Energy consumption and environmental impacts of distributed systems

Anne-Cécile Orgerie

ICTEAM seminar, UCLouvain
17th January 2024

CNRS IRISA EcoInfo

Who I am

- Full-time researcher at CNRS (about 32,000 people)
- Located in Rennes, France.
- IRISA laboratory (about 850 people)
- Magellan team: INRIA, CNRS, University of Rennes, INSA, ENS Rennes (about 25 people)
- Energy efficiency in large-scale distributed systems

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

Outline

- Context
- Understanding the energy consumption of distributed systems
- Measuring accurately the energy consumption of distributed systems
- Modeling energy consumption and environmental impacts of distributed systems
- Concluding broader remarks

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What is the ICT (Information and Communication Technologies) part in the global carbon impact?

- 1.8%
- 3.9%
- 8.6%
- 15.4%

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- 3.9%
- 8.6%
- 15.4%

Civil aviation: 2.4% in 2018

Difficulties: electricity mix, device lifetime, complex manufacturing processes, ICT perimeter, lack of data, …

"The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations'', C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. Blair, A. Friday, Patterns, 2021.

Electricity consumption

ICT in France: **11% of the electricity consumption** in 2020 (52 TWh)

→ Planned to reach 93 TWh in 2050 (**+79%**)

"Évaluation de l'impact environnemental du numérique en France et analyse prospective'', rapport ADEME – ARCEP, 2022.

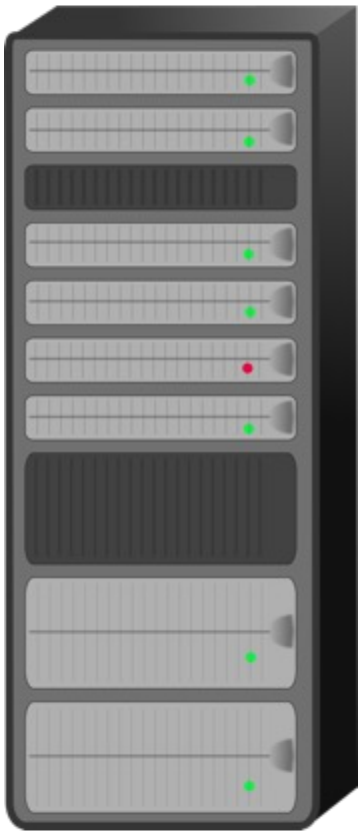
Worldwide electricity consumption: 22,848 TWh in 2019

→ +1,7% compared to the previous year

https://www.iea.org/reports/electricity-information-overview/electricity-consumption#

My scientific context

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



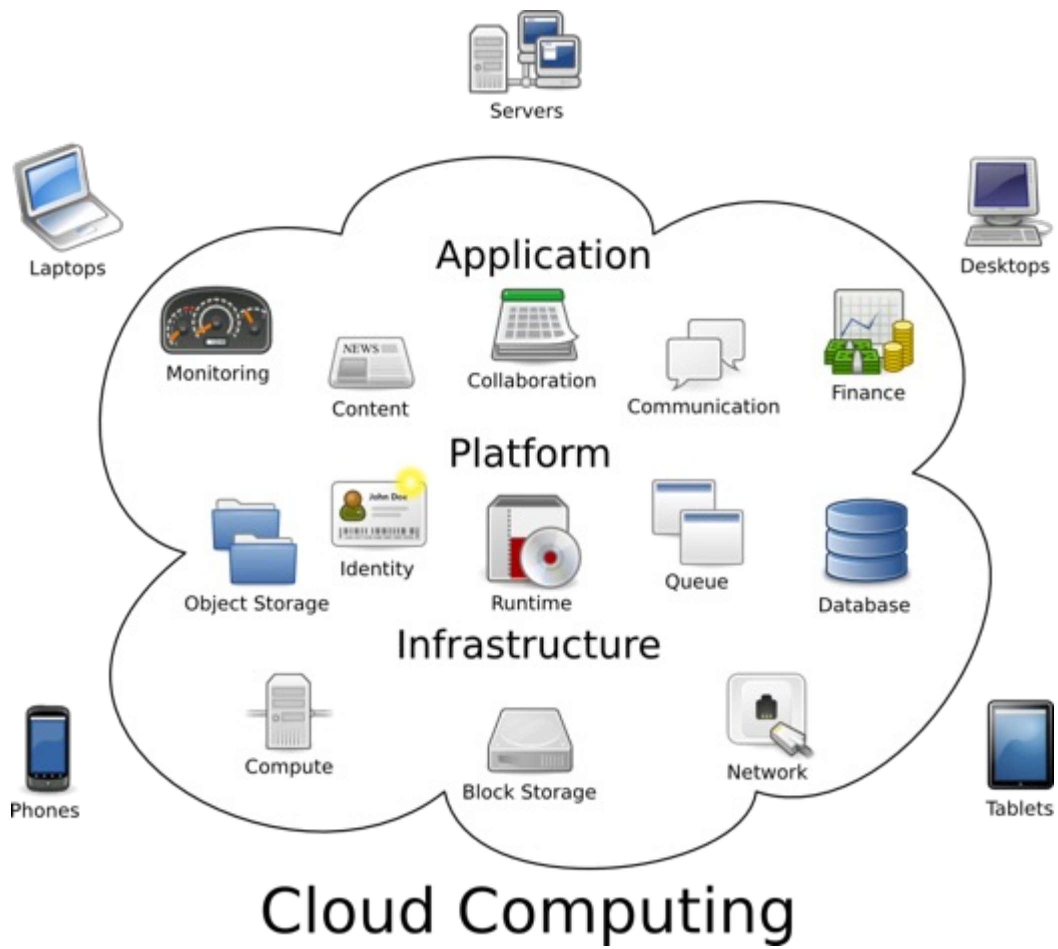
Started with Grid computing some years ago…

Cloud computing in 1 slide

Cloud computing: access through networks to on-demand, self-service, configurable, shared computing resources.

- Mutualization of services
- Elasticity of infrastructures
- Externalization of data

↳ **Economies of scale**



Cloud computing in 1 slide

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- Elasticity of infrastructures
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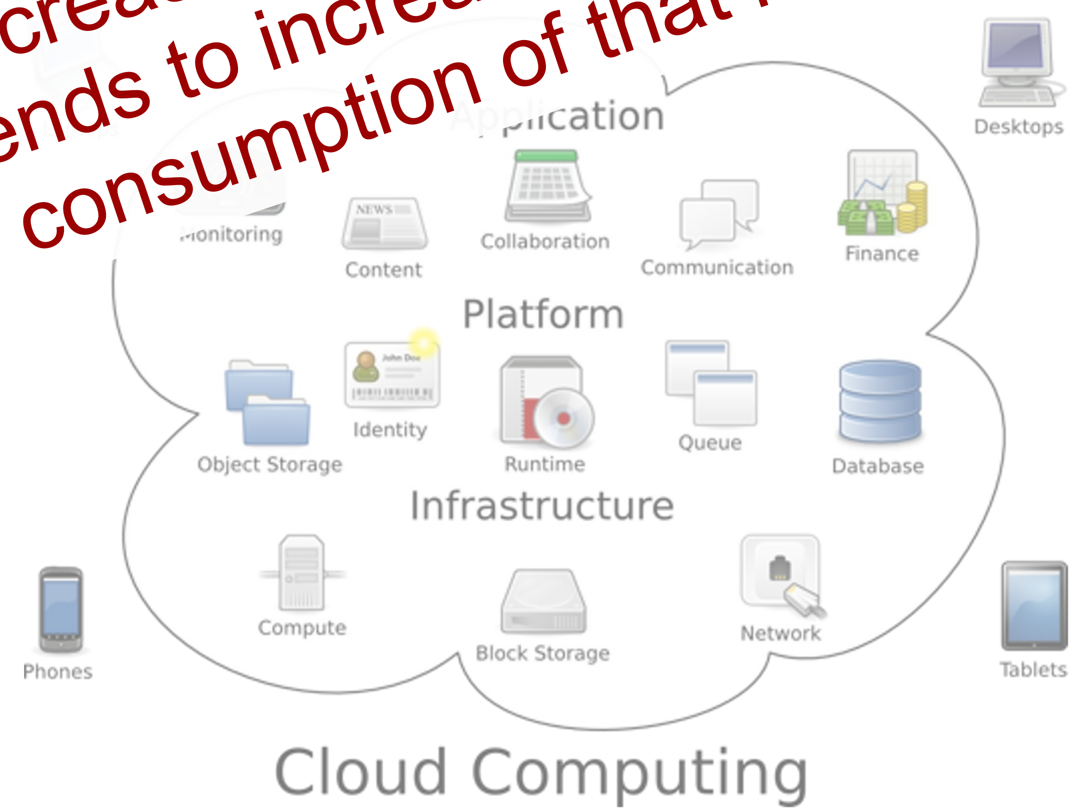
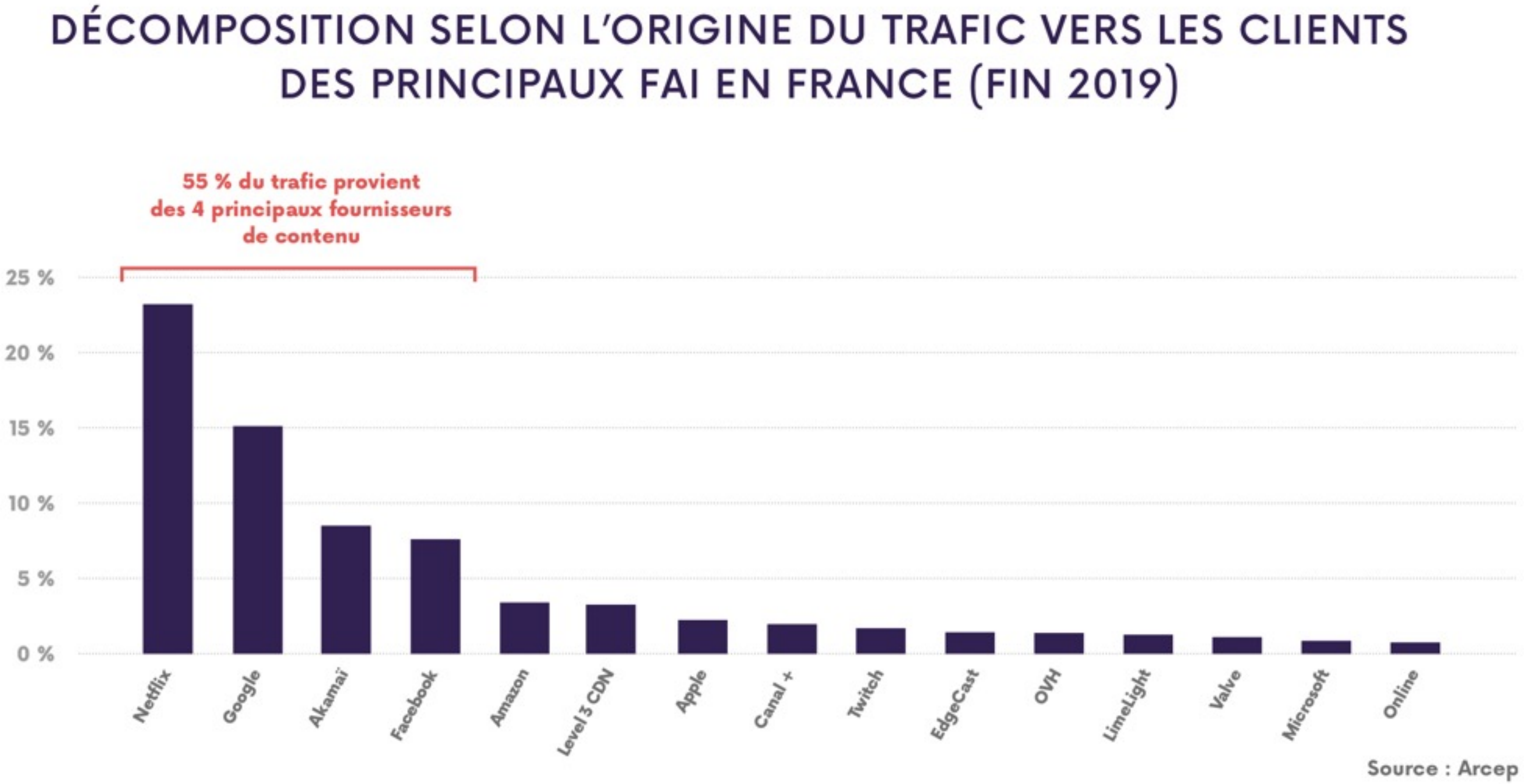
Jevons Paradox: the increase in efficiency with which a resource is used tends to increase (rather than decrease) the rate of consumption of that resource.

⮡ **Economies of scale**



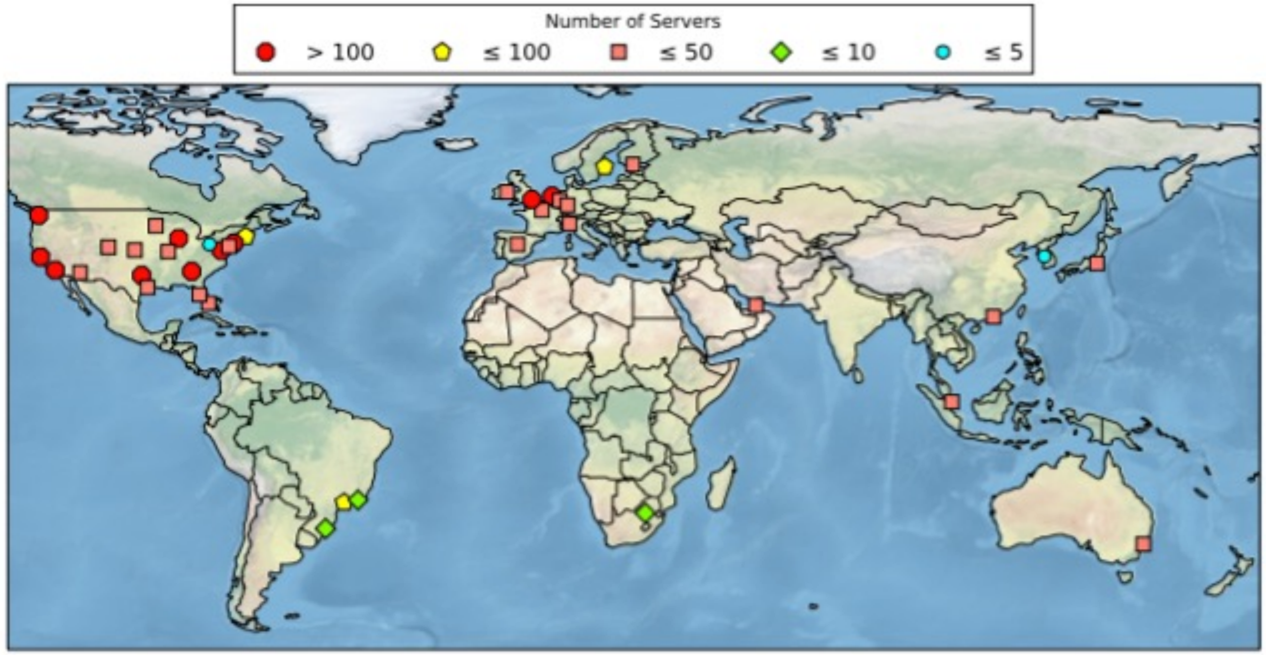
Internet trafic in France



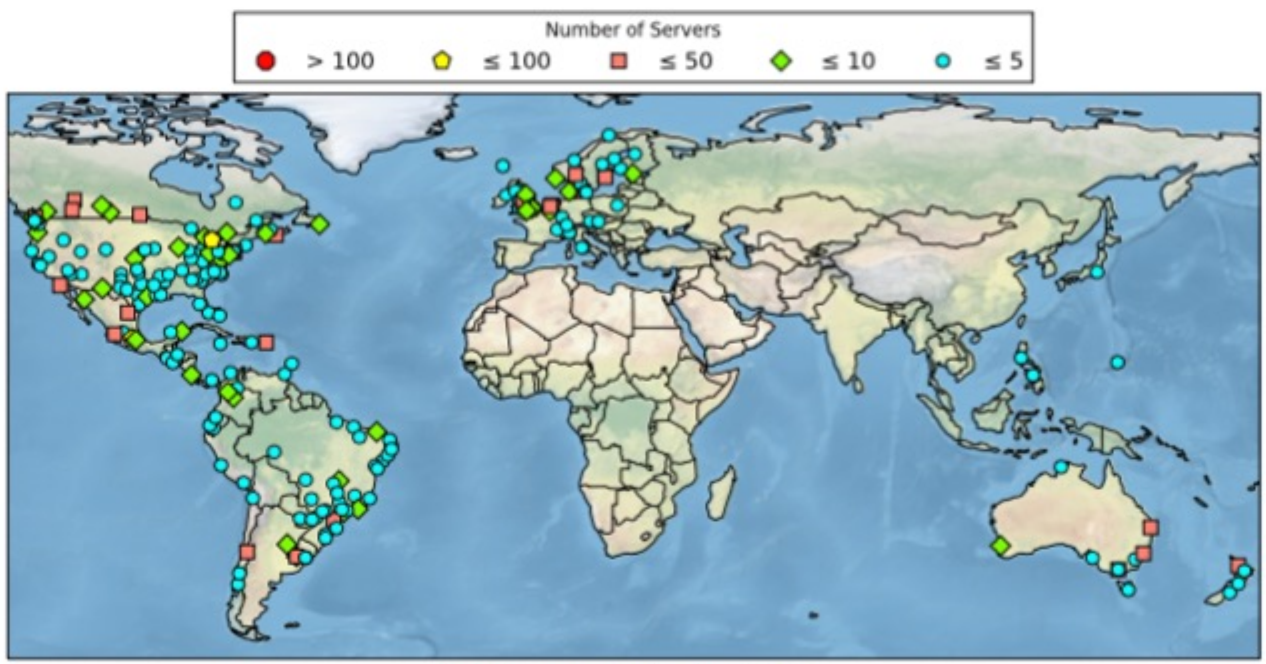
Trafic Internet en France selon l'Arcep en 2019.

Netflix resources

[Source : Open Connect Everywhere: A Glimpse at the Internet Ecosystem through the Lens of the Netflix CDN, T. Boettger, F. Cuadrado, G. Tyson, I. Castro, S. Uhlig, ACM SIGCOMM Computer Communication Review, 2018.]



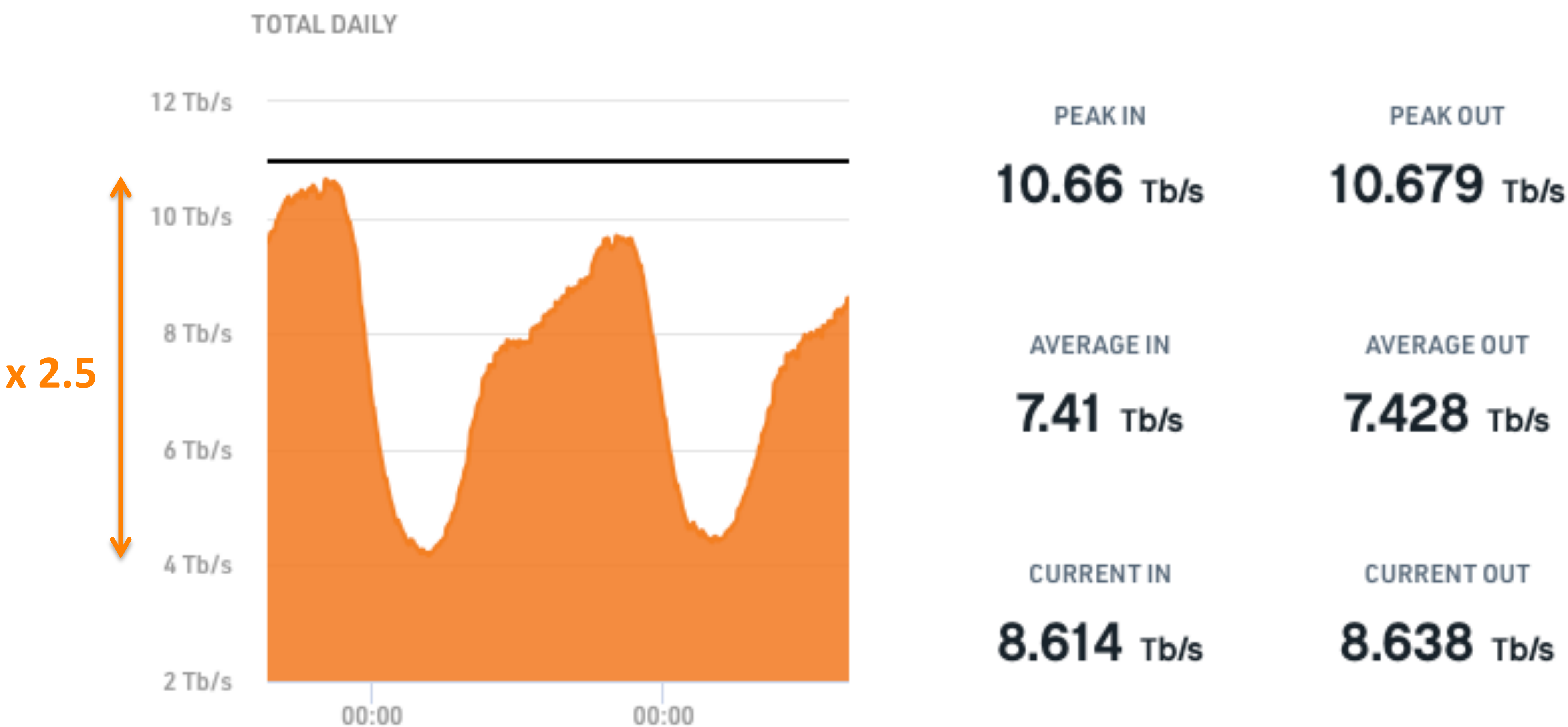
(a) CDN servers operated by Netflix at IXPs.



(b) CDN servers deployed within ISPs.

Resource waste in networks

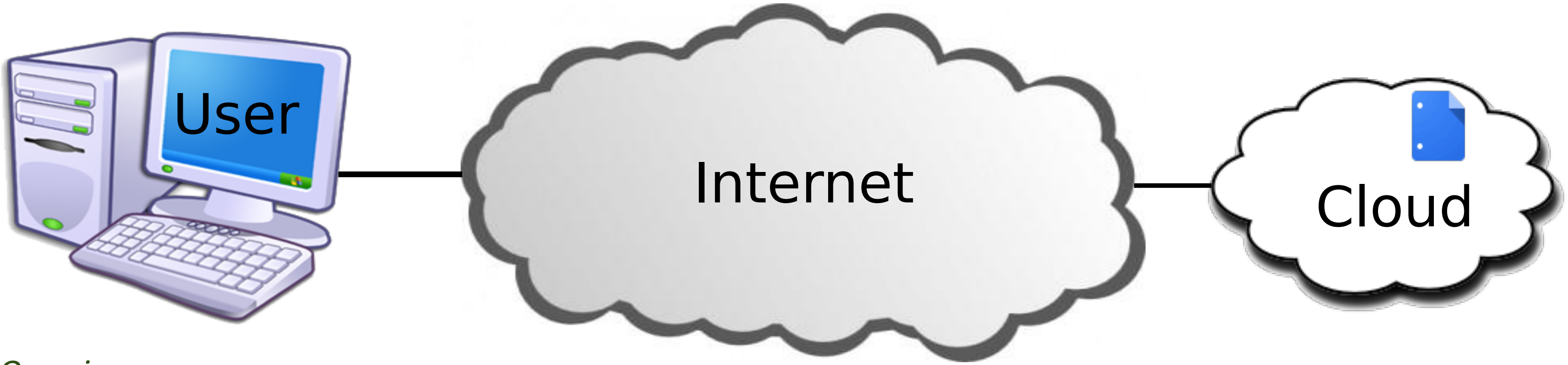
Networks are lightly of unevenly utilized



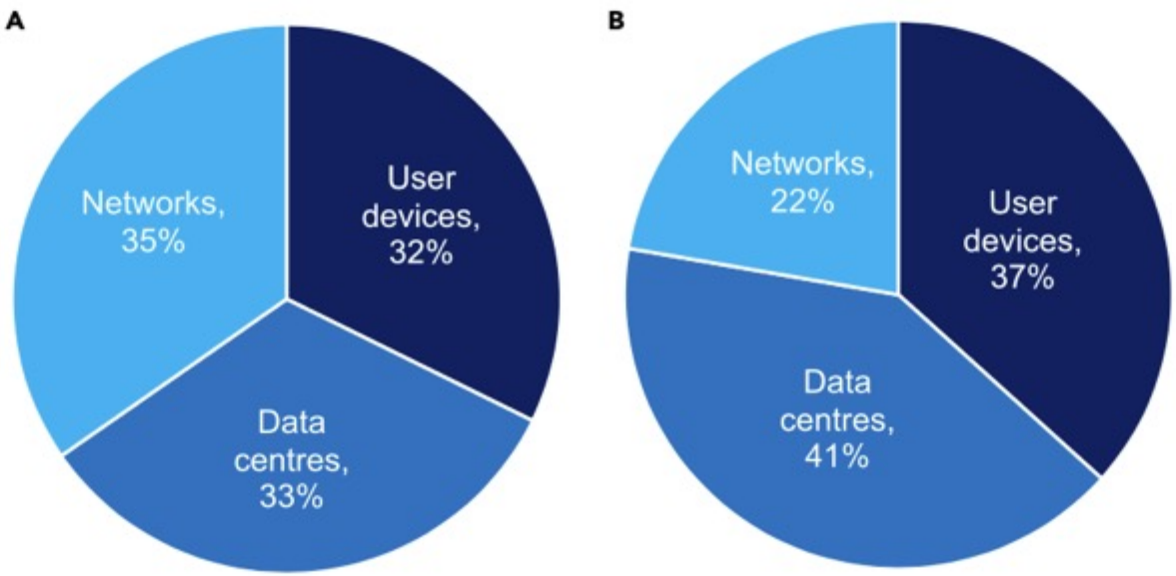
Daily aggregated traffic on AMS-IX(Amsterdam Internet eXchange Point), February 2022.

[Source : https://www.ams-ix.net/ams]

Inside the cloud



Distribution of ICT energy consumption

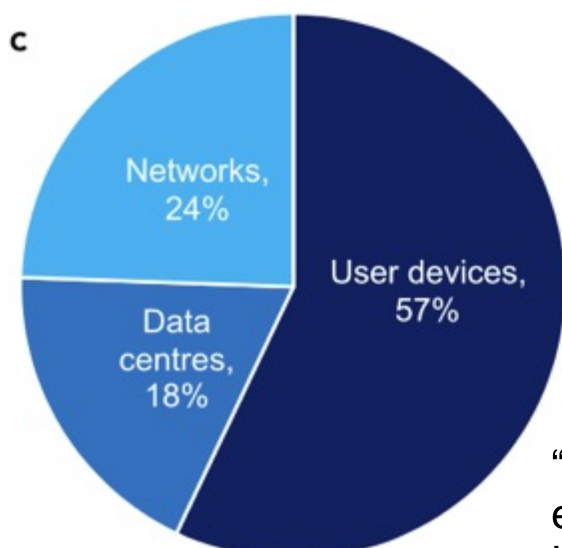


Proportional breakdown of ICT's carbon footprint, excluding TV

(A) Andrae and Edler (2015): 2020 best case (total of 623 $MtCO_2e$).

(B) Belkhir and Elmeligi (2018): 2020 average (total of 1,207 $MtCO_2e$).

(C). Malmodin (2020): 2020 estimate (total of 690 $MtCO_2e$).



"The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations'', C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. Blair, A. Friday, Patterns, 2021.

Wrong idea #0 – the good

Cloud computing is carbon neutral.

FACEBOOK
Sustainability

Net Zero
reached net zero in operational GHG emissions

In 2020, we achieved net zero emissions in our operations by reducing emissions by 94 percent* and supporting carbon removal projects.

*from a 2017 baseline

Microsoft
2021 Environmental Sustainability Report

100%
renewable energy
In 2020, we matched 100% of the electricity consumption of our operations with renewable energy purchases for the fourth consecutive year.

Google
Environmental Report

Our commitments

Carbon negative
By 2030, we will be carbon negative, and by 2050, we will remove our historical emissions since we were founded in 1975.

Reduce direct emissions
We will reduce our Scope 1 and 2 emissions to near zero by 2025 through energy efficiency work and by reaching 100 percent renewable energy.

Environmental Progress Report

100%
renewable energy sourced for all Apple facilities

Carbon neutral
for corporate operations since April 2020

Wrong idea #0 – the bad

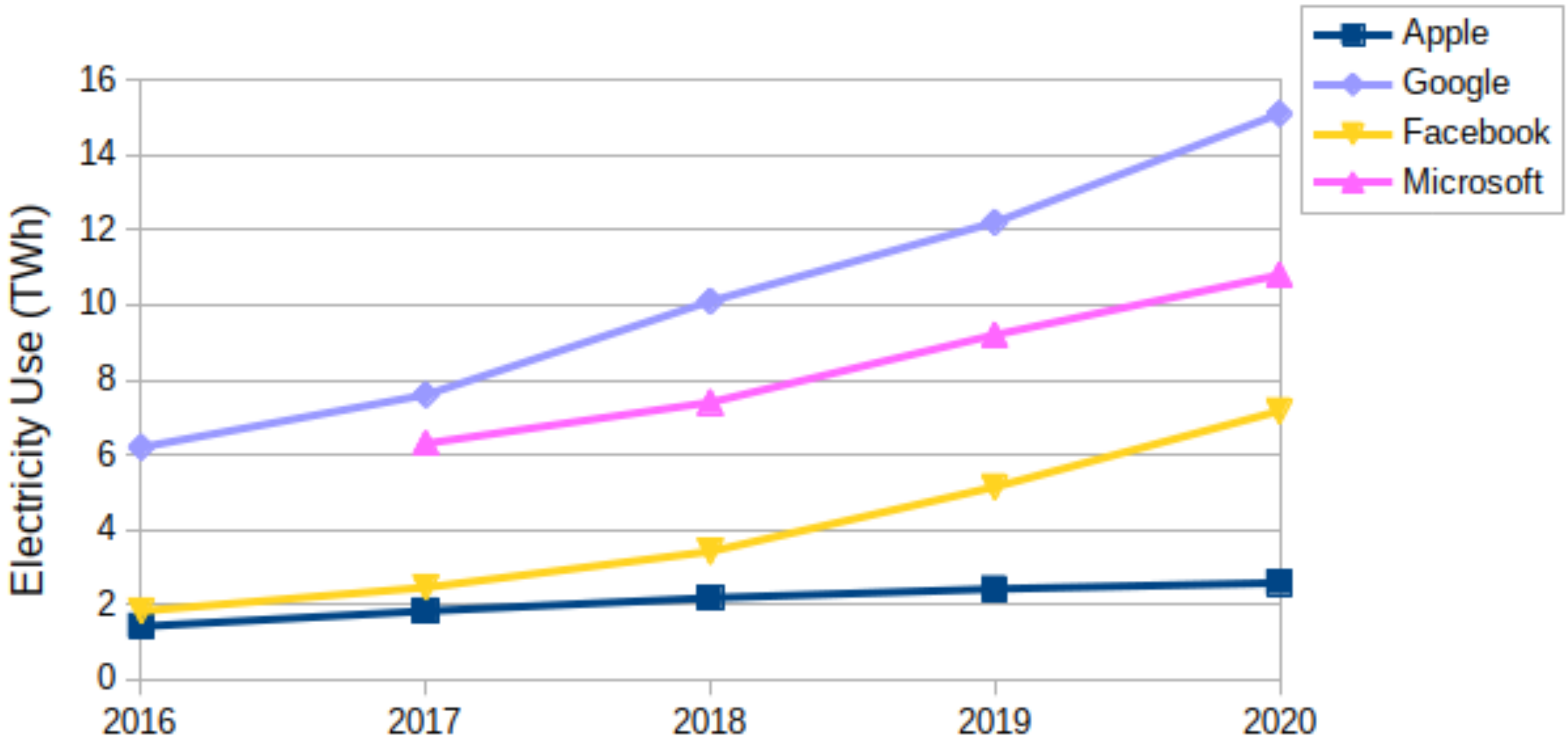


Figure: Anne-Laure Ligozat

Net electricity use still growing.

"Carbon neutralities" of ICT companies, Anne-Laure Ligozat, https://ecoinfo.cnrs.fr/2022/07/05/carbon-neutralities-of-ict-companies/, 2022.

Wrong idea #0 – the ugly

Carbon footprint : 3 scopes

- Scope 1: emissions resulting directly from the company's activities, such as internal electricity generation, air conditioning refrigerant gas emissions, etc.
- Scope 2: emissions resulting from the company's energy consumption, typically purchased electricity and heating.
- Scope 3: everything else! i.e. purchases, business travel of employees and commuting, waste management…

In 2021, partial GHG assessment for Microsoft indicates that at least 77% of their impact belong to scope 3.

https://download.microsoft.com/download/7/2/8/72830831-5d64-4f5c-9f51-e6e38ab1dd55/Microsoft_Scope_3_Emissions.pdf

First rule: measuring for real

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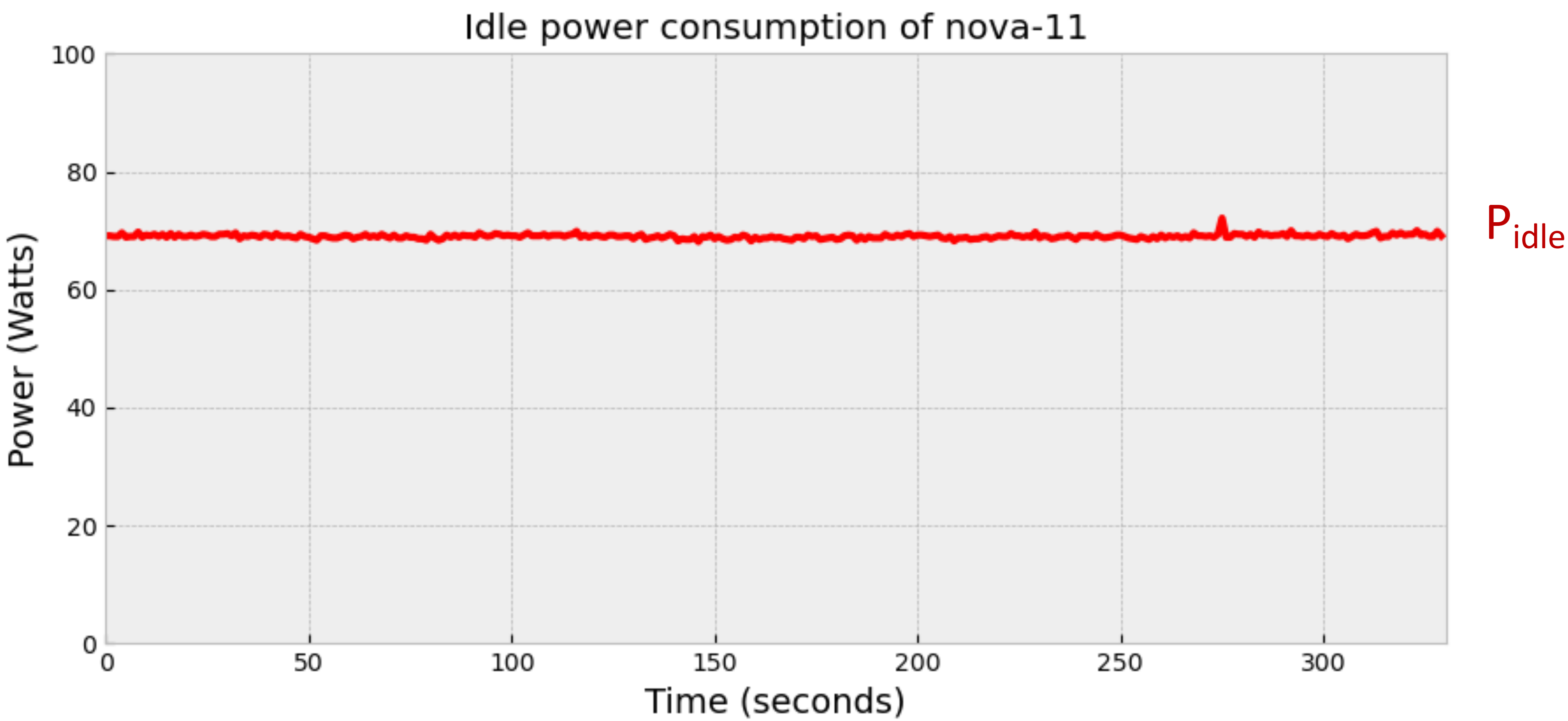
Wrong idea #1

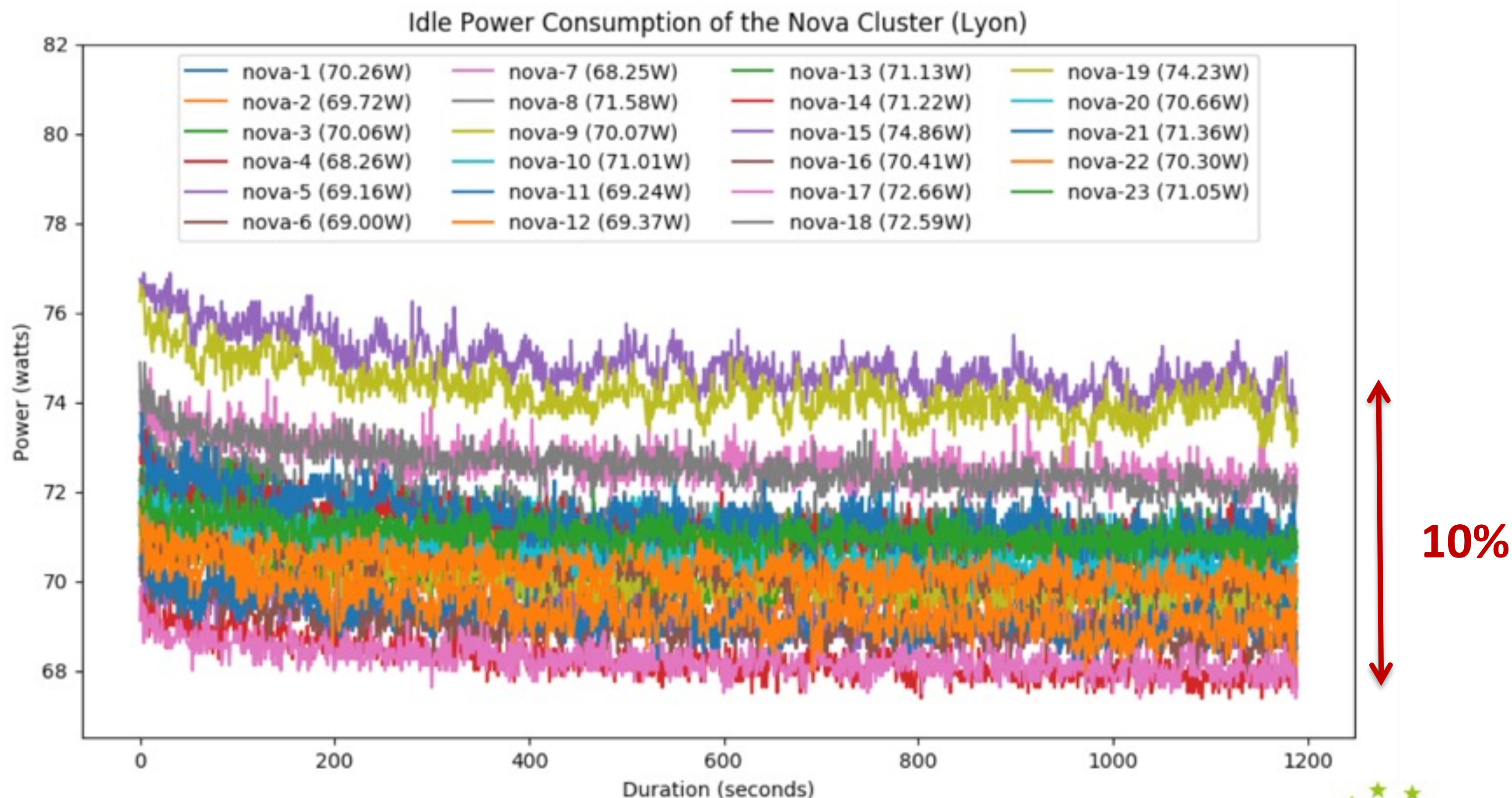
Idle server consumes nothing or little.



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

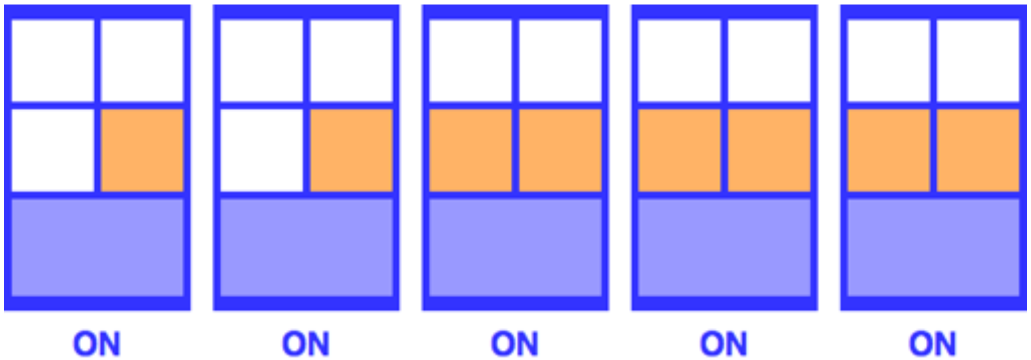
Wrong idea #2

This server model consumes that amount of power.



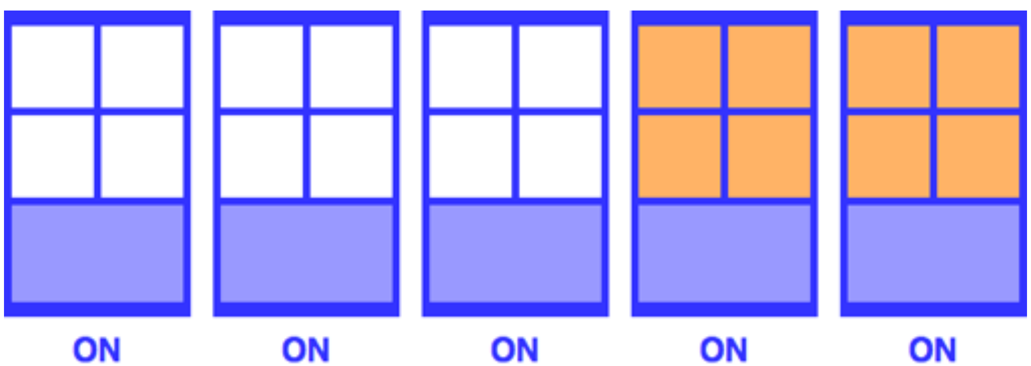
10% difference in idle and more at maximal consumption.

No chance for naive modeling



Naive model:

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



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

Best configuration for power consumption ?

It depends.

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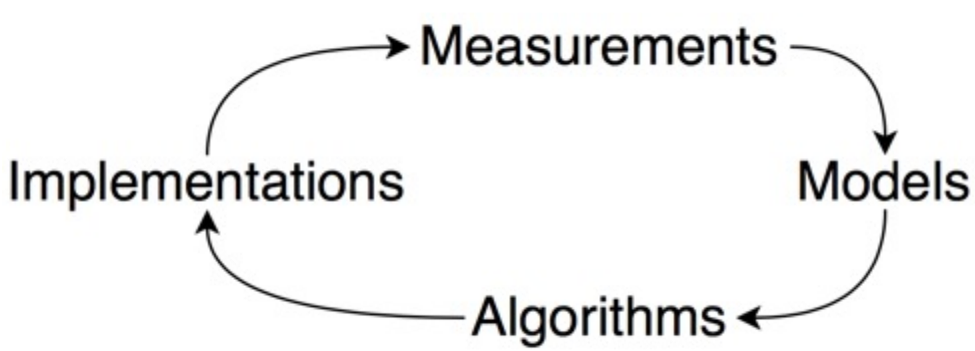
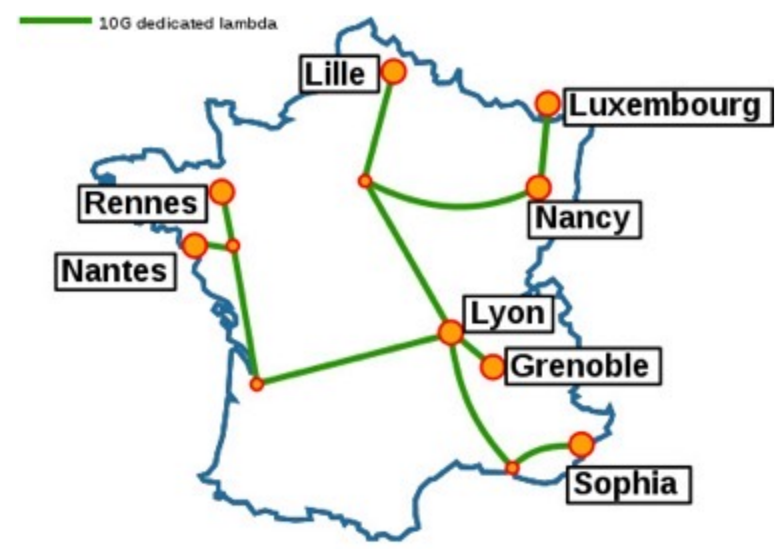
Energy consumption: a complex phenomenon

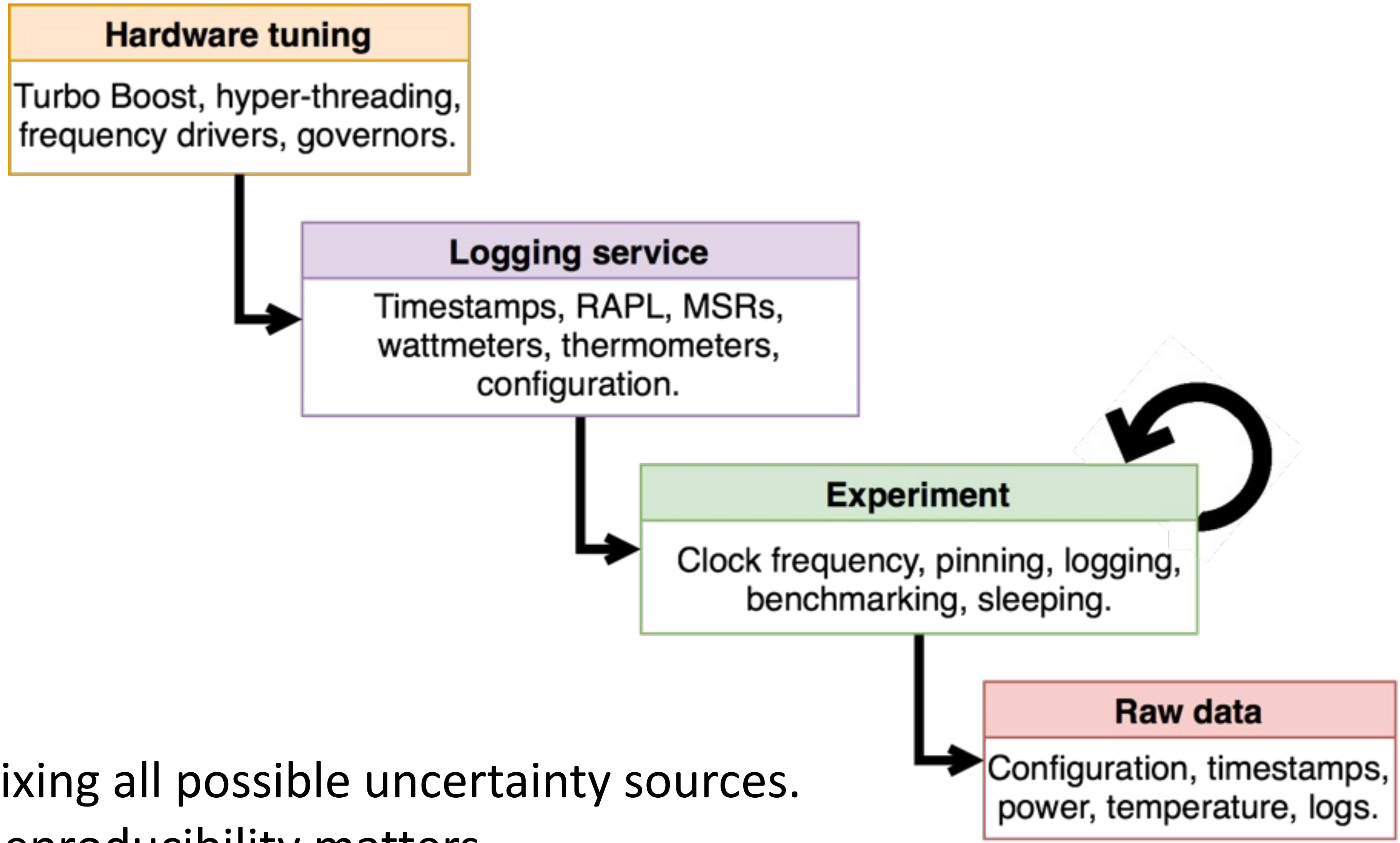
Need for **wattmeters** and sound experimental campaigns

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





Second rule: pay attention to your experimental process

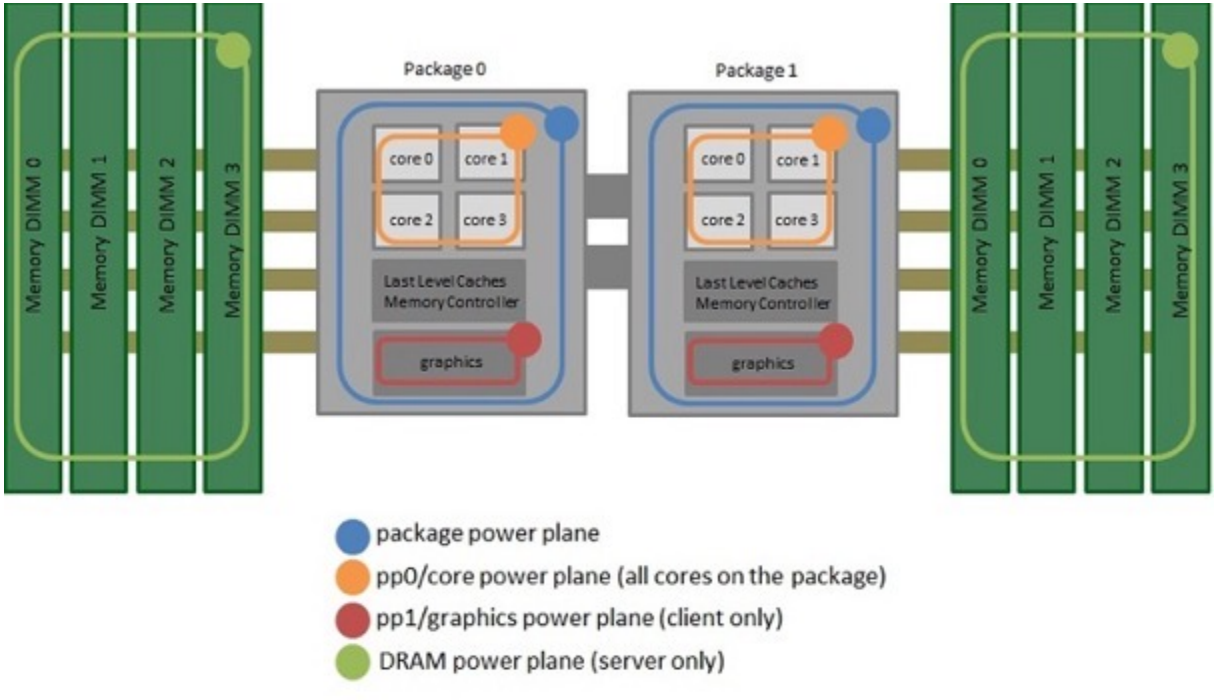


Fixing all possible uncertainty sources.
Reproducibility matters.

[ISCC 2021]

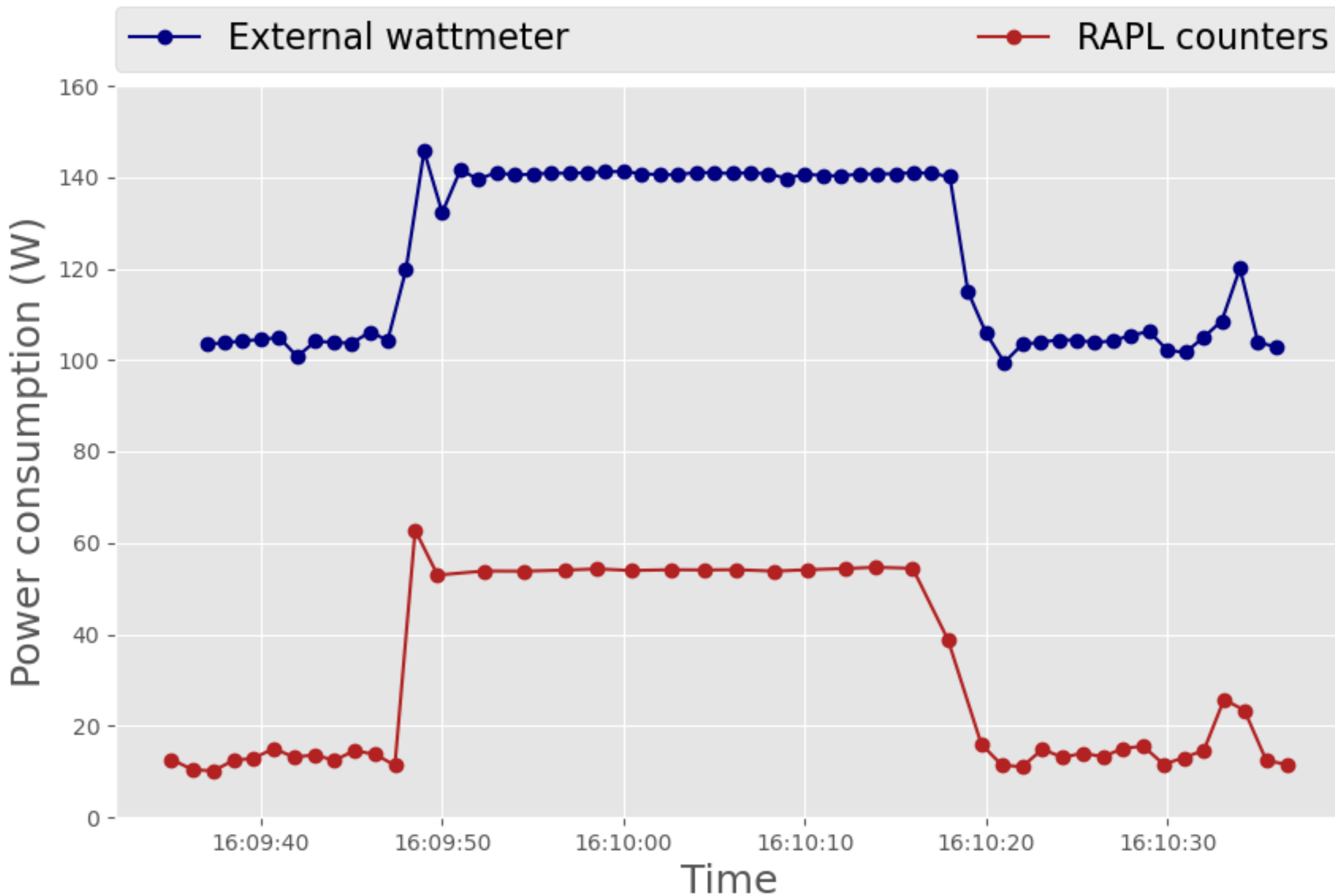
Performing measurements

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)
```

Knowing what you measure



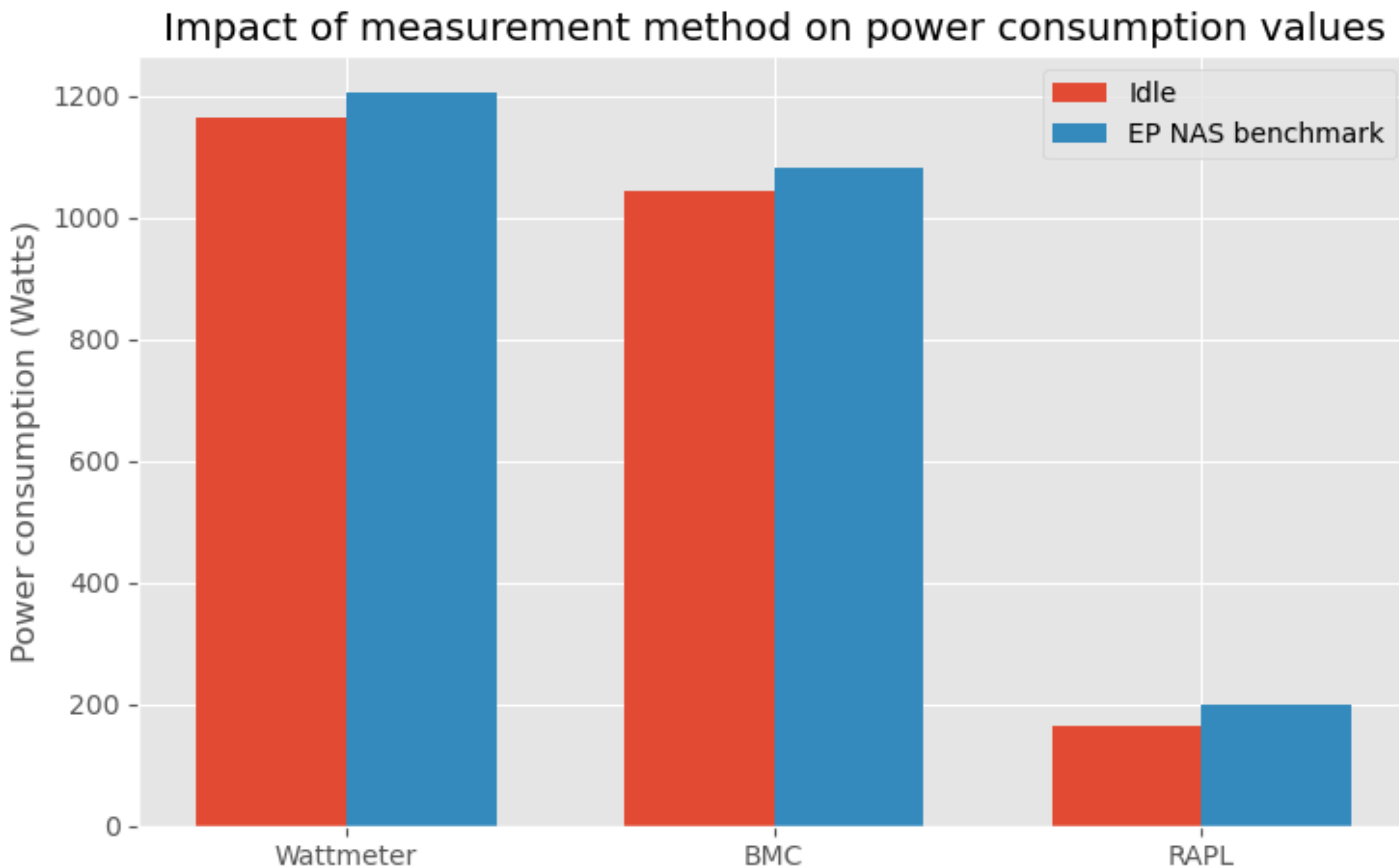
Grid'5000

Big difference

Power consumption of Taurus-12

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

Wattmeter vs. BMC vs. RAPL

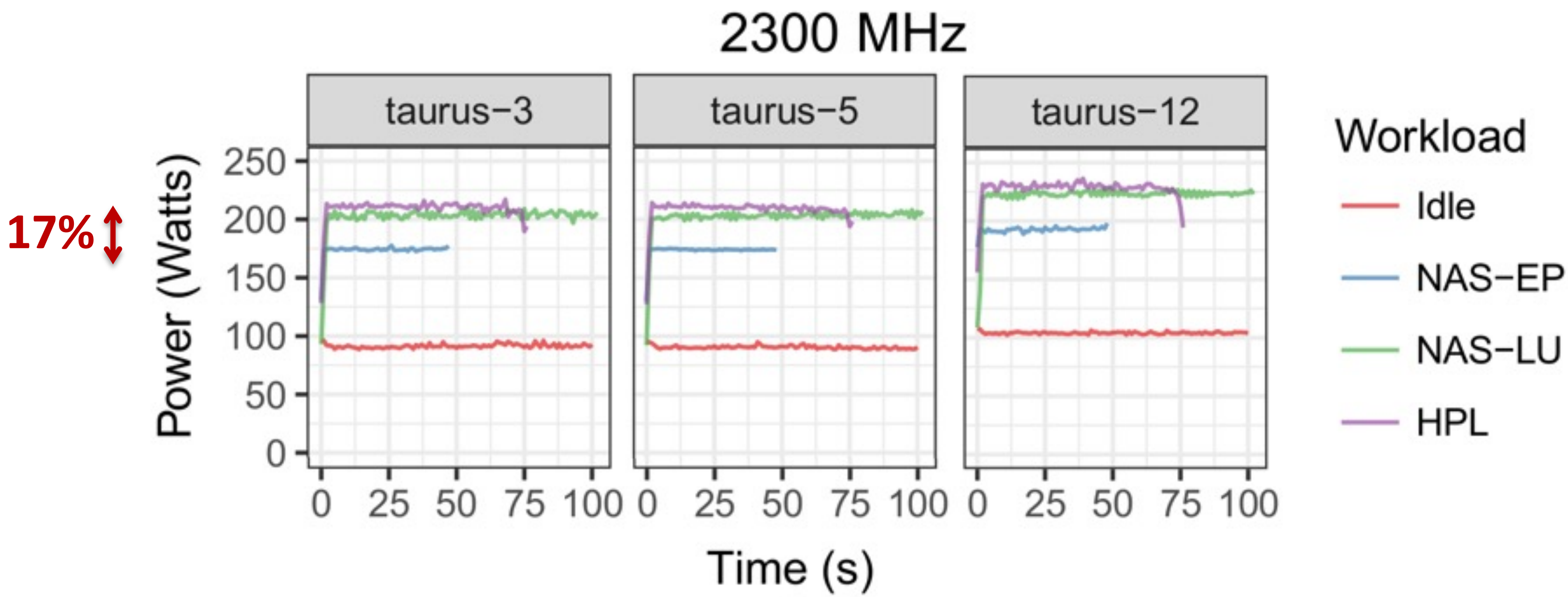


Gemini node: 2 x Intel Xeon E5-2698 v4, 20 cores/CPU, 512 GiB RAM, 480 GB SSD,
8 x Nvidia Tesla V100 (2019)

[CCGrid 2023]

Wrong idea #3

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



[Cluster 2017]

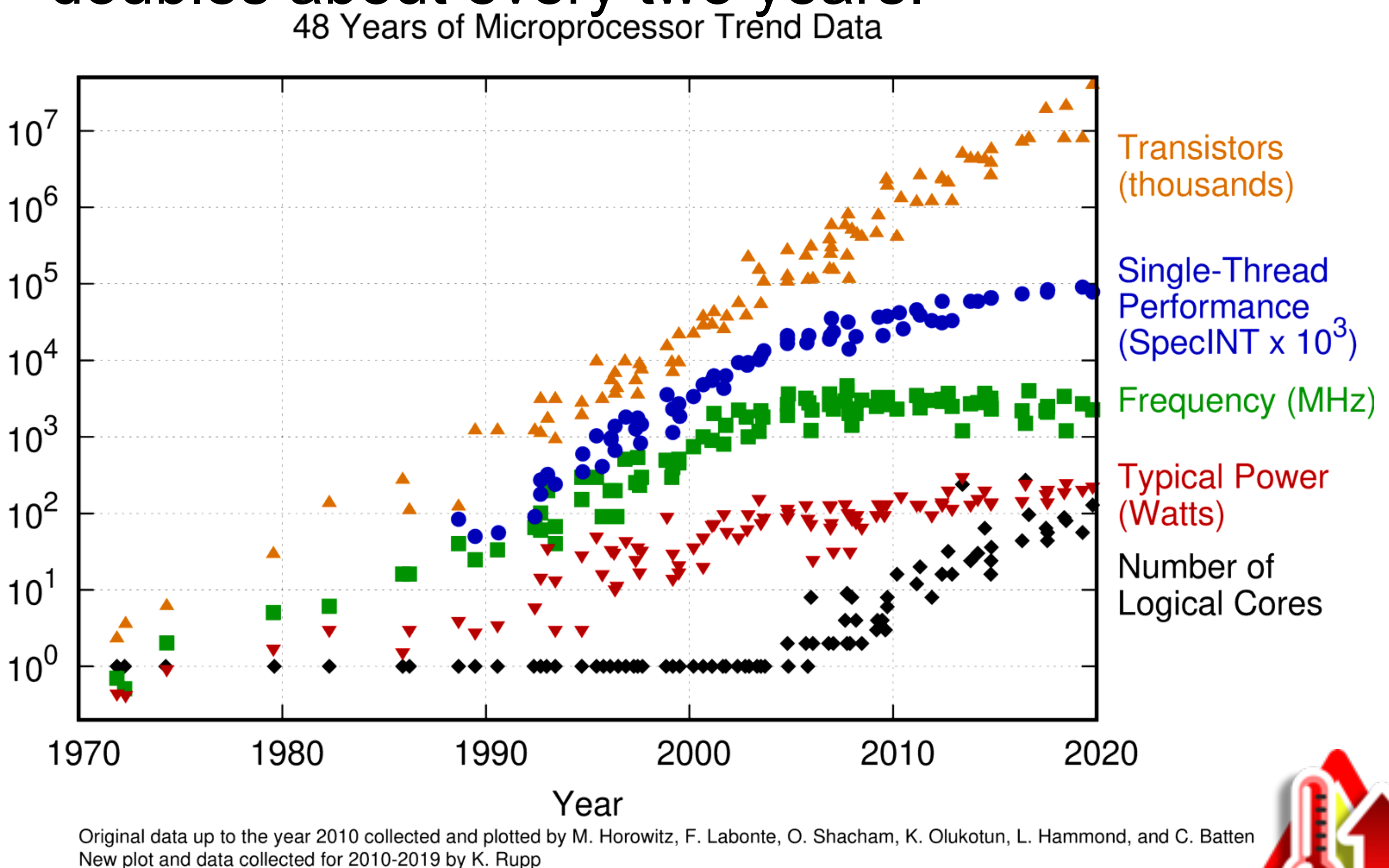
Taurus node: 2 x Intel Xeon E5-2630, 6 cores/CPU, 32 GiB RAM, 300 GB HDD (2012)

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

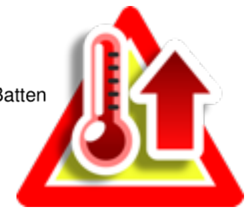
Wrong idea #4 (and much more)

Improvement in energy efficiency will never stop.

Moore's law: the number of transistors in a dense integrated circuit doubles about every two years.



- Increase the processor's frequency
- Increase the number of cores per processor
- Increase the fineness of processor engraving



Physical limits.

[Source : Karl Rupp, https://github.com/karlrupp/microprocessor-trend-data]

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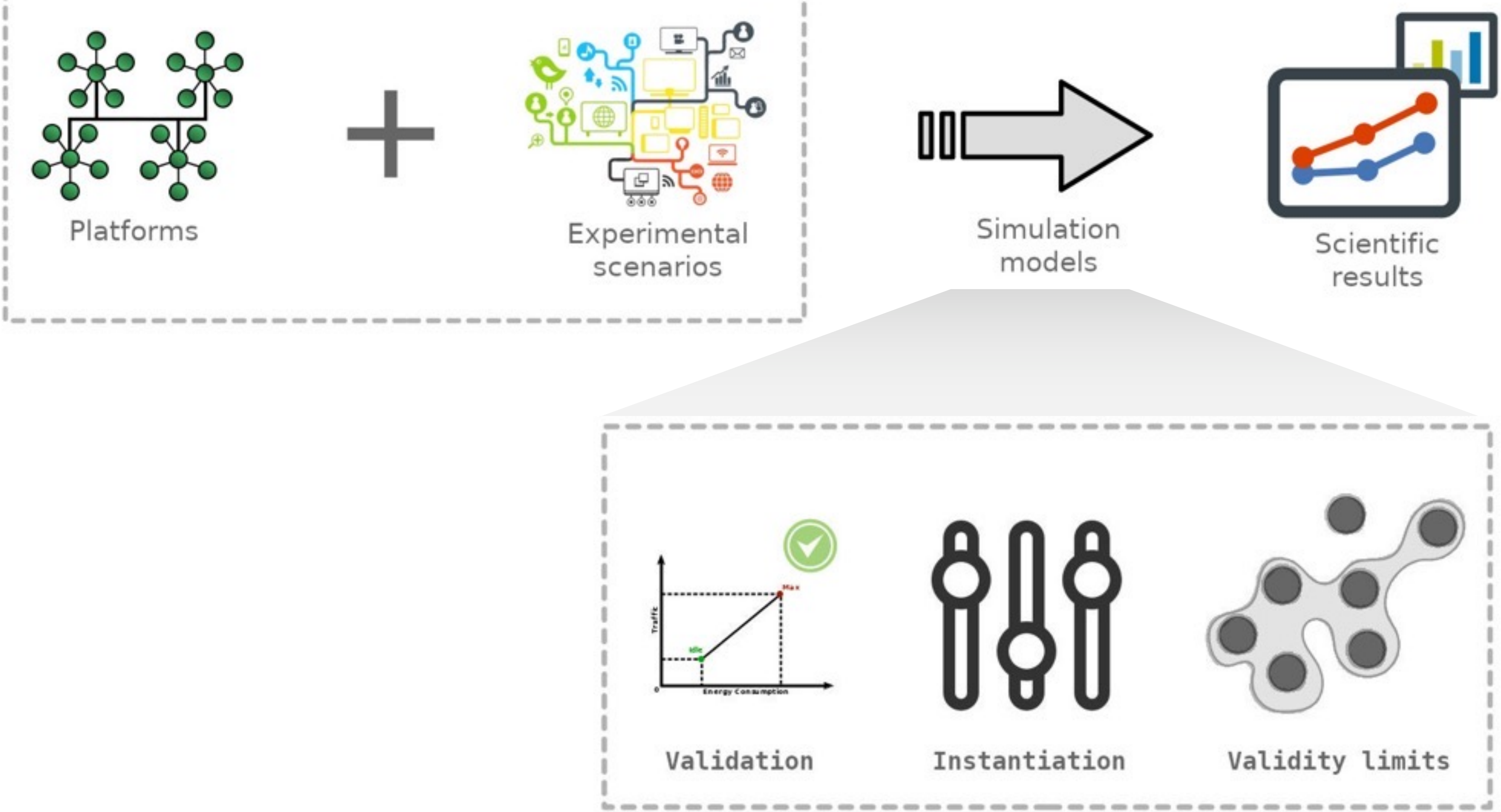
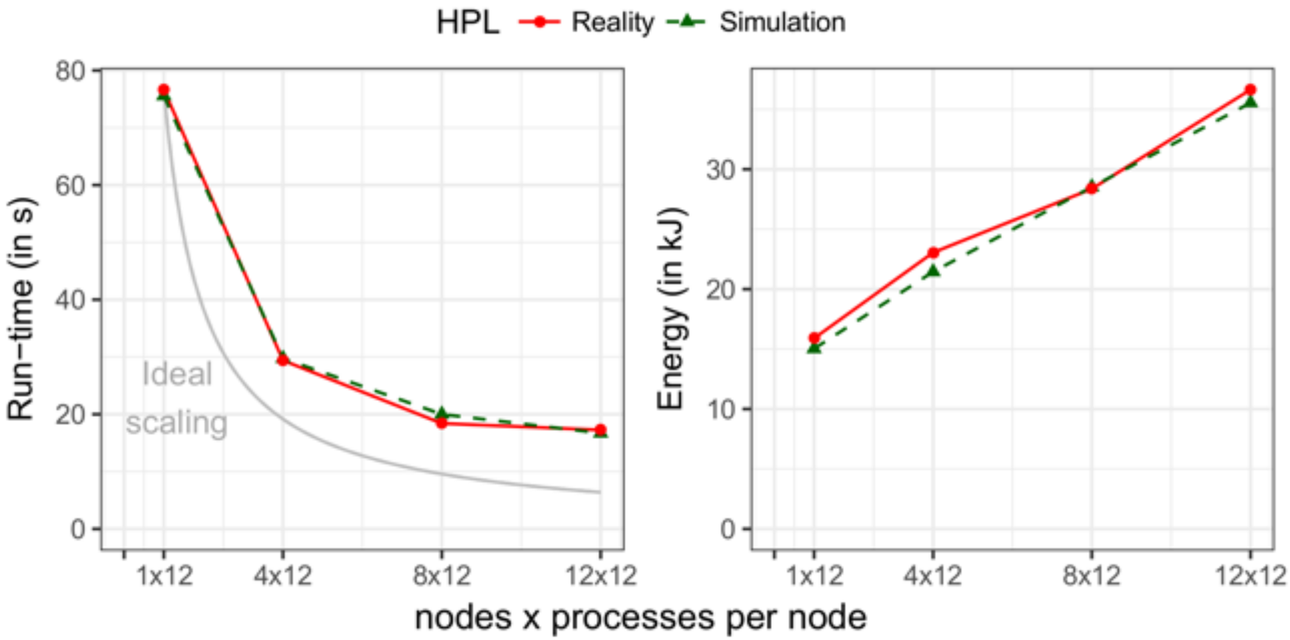
Simulating energy consumption



Validating simulation tools

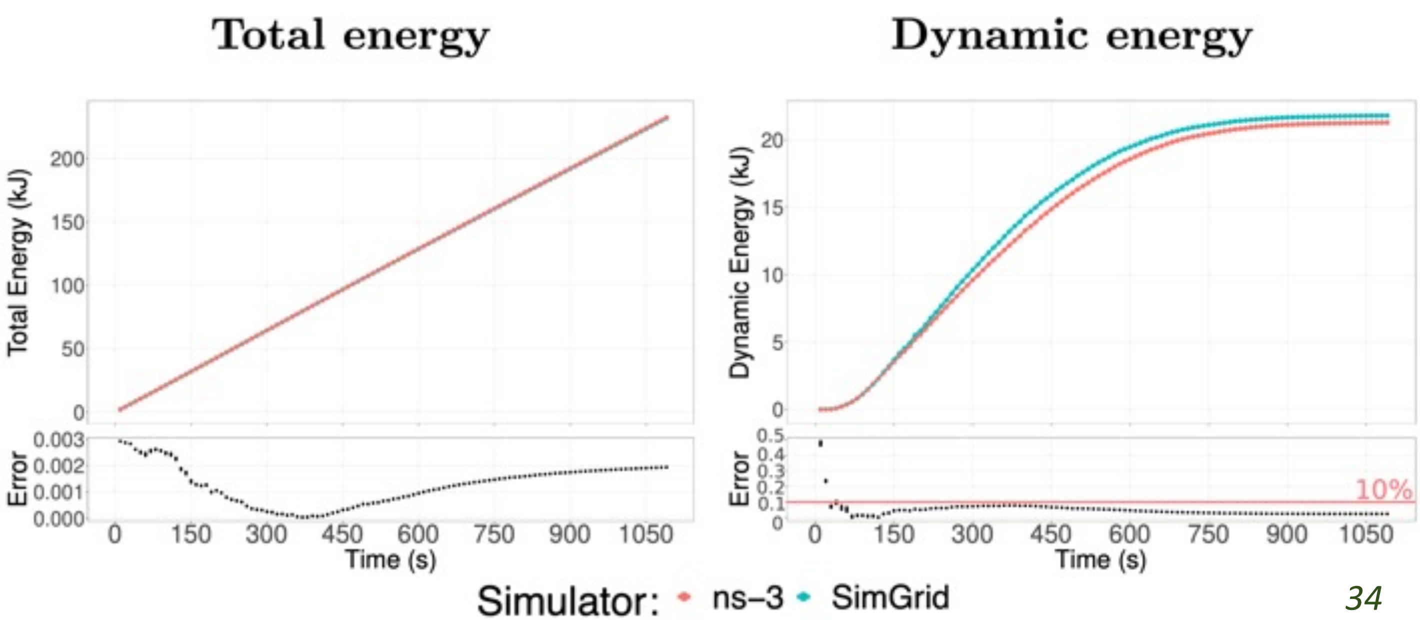


[Cluster 2017]

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

[WoWMoM 2023]

Reproducible results: https://github.com/klementc/wifi_energy_experiments



Models and simulation tools for what?

Capacity and energy planing

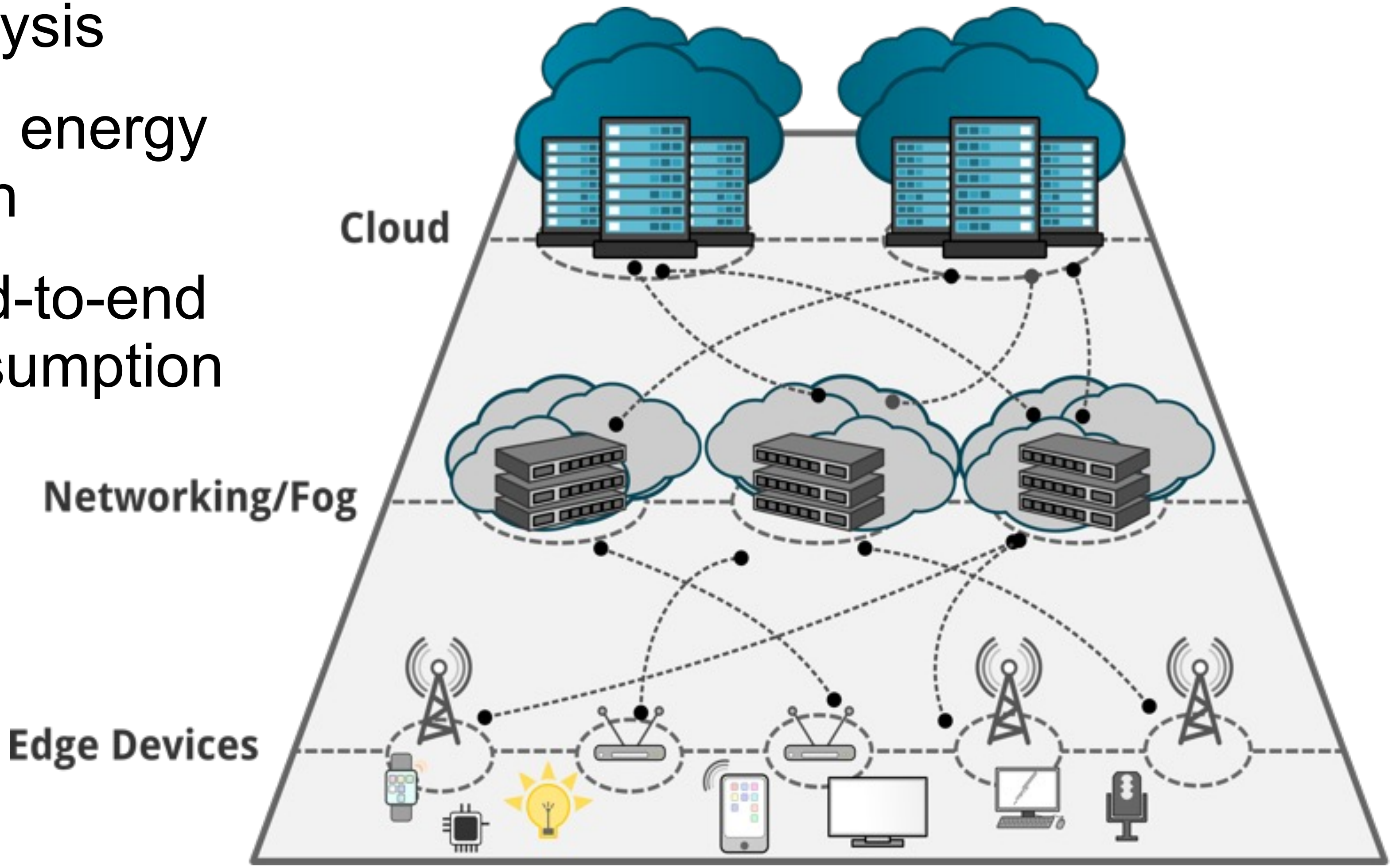
What-if scenarios

Algorithm analysis

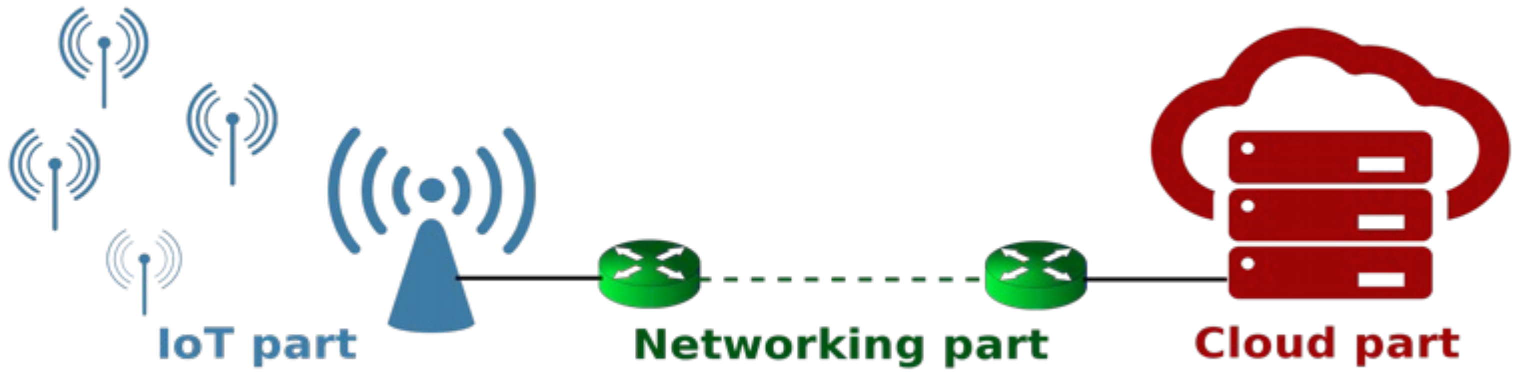
Estimating VM energy consumption

Estimating end-to-end energy consumption

Closing doors

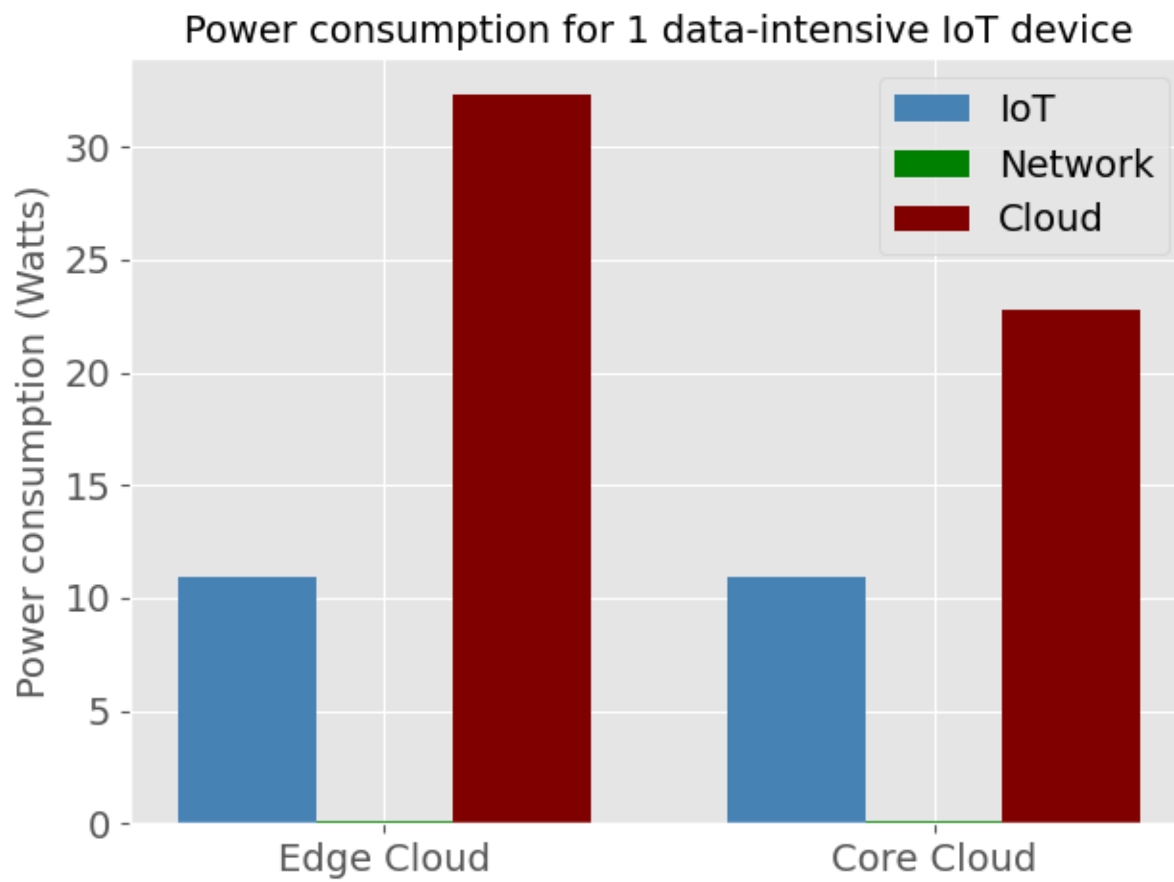


Power consumption of IoT



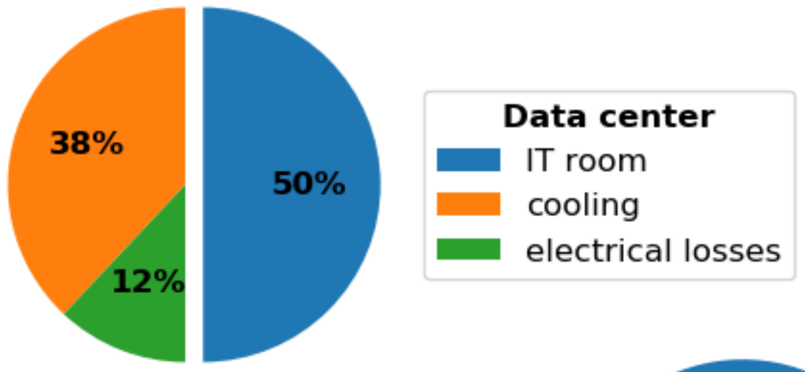
[FGCS 2018]

Tradeoff between:
- Performance
- Application accuracy
- Energy consumption

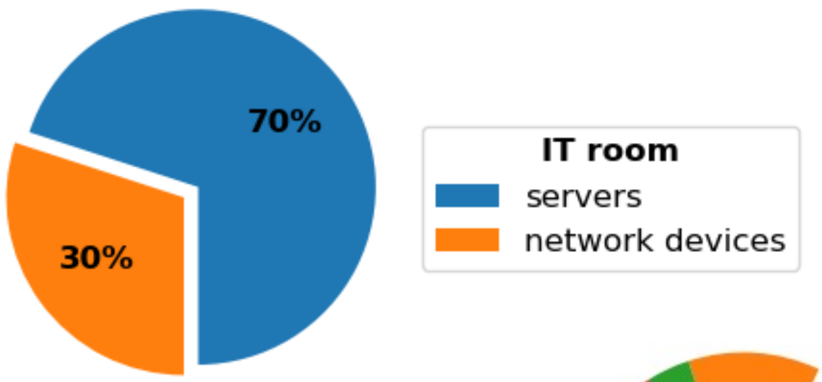


It depends.

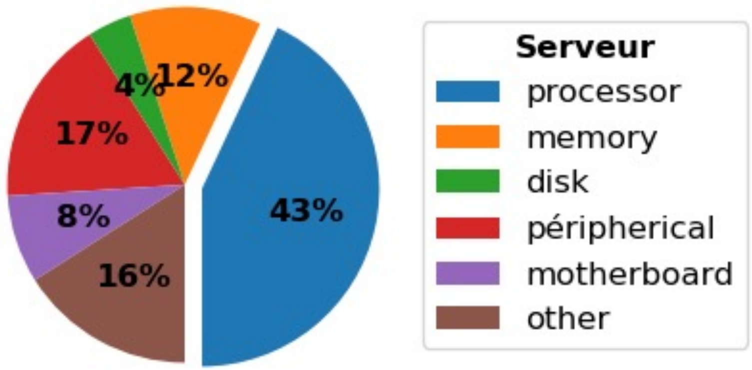
Wasted energy at all levels of data centers



Cooling
Power generators
Batteries
…



Unused servers
Overprovisioning
Redundancy
…



Power non-proportionality
Dark silicon
Unused components
…

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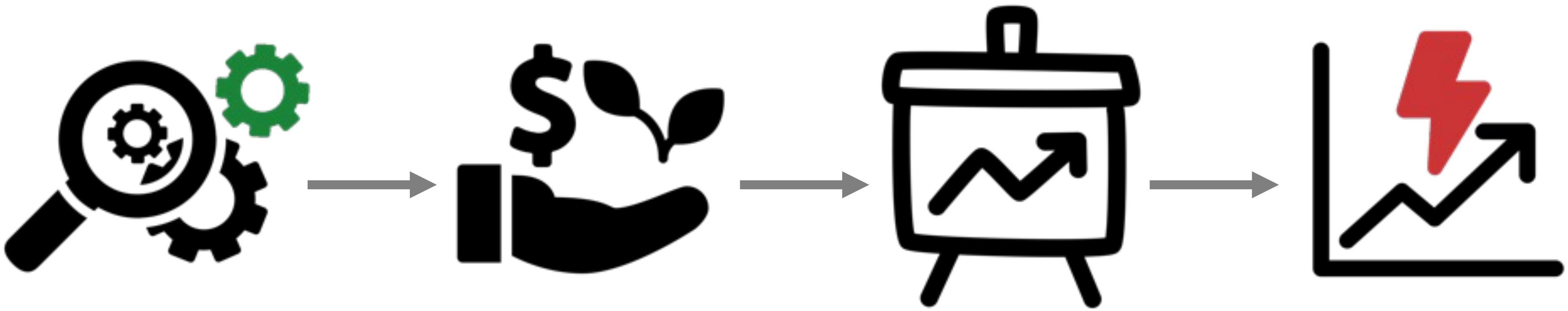
ICT for Green ≠ Green ICT

- **ICT for Green**
  - Use ICT technologies to reduce the environmental footprint of other processes and sectors
  - E.g. smart grids, climate simulations, etc.
- **Green ICT**
  - Reduction of the ICT's environmental footprint
  - E.g. energy-aware data centers
  - 4 ways: measurement, efficiency, sobriety, resilience

Increasing energy efficiency
≠ reducing consumption



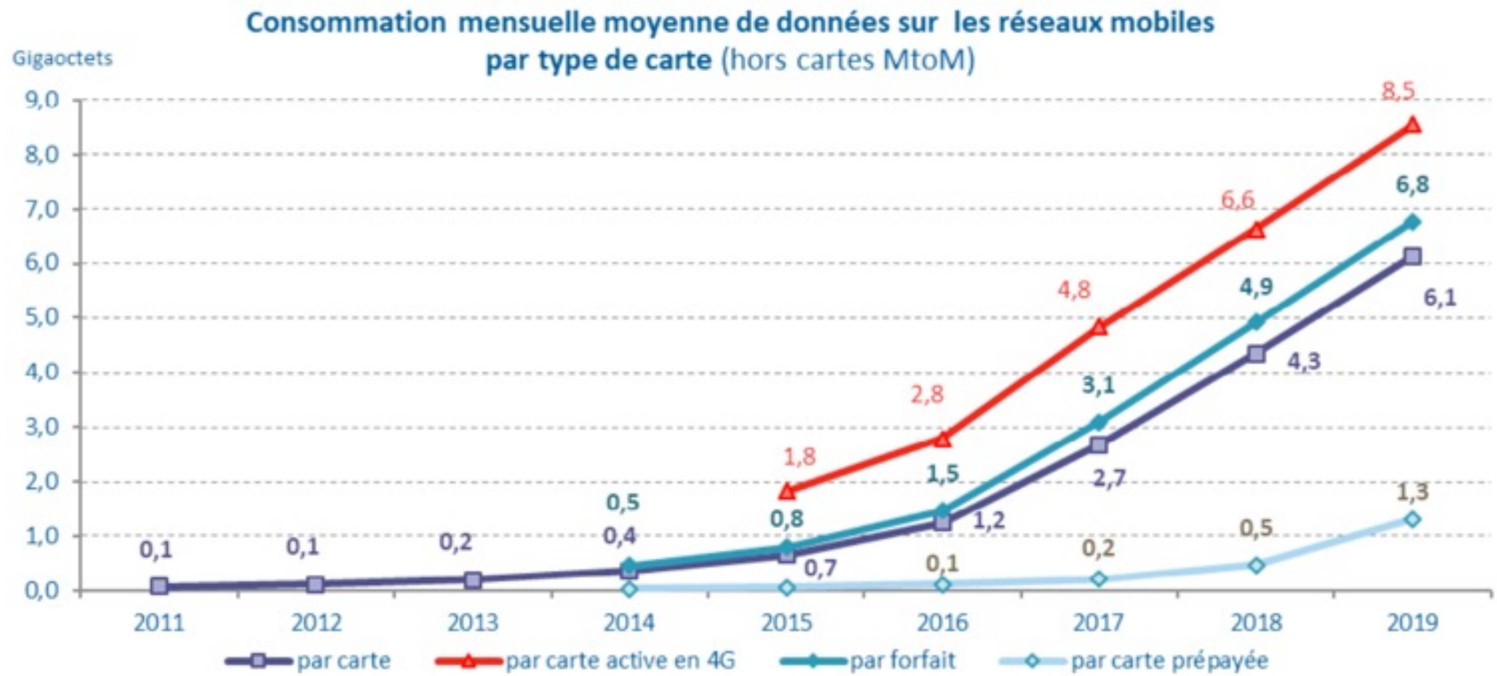
Energy **optimization** → Resource cost reduction → Usage increase → Energy consumption **increase**

Underlying trends:

- Acceleration of equipment renewal rate
- Explosion of uses and consumption of data
- Digitization of all sectors, without prior study of environmental impacts

Beware of rebound effects!

More and more traffic



[Source: Marché des communications électroniques en France - Année 2019, ARCEP]

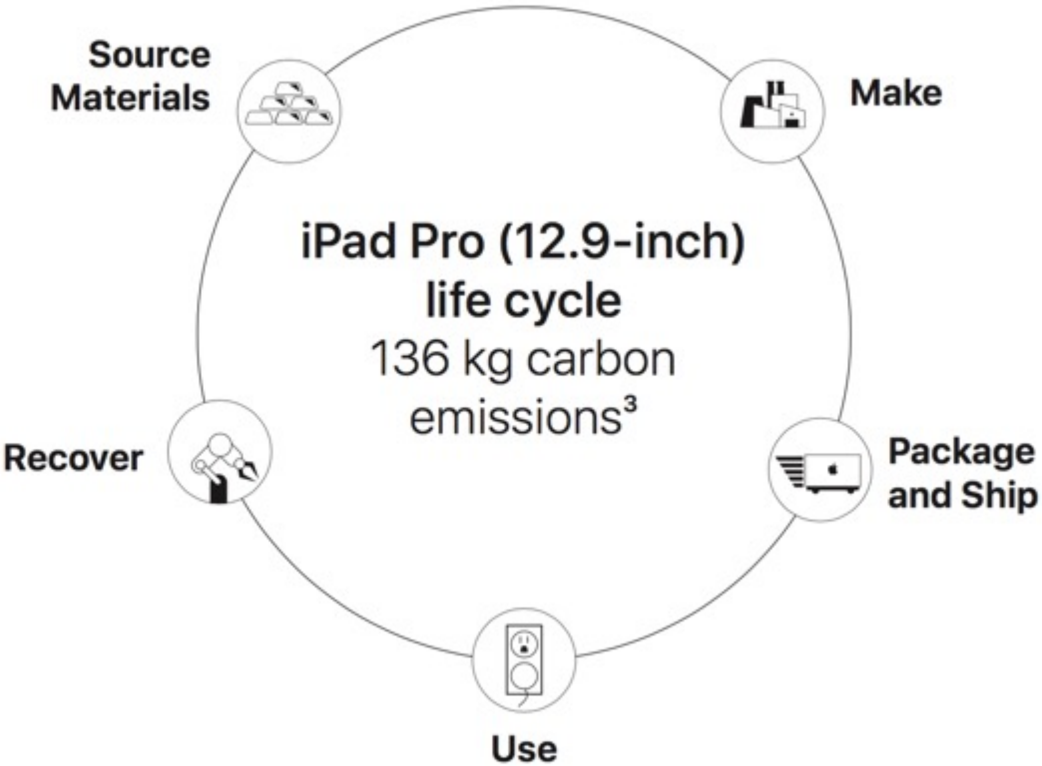
In Q4 2011 :

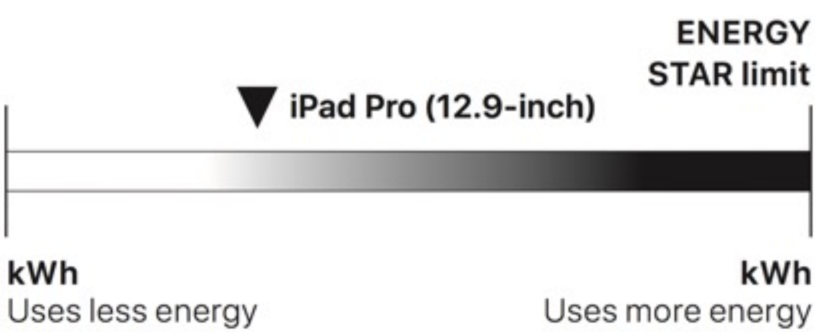
- 65.9 million SIM cards in France (prepaid and subscription)
- average monthly data consumption per SIM card: 0.1 GB/month

In Q4 2021 :

- 80.4 million SIM cards in France
- 10.4 GB/month (x100 in 10 years per user)

Life cycle of end devices





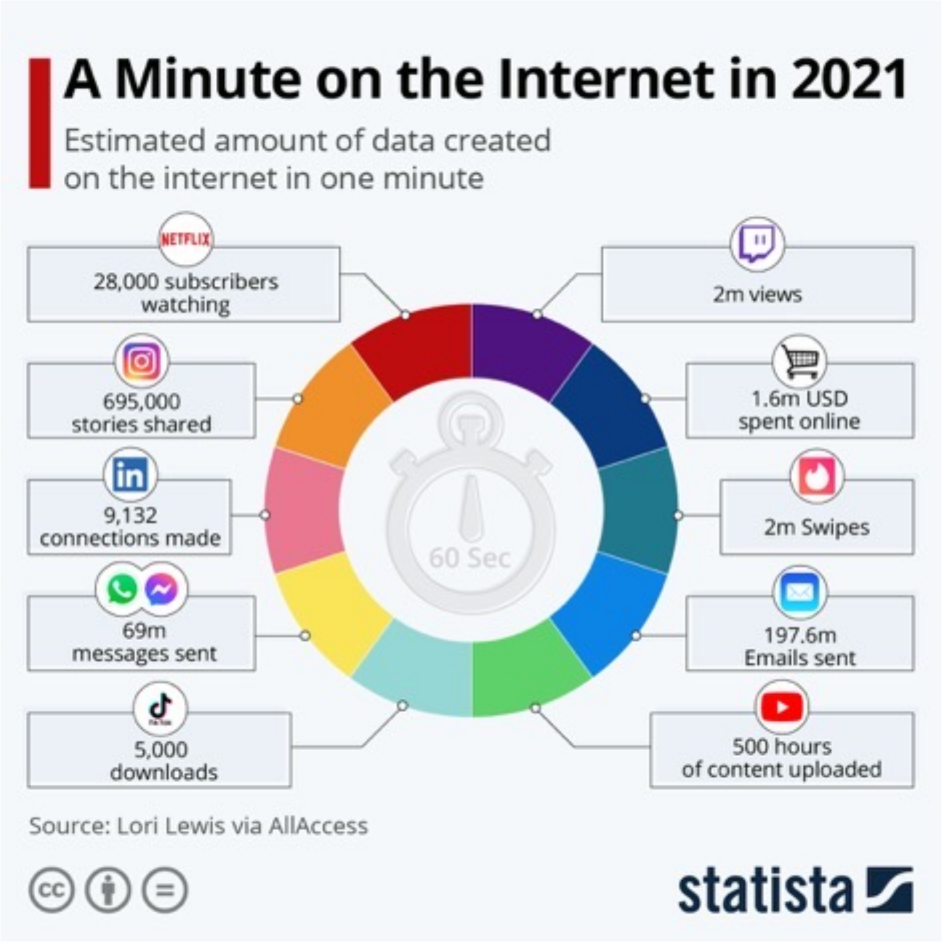
iPad Pro (12.9-inch) life cycle carbon emissions

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

4 years of use

Source: Product environmental report, Apple, 2018.

Can we continue to design distributed systems …



… without changing users' habits? And our habits?

Studying environmental impacts of ICT

https://ecoinfo.cnrs.fr

Ongoing projects

- **CARECloud**: Comprendre, Améliorer, Réduire les impacts Environnementaux du Cloud computing

  Project on estimating the environmental impacts, improving the efficiency and proposing sobriety approaches for Cloud infrastructures

  → *Large-scale end-to-end simulation, environmental indicators for end-users, low-tech and intermittent infrastructures*

- **NF-JEN**: Just Enough Networks

  Project on energy and EMF exposure efficiency and sobriety for 5G and future networks

  → *Orchestration of energy-efficient mechanisms for mobile infrastructures (e.g. sleep modes)*

Thank you for your attention

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