Energy consumption and environmental impacts of distributed systems

Anne-Cécile Orgerie

Normastic, Caen
7th February 2023

CNRS dépasser les frontières
UMR IRISA
EcoInfo Groupement de service

Outline

- Context
- Understanding the energy consumption of distributed systems
- Measuring accurately the energy consumption of distributed systems
- Modeling energy consumption 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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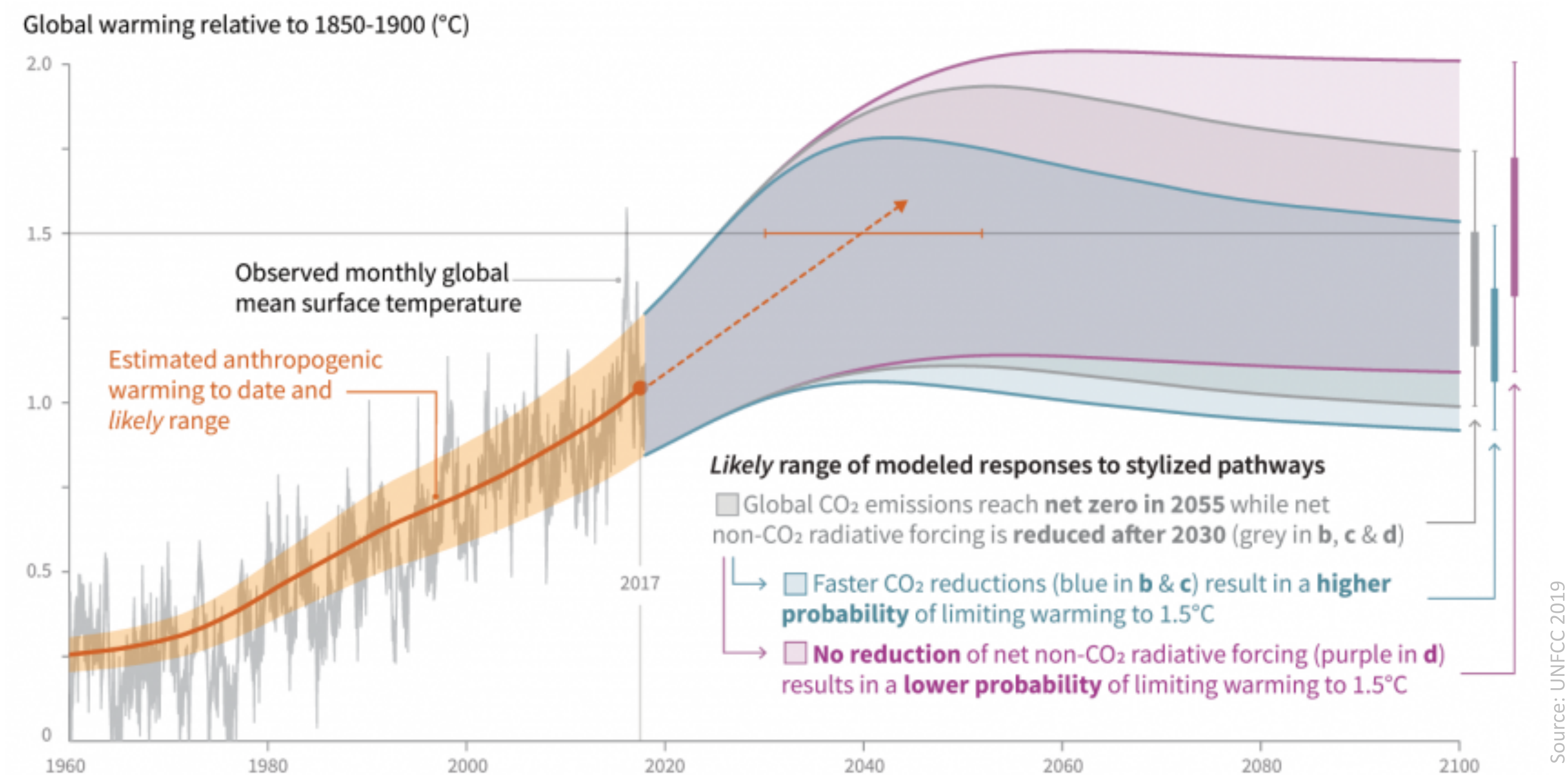
- 15.4%

Electricity mix, device lifetime, complex manufacturing processes, ICT perimeter, …

"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.

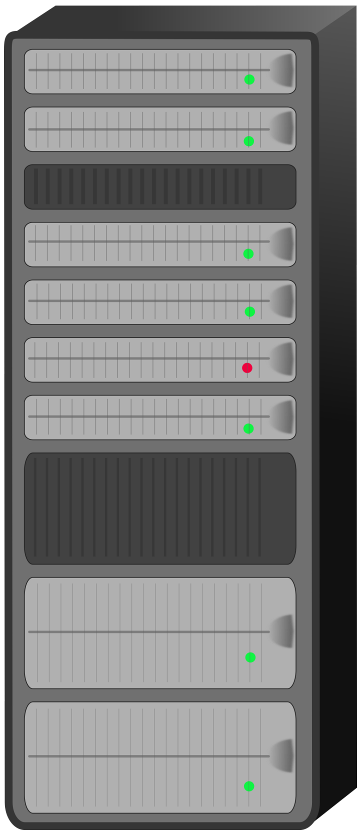
Paris Agreement: 1.5℃



Objective in 2019: reducing global greenhouse gas emissions by **8%** each year

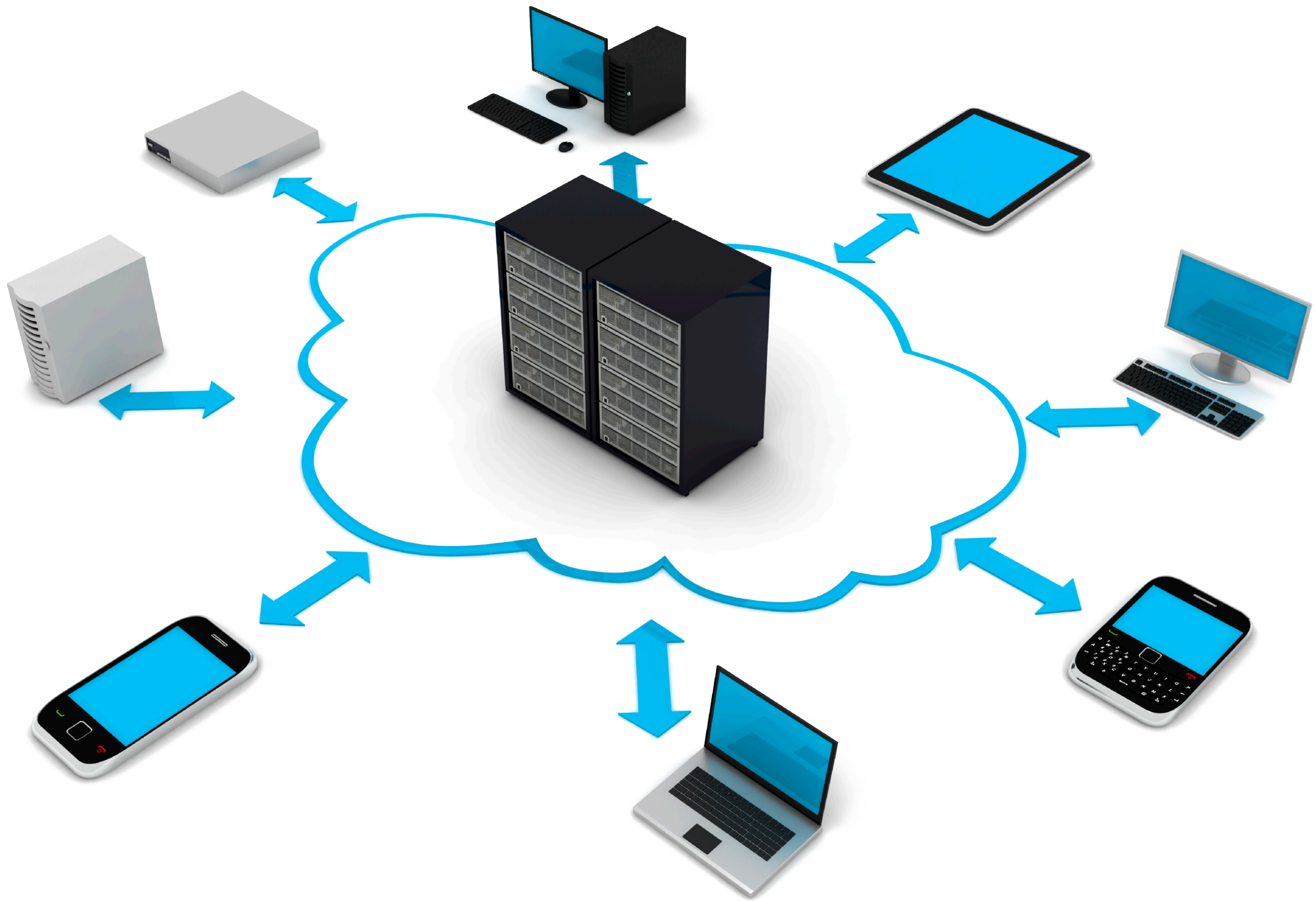
My scientific context

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



Started with Grid computing some years ago…

The Cloud



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

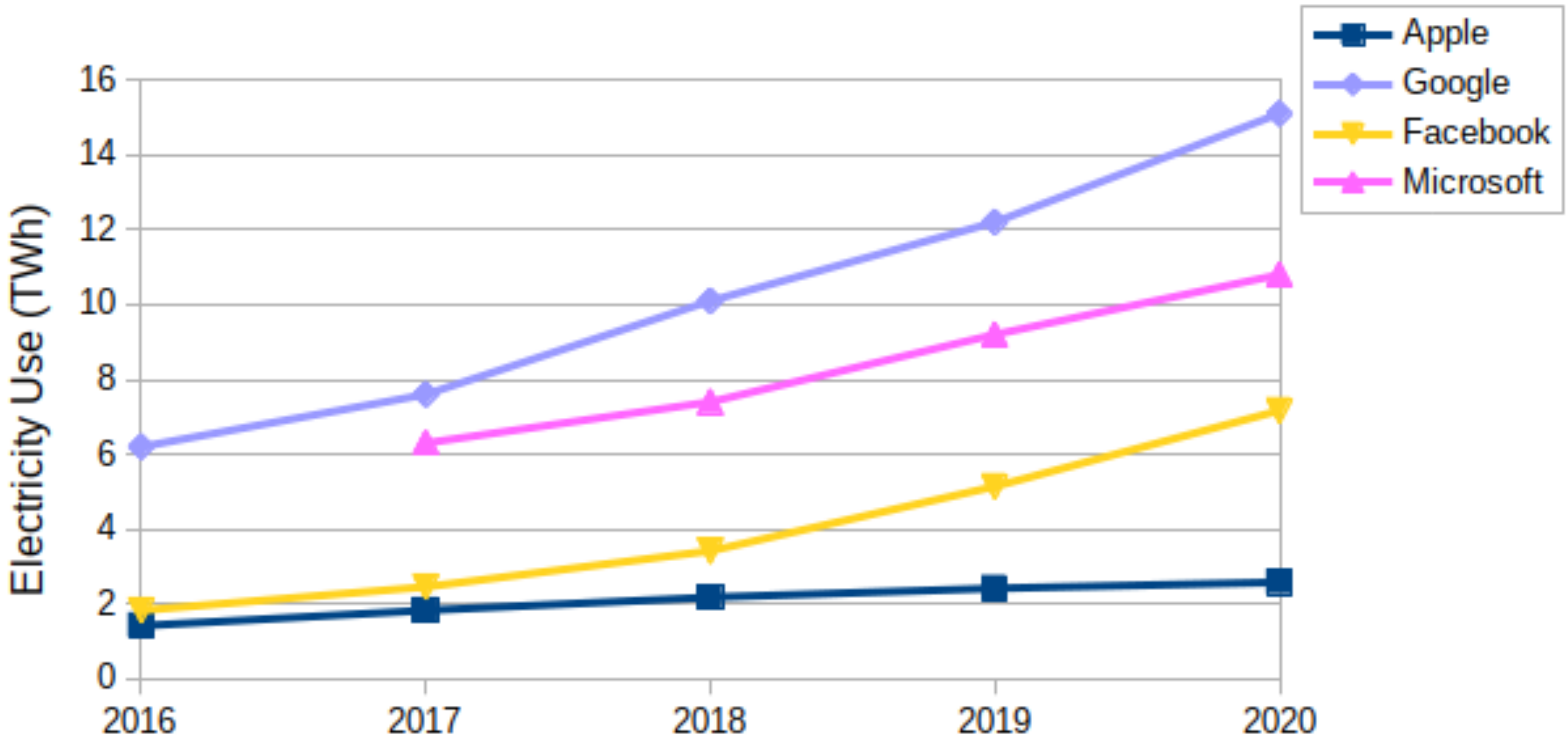


Figure: Anne-Laure Ligozat

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

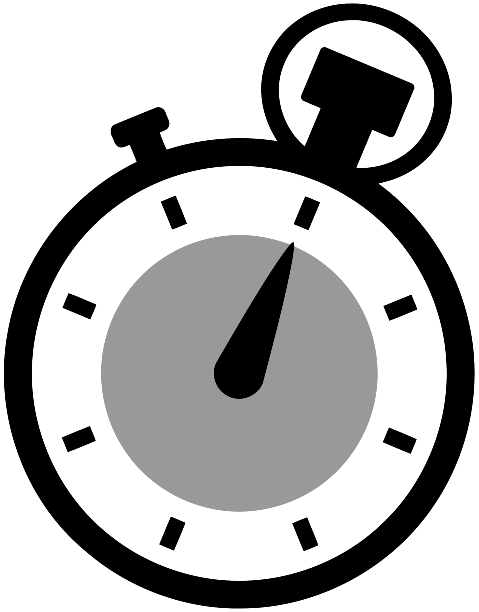
Carbon footprint : 3 scopes

- 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.

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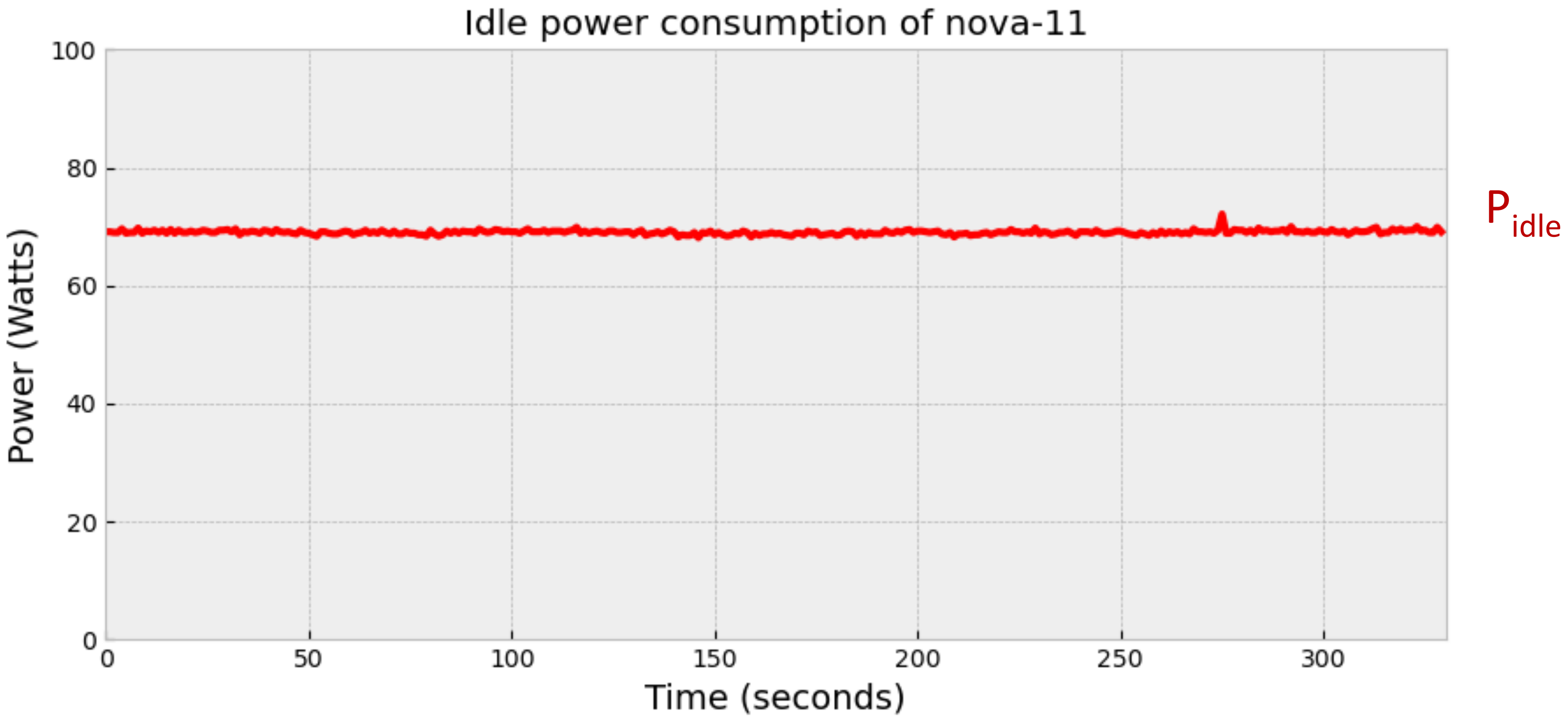

Nova node: 2 x Intel Xeon E5-2620 v4, 8 cores/CPU, 64 GiB RAM, 598 GB HDD (2016)

Grid'5000

Wrong idea #2

This server model consumes that amount of power.

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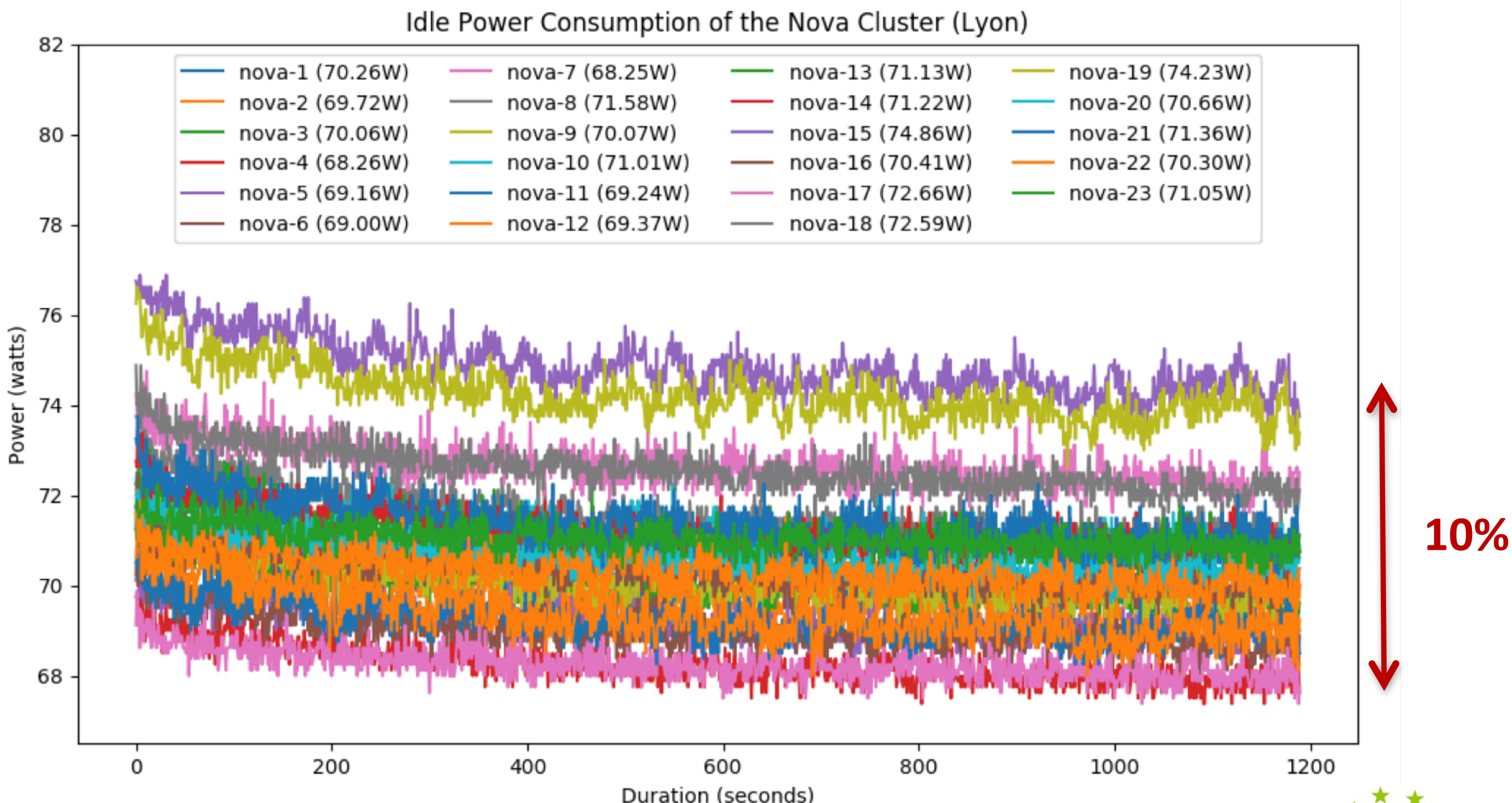
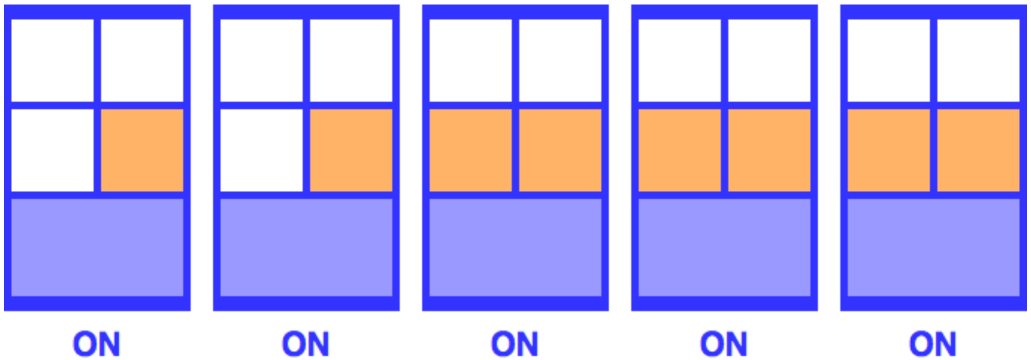


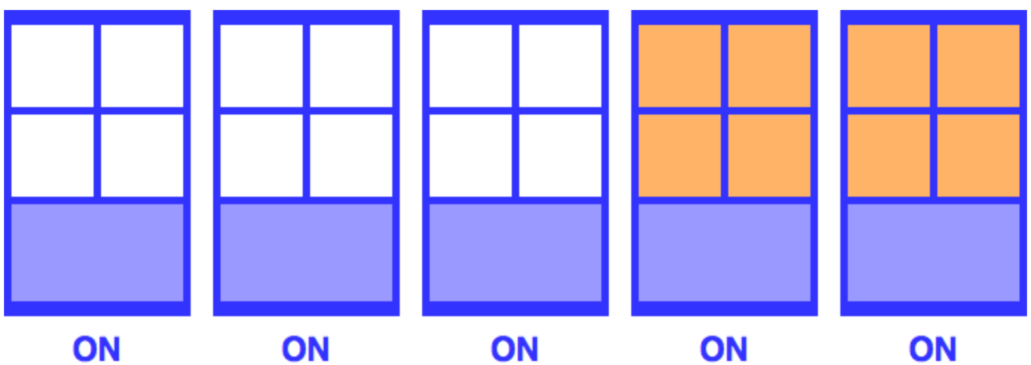
10% difference in idle and more at maximal consumption.

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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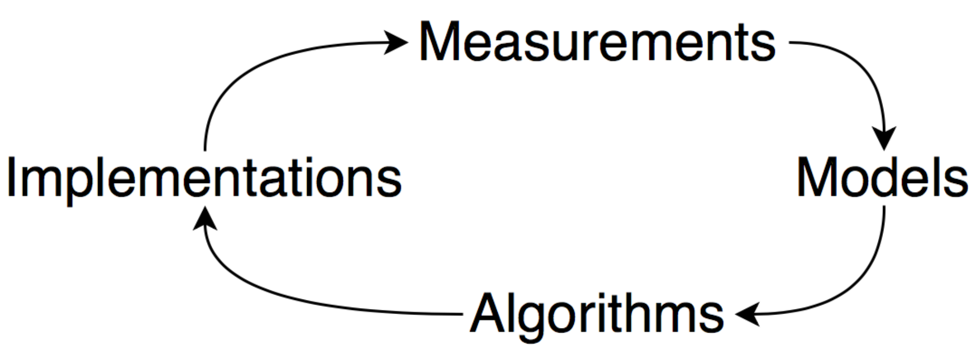
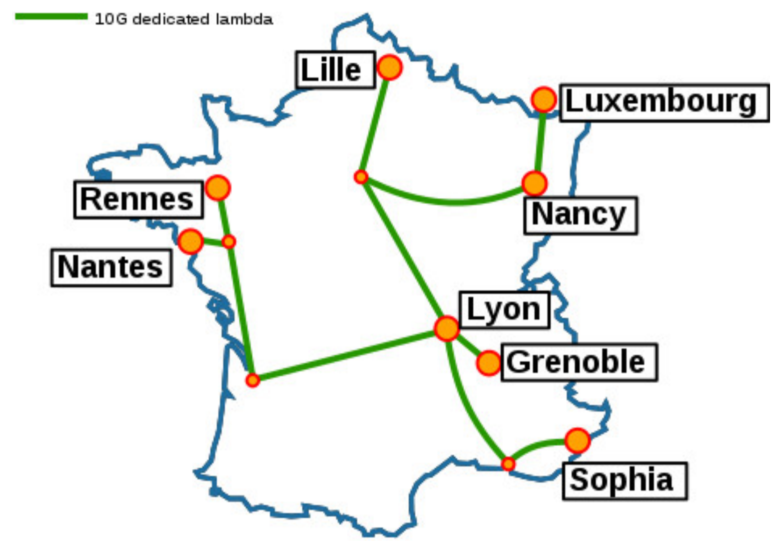
Energy consumption: a complex phenomenon

Need for **wattmeters** and sound experimental campaigns

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

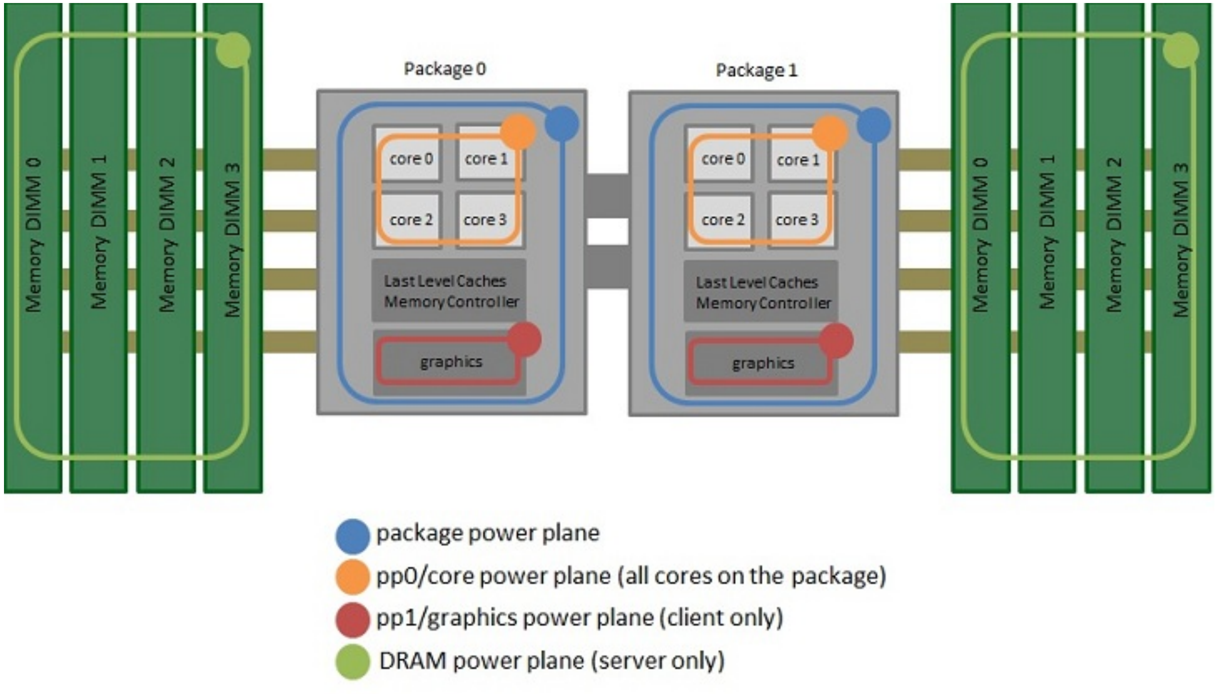
Grid'5000





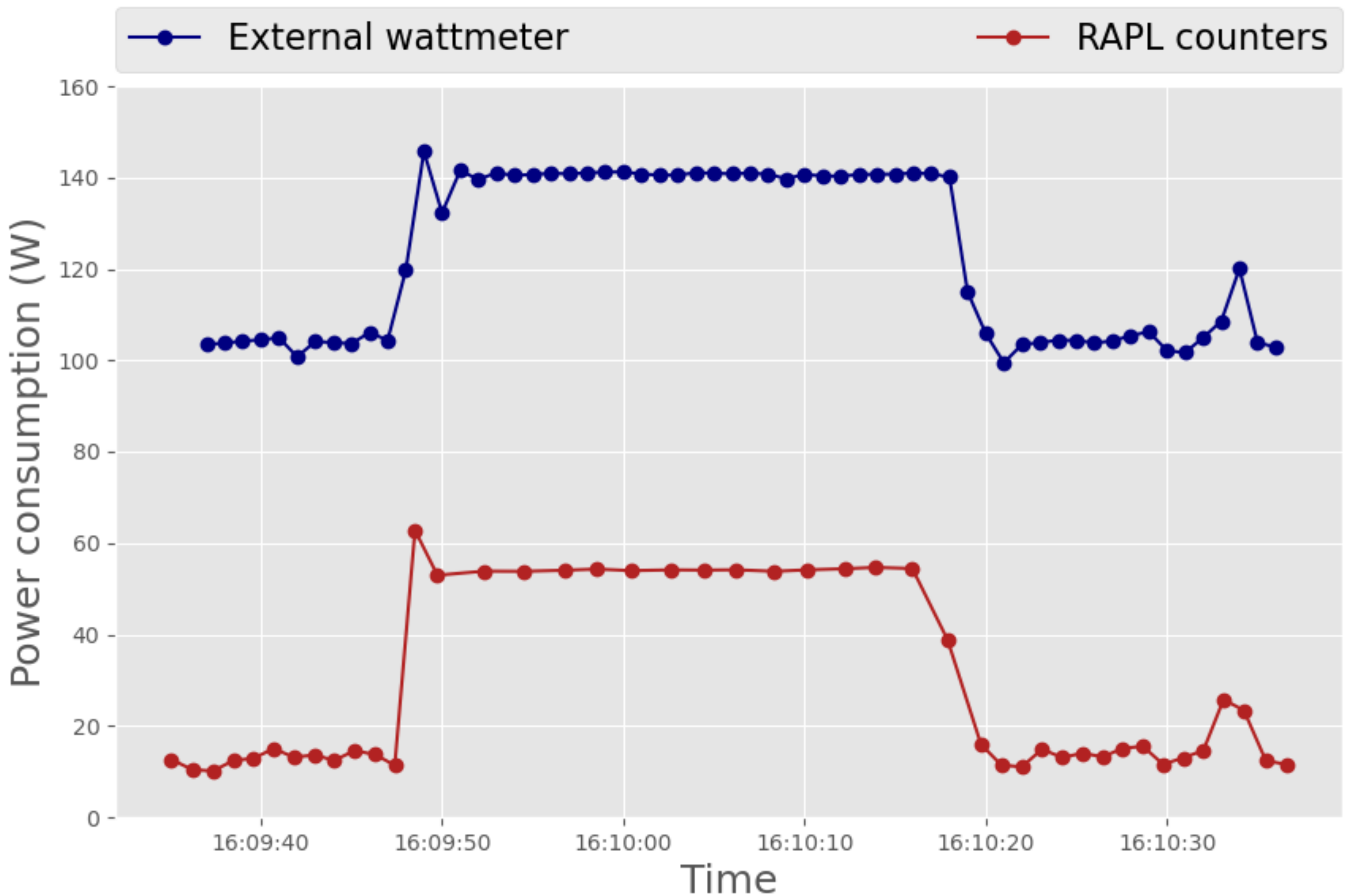
Performing measurements

Intel's RAPL (Running Average Power Limit) interface



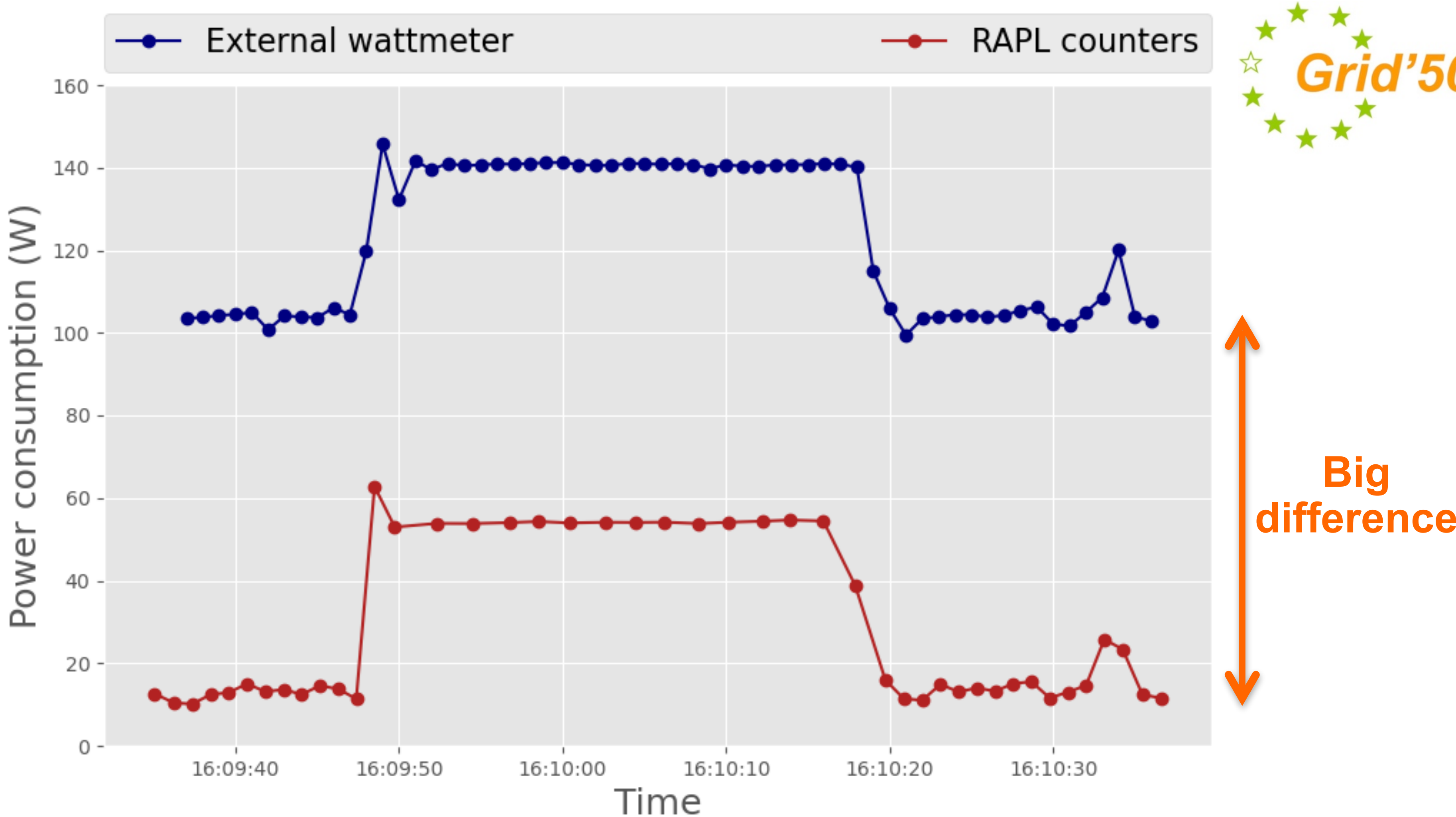

```
Energy measurements:
PACKAGE_ENERGY:PACKAGE0    176.450363J   (Average Power 42.9W)
PACKAGE_ENERGY:PACKAGE1     75.812454J   (Average Power 18.4W)
DRAM_ENERGY:PACKAGE0        11.899246J   (Average Power 2.9W)
DRAM_ENERGY:PACKAGE1         8.341141J   (Average Power 2.0W)
PP0_ENERGY:PACKAGE0      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

Knowing what you measure



Grid'5000

Knowing what you measure



Power consumption of Taurus-12

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

Wrong idea #3

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

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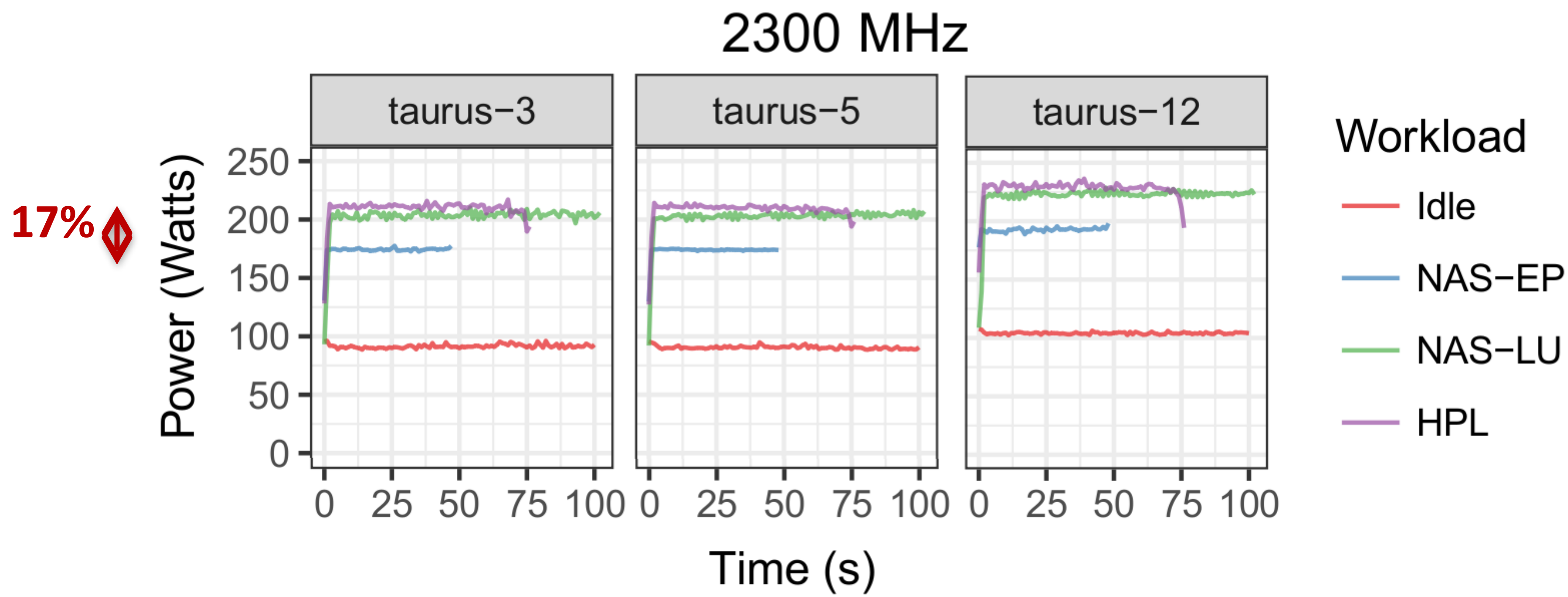


[Cluster 2017]

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

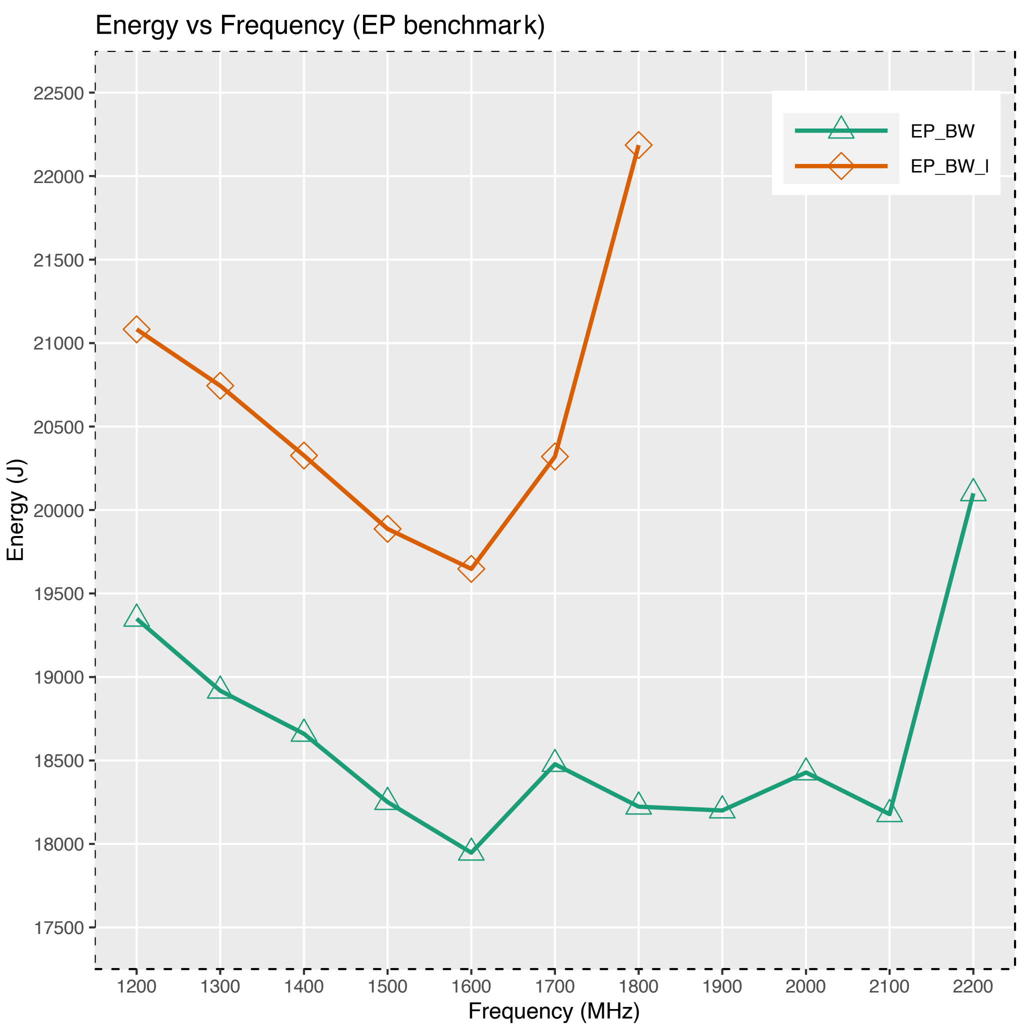
17% difference in consumption for applications fully loading the server.

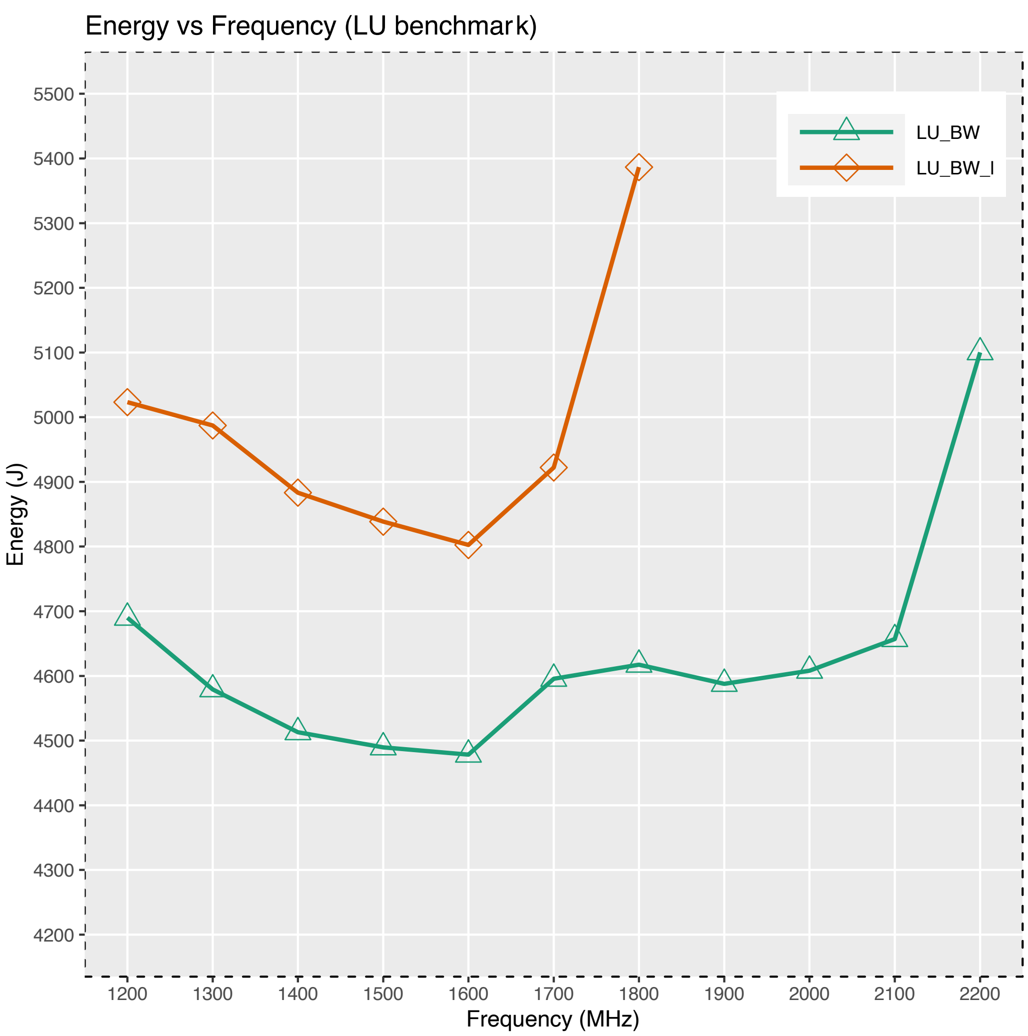
Wrong idea #4

Low power processors consume less energy.

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.

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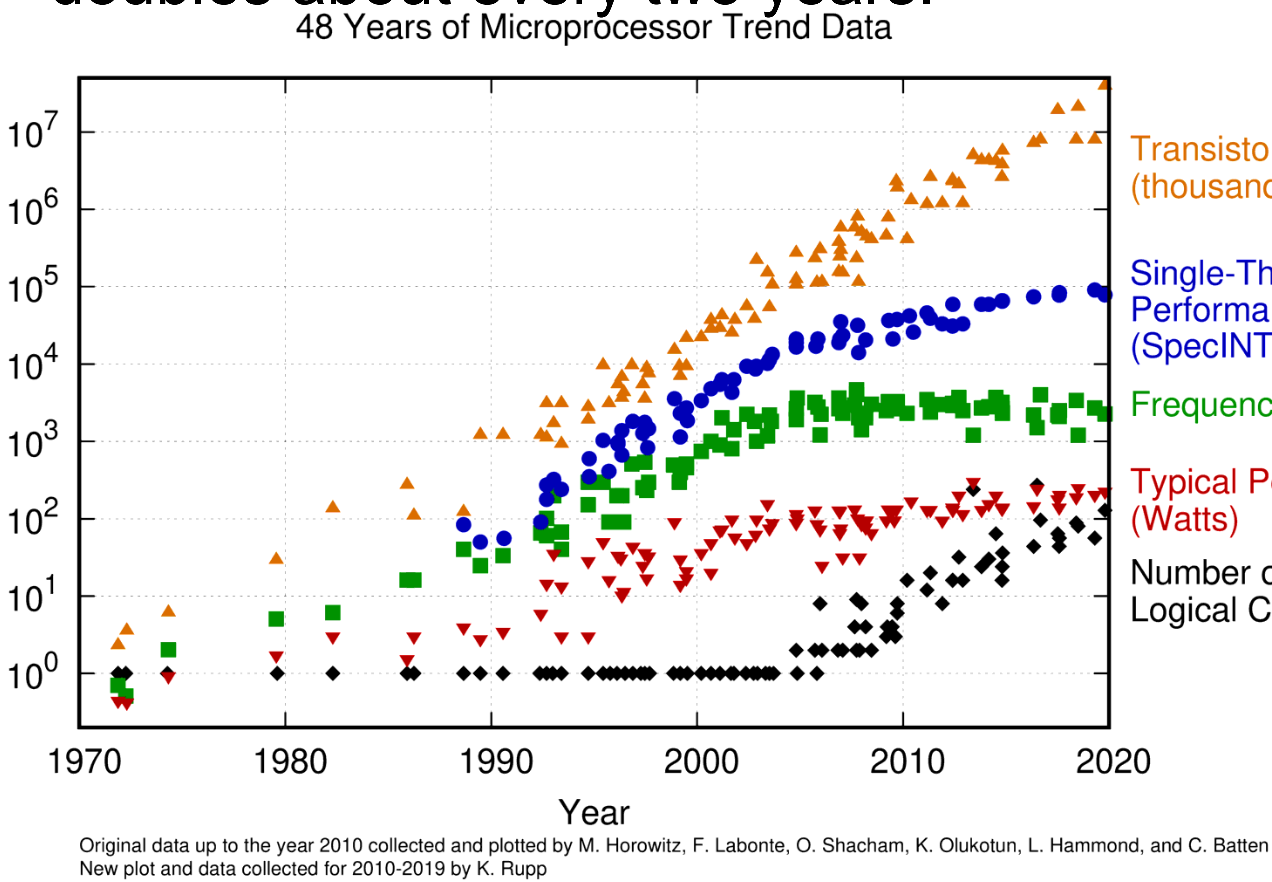
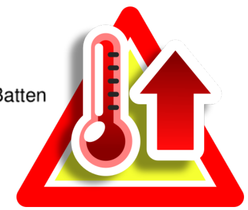
Improvement in energy efficiency will never stop.

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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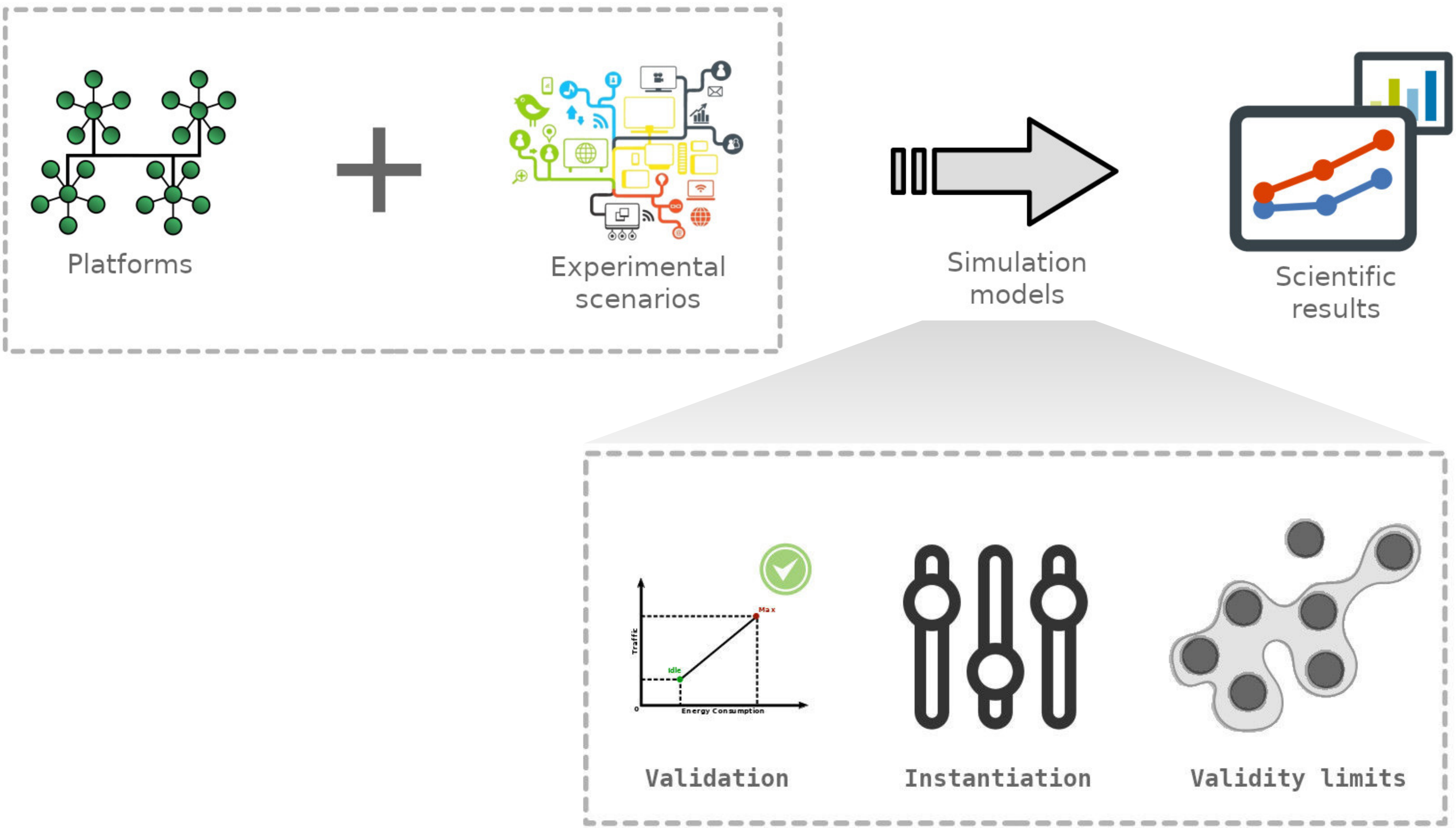
Simulating energy consumption



Models and simulation tools for what?

Capacity and energy planing

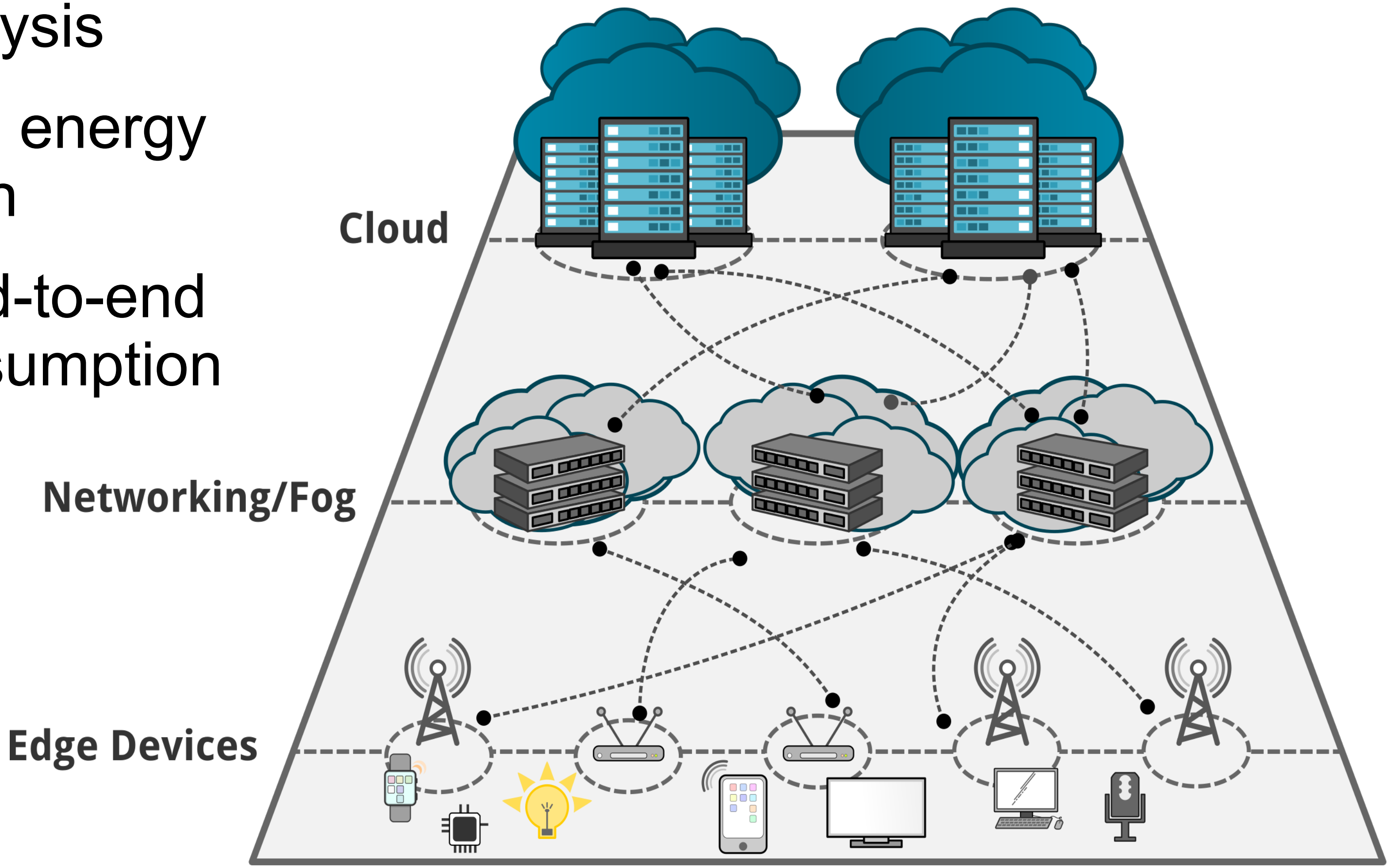
What-if scenarios

Algorithm analysis

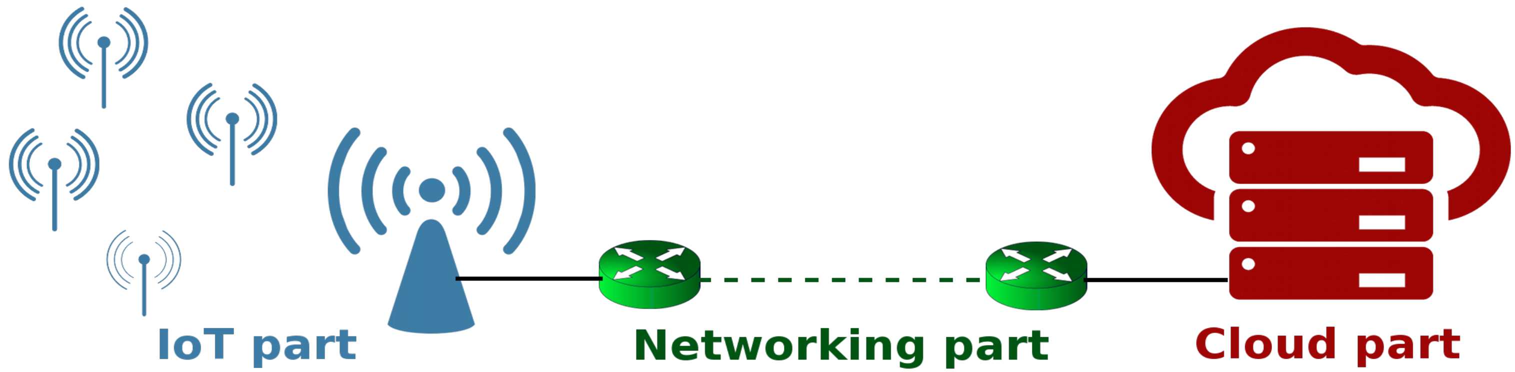
Estimating VM energy consumption

Estimating end-to-end energy consumption

Closing doors



Power consumption of IoT

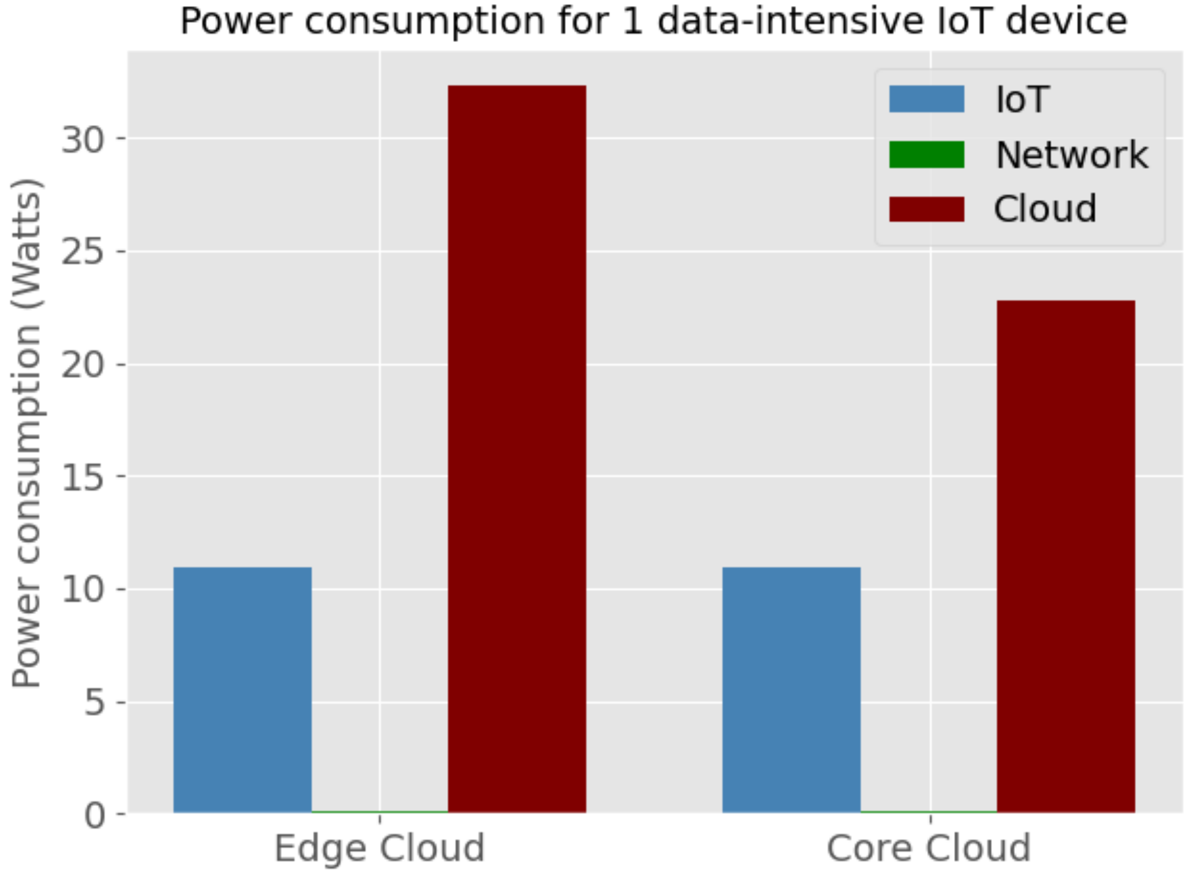


THE STATE UNIVERSITY OF NEW JERSEY RUTGERS

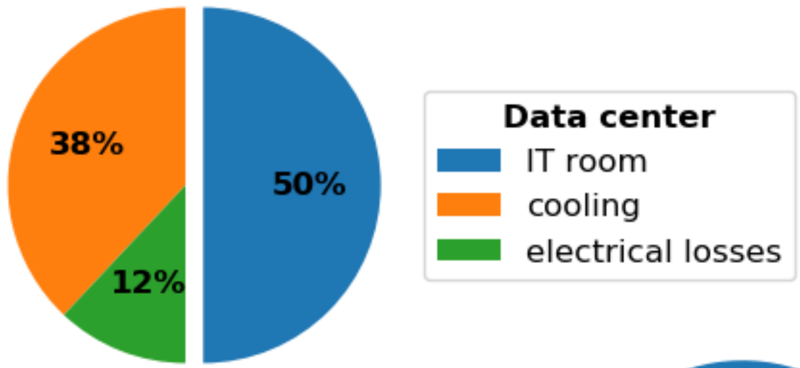
[FGCS 2018]

Tradeoff between:
- Performance
- Application accuracy
- Energy consumption

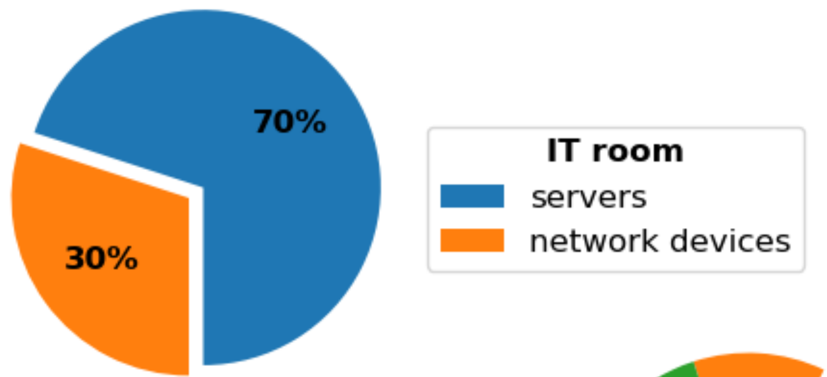
It depends.



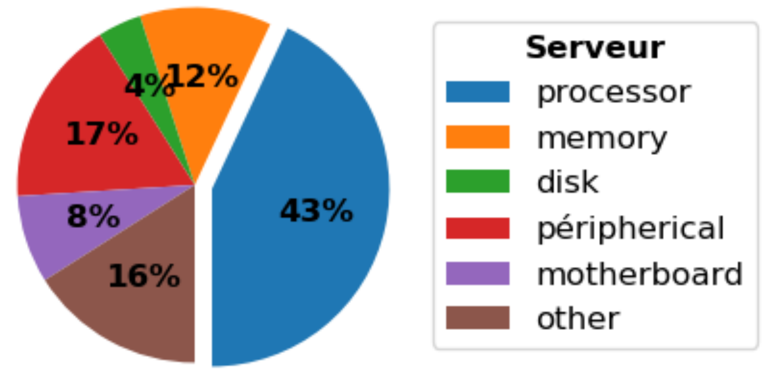
Wasted energy at all levels of data centers



Cooling
Power generators
Batteries
…



Unused servers
Overprovisioning
Redundancy
…



Power non-proportionality
Dark silicon
Unused components
…

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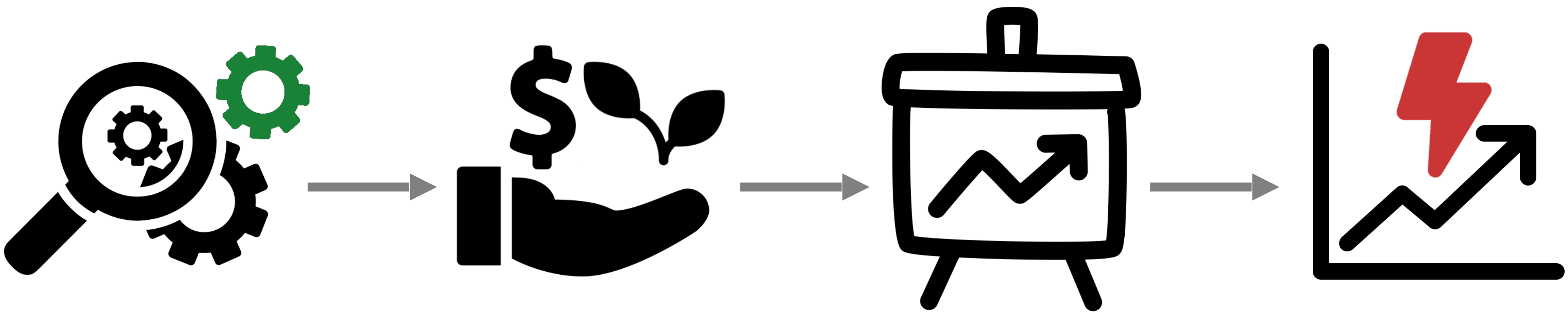
ICT for Green ≠ Green ICT

- **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:

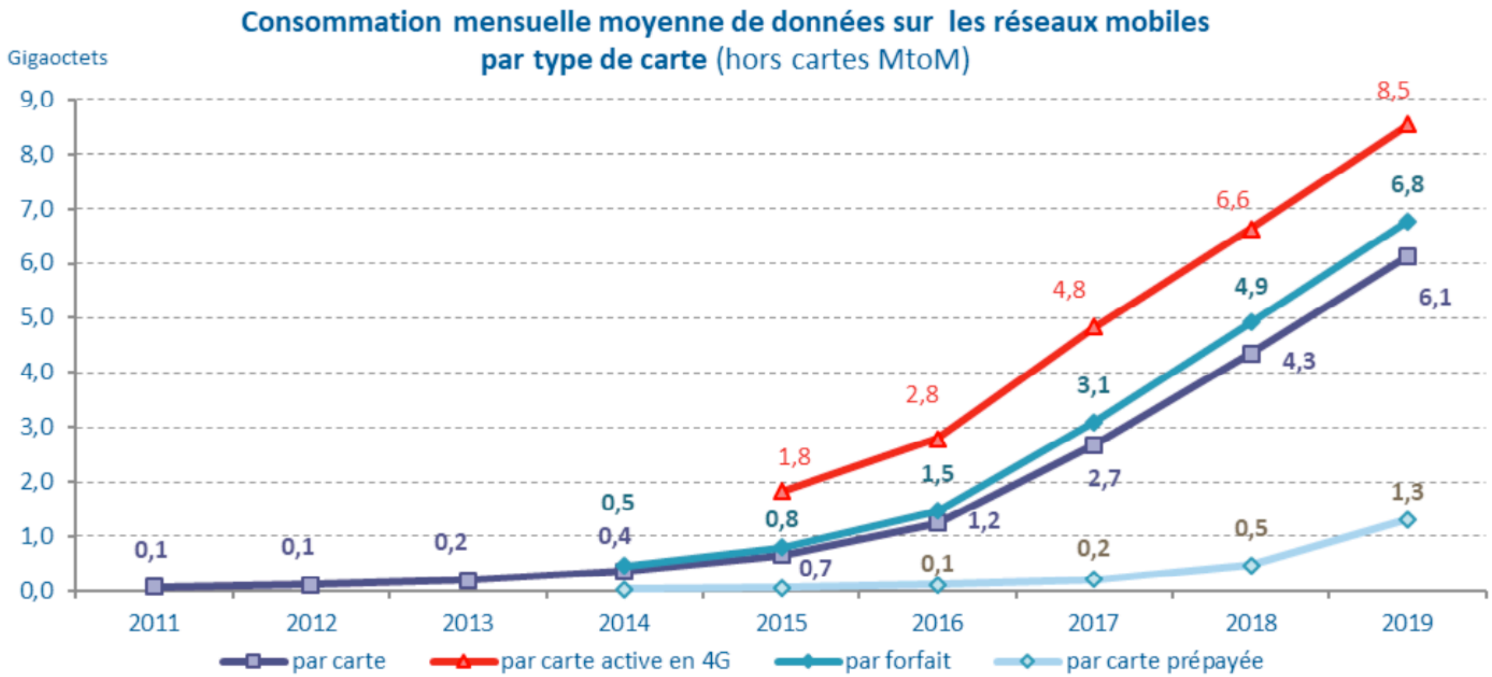
- Acceleration of equipment renewal rate
- Explosion of uses and consumption of data
- Digitization of all sectors, without prior study of environmental impacts

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

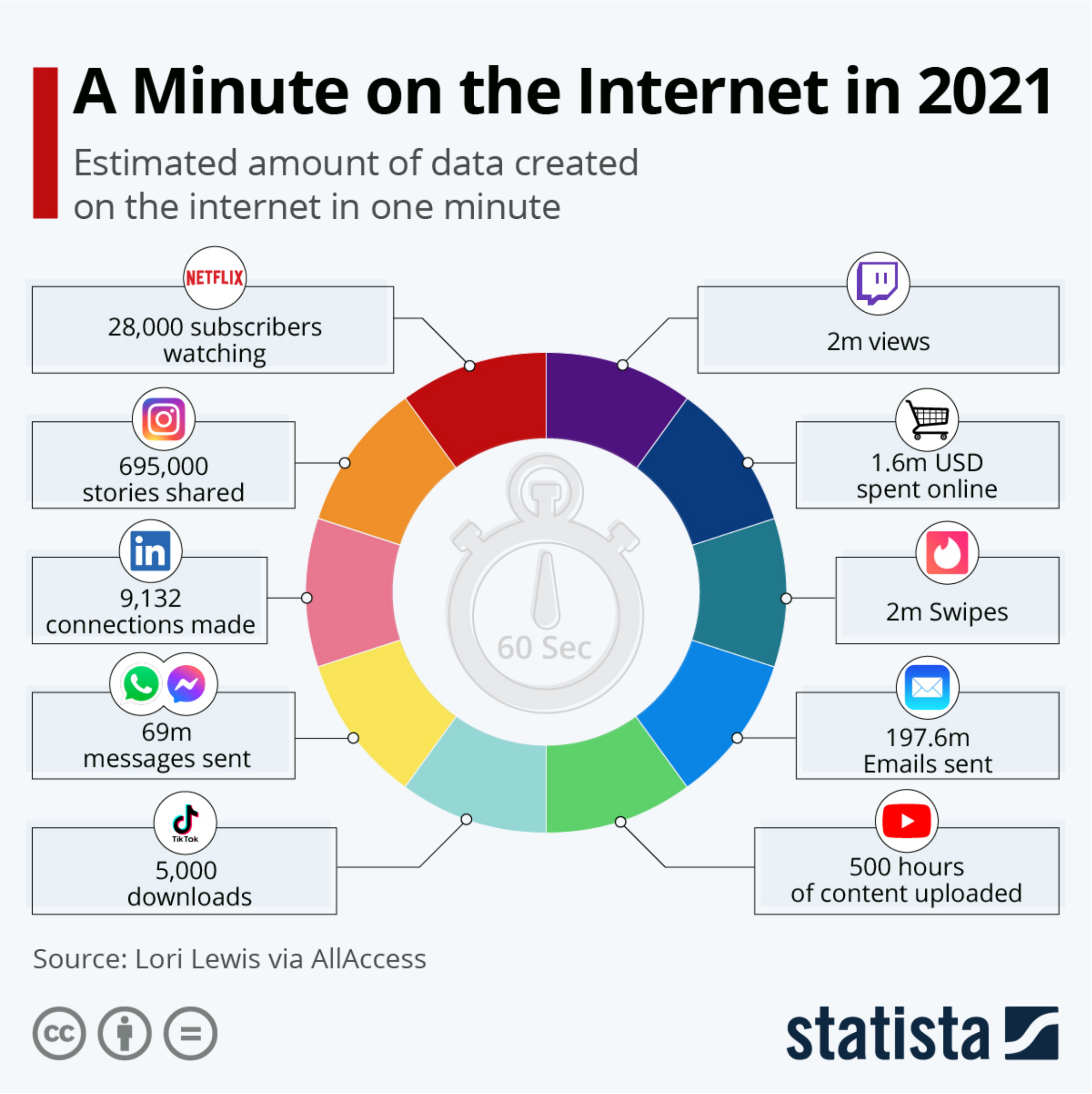


[Source: Marché des communications électroniques en France - Année 2019, ARCEP]

In Q4 2021 :
- 80.4 million SIM cards in France (prepaid and subscription)
- average monthly data consumption per SIM card: 10.4 GB/month

In Q4 2011 :
- 65.9 million SIM cards in France
- 0.1 GB/month (x100 in 10 years per user)

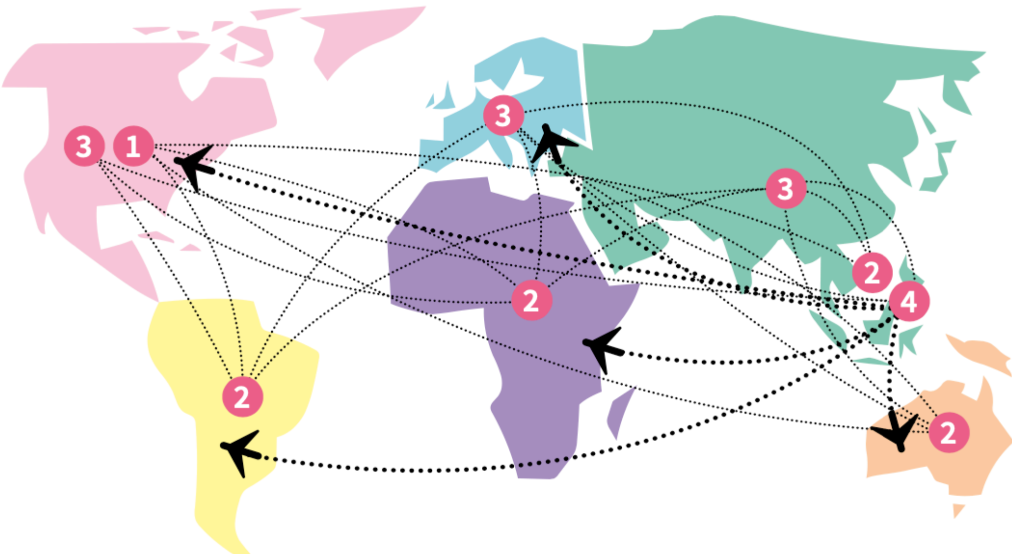
Can we save ICT…



… without changing users' 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

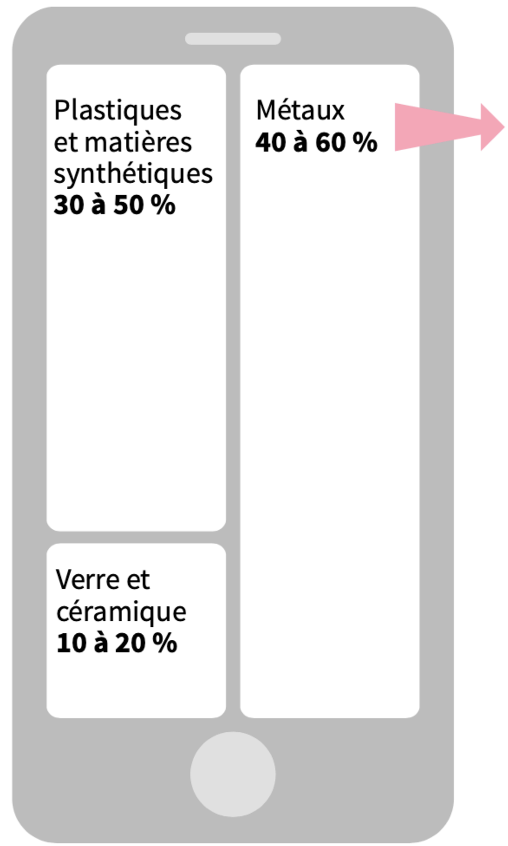
3. Fabrication des principaux composants en Asie, aux États-Unis et en Europe

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…

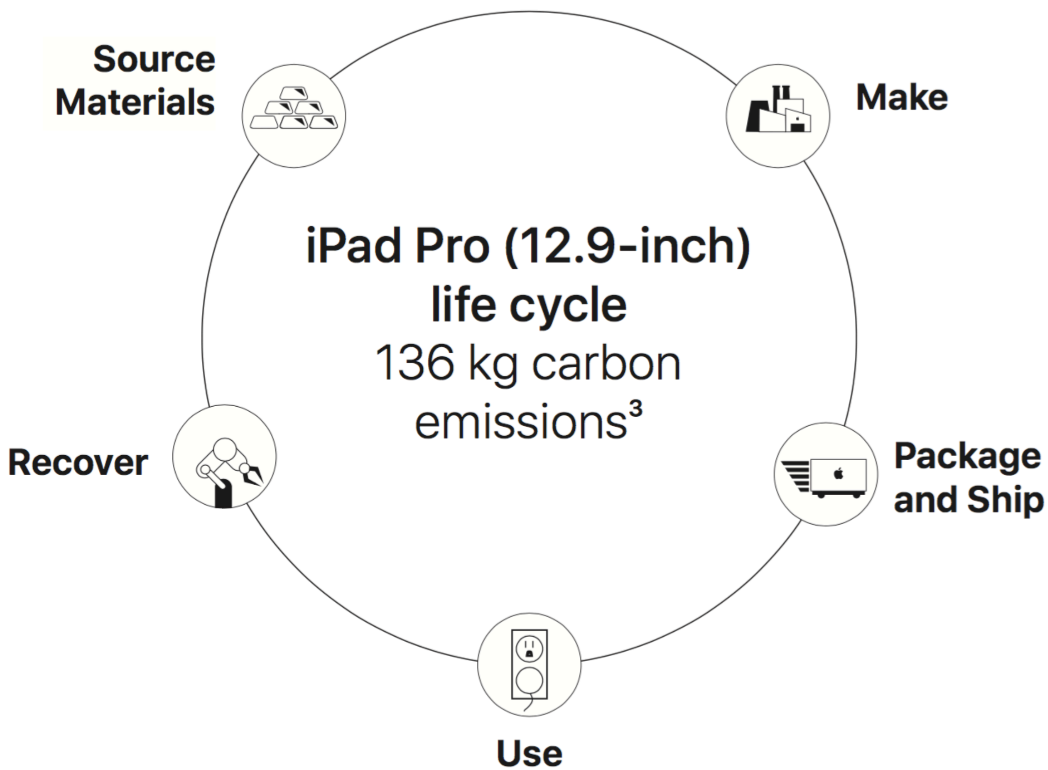
0,1 % de terres rares et métaux spéciaux : europium, yttrium, terbium, gallium, tungstène, indium, tantale…

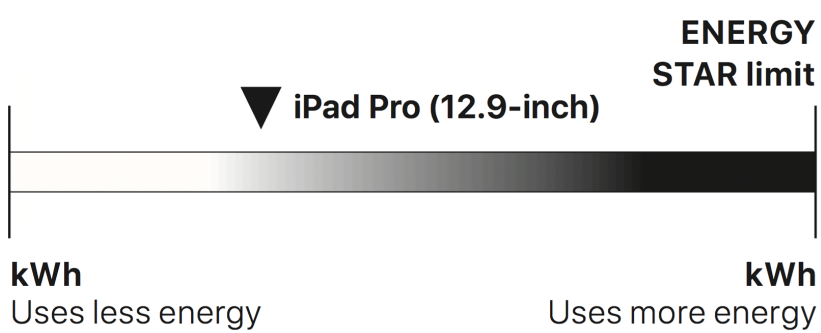
15 à 20 % d'autres substances : magnésium, carbone, cobalt, lithium…

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 — *4 years of use*

<1% End-of-life processing

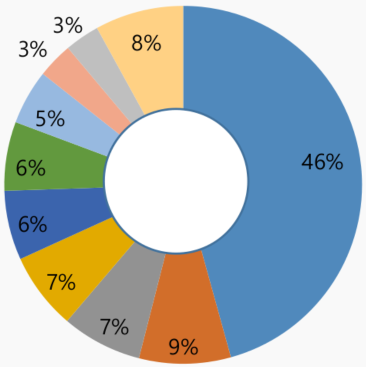
Source: Product environmental report, Apple, 2018.

Numerous other environmental impacts

Product Features

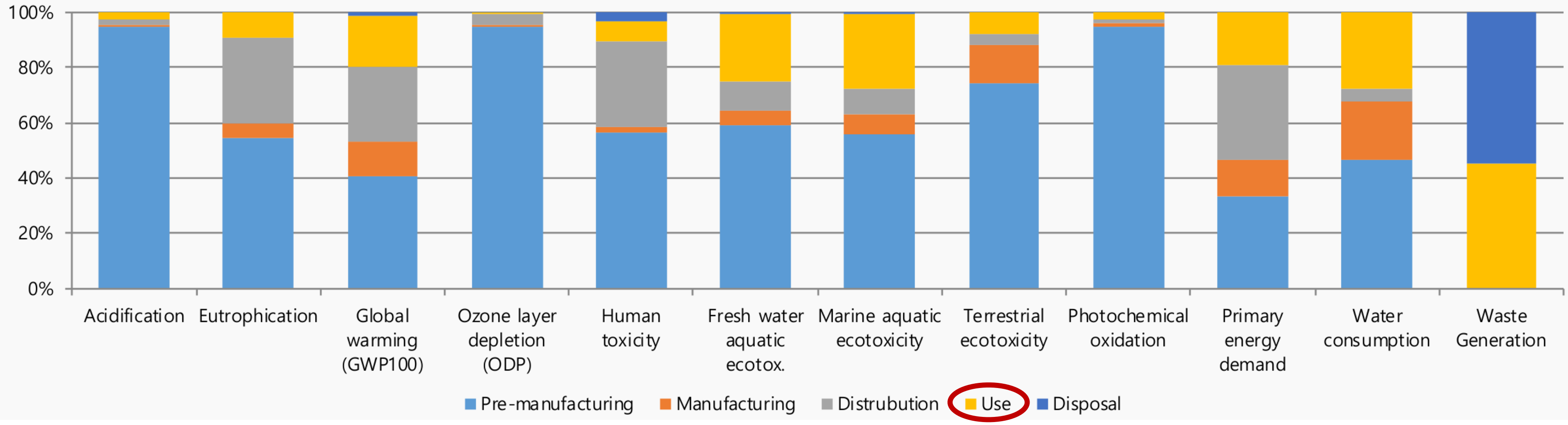
Model name	SM-N950U (Galaxy Note8)
Processor	Qualcomm 2.35GHz, 1.9GHz Octa-Core 64bit
Dimension	162.5 x 74.8 x 8.6 mm
Display	6.3" 2960 x 1440, 16M In-Cell Touch LCD
Battery	Li-Ion 3300 mAh
Camera	12 MP / 5MP
Wt.(g)	186.34g

Material Use



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

Characterized Environment Impact



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

Carbon footprint of astronomical research infrastructures

Estimate of the carbon footprint of astronomical research infrastructures

Jürgen Knödlseder, Sylvie Brau-Nogué, Mickael Coriat, Philippe Garnier, Annie Hughes, Pierrick Martin & Luigi Tibaldo

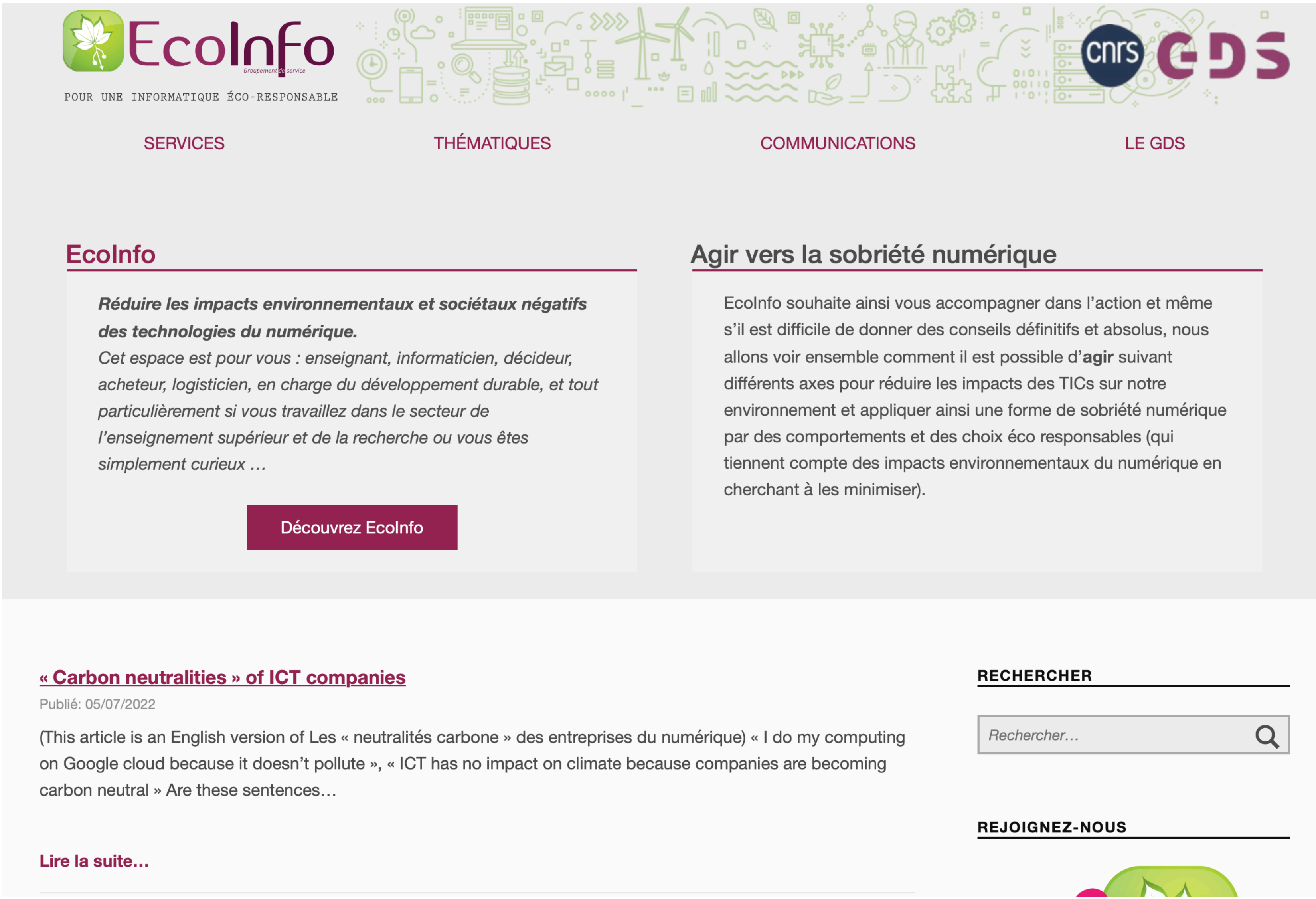
Nature Astronomy (2022) | Cite this article

989 Accesses | **2** Citations | **504** Altmetric | Metrics

Abstract

The carbon footprint of astronomical research is an increasingly topical issue with first estimates of research institute and national community footprints having recently been published. As these assessments have typically excluded the contribution of astronomical research infrastructures, we complement these studies by providing an estimate of the contribution of astronomical space missions and ground-based observatories using greenhouse gas emission factors that relates cost and payload mass to carbon footprint. We find that worldwide active astronomical research infrastructures currently have a carbon footprint of 20.3 ± 3.3 $MtCO_2$ equivalent (CO_2e) and an annual emission of 1,169 ± 249 $ktCO_2e$ yr^{-1} corresponding to a footprint of 36.6 ± 14.0 tCO_2e per year per astronomer. Compared

Studying environmental impacts of ICT



https://ecoinfo.cnrs.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