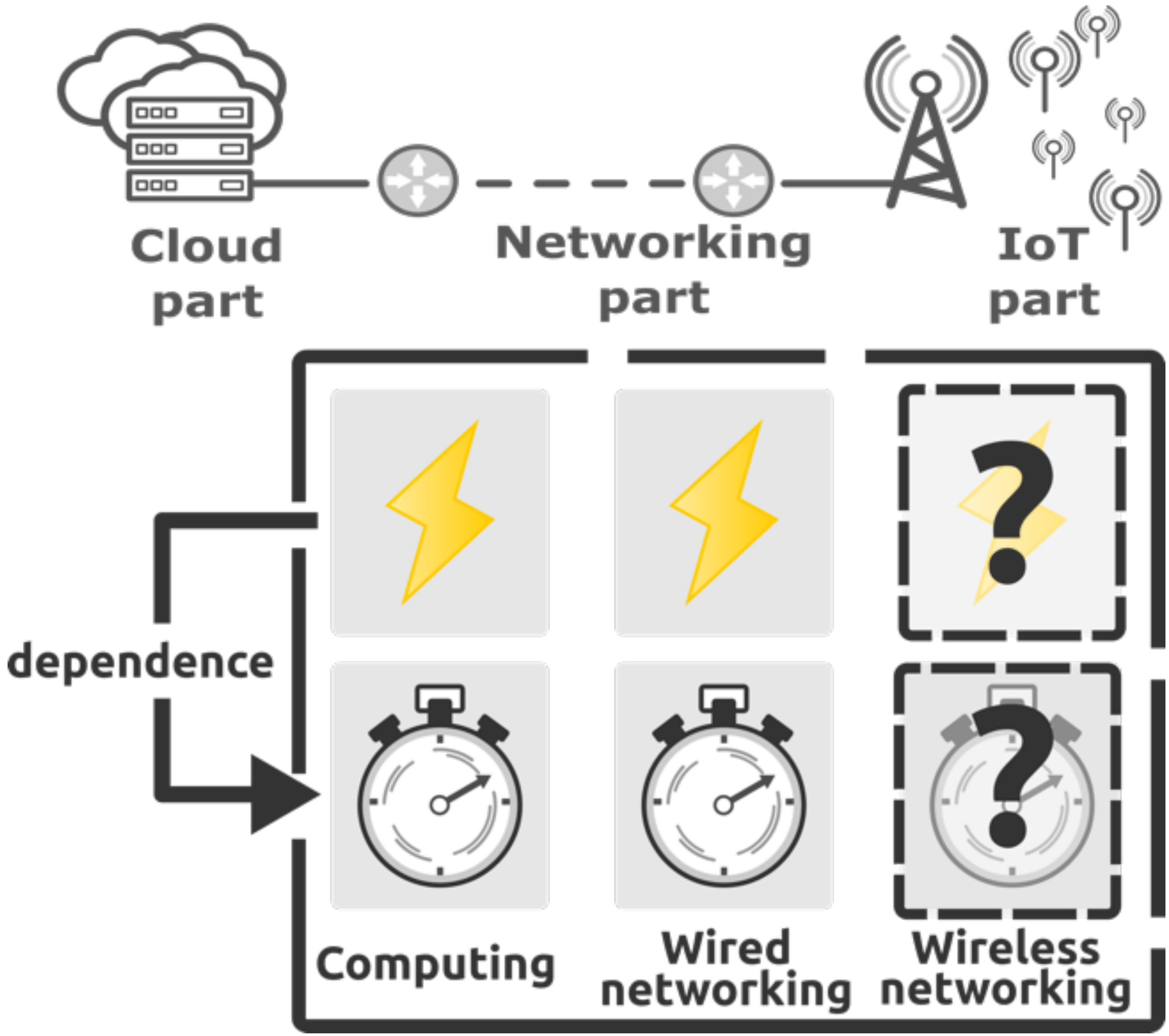
Simulating server clusters



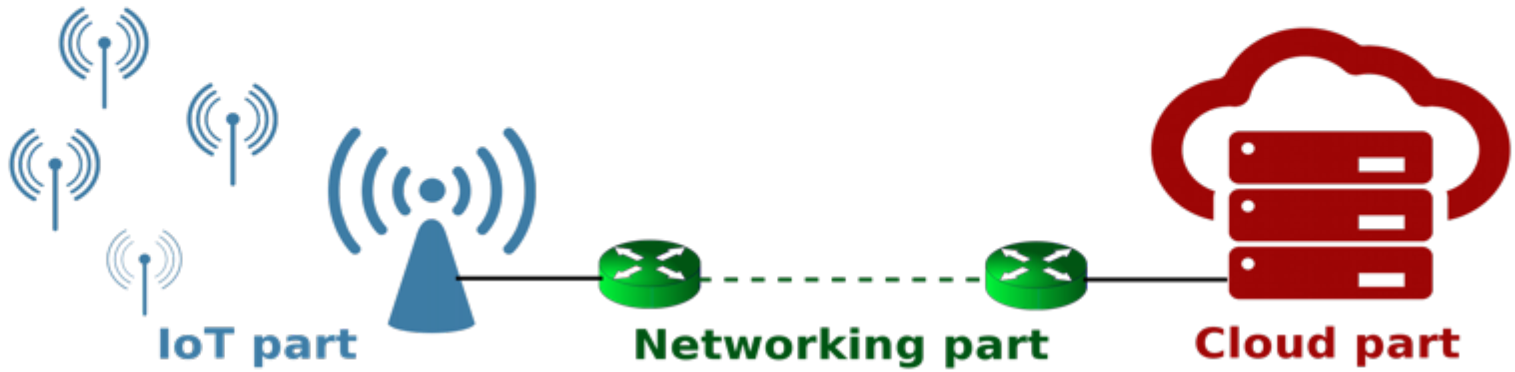
[Cluster 2017]

Reproducible results: https://gitlab.inria.fr/fheinric/paper-simgrid-energy

Simulating distributed infrastructures



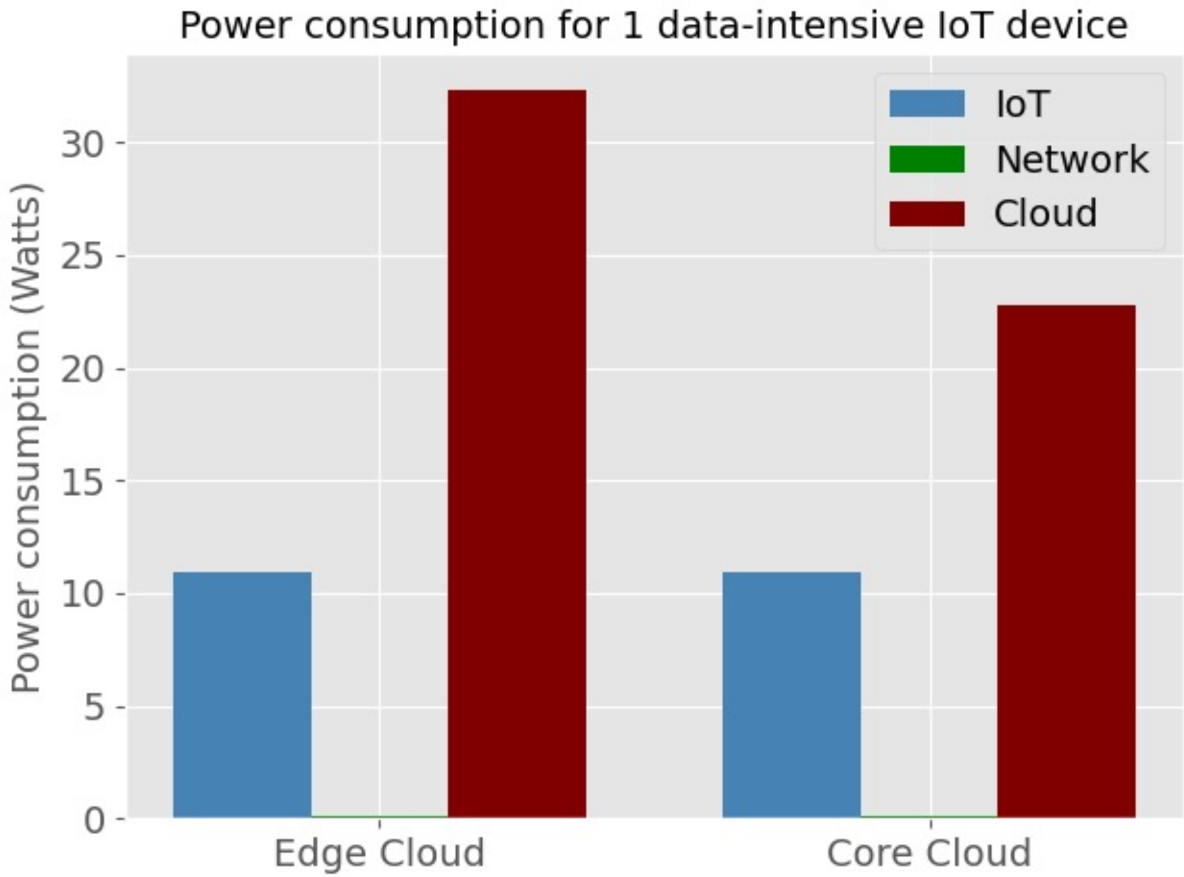
Power consumption of IoT



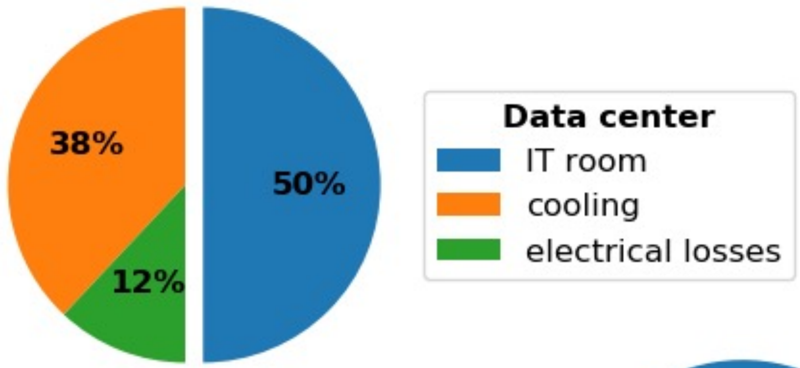
[FGCS 2018]

Tradeoff between:
- Performance
- Application accuracy
- Energy consumption

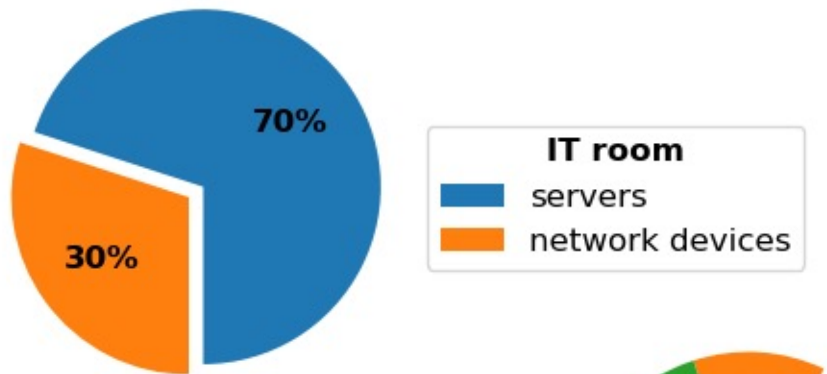
It depends.



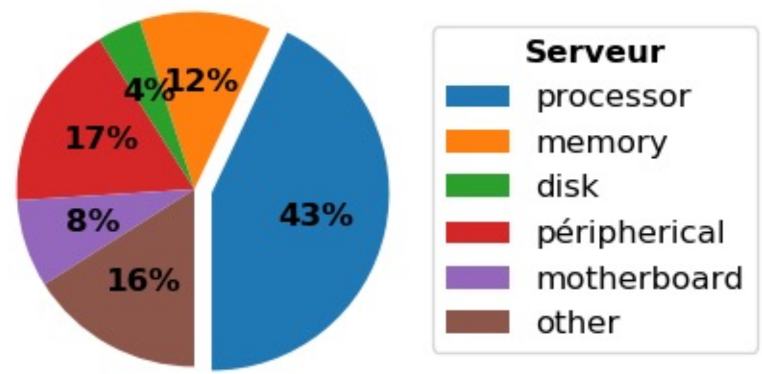
Wasted energy at all levels of data centers



Cooling
Power generators
Batteries
…



Unused servers
Overprovisioning
Redundancy
…



Power non-proportionality
Dark silicon
Unused components
…

Models and simulation tools for what?

Capacity and energy planing

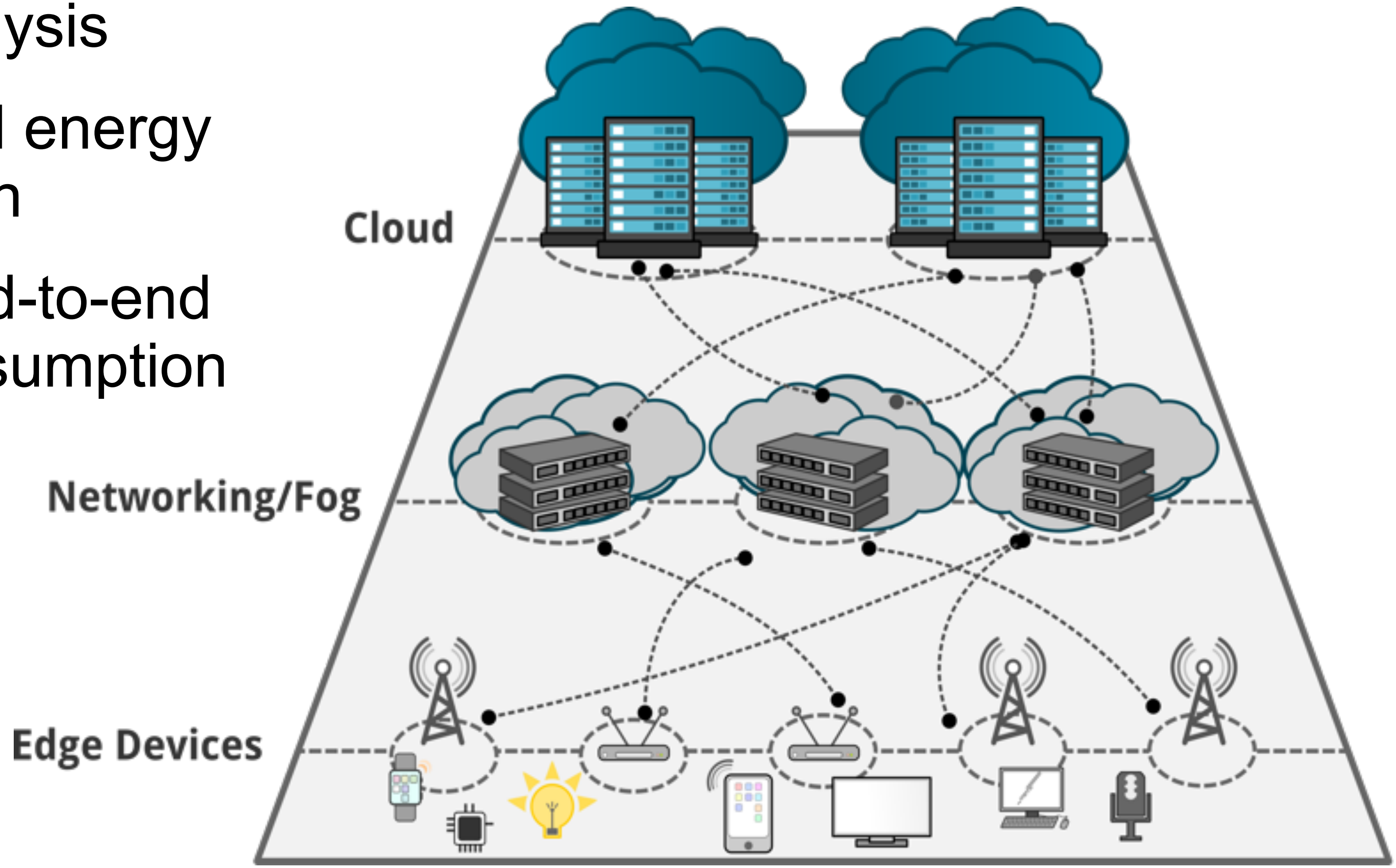
What-if scenarios

Algorithm analysis

Estimating VM energy consumption

Estimating end-to-end energy consumption

Closing doors



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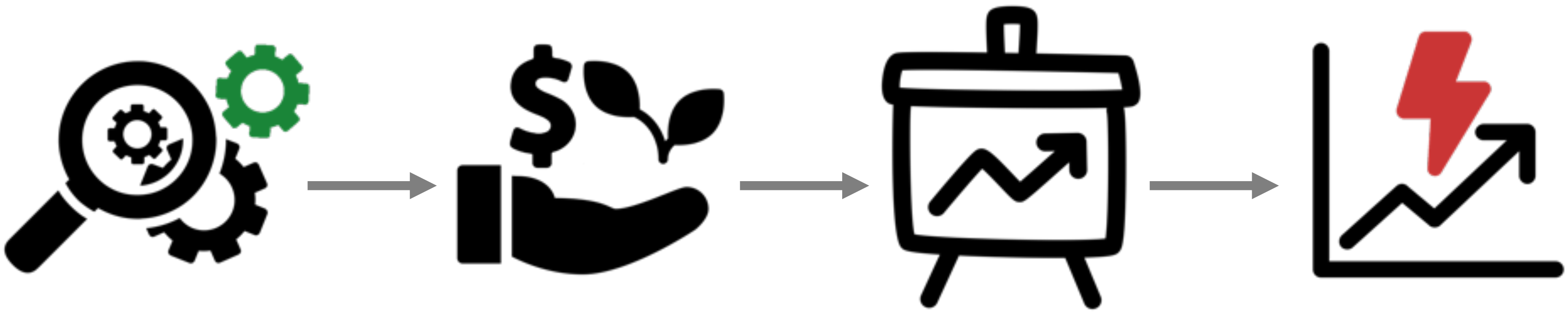
Increasing energy efficiency ≠ reducing consumption



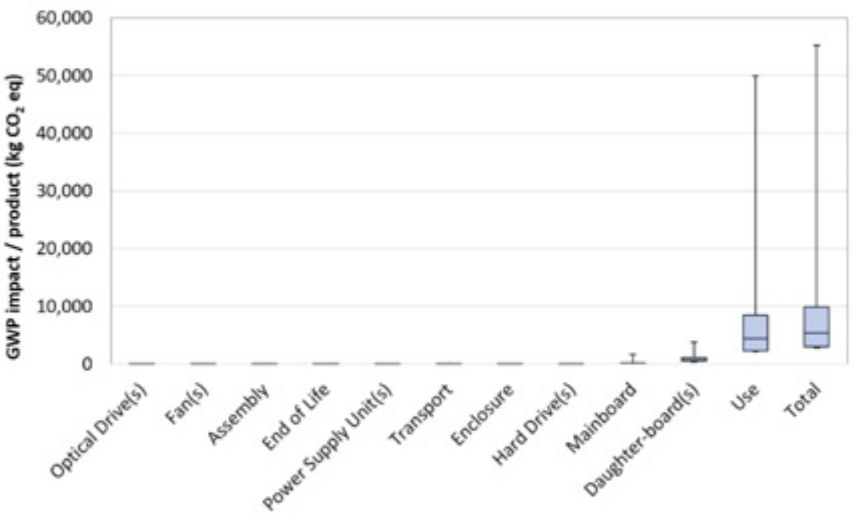
Energy **optimization** → Resource cost reduction → Usage increase → Energy consumption **increase**

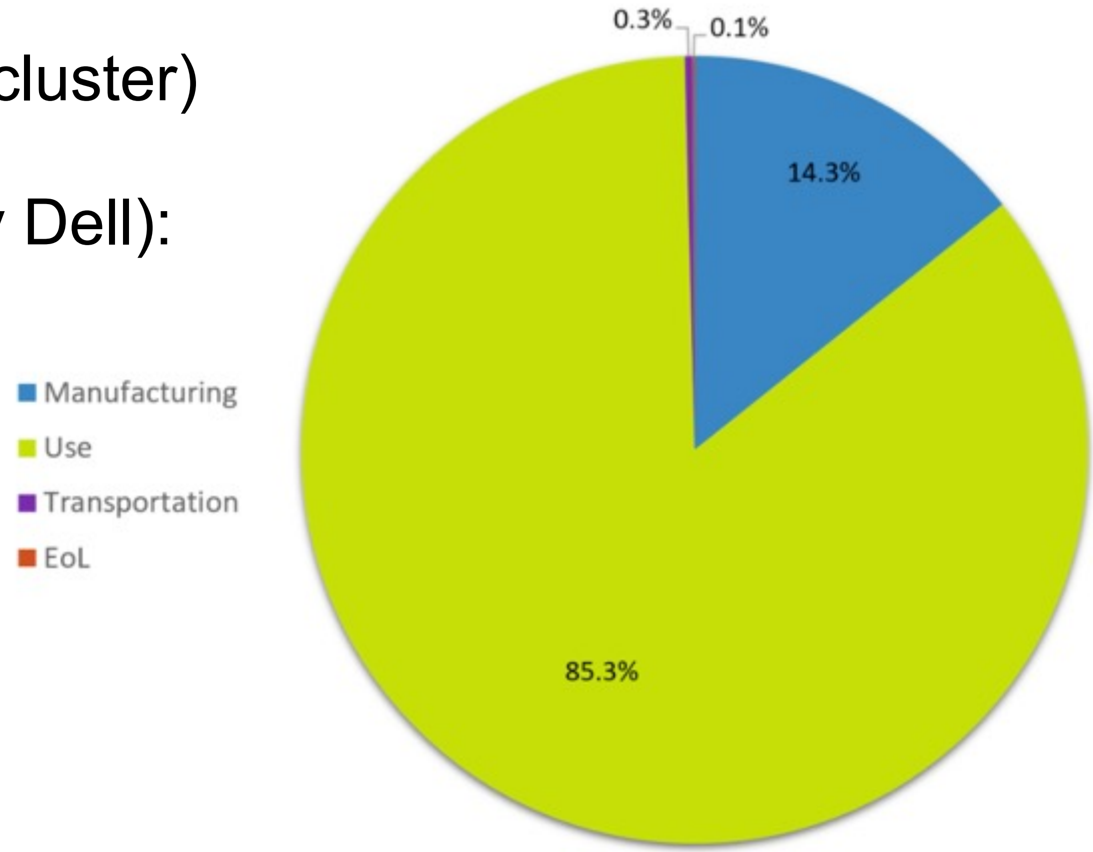
Beware of rebound effects!

Full life cycle of servers

Dell PowerEdge R430 (Nova cluster)

Estimated carbon footprint (by Dell):
8,150 kgCO2e



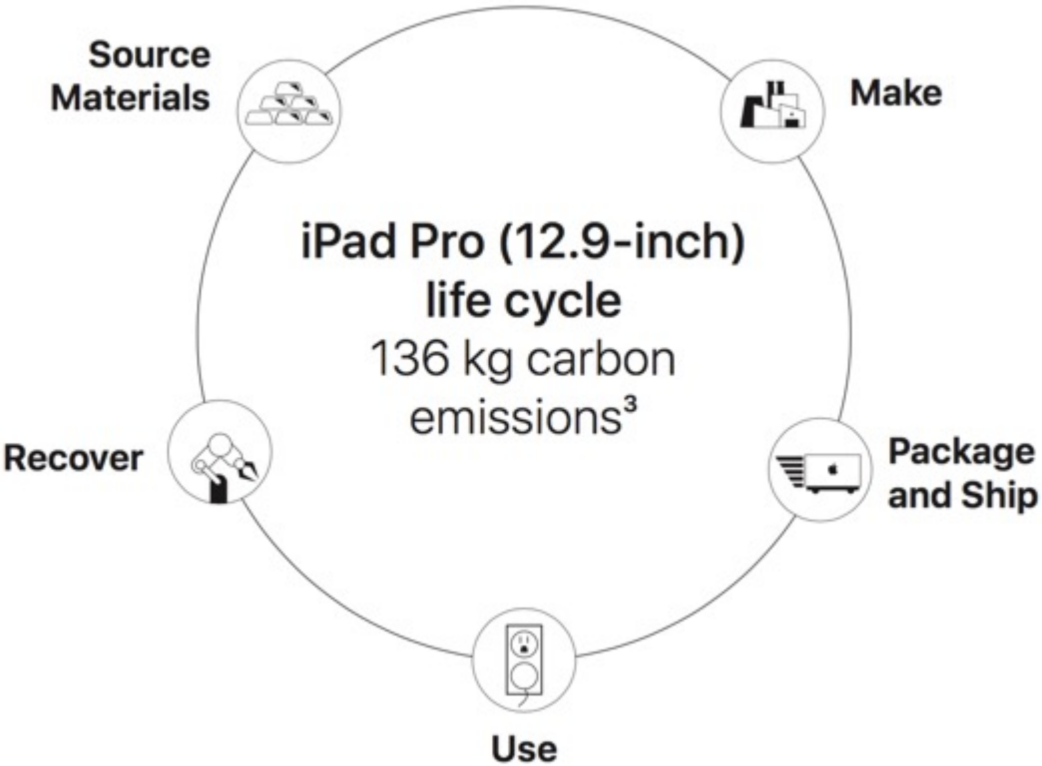


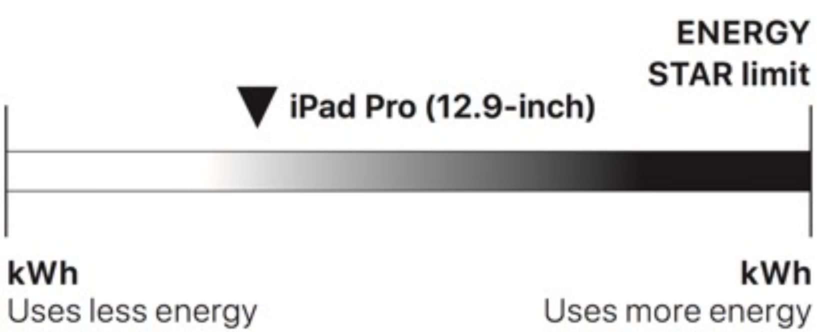
Assumptions for calculating product carbon footprint:

Product Weight	26.3 kg	**Server Type**	Rack	**Assembly Location**	EU
Product Lifetime	4 years	**Use Location**	EU	**Energy Demand (Yearly TEC)**	1760.3 kWh
HDD/SSD Quantity	x2 1TB 3.5" HDD	**DRAM Capacity**	16GB	**CPU Quantity**	2

Source: Dell PowerEdge R430 carbon footprint, 2019.

Life cycle of end devices





iPad Pro (12.9-inch) life cycle carbon emissions

83%	Production
11%	Transport
6%	Use
<1%	End-of-life processing

4 years of use

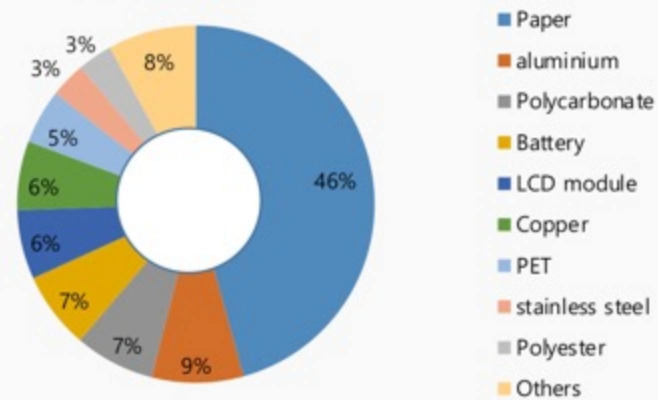
Source: Product environmental report, Apple, 2018.

Numerous other environmental impacts

Product Features

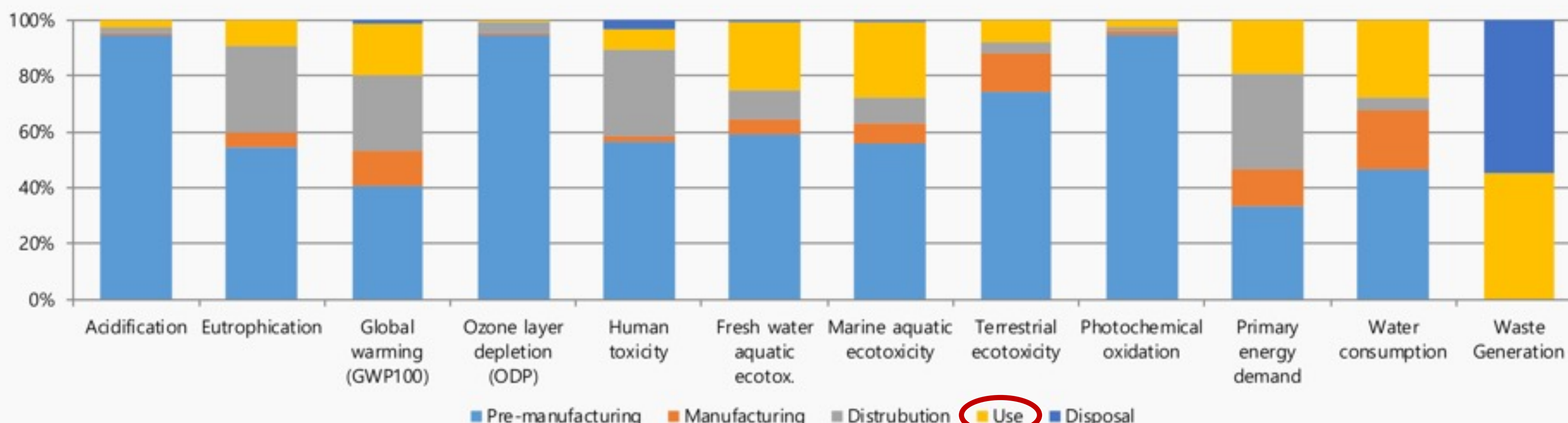
Model name	SM-N950U (Galaxy Note8)
Processor	Qualcomm 2.35GHz, 1.9GHz Octa-Core 64bit
Dimension	162.5 x 74.8 x 8.6 mm
Display	6.3" 2960 x 1440, 16M In-Cell Touch LCD
Battery	Li-Ion 3300 mAh
Camera	12 MP / 5MP
Wt.(g)	186.34g

Material Use



Characterized Environment Impact

Source: Life Cycle Assessment for Mobile Products, Samsung, 2018.



Standard	ISO 14040:2006 and 14044:2006
Database	Ecoinvent 2.2
Method for impact assessment	Life cycle impact assessment classification and characterization factors according to CML 2001 as provided in the SimaPro 7.1.5 LCA tool
LCA software	SimaPro 7.1.5

Pre-manufacturing	Parts and materials constituting the products and its transportation (from supplier to Samsung factory)
Manufacturing	Product assembly by Samsung Electronics (Data collection period : 3 months ahead of assessment)
Distribution	From China or Vietnam to United States
Usage	2 years use
Disposal	Waste treatment of parts and material

Thank you for your attention

http://people.irisa.fr/Anne-Cecile.Orgerie

Citations

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- [SUSCOM 2018b] **“Energy-proportional Profiling and Accounting in Heterogeneous Virtualized Environments”,** M. Kurpicz, A.-C. Orgerie, A. Sobe and P. Felber, *Sustainable Computing: Informatics and Systems*, Elsevier, volume 18, pages 175-185, June 2018.

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