# Measuring and modeling the energy consumption of servers

Anne-Cécile Orgerie

*DIPOpt workshop, Lyon*
*30th November 2023*

# 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?

- 2.1%
- 3.9%
- 8.6%
- 15.4%

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- 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, not counting data centers outside of France)

→ 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

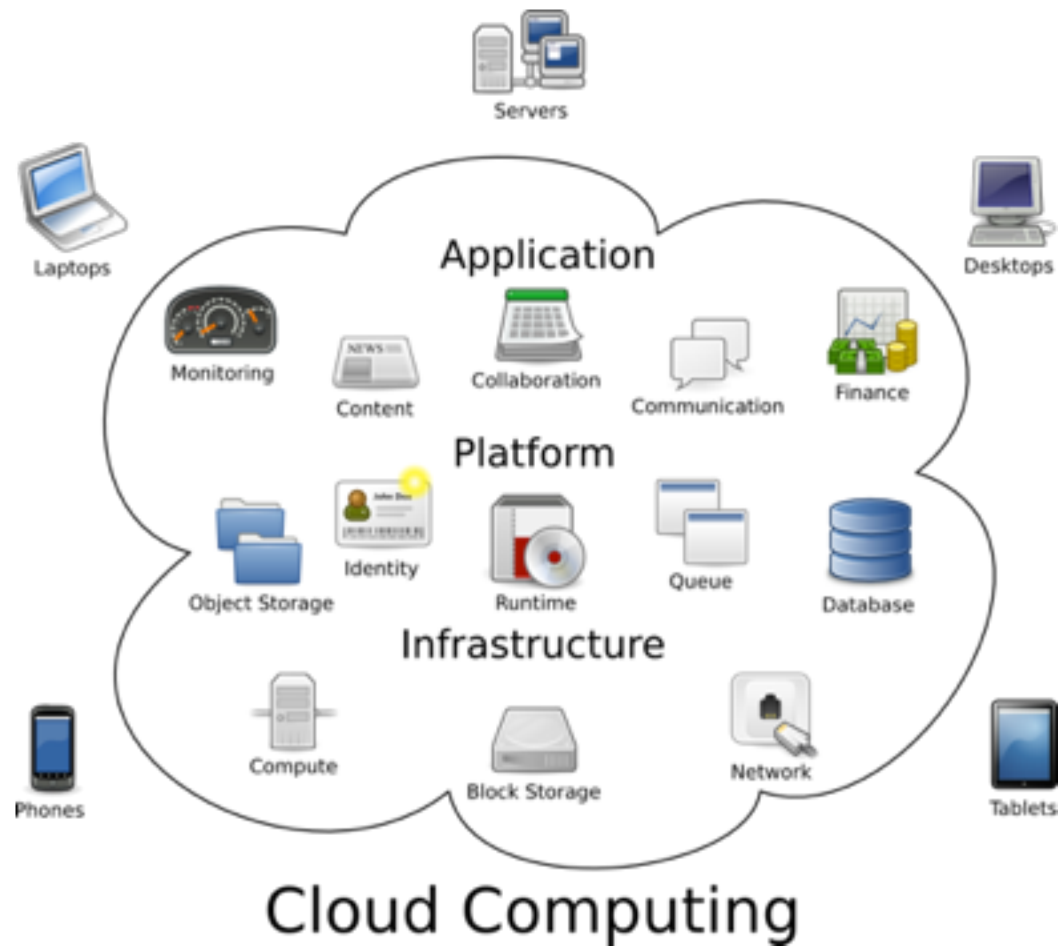
Started with Grid computing some years ago…

# 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

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

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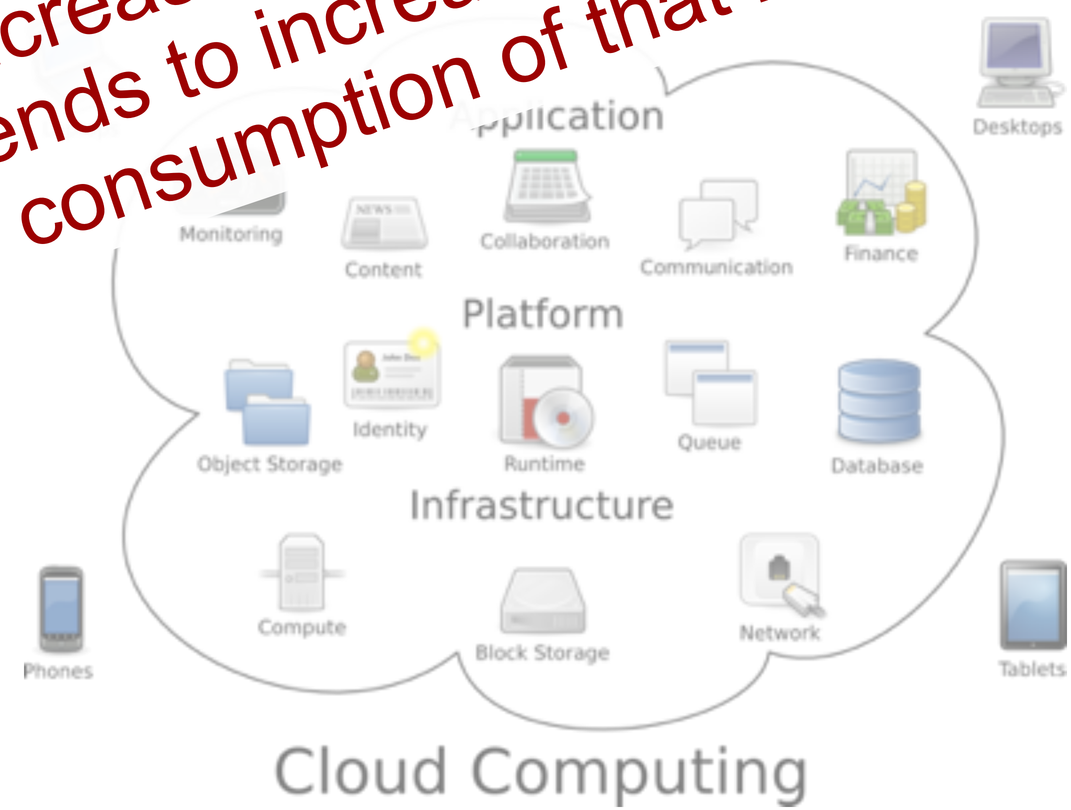
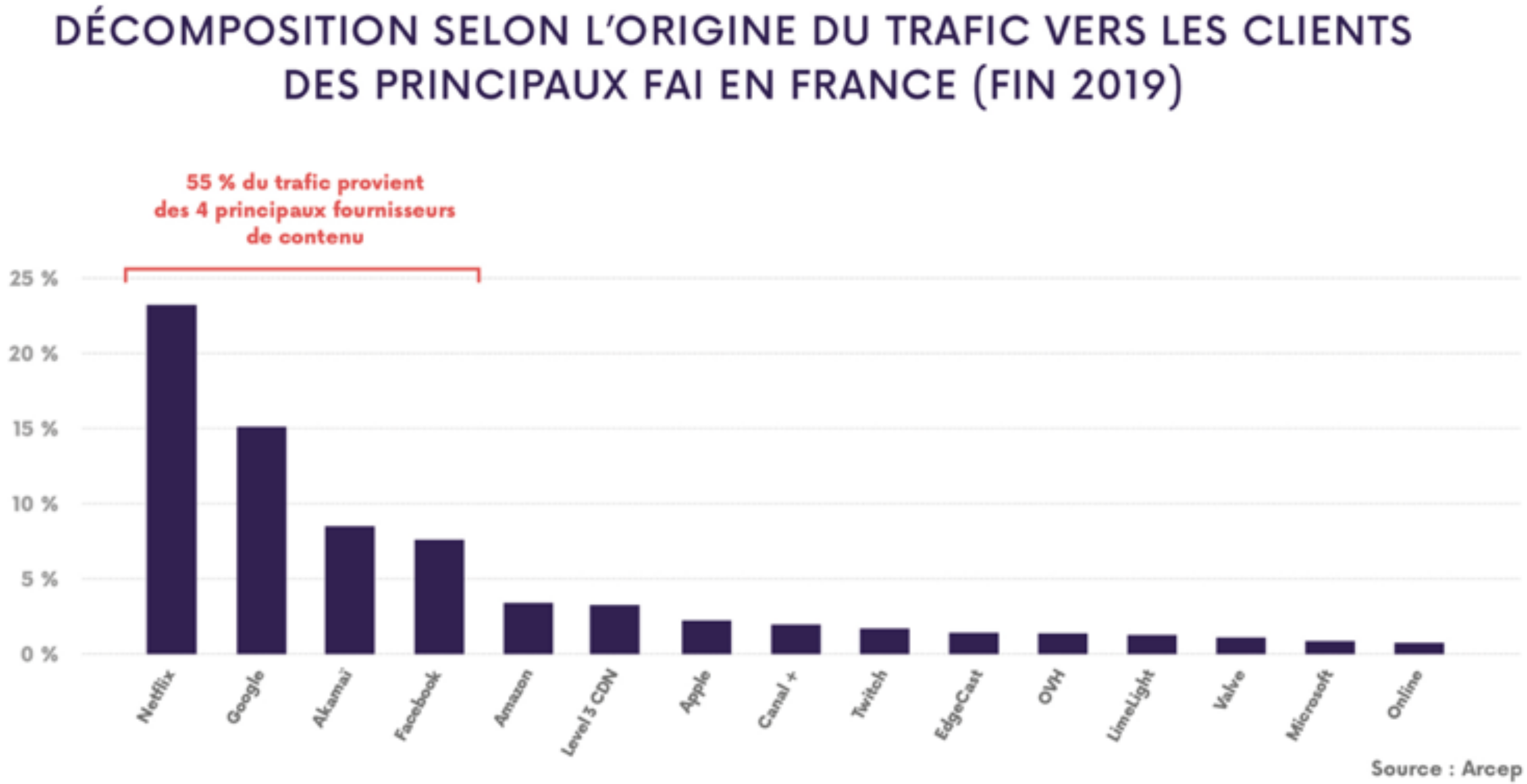
- Externalization of data

**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**

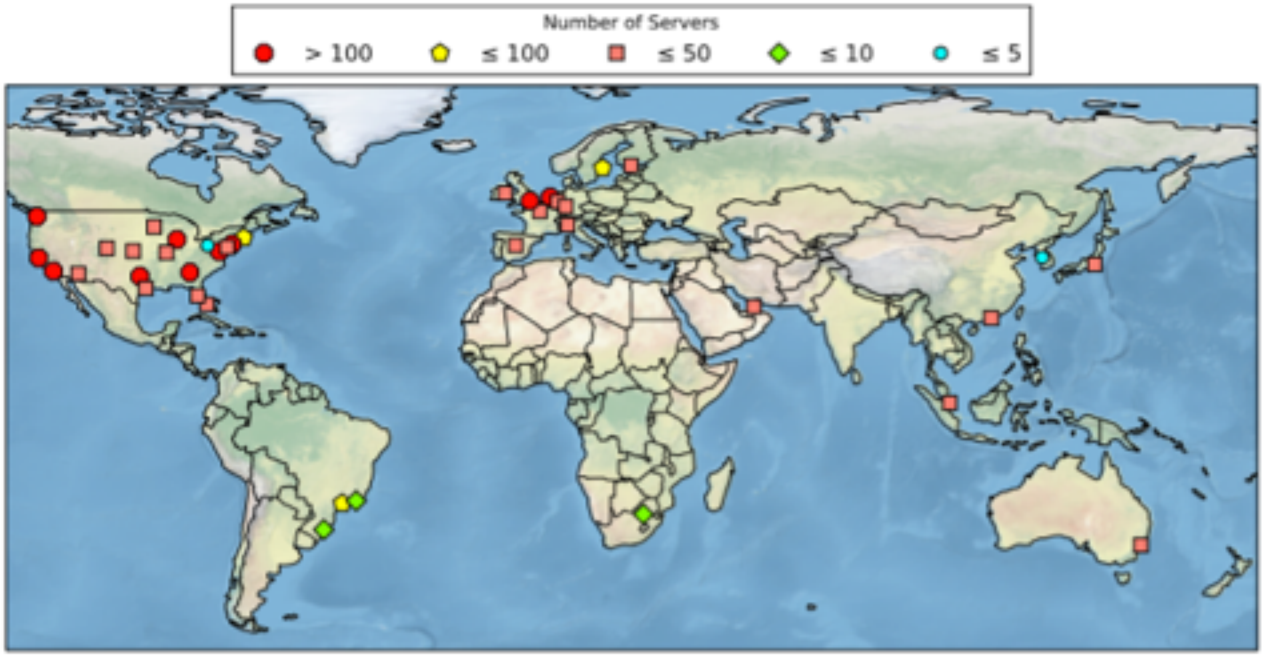


# Internet trafic in France

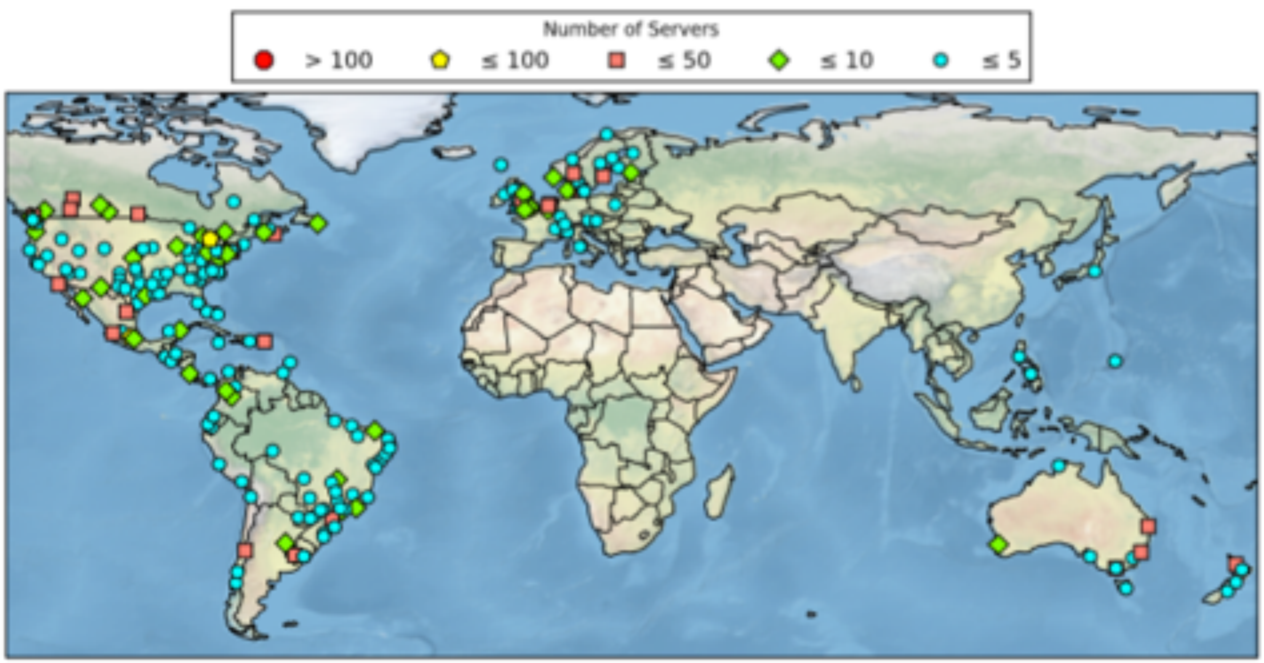



*Trafic Internet en France selon l'Arcep en 2019.*

# Netflix resources




(a) CDN servers operated by Netflix at IXPs.

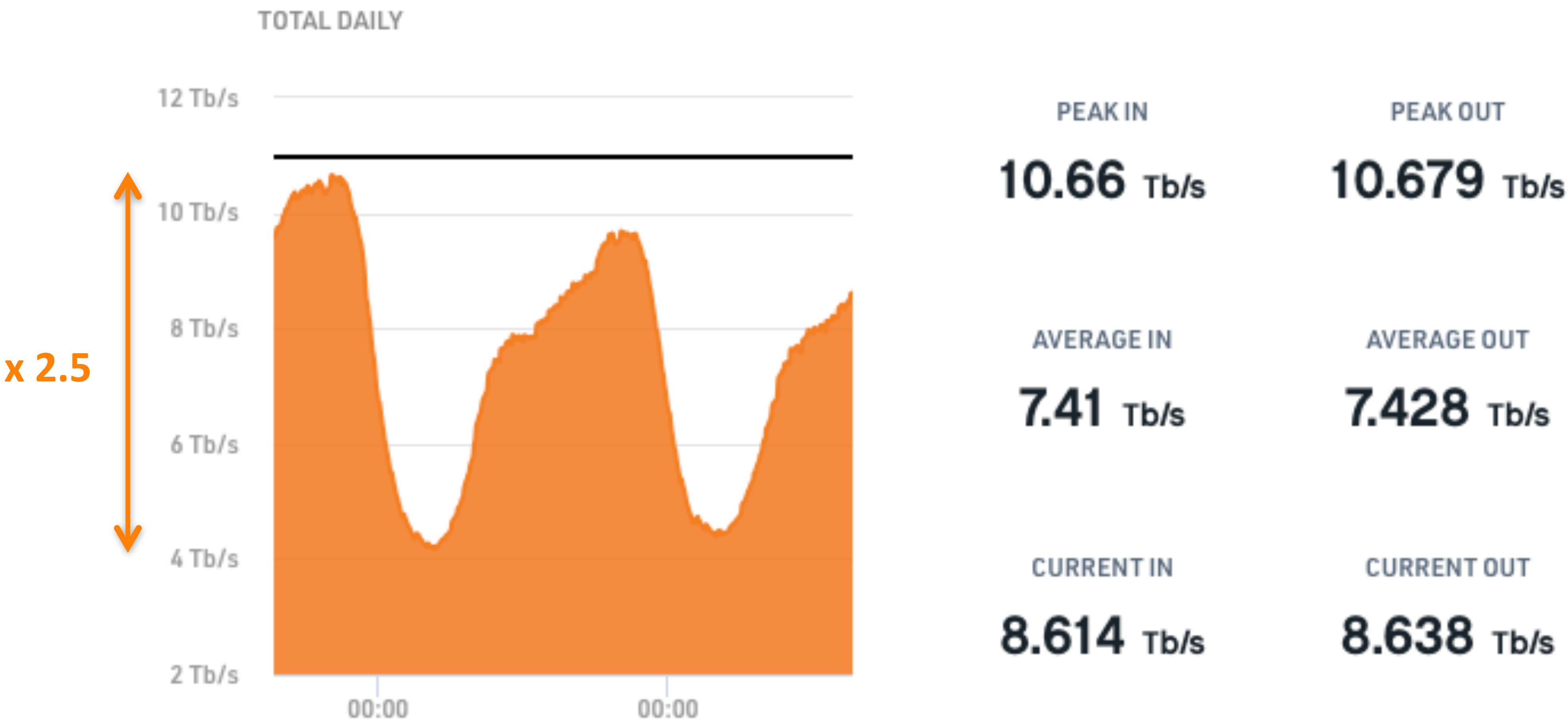



(b) CDN servers deployed within ISPs.

[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.]

# Resource waste in networks

Networks are lightly of unevenly utilized

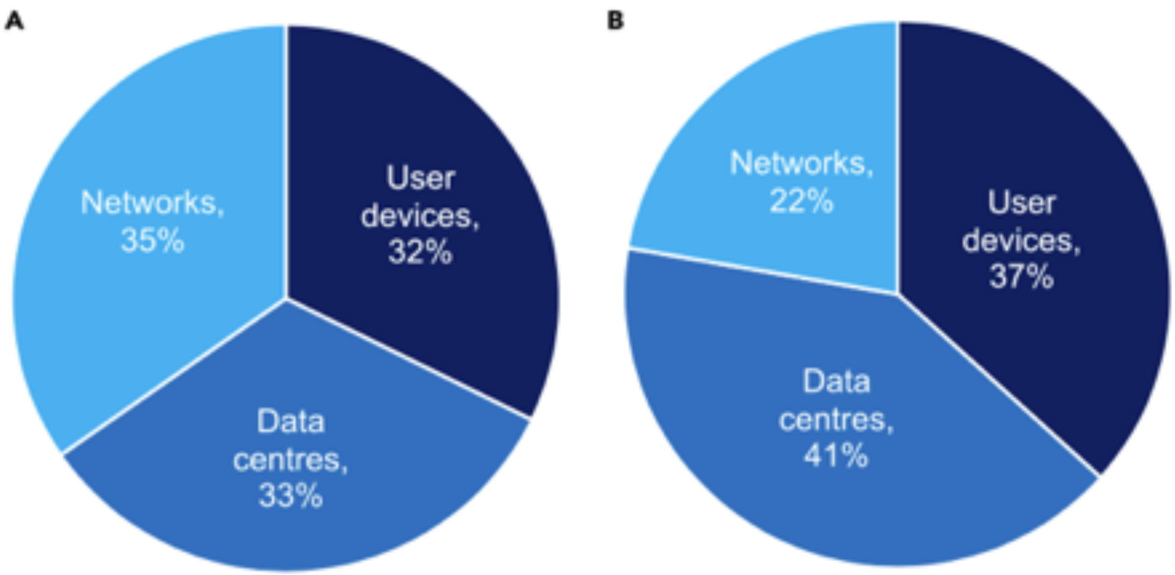



Daily aggregated traffic on AMS-IX(Amsterdam Internet eXchange Point), February 2022.

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

# Inside the cloud

# Distribution of ICT energy consumption

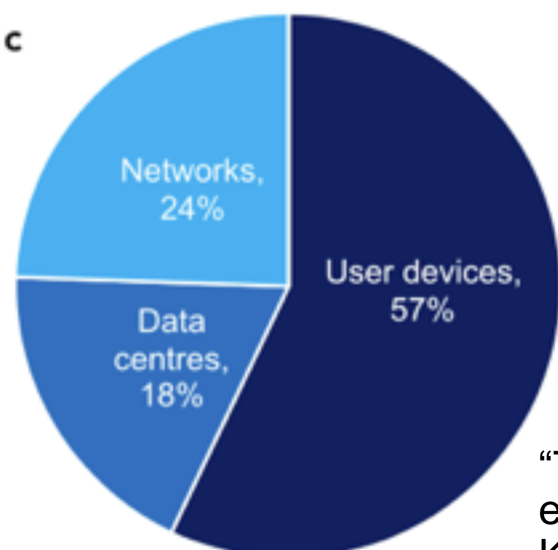



**Proportional breakdown of ICT's carbon footprint, excluding TV**

(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

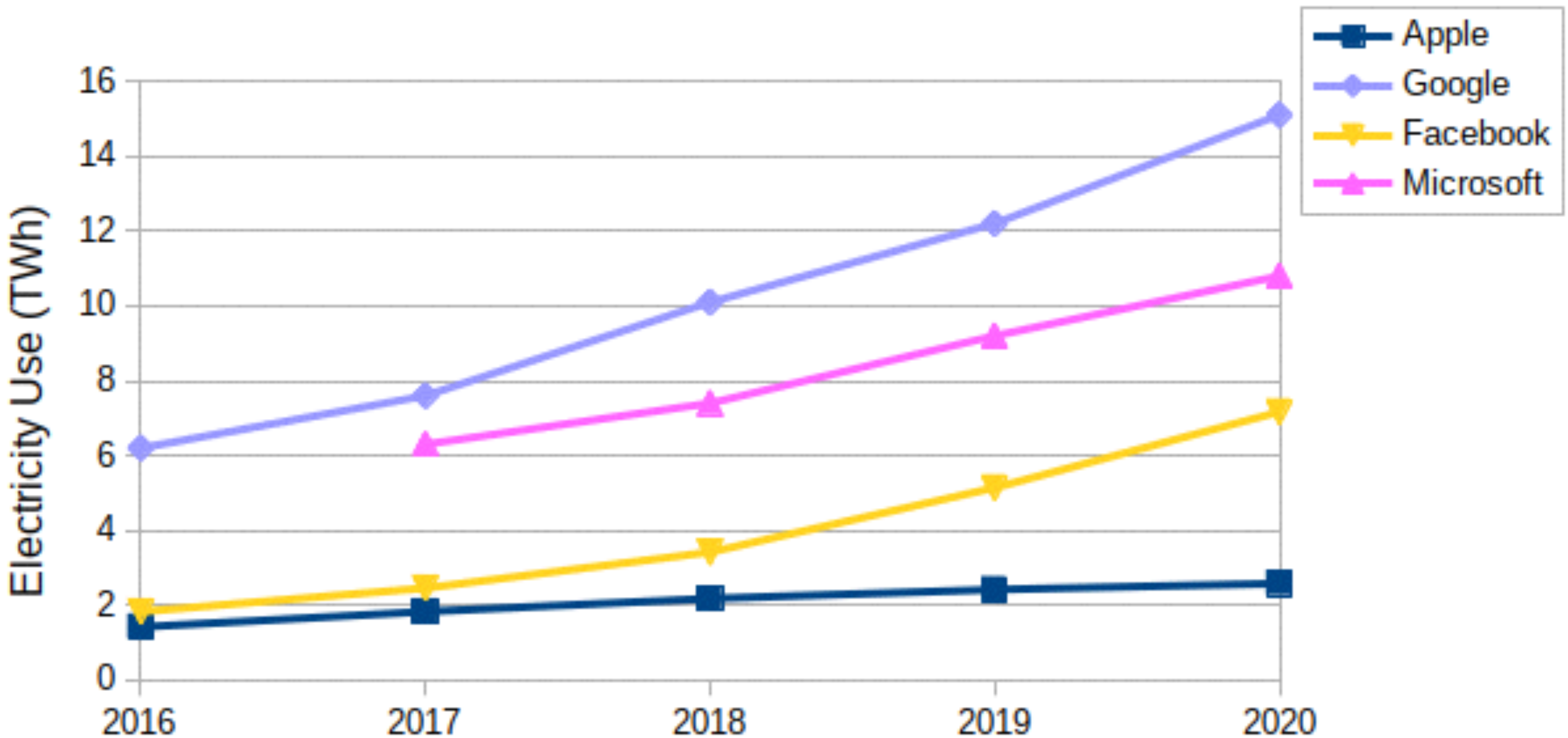



Figure: Anne-Laure Ligozat

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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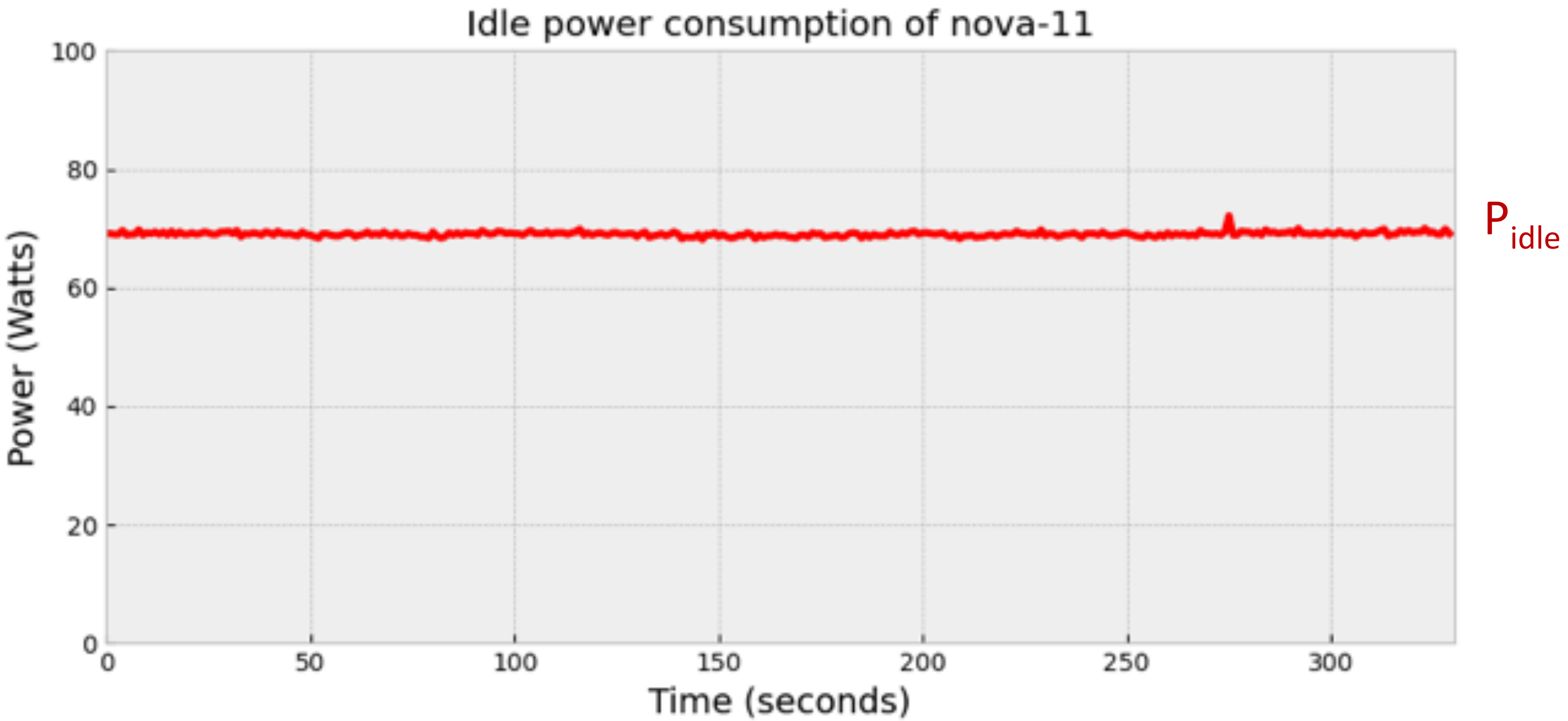
# Wrong idea #1

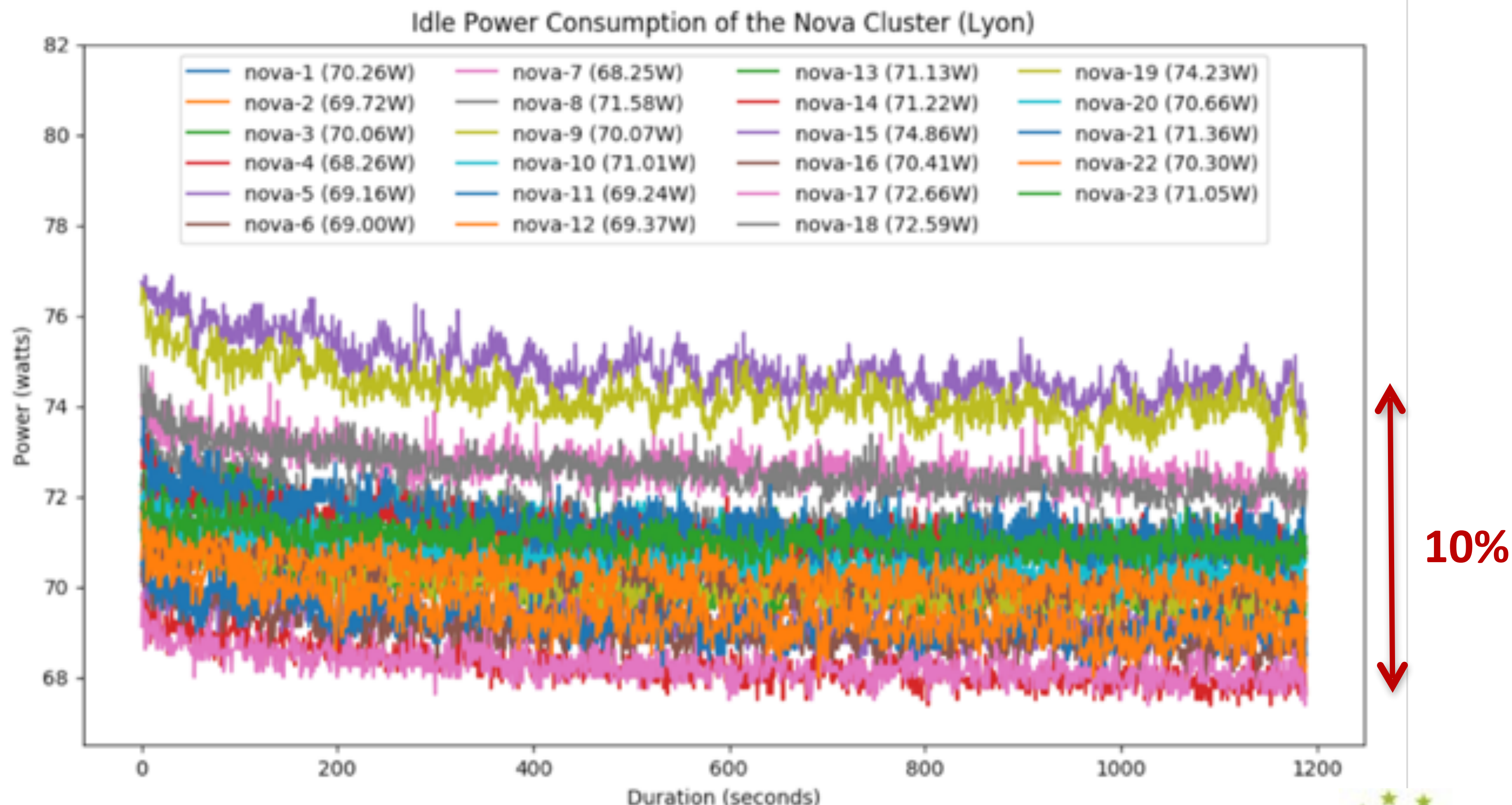
*Idle server consumes nothing or little.*




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

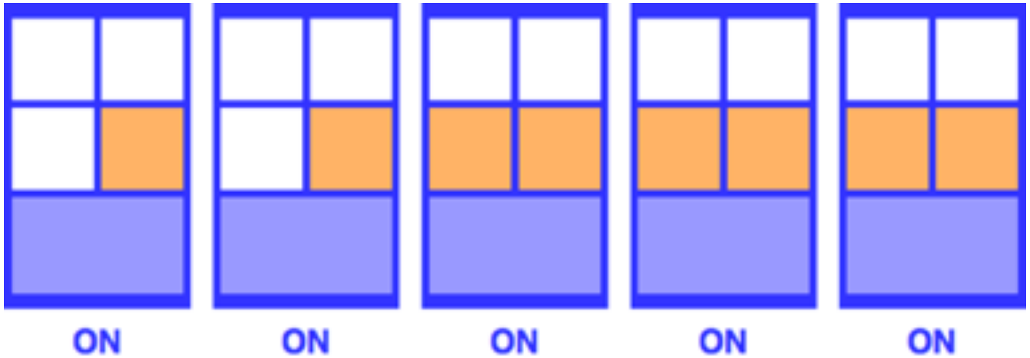
# Wrong idea #2

*This server model consumes that amount of power.*



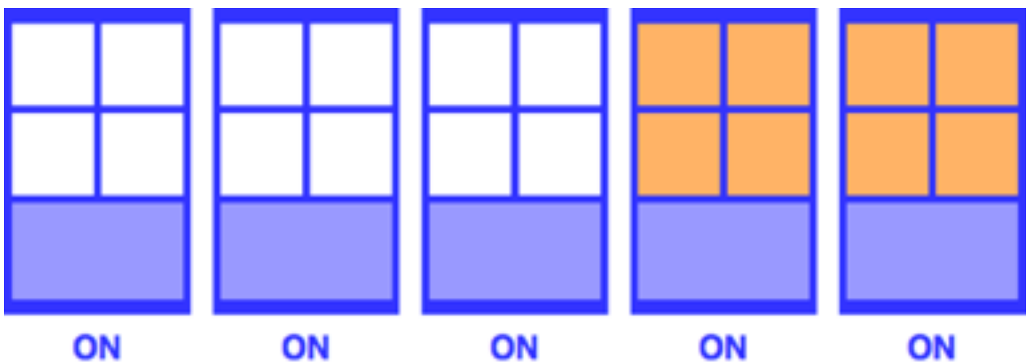

10% difference in idle and more at maximal consumption.

# No chance for naive modeling




Naive model:

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




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

*Best configuration for power consumption ?*

It depends.

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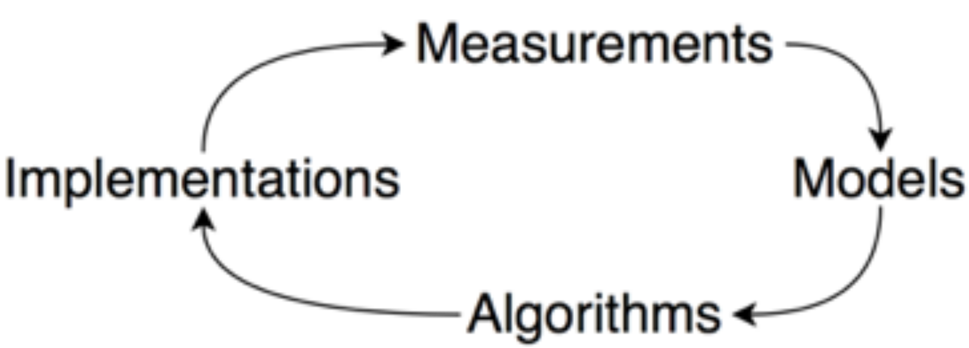
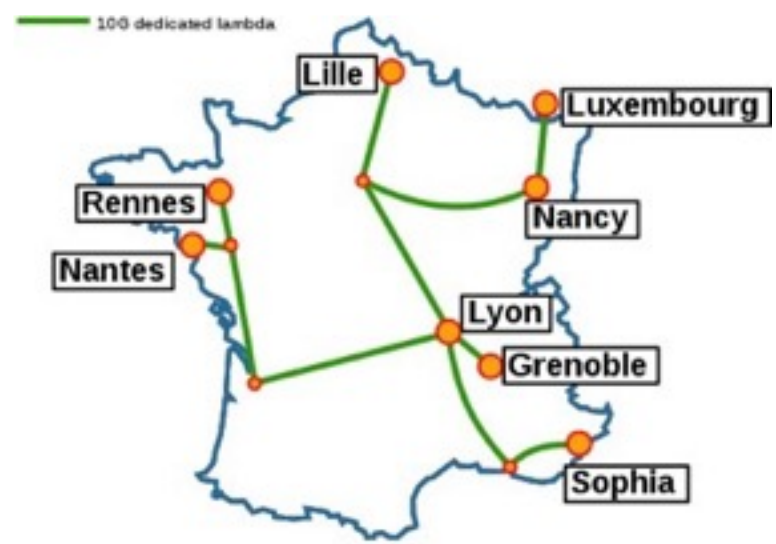
# Energy consumption: a complex phenomenon

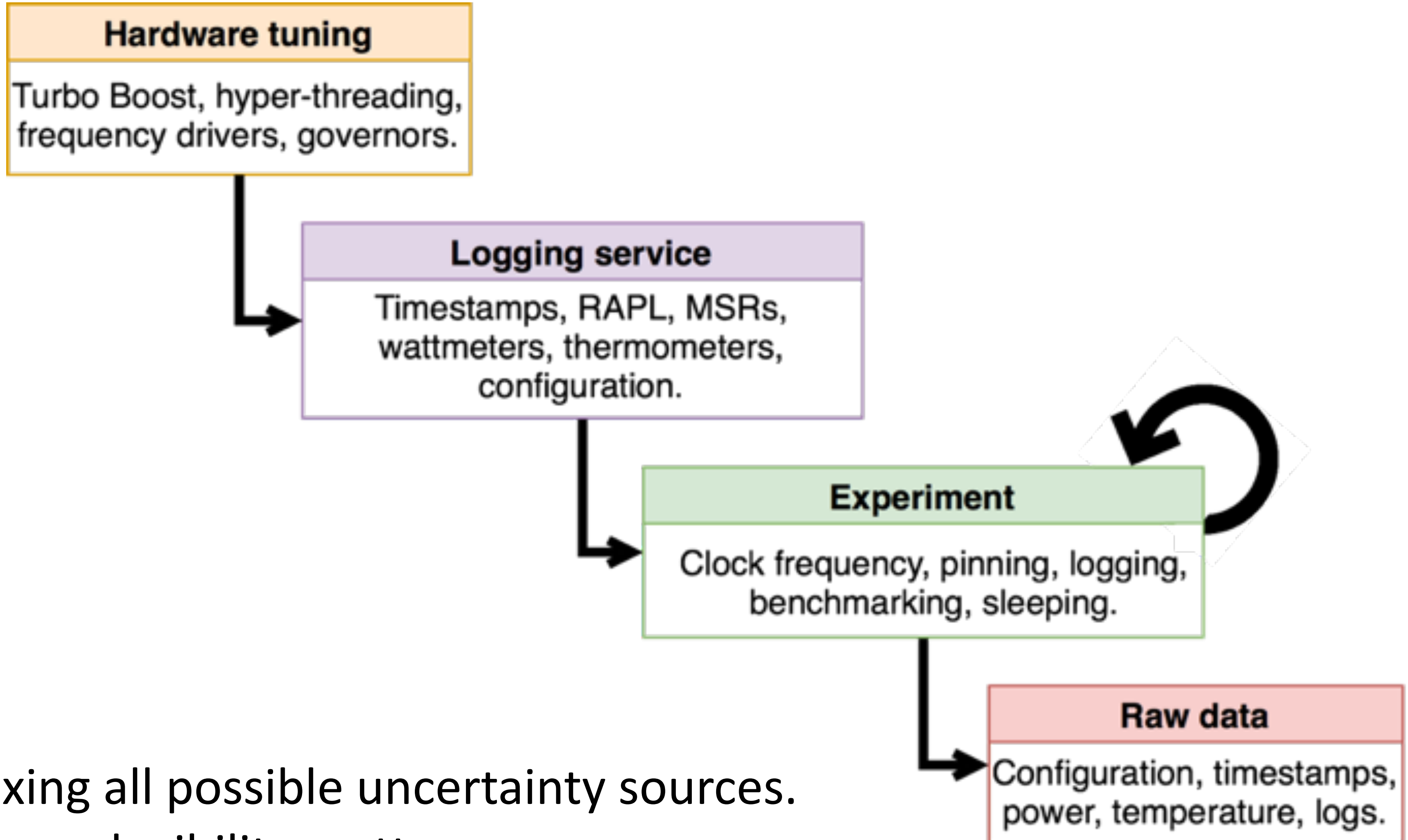
Need for **wattmeters** and sound experimental campaigns

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



# Second rule: pay attention to your experimental process



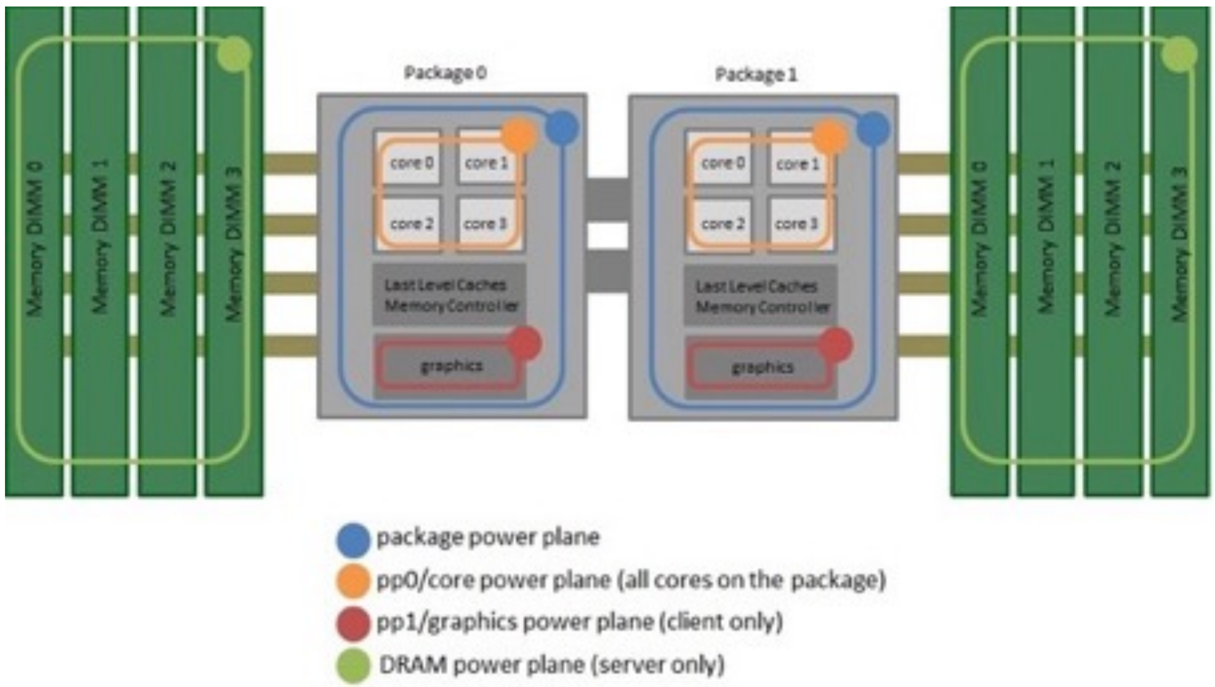

Fixing all possible uncertainty sources.

Reproducibility matters.

[ISCC 2021]

# Performing measurements

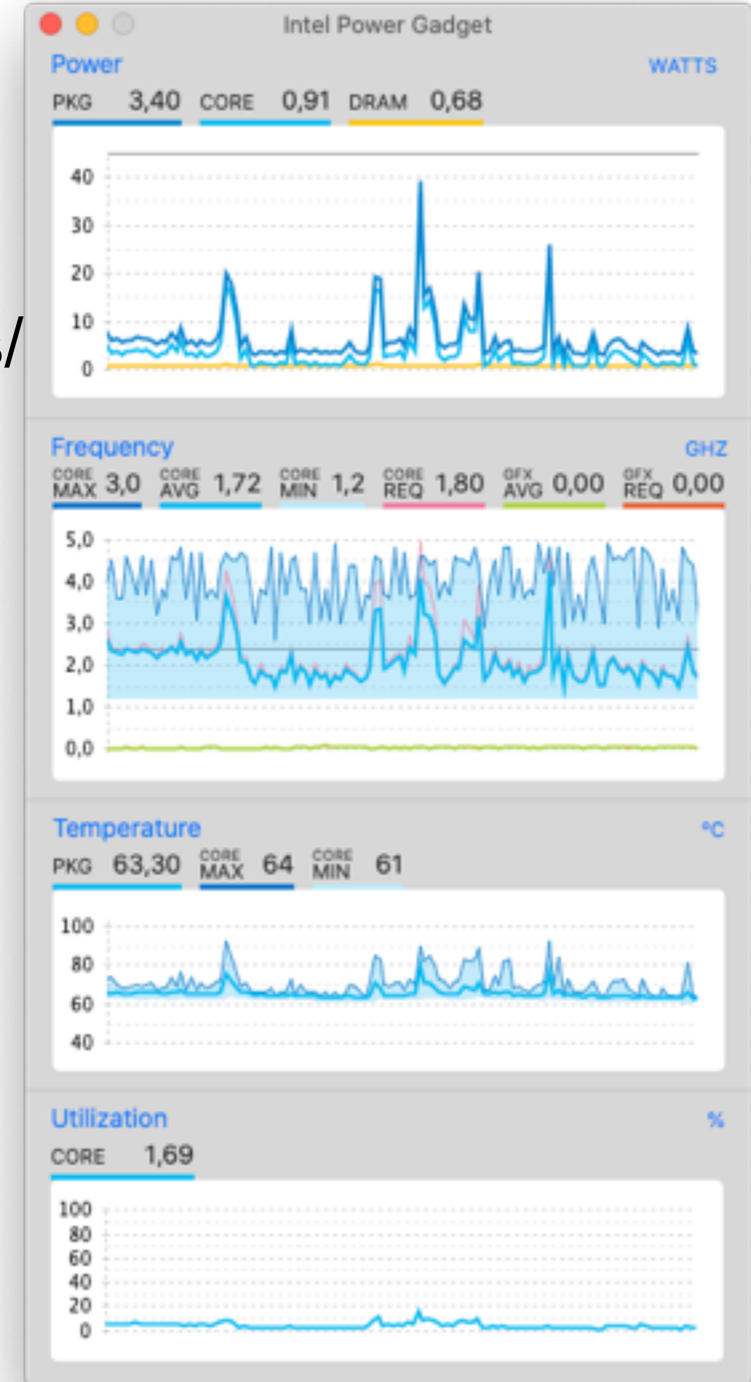
Intel's RAPL (Running Average Power Limit) interface



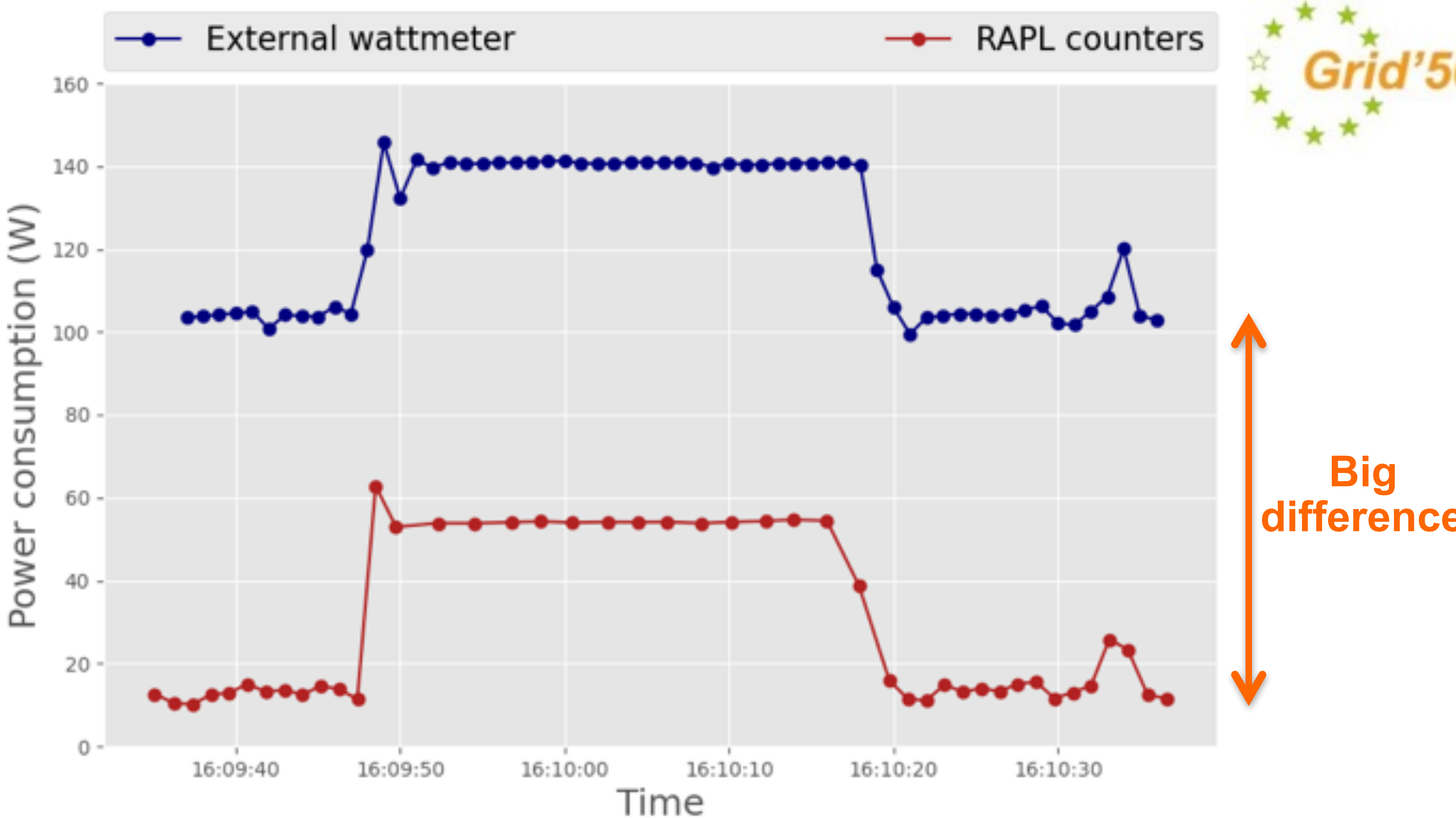

```
Energy measurements:
PACKAGE_ENERGY:PACKAGE0    176.450363J   (Average Power 42.9W)
PACKAGE_ENERGY:PACKAGE1     75.812454J   (Average Power 18.4W)
DRAM_ENERGY:PACKAGE0        11.899246J   (Average Power 2.9W)
DRAM_ENERGY:PACKAGE1         8.341141J   (Average Power 2.0W)
PP0_ENERGY:PACKAGE0      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

# Intel Power Gadget

https://software.intel.com/en-us/articles/intel-power-gadget-20



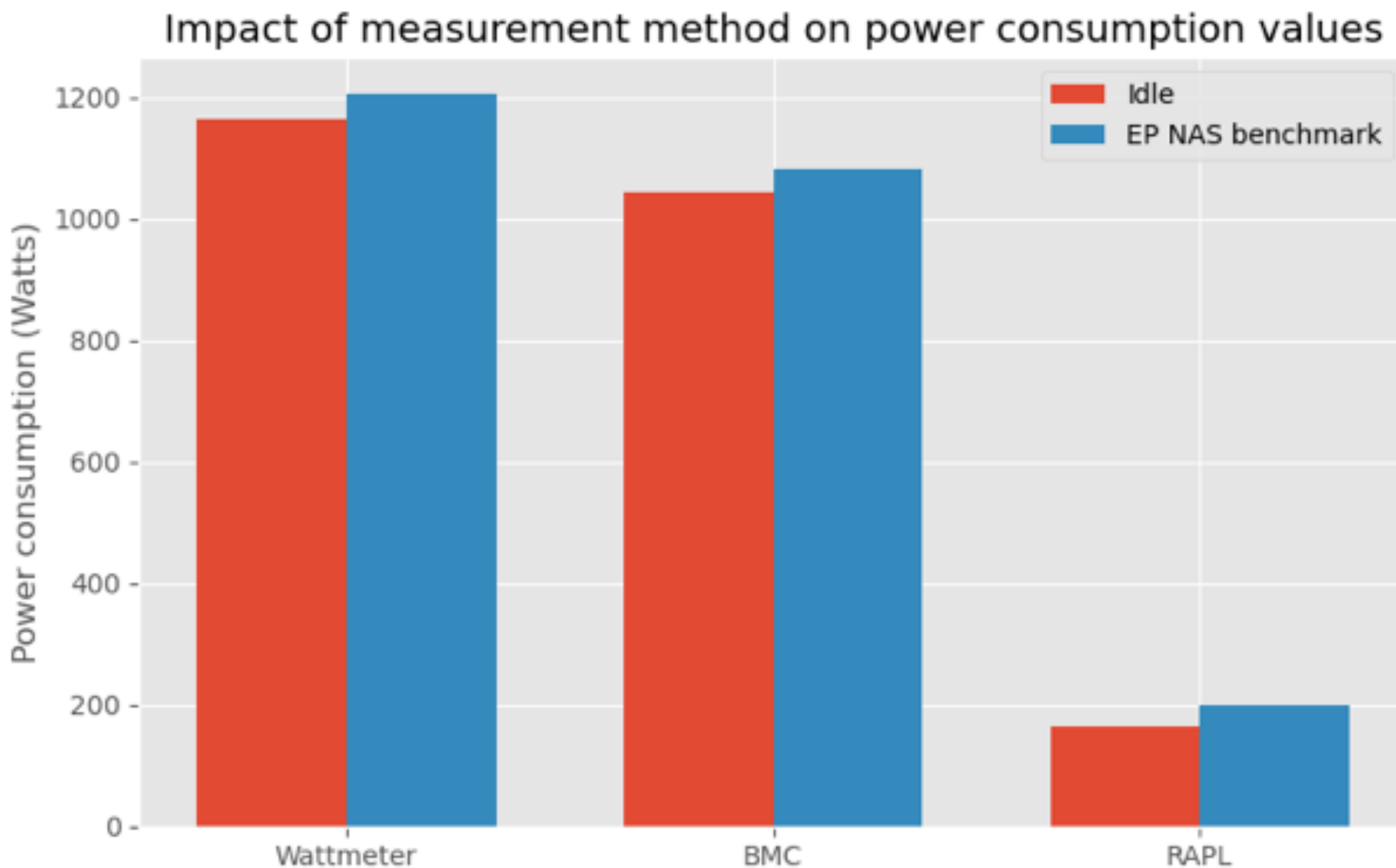
# Knowing what you measure




Power consumption of Taurus-12

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

# Wattmeter vs. BMC vs. RAPL

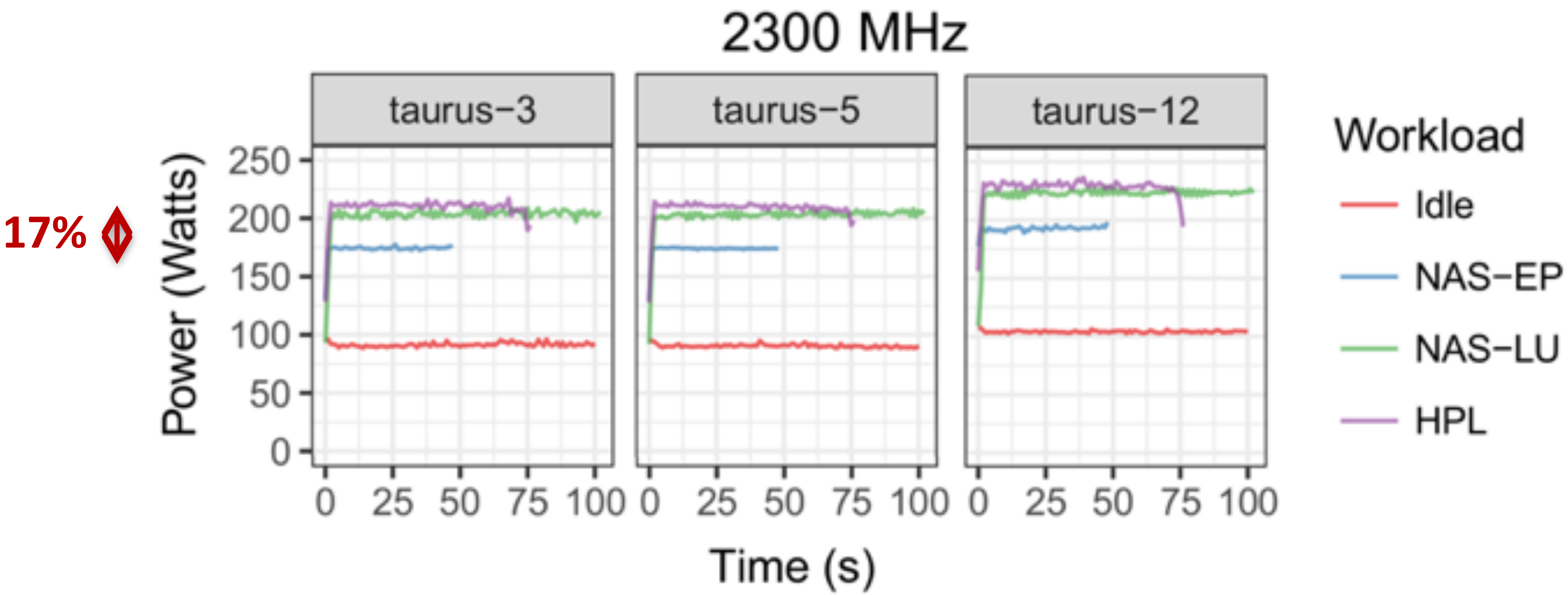



Gemini node: 2 x Intel Xeon E5-2698 v4, 20 cores/CPU, 512 GiB RAM, 480 GB SSD, 8 x Nvidia Tesla V100 (2019)

[CCGrid 2023]

# Wrong idea #3

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



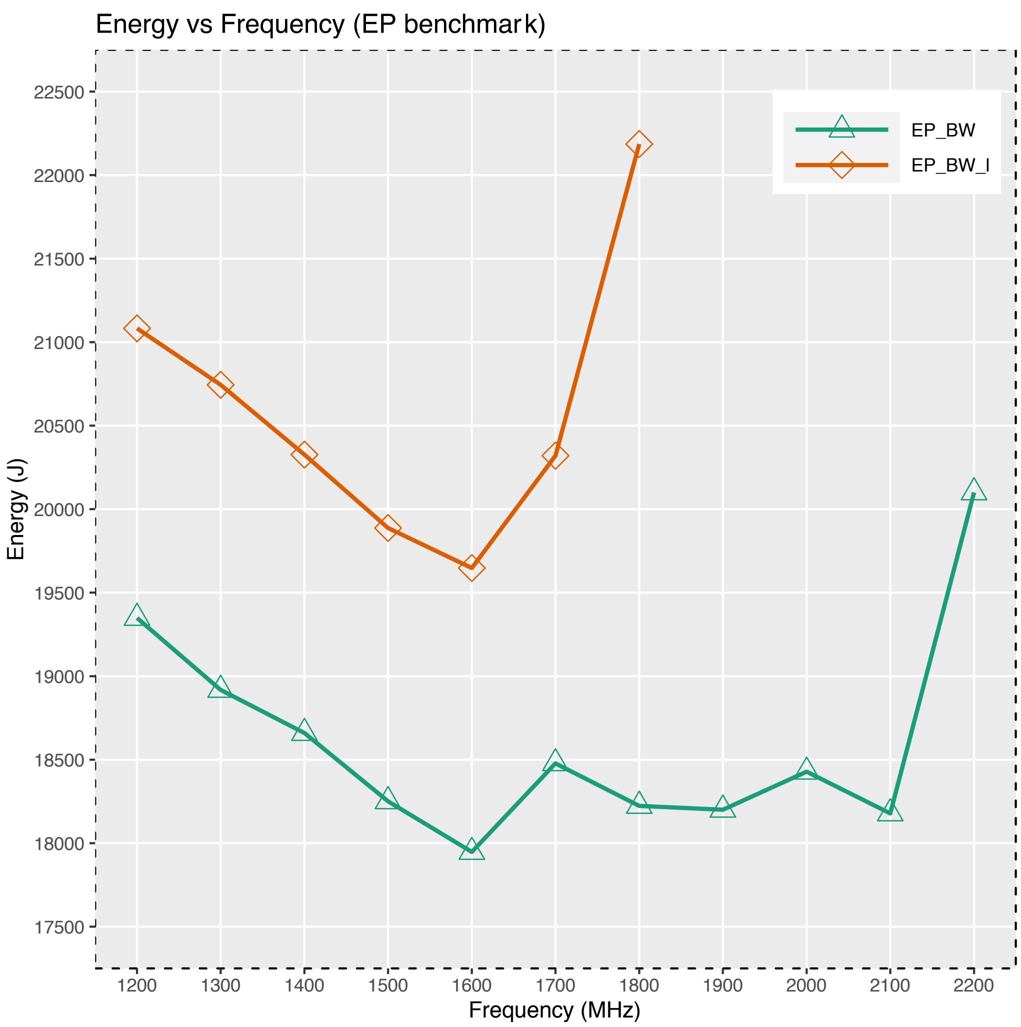

[Cluster 2017]

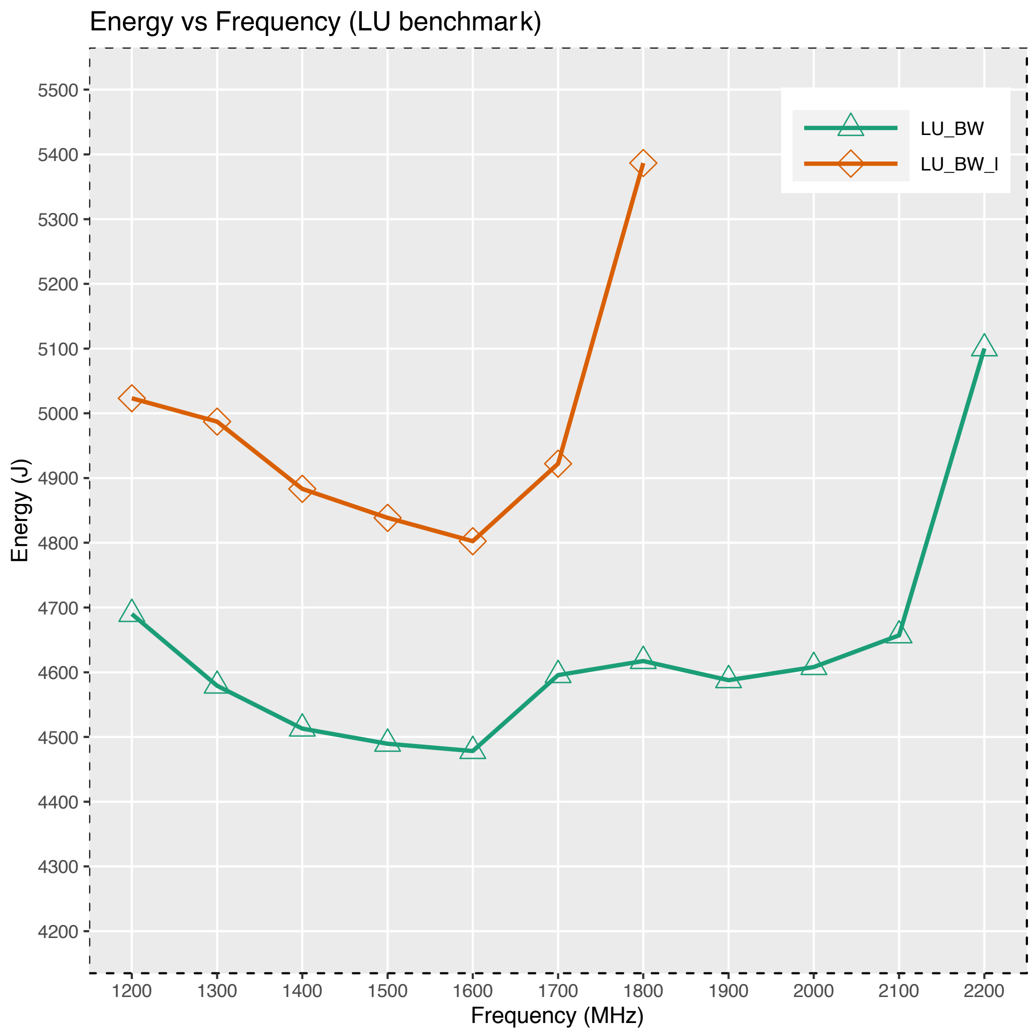
Taurus node: 2 x Intel Xeon E5-2630, 6 cores/CPU, 32 GiB RAM, 300 GB HDD (2012)

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

# Wrong idea #4

*Low power processors consume less energy.*



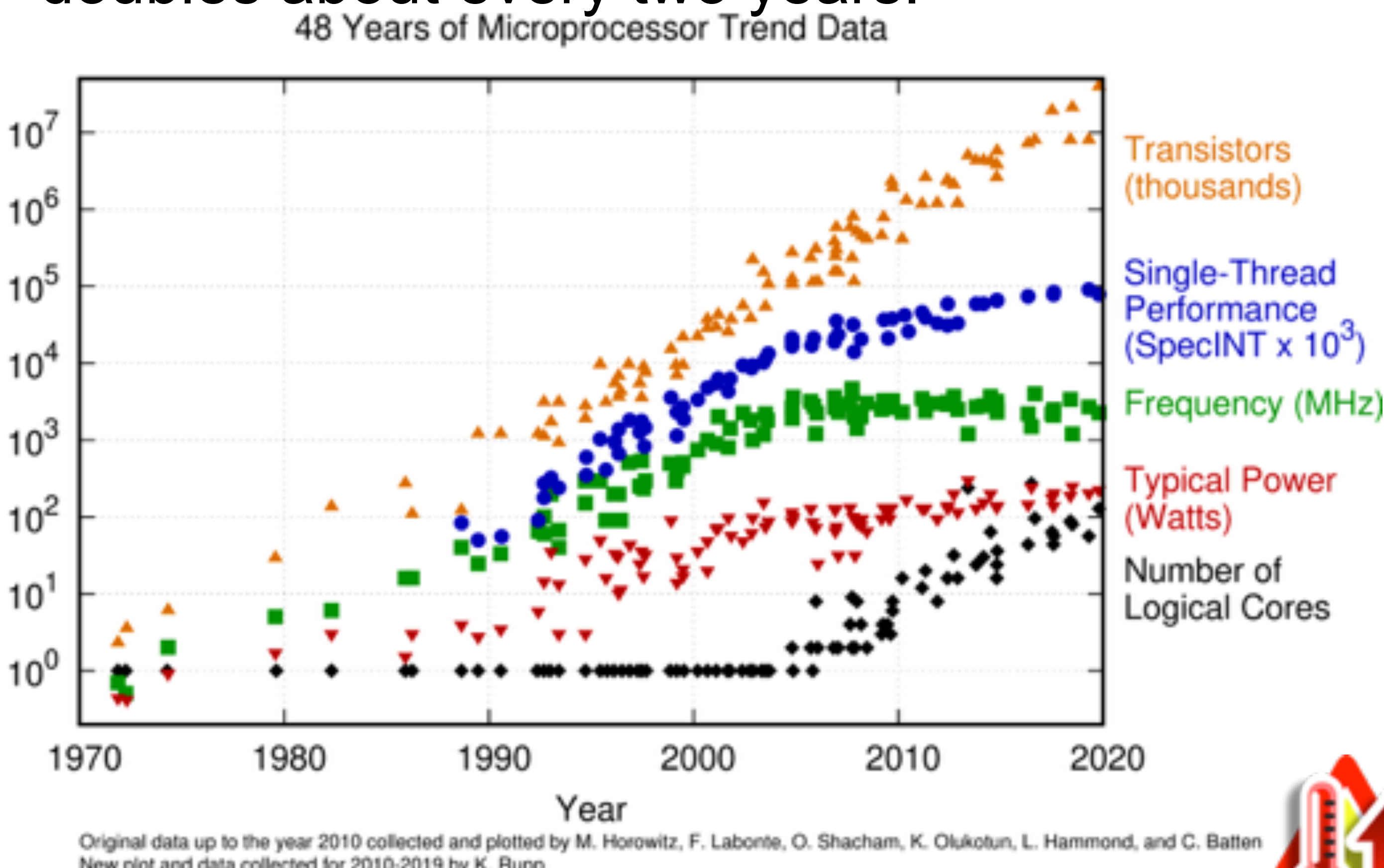

BW_l: Xeon E5-2630L v4 (Broadwell) -> low power processor (orange)
BW: Xeon E5-2630 v4 (Broadwell) (green)

[ISCC 2021]

# Wrong idea #5 (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

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

Physical limits.

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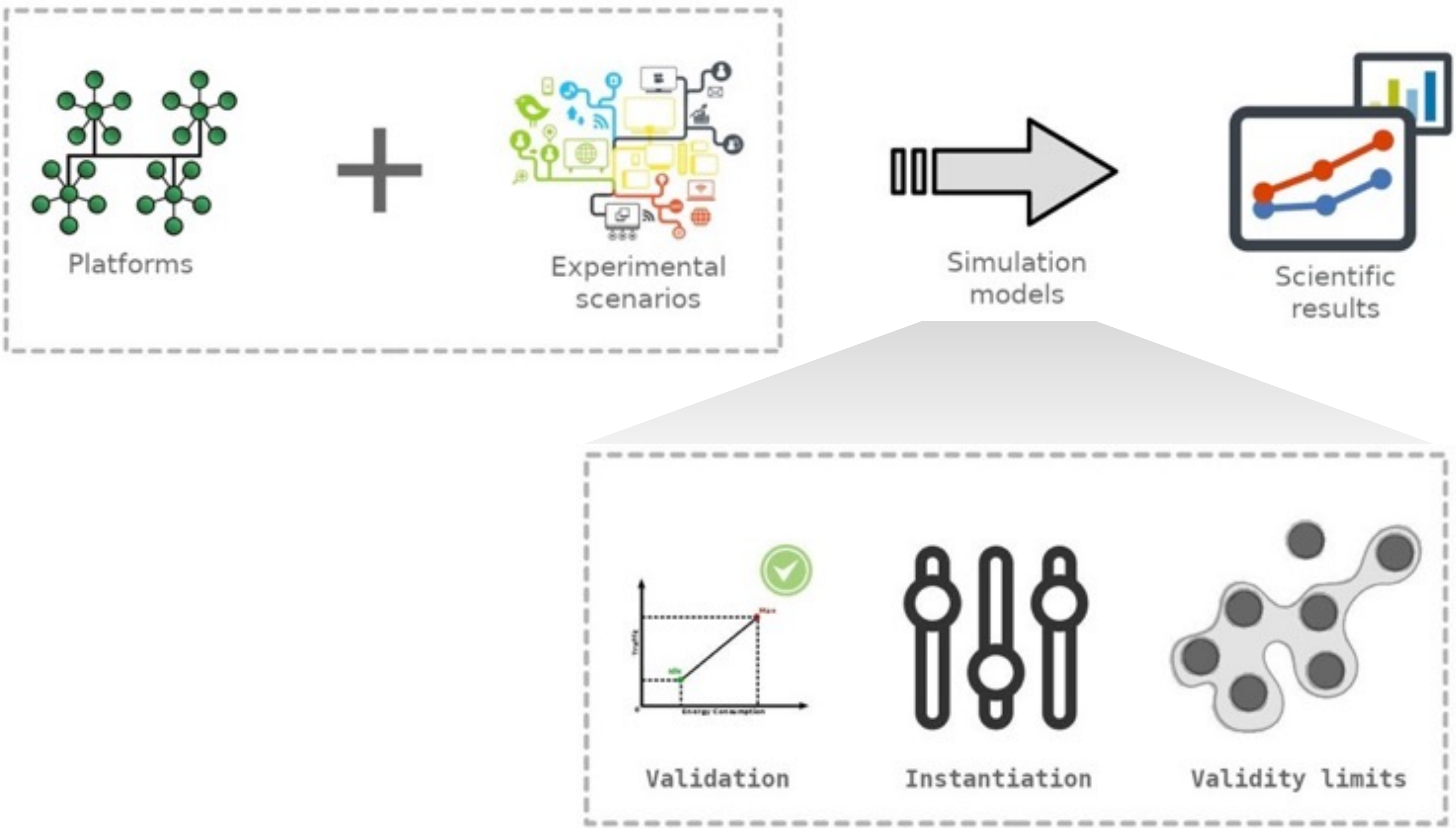
# Simulating energy consumption



# Models and simulation tools for what?

Capacity and energy planing

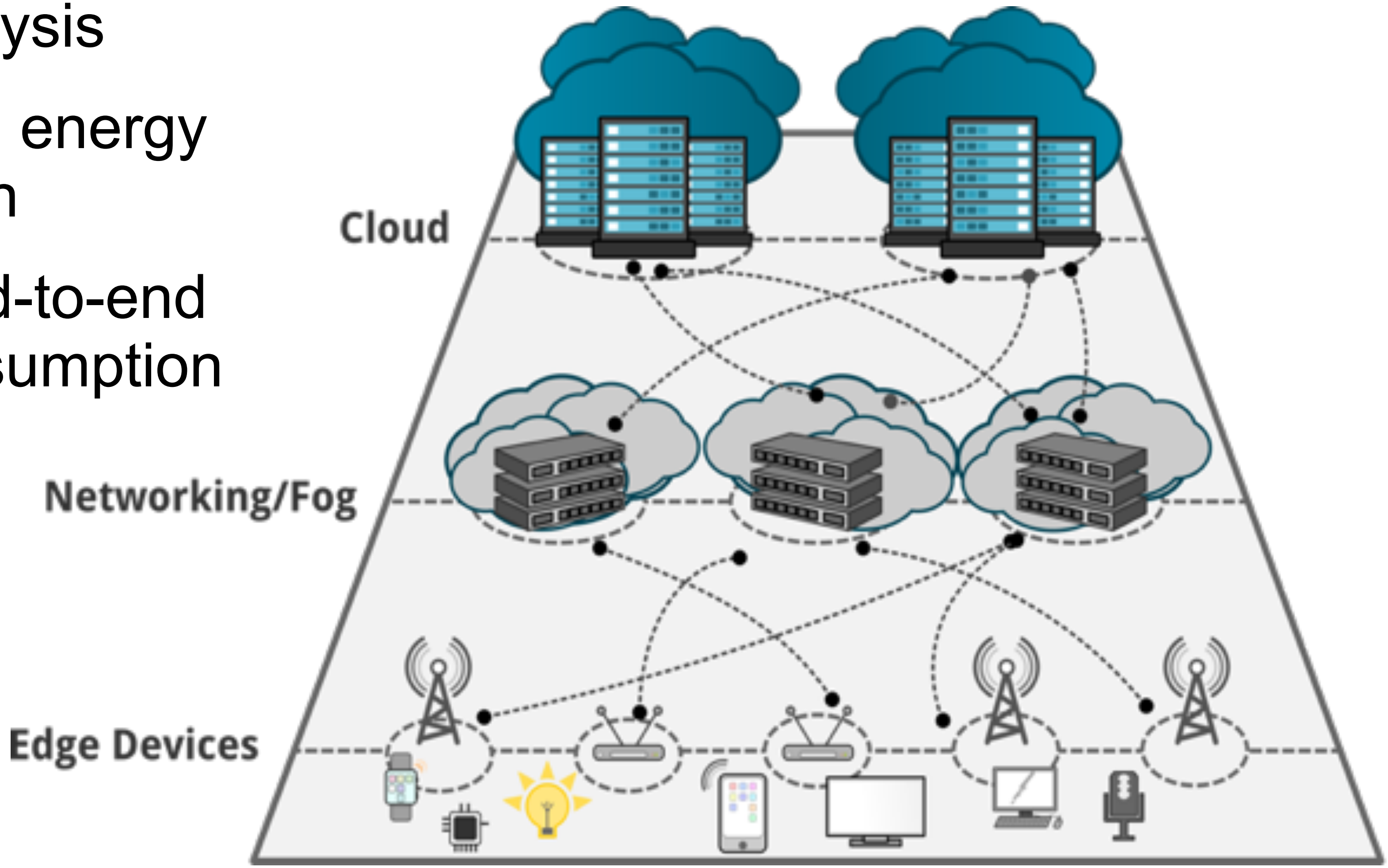
What-if scenarios

Algorithm analysis

Estimating VM energy consumption

Estimating end-to-end energy consumption

Closing doors



# Power consumption of IoT

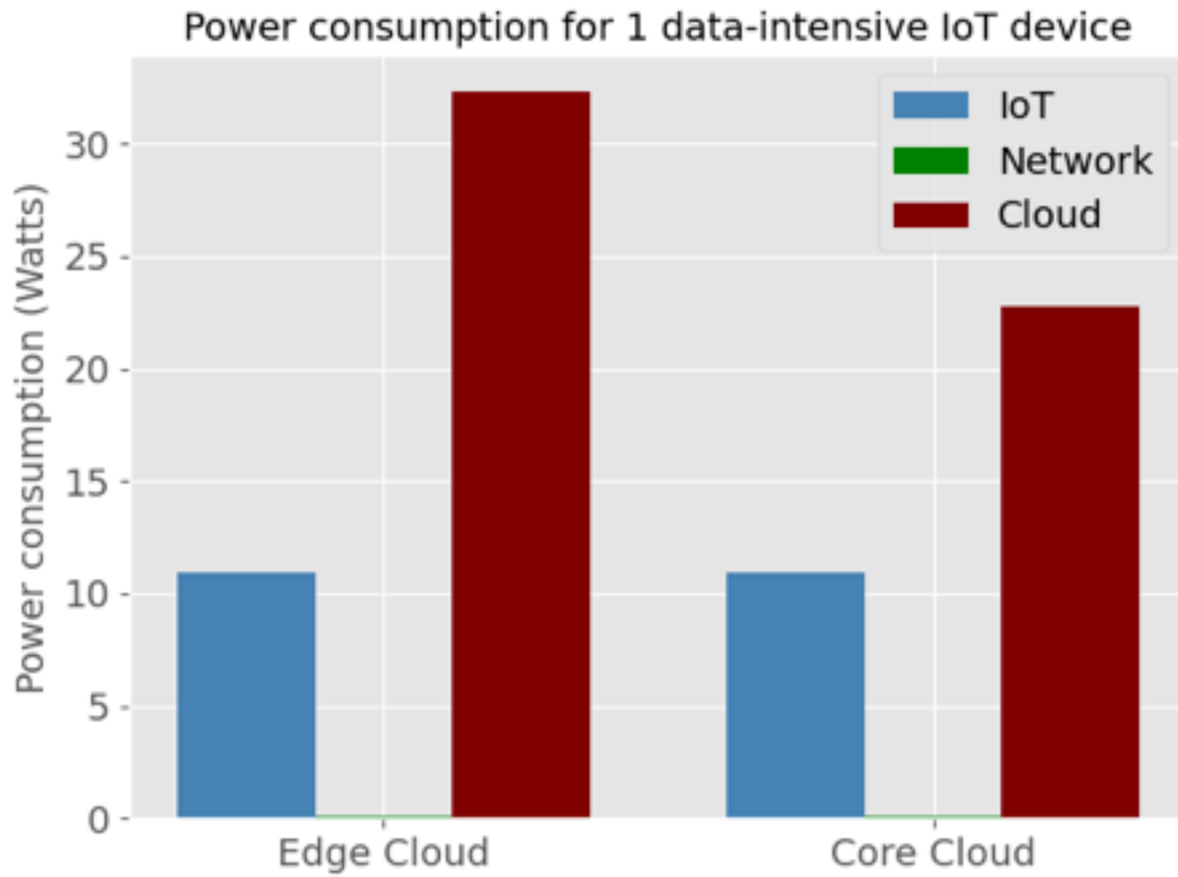

THE STATE UNIVERSITY OF NEW JERSEY RUTGERS

[FGCS 2018]

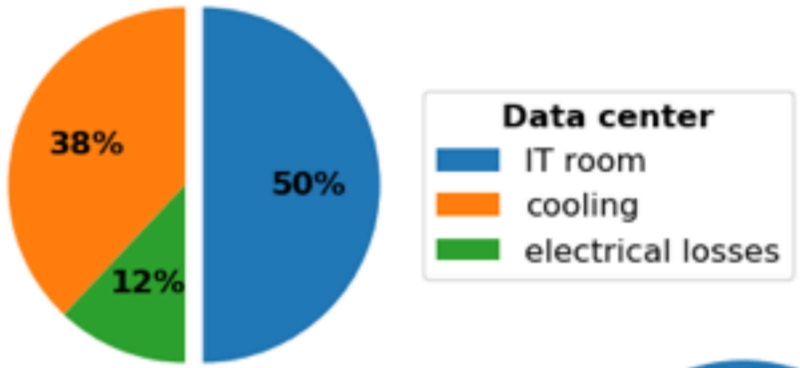
**Tradeoff** between:

- Performance
- Application accuracy
- Energy consumption

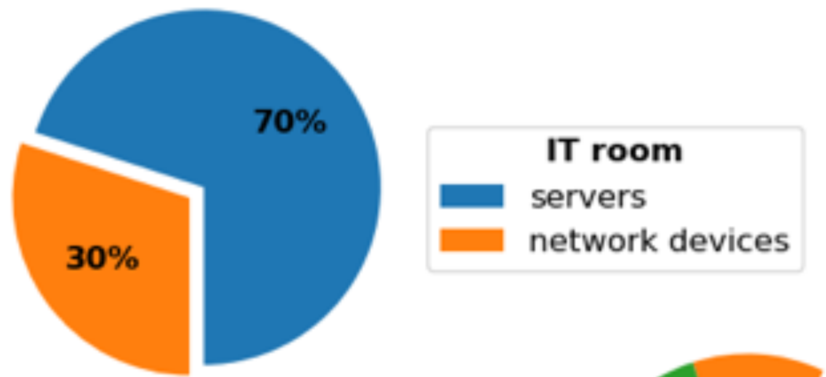
It depends.



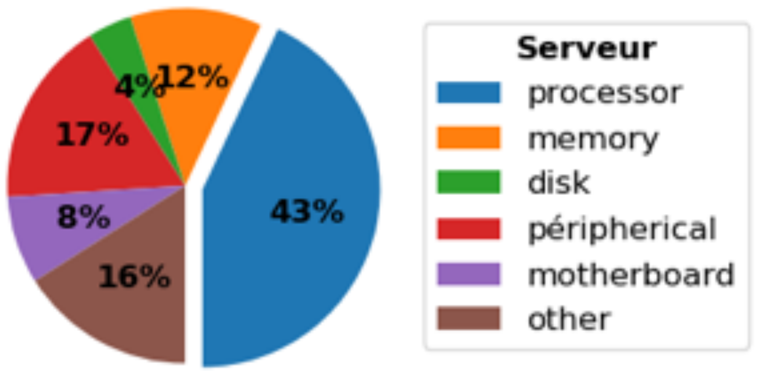
# Wasted energy at all levels of data centers




Cooling
Power generators
Batteries
…

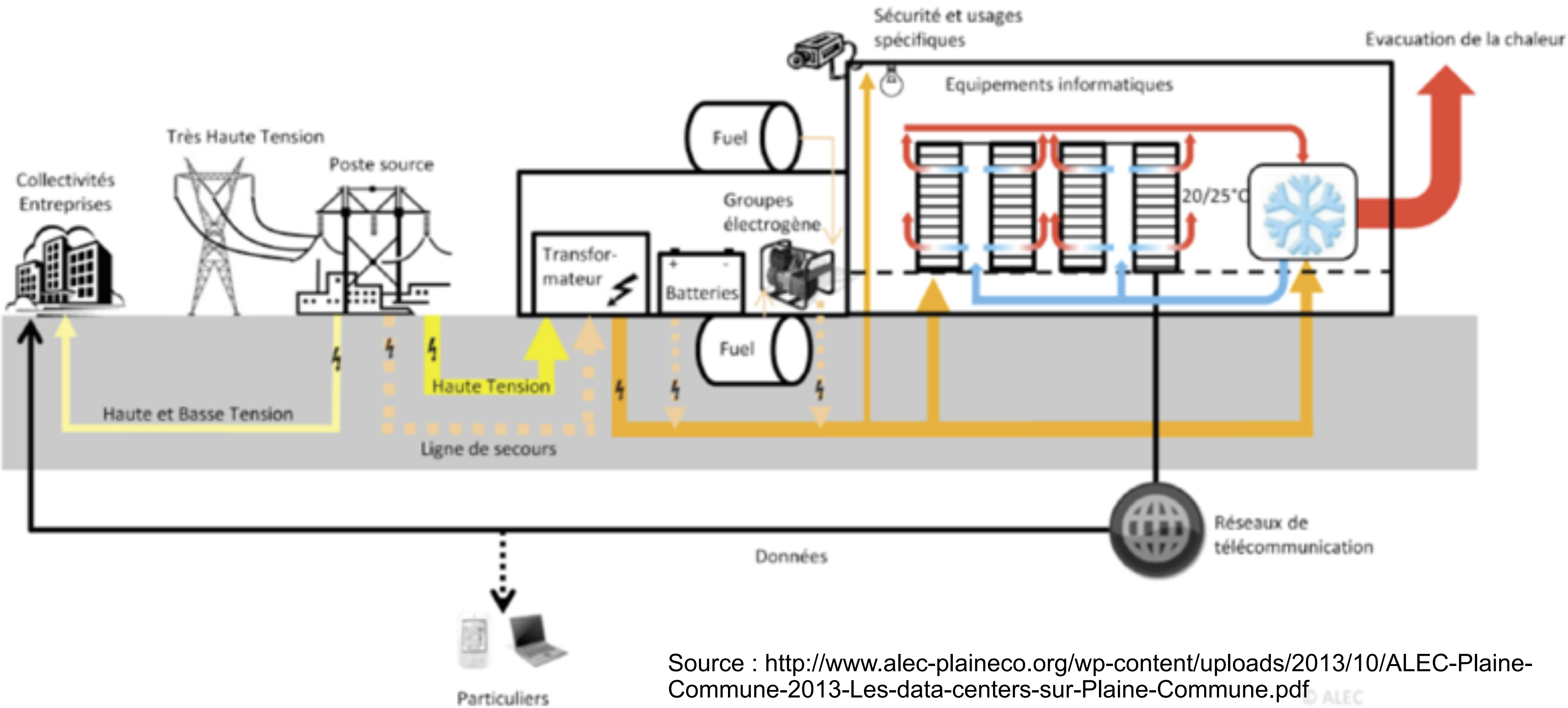



Unused servers
Overprovisioning
Redundancy
…




Power non-proportionality
Dark silicon
Unused components
…

# Overall data center view

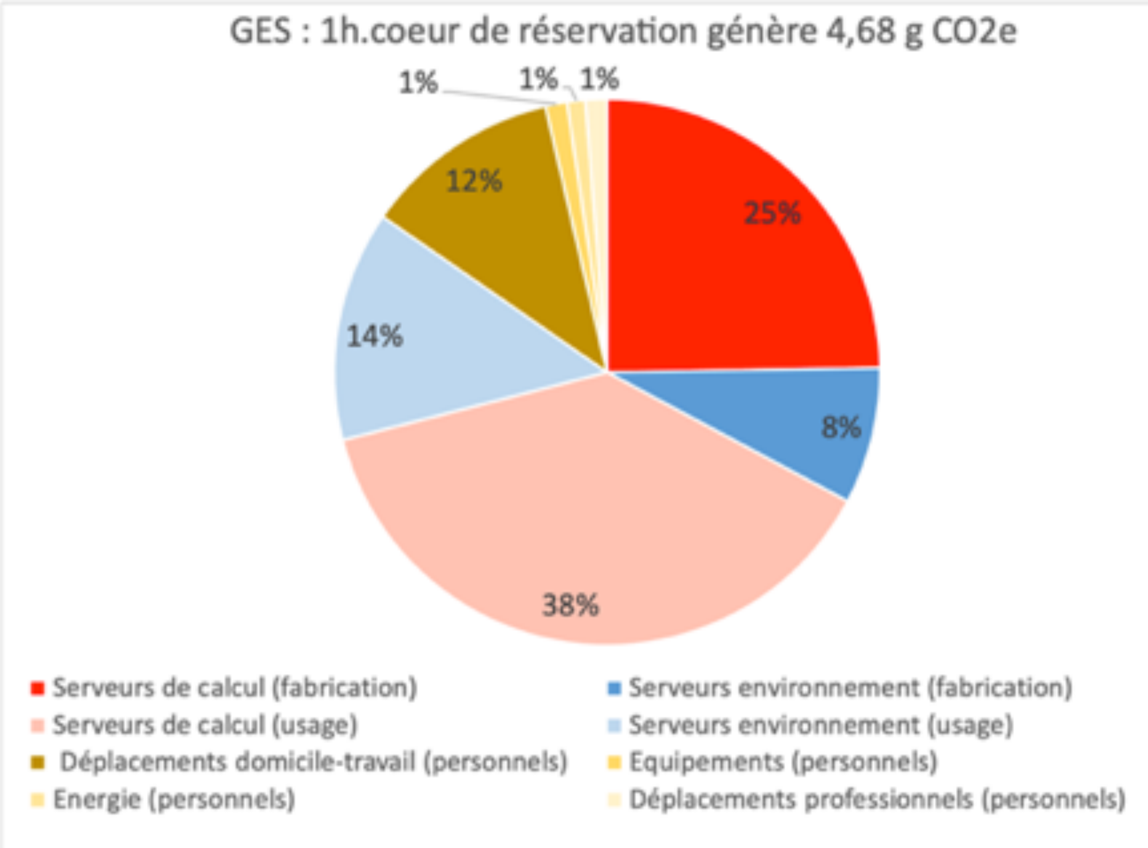



Source : http://www.alec-plaineco.org/wp-content/uploads/2013/10/ALEC-Plaine-Commune-2013-Les-data-centers-sur-Plaine-Commune.pdf

# Carbon footprint of a data center?

- Electricity use (including cooling)
  - → *Monitoring of the whole infrastructure*
- Embodied energy for manufacturing components
  - → Exhaustive inventory
  - → Ecodiag for ICT devices: https://ecoinfo.cnrs.fr/ecodiag-calcul/
- End of life of ICT devices?
- Carbon footprint of the building?
- Maintenance (including transport)?
- Technical staff (including devices and commuting)
- *Allocation model for functional unit*

# Example:1 hour.core on a data center




[Source : "Estimation de l'empreinte carbone d'une heure.coeur de calcul", F. Berthoud, B. Bzeznik, N. Gibelin, M. Laurens, C. Bonamy, M. Morel, X. Schwindenhammer, rapport, 2020]

**1 h.core** → 4.68 g $CO_2$eq

- 15% for technical staff (including commuting)
- 85% (3.97 g $CO_2$eq) for equipment (of which 40% for manufacturing despite a 7-year lifetime for servers)

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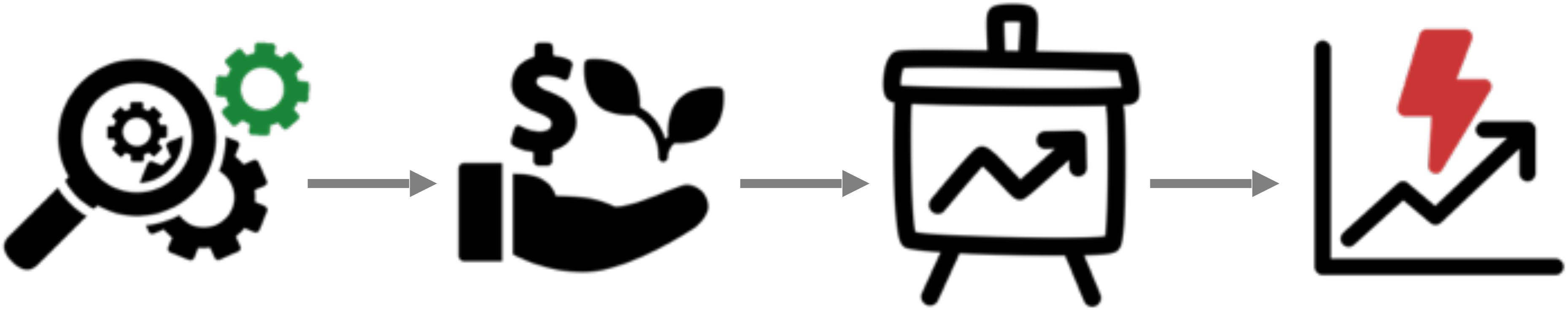
# ICT for Green ≠ Green ICT

- **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
  - 3 ways: measurement, efficiency, sobriety

# Increasing energy efficiency ≠ reducing consumption



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

Underlying trends:

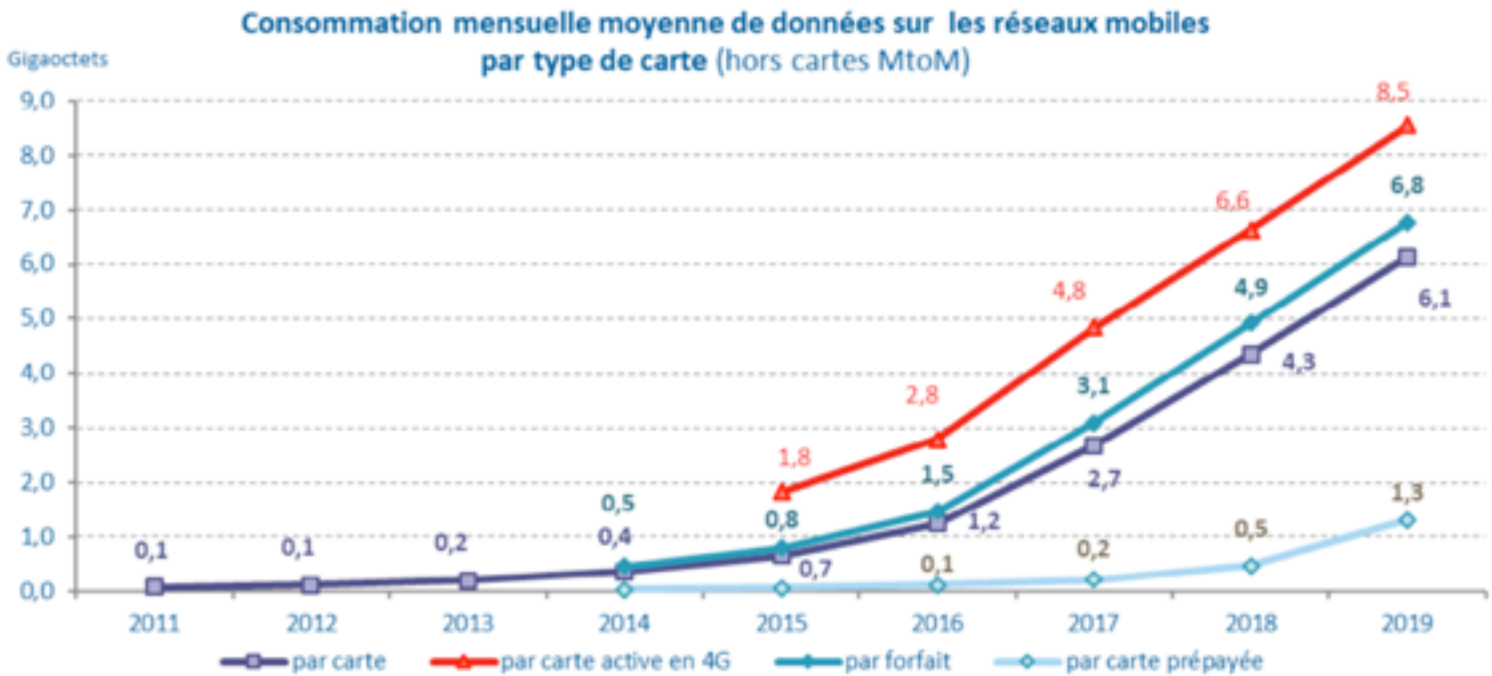
- Acceleration of equipment renewal rate
- Explosion of uses and consumption of data
- Digitization of all sectors, without prior study of environmental impacts

Beware of rebound effects!

# ICT impacts

- Direct effects at each stage of the life cycle
  - Extraction : pollution, destruction of ecosystems, armed conflicts, depletion of resources
  - Transport
  - Use : electricity mix
  - Waste : insufficient collection, limited reuse, limited recycling
- More or less positive indirect effects
  - Optimization of other sectors
  - Obsolescence
  - Rebound effects
  - Interdependence linked to ICT
  - Digital divide, health (myopia, addictions, etc.)

# More and more traffic




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

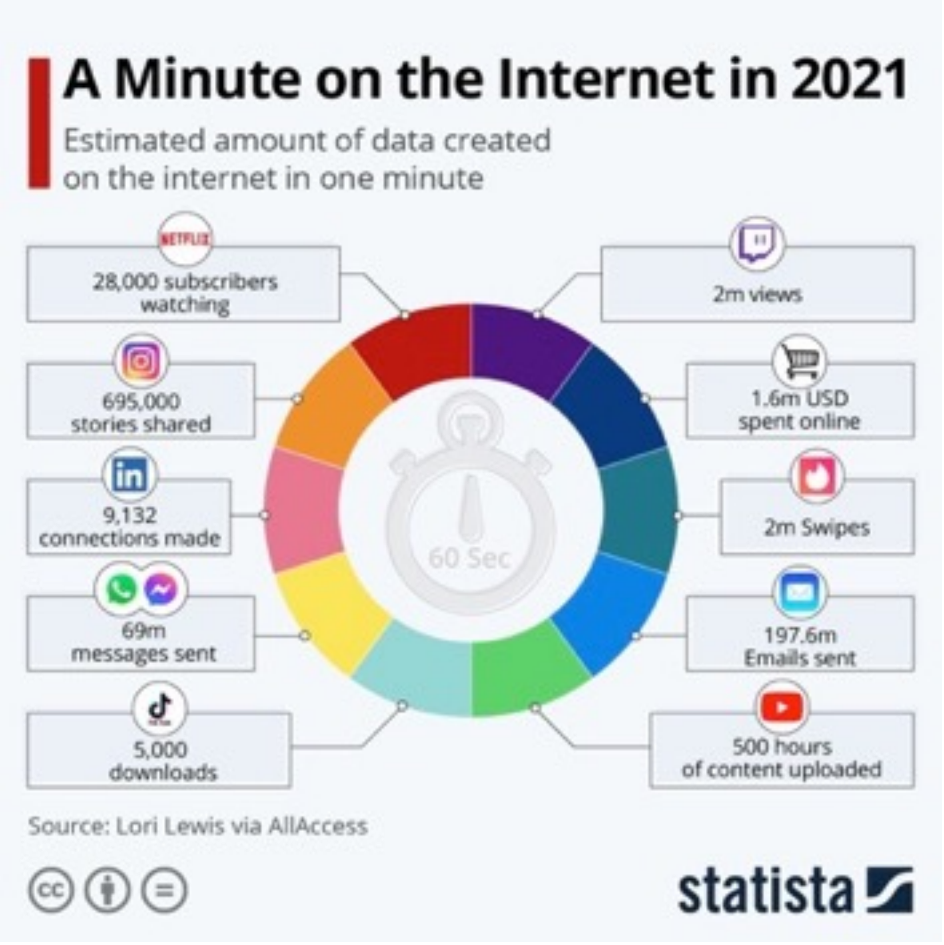
In Q4 2011 :

- 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)

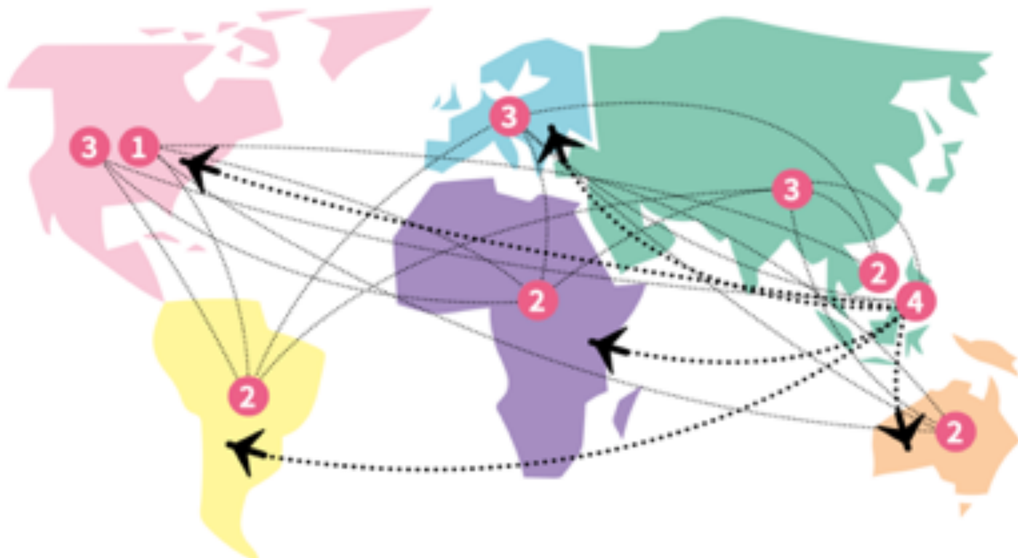
# Can we continue to design distributed systems …




***… without changing users' habits? And our habits?***

# Things more and more indispensable

**QUATRE TOURS DU MONDE POUR FABRIQUER UN SMARTPHONE**




1. **Conception** le plus souvent aux États-Unis

2. **Extraction et transformation des matières premières** en Asie du Sud-Est, en Australie, en Afrique centrale et en Amérique du Sud

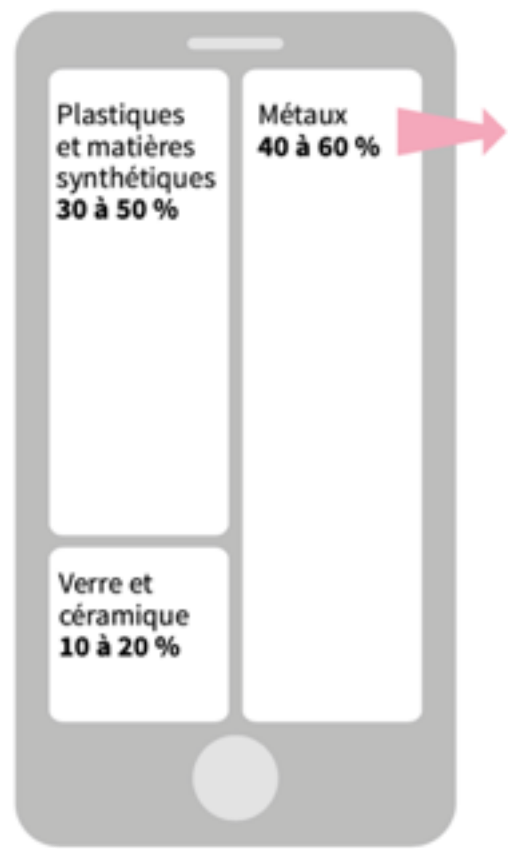
3. **Fabrication des principaux composants** en Asie, aux États-Unis et en Europe

4. **Assemblage** en Asie du Sud-Est

**Distribution** vers le reste du monde, souvent en avion.

**70 MATÉRIAUX POUR FABRIQUER UN SMARTPHONE**

**RÉPARTITION DU POIDS DES MATÉRIAUX DANS LA COMPOSITION D'UN SMARTPHONE**




**PROPORTION DES MÉTAUX**

**80 à 85 %** de métaux ferreux et non ferreux : cuivre, aluminium, zinc, étain, chrome, nickel…

**0,5 %** de métaux précieux : or, argent, platine, palladium…

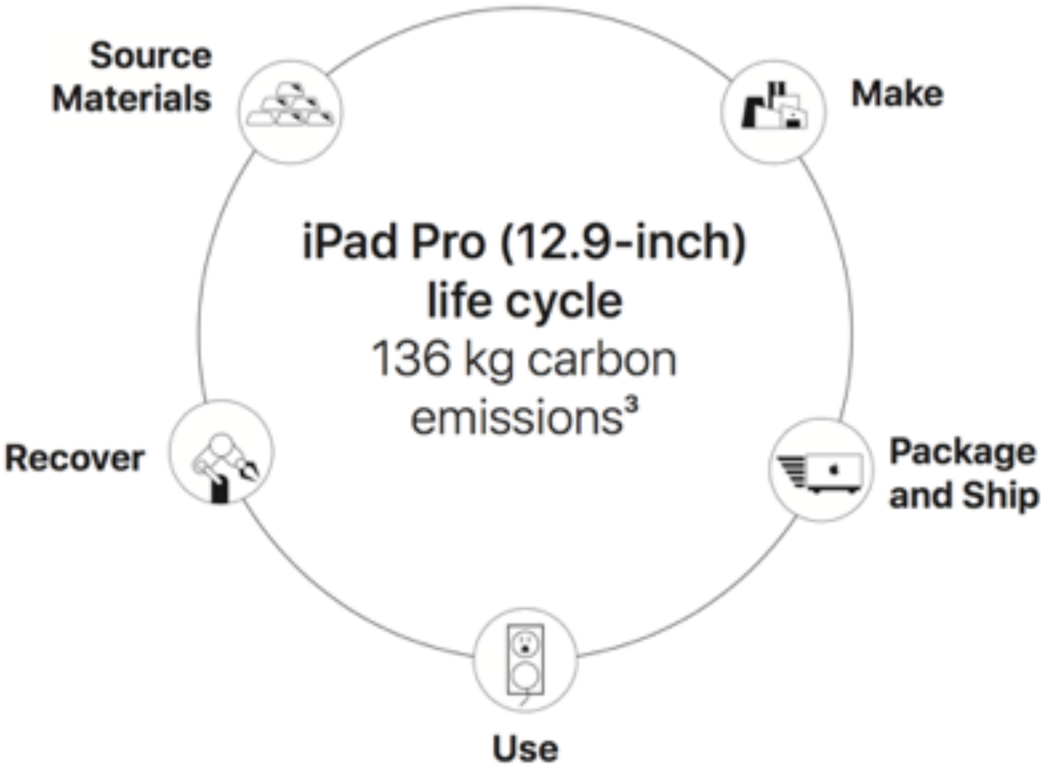
**0,1 %** de terres rares et métaux spéciaux : europium, yttrium, terbium, gallium, tungstène, indium, tantale…

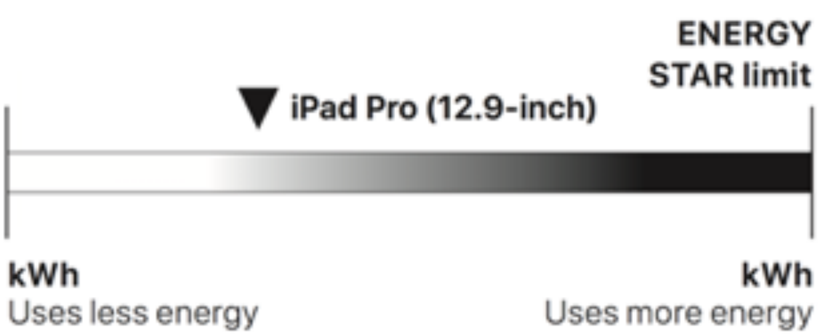
**15 à 20 %** d'autres substances : magnésium, carbone, cobalt, lithium…

Source : Oeko-Institut, EcoInfo et Sénat

“Les impacts du smartphone”, ADEME, 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*

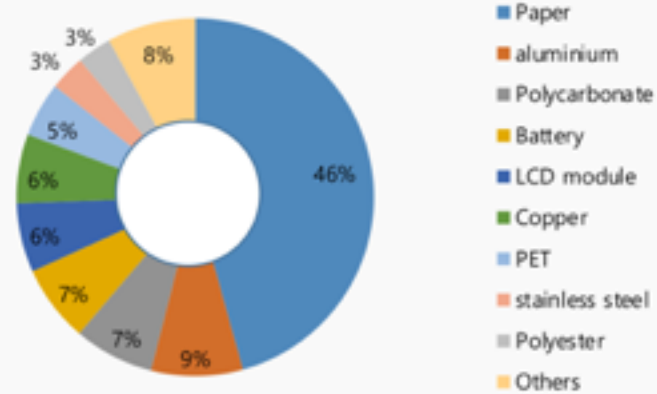
Source: Product environmental report, Apple, 2018.

# Numerous other environmental impacts

## Product Features

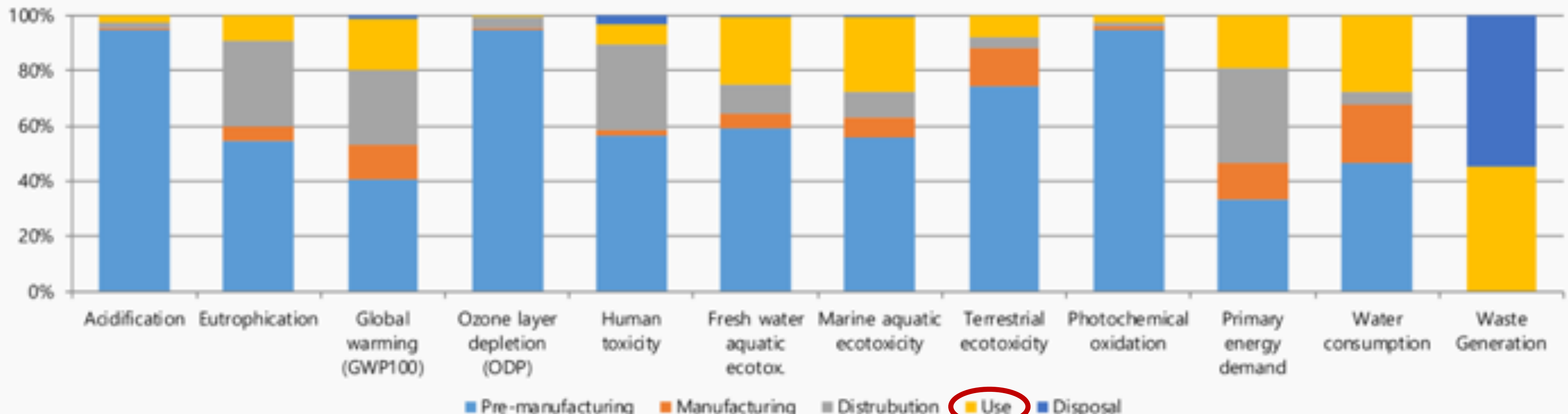
| | |
|---|---|
| Model name | SM-N950U (Galaxy Note8) |
| Processor | Qualcomm 2.35GHz, 1.9GHz Octa-Core 64bit |
| Dimension | 162.5 x 74.8 x 8.6 mm |
| Display | 6.3" 2960 x 1440, 16M In-Cell Touch LCD |
| Battery | Li-Ion 3300 mAh |
| Camera | 12 MP / 5MP |
| Wt.(g) | 186.34g |

## 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 |

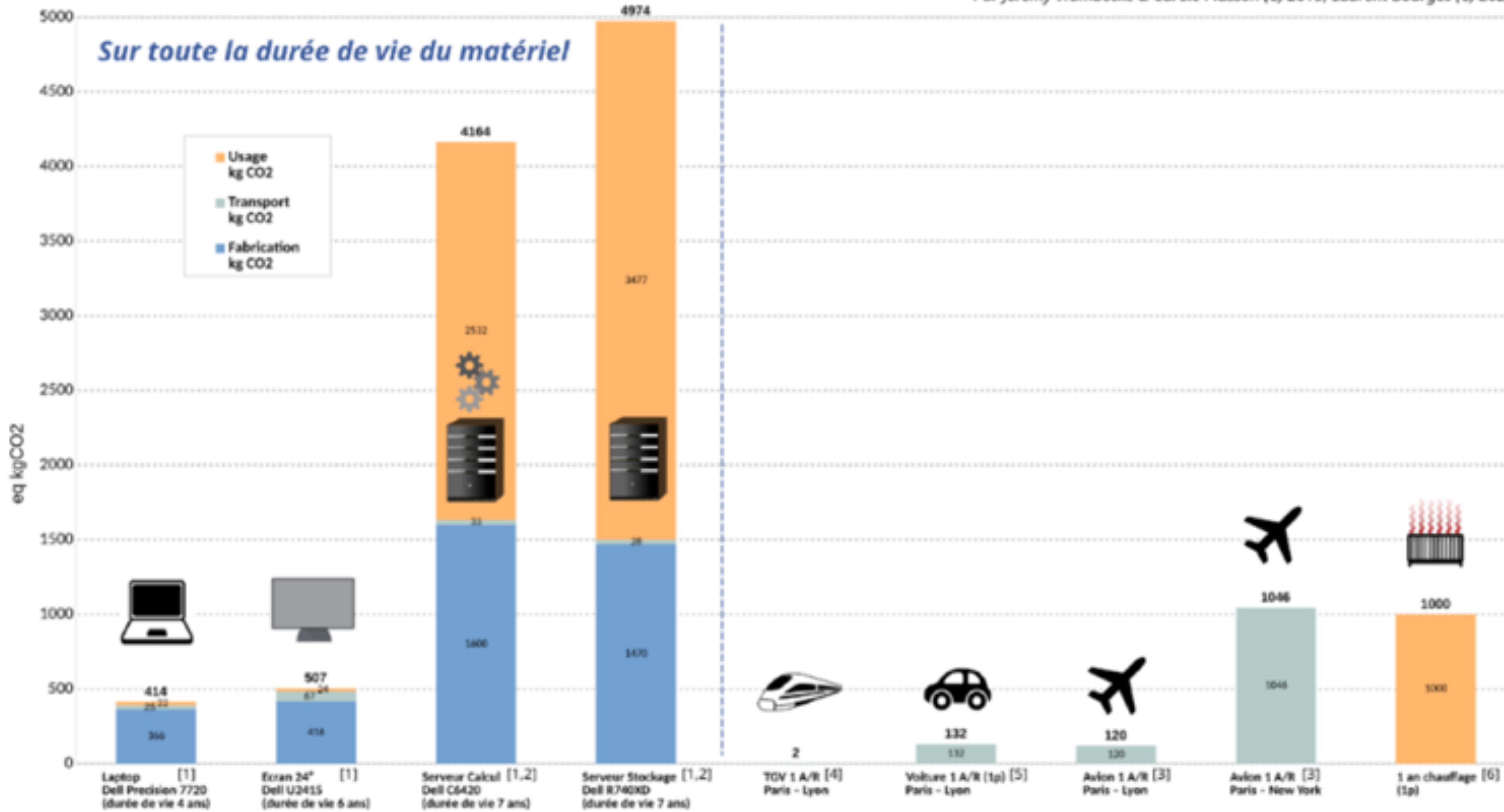
| | |
|---|---|
| Pre-manufacturing | Parts and materials constituting the products and its transportation (from supplier to Samsung factory) |
| Manufacturing | Product assembly by Samsung Electronics (Data collection period : 3 months ahead of assessment) |
| Distribution | From China or Vietnam to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

# Studying environmental impacts of ICT


https://ecoinfo.cnrs.fr

# Examples

Par Jérémy Wambecke & Carole Plasson (C) 2019, Laurent Bourgès (C) 2020




[1] Données Fiches Dell (usage corrigé pour usage FR) : (https://www.dell.com/learn/us/en/uscorp1/corp-comm/environment_carbon_footprint_products)

[2] Usage à partir de la consommation moyenne (Berthoud et al. 2020) d'un noeud = 275W (C6420), 375W (R740XD) (https://hal.archives-ouvertes.fr/hal-02549565)

[3] https://eco-calculateur.dta.aviation-civile.gouv.fr/

[4] https://ressources.data.sncf.com/explore/dataset/emission-co2-tgv/table/

[5] Trajet de 473km, pour une voiture émettant 140g CO2/km

[6] https://www.insee.fr/fr/statistiques/fichier/1281320/ip1445.pdf

**Facteur d'impact : 0,108 kgCO2e/kWh (FR)**

# Opportunities

To think differently

To propose new things

To build differently

To design a sustainable future

*Sobriety*

*Resilience*

*Low-tech*

*Sustainable computing*

*Computational sustainability*


# Thank you for your attention

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