Green ICT

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Lecture, Telecom SudParis
13th January 2023

Who I am

- Full-time researcher at CNRS (about 33,000 people)
- Located in Rennes, France.
- IRISA laboratory (about 1,000 people)
- Myriads team: INRIA, CNRS, University of Rennes, INSA, ENS Rennes (about 30 people)
- Energy efficiency in large-scale distributed systems

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

Green Computing?

"*Designing, manufacturing, using, and disposing of computers, servers, and associated subsystems -- such as monitors, printers, storage devices, and networking and communications systems -- efficiently and effectively with minimal or no effect on the environment.*"

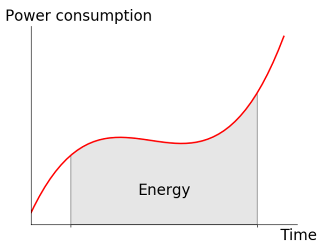
Sam Murugesan, "*Harnessing Green IT: Principles and Practices*" IEEE IT Professional, 2008.

Outline

Energy for dummies

Physical measure	Unit
Current (I)	Amperes (A)
Voltage (U)	Volts (V)
Power (P)	Watts (W)
Energy (E)	Joules (J) or Wh

P = U x I
E = P x t



ICT impact ?

- What is ICT carbon impact in comparison with global impact?
- What is carbon impact?

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

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

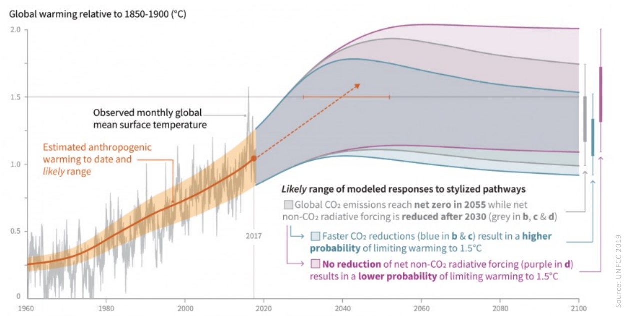
"The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations", C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. Blair, A. Friday, Patterns, 2021.

Carbon footprint ?

- Expressed in **g CO_2e**: weight of CO_2e
- Greenhouse gas: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), halocarbons…
- CO_2e computed thanks to global warming potential: ratio between the heat absorbed by a greenhouse gas in the atmosphere over the heat absorbed by CO_2 over a given period of time (100 years)

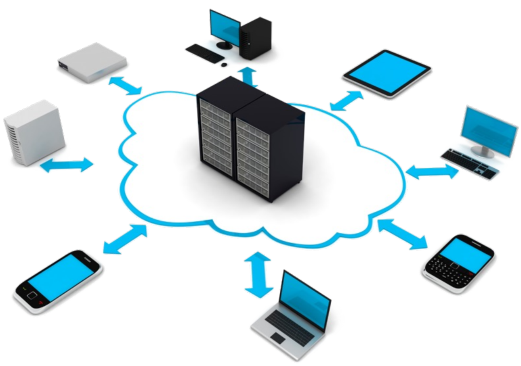
Maribor, Slovenia
https://www.interregeurope.eu/intensify/news/news-article/10745/what-1-tonne-of-co2-looks-like/

Paris Agreement: 1.5°C



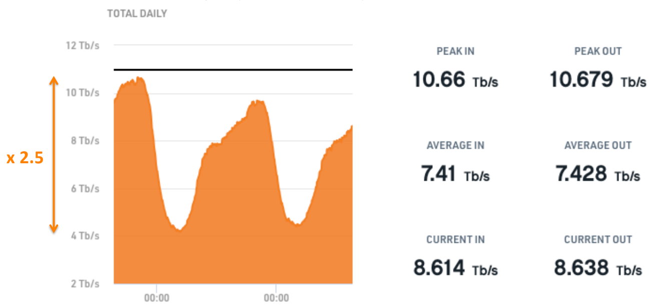
Objective in 2020: reducing global greenhouse gas emissions by **8%** each year.

The Cloud



Resource waste

Networks are lightly of unevenly utilized



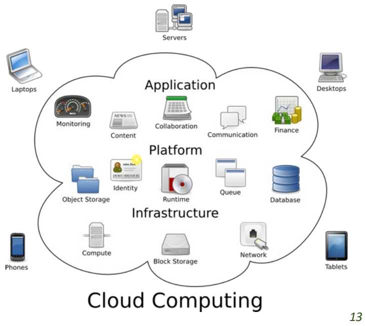
Daily aggregated traffic on AMS-IX(Amsterdam Internet eXchange Point), February 2022.
[Source : https://www.ams-ix.net/ams]

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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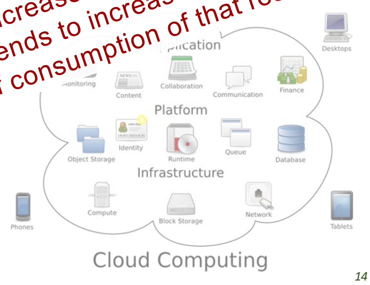
- Externalization of data

⮡ **Economies of scale**

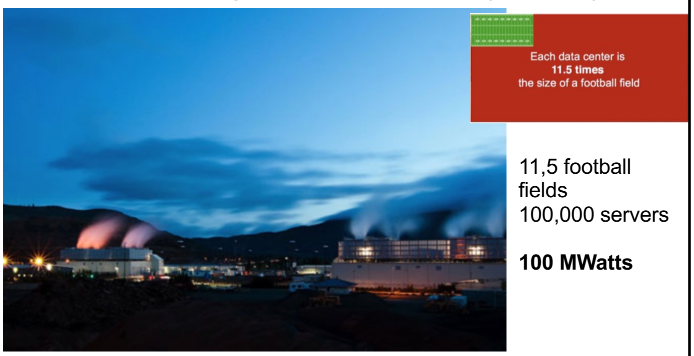
Jevons Paradox: the increase in efficiency with which a resource is used tends to increase (rather than decrease) the rate of consumption of that resource.



Let's have a look inside

[Source : https://www.google.fr/about/datacenters]

One Google Data Center (Dalles)



11,5 football fields
100,000 servers

100 MWatts

https://www.google.com/about/datacenters/inside/locations/the-dalles/

UPS to the rescue

Uninterruptible power supply:

- Emergency power system
- Used to protect hardware from power disruption
- Supplies energy stored in batteries, supercapacitors of flywheels (converted into alternating current)

But only for few minutes!

And then?

Engine-generator

OVH example

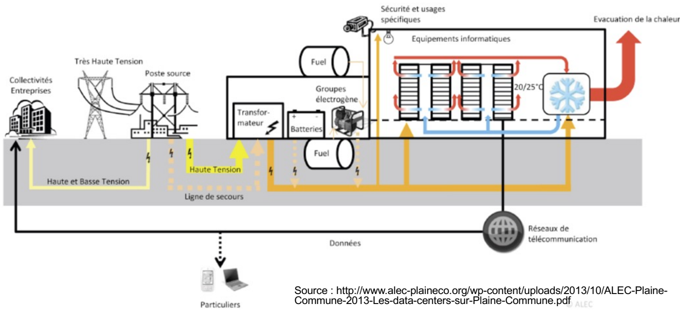
Roubaix site in 2011:
~ 10,000 servers

8 MVA at max: 1,600L/h of oil

Tests: every 2-3 weeks

https://lafibre.info/ovh-datacenter/test-de-groupes/

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

Wrong idea #0 – the good

Cloud computing is carbon neutral.

Wrong idea #0 – the bad

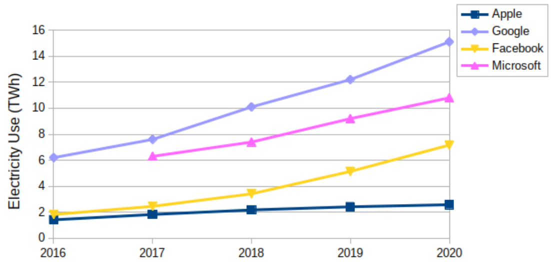


Figure: Anne-Laure Ligozat

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

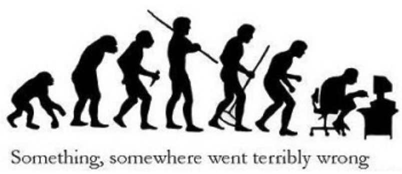
Carbon footprint : 3 scopes

- 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

Green computing history



First eco-labels

- Energy Star: international standard for energy efficient consumer products
  - 1992, USA
  - Voluntary labeling program
  - To promote energy-efficient monitors, climate control equipment and other technologies
  - Main result: sleep mode
- TCO certification
  - 1992, Sweden
  - To promote low magnetic and electrical emissions from CRT-based computer displays

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Specific eco-labels

- 80 Plus: voluntary certification program to promote efficient energy use in computer power supply units (2004):
  - More than 80% energy efficiency at 20%, 50% and 100% of rated load
  - Power factor of 0.9 or greater at 100% load
  - 80 Plus Titanium : 90% energy efficient
- RoHS: Restriction of Hazardous Substances Directive (2003):
  - Adopted in 2003, effective in 2006 in EU
  - Restricted use of six materials

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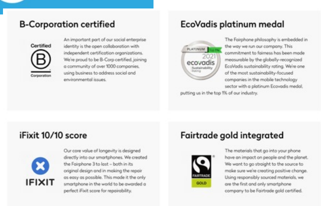
Fairphone



https://www.fairphone.com/en/impact/fair-materials/

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Outline

I. Introduction to (not) green ICT
   A. General context
   B. Green computing history
II. **Trails to green ICT from my research point of view**
   A. Data center level
   B. Measuring energy consumption of servers
   C. Saving energy
   D. Greening data centers
III. Concluding remarks

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Data center level

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Let's reduce the heat

- Water-based cooling

https://www.datacenterknowledge.com/archives/2012/12/11/defense-department-cool-servers-with-hot-water

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Let's reduce the heat

- Oil-based cooling

Green Revolution Cooling, https://www.grcooling.com

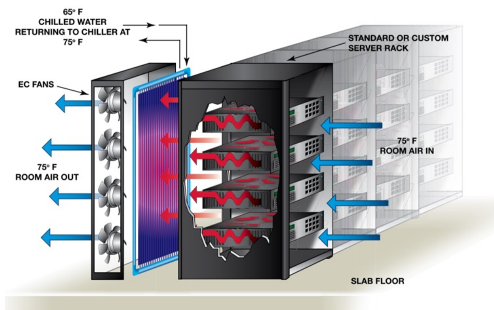
Let's reduce the heat

- Free cooling

https://www.google.com/about/datacenters/inside/locations/hamina/

Water-cooled doors

- Hybrid cooling



Exploded View of Chilled Door®

https://www.monman.com/motivair-chilled-door-rack-cooling-details

Water required!

Water tanks capacity: 900,000 liters

Google data center in South Carolina, US

https://www.google.com/about/datacenters/gallery/index.html#/tech/19

N° 1: Frontier (TOP500 November 2022)

1.685 Exaflops, 21.1 MW, **8,730,112 cores,**

Typical applications:
- Astrophysical simulations
- Genome-wide epistasis studies
- Fluid turbulence simulations
- …

https://www.olcf.ornl.gov/frontier/

Top500

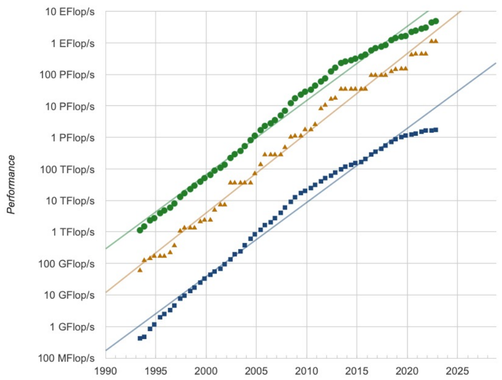
TOP500 The List.

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	8,730,112	1,102.00	1,685.65	21,100
2	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu RIKEN Center for Computational Science Japan	7,630,848	442.01	537.21	29,899
3	**LUMI** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE EuroHPC/CSC Finland	2,220,288	309.10	428.70	6,016
4	**Leonardo** - BullSequana XH2000, Xeon Platinum 8358 32C 2.6GHz, NVIDIA A100 SXM4 64 GB, Quad-rail NVIDIA HDR100 Infiniband, Atos EuroHPC/CINECA Italy	1,463,616	174.70	255.75	5,610
5	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148.60	200.79	10,096

http://www.top500.org, Top500 list, November 2022.

Performance development

Projected Performance Development



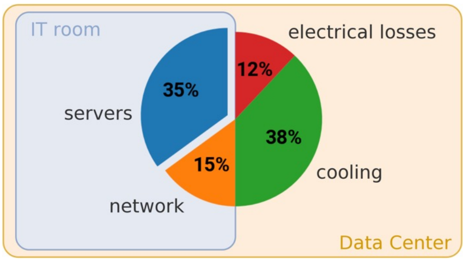
https://www.top500.org/statistics/perfdevel/

The Green500

Rank	TOP500 Rank	System	Cores	Rmax (PFlop/s)	Power (kW)	Energy Efficiency (GFlops/watts)
1	405	**Henri** - Lenovo ThinkSystem SR670 V2, Intel Xeon Platinum 8362 2800Mhz (32C), NVIDIA H100 80GB PCIe, Infiniband HDR, Lenovo Flatiron Institute United States	5,920	2.04	31	65.091
2	32	**Frontier TDS** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	120,832	19.20	309	62.684
3	11	**Adastra** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Grand Equipement National de Calcul Intensif - Centre Informatique National de l'Enseignement Suprieur (GENCI-CINES) France	319,072	46.10	921	58.021
4	15	**Setonix – GPU** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Pawsey Supercomputing Centre, Kensington, Western Australia Australia	181,248	27.16	477	56.983
5	68	**Dardel GPU** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE KTH - Royal Institute of Technology	52,864	8.26	146	56.491

https://www.top500.org/green500/, Green500 list, November 2022.

How to measure energy efficiency?



Courtesy of David Guyon

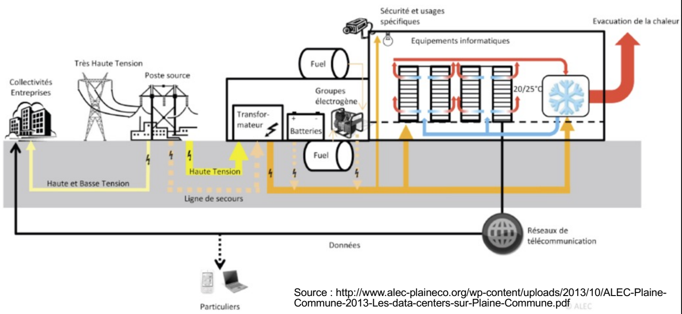
PUE: Power usage effectiveness

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

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

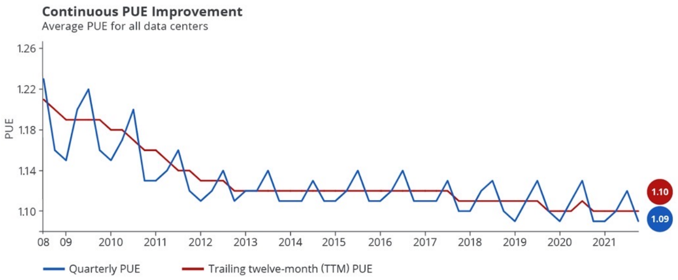
the green grid

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

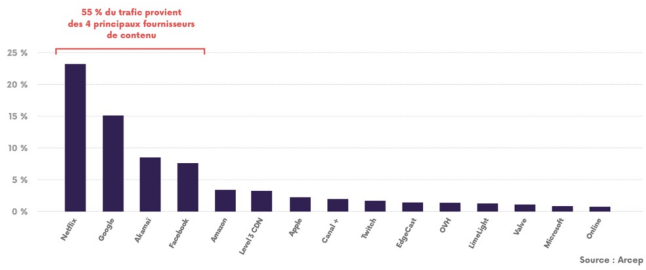
PUE as a selling point: Google case



https://www.google.fr/about/datacenters/efficiency/

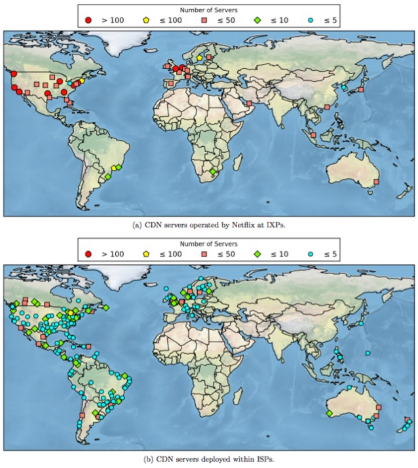
Internet trafic in France

DÉCOMPOSITION SELON L'ORIGINE DU TRAFIC VERS LES CLIENTS DES PRINCIPAUX FAI EN FRANCE (FIN 2019)



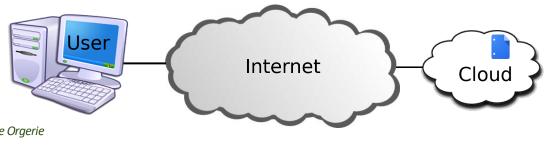
Trafic Internet en France selon l'Arcep en 2019.

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.]

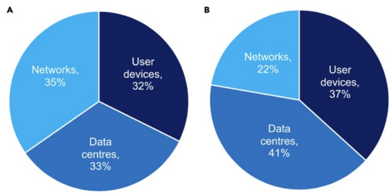
Inside the cloud



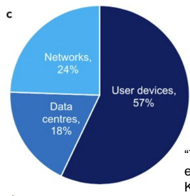
ICT impact ?

- What is ICT carbon impact in comparison with global impact?
- What is carbon impact?

Distribution of ICT energy consumption

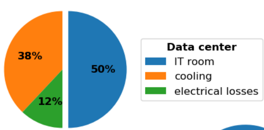


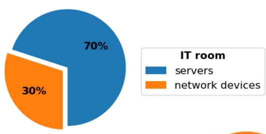
Proportional breakdown of ICT's carbon footprint, excluding TV
(A) Andrae and Edler (2015): 2020 best case (total of 623 $MtCO_2e$).
(B) Belkhir and Elmeligi (2018): 2020 average (total of 1,207 $MtCO_2e$).
(C). Malmodin (2020): 2020 estimate (total of 690 $MtCO_2e$).

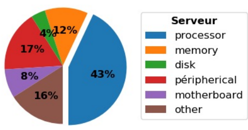


"The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations'', C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. Blair, A. Friday, Patterns, 2021.

Wasted energy



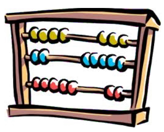




D. Kliazovich, P. Bouvry, and S. U. Khan, "GreenCloud: A Packet-level Simulator of Energy- aware Cloud Computing Data Centers", The Journal of Supercomputing, vol. 62, no. 3, pp. 1263–1283, 2012

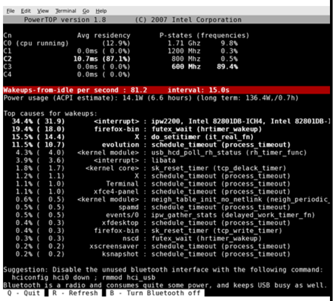
Courtesy of David Guyon

Measuring energy consumption of servers



How to measure energy consumption?

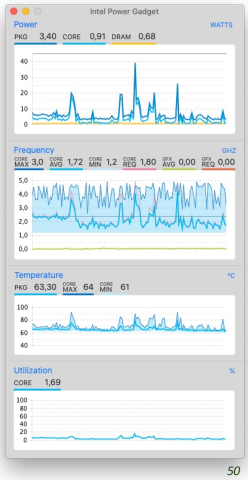
- Power usage per device, per process, per service, per rack?
- Software tools: **powertop**
- Event counters
- Sensors



"*Balancing power consumption in multiprocessor systems*", A. Merkel and F. Bellosa, SIGOPS Oper. Syst. Rev., 2006.

Intel Power Gadget

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



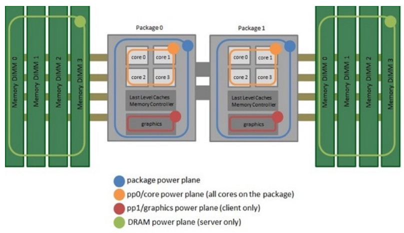
Without wattmeters

PAPI (Performance Application Programming Interface) can read **RAPL (Running Average Power Limit)** values

- Uses software power model, hardware performance counters, temperature, leakage models and I/O models
- Directly accessible or through libraries like *perf* or *likwid*
- Provide energy, temperature, etc.

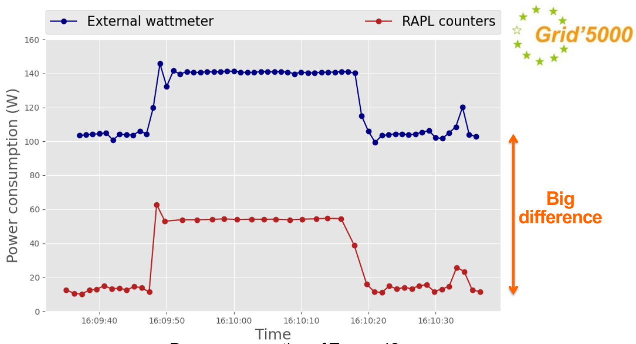
Performing measurements

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

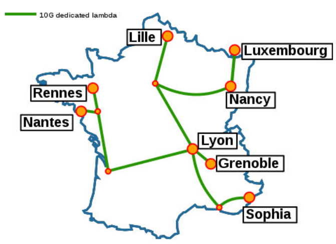


Power consumption of Taurus-12

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

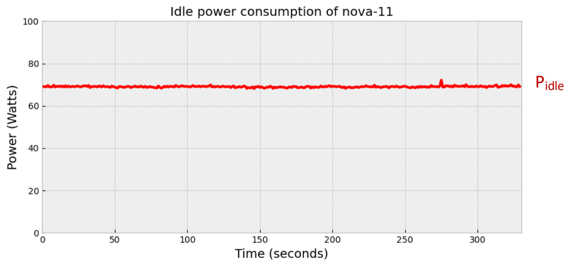
With an example: Grid'5000

- French experimental testbed
- 15,000 cores, 800 servers
- 8 sites
- Dedicated Gb network
- Designed for research on large-scale parallel and distributed systems



Wrong idea #1

Idle server consumes nothing or little.

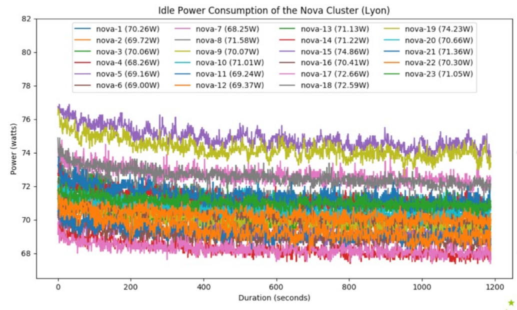


Nova node: 2 x Intel Xeon E5-2620 v4, 8 cores/CPU, 64 GiB RAM, 598 GB HDD (2016)

Grid'5000

Wrong idea #2

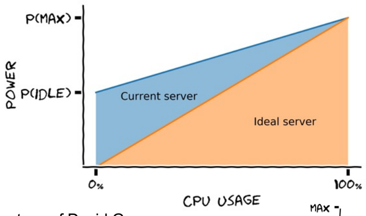
This server model consumes that amount of power.



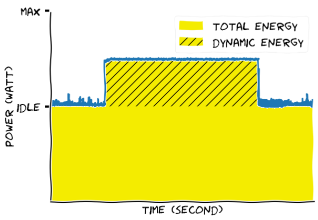
Grid'5000

10% difference in idle and more at maximal consumption.

Ideal server vs. current server

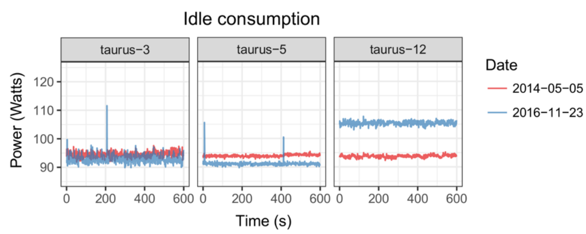


Courtesy of David Guyon



Wrong idea #3

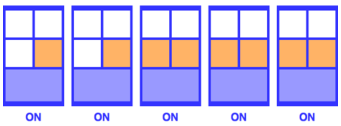
Idle power consumption is stable over time.



[Cluster 2017]

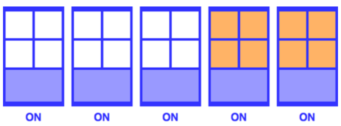
Idle power consumption varies over time.

No chance for naive modeling



Naive model:

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



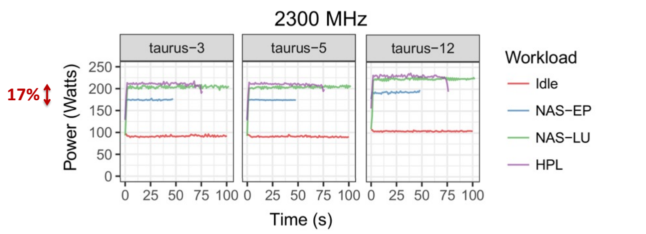
5 x P_{idle} + 8 x $P_{process}$ = *X* Watts

Best configuration for power consumption ?

It depends.

Wrong idea #4

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



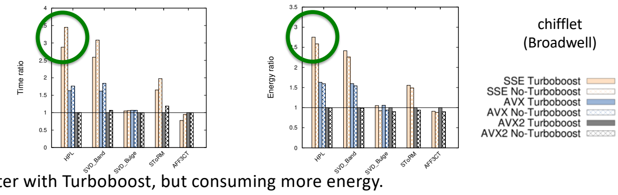
[Cluster 2017]

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

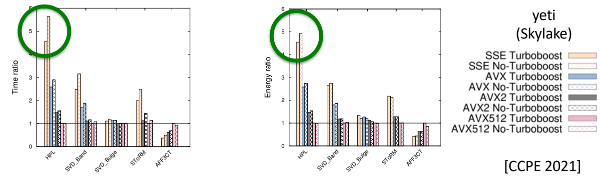
17% difference in consumption for applications fully loading the server.

Wrong idea #5

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



Faster with Turboboost, but consuming more energy.

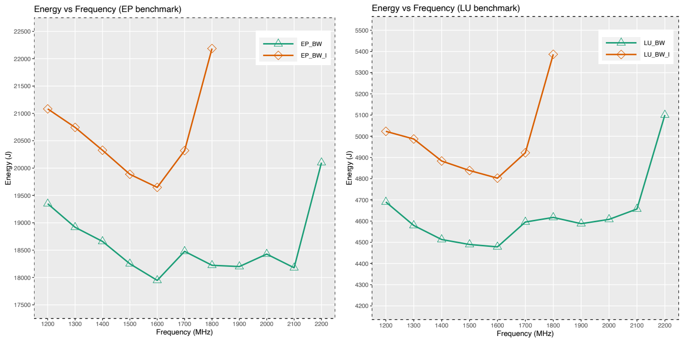


[CCPE 2021]

Faster with Turboboost, and comsuming less energy.

Wrong idea #6

Low power processors consume less energy.



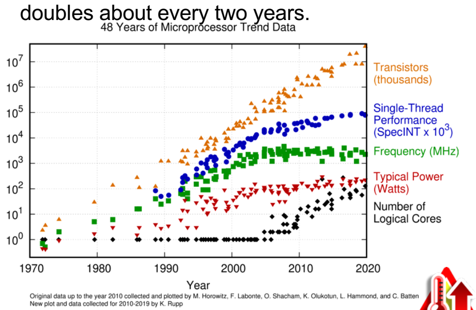
BW_l: Xeon E5-2630L v4 (Broadwell) -> low power processor (orange)
BW: Xeon E5-2630 v4 (Broadwell) (green)

[ISCC 2021]

Wrong idea #7 (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.

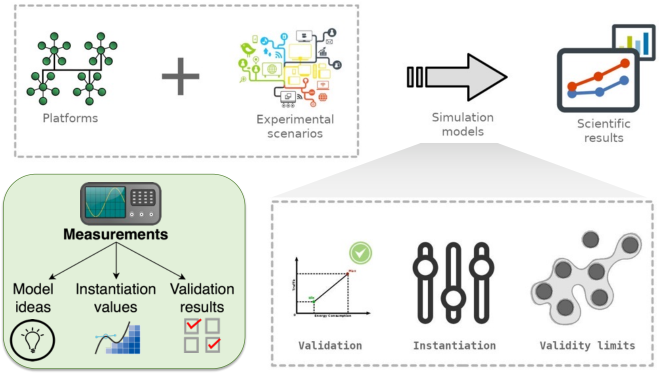


- Increase the processor's frequency
- Increase the number of cores per processor
- Increase the fineness of processor engraving

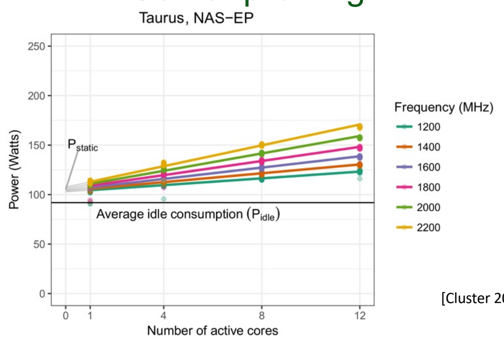
Physical limits.

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

Simulating energy consumption



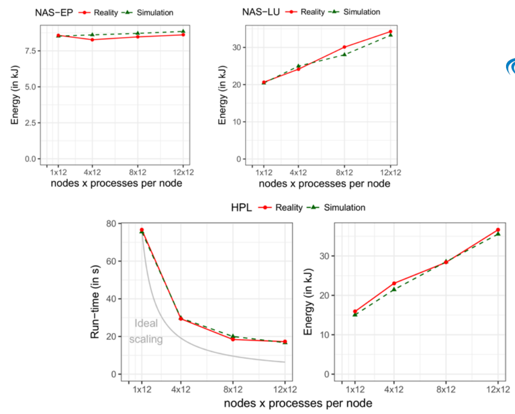
Server profiling



[Cluster 2017]

To do for each computing kernel.
At each frequency.
And each time we want to compare the model to real life.

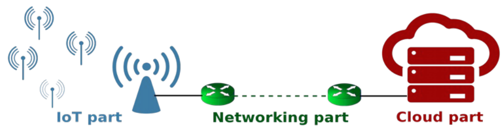
Simulating server clusters



[Cluster 2017]

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

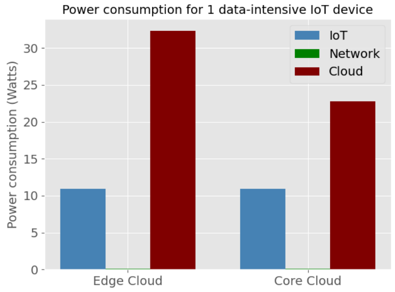
Power consumption of IoT



[FGCS 2018]

Tradeoff between:
- Performance
- Application accuracy
- Energy consumption

It depends.



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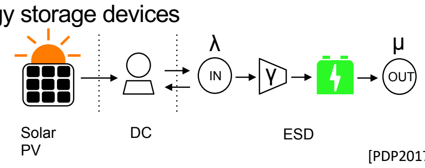
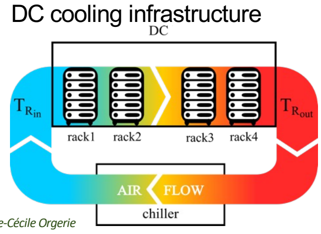
Other simulation models

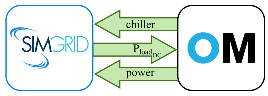
- Energy storage devices



[PDP2017]

- DC cooling infrastructure





[PADS 2018]

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Models and simulation tools for what?

Capacity and energy planing

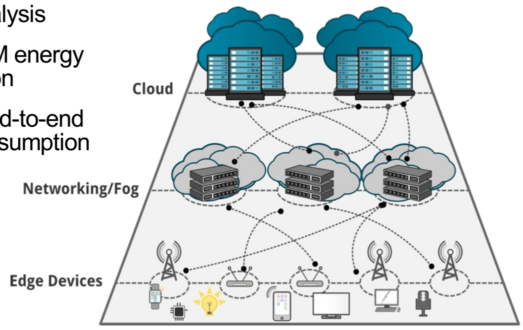
What-if scenarios

Algorithm analysis

Estimating VM energy consumption

Estimating end-to-end energy consumption

Closing doors



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Saving energy

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big.LITTLE architecture

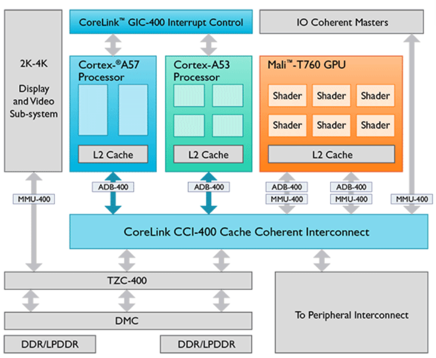

Fig. 3: Block diagram of a big.LITTLE System on Chip design representation

https://www.arm.com/products/processors/technologies/biglittleprocessing.php

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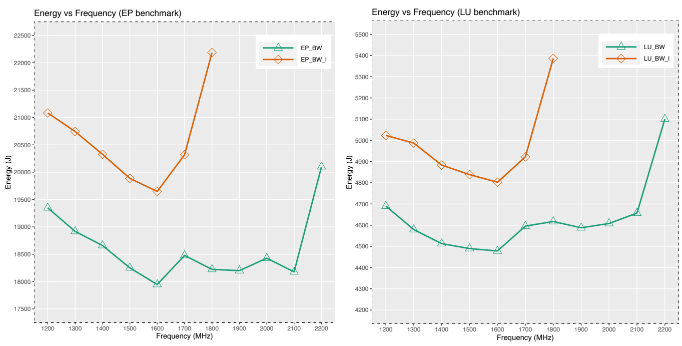
CPU frequencies and energy



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

BW: Xeon E5-2630 v4 (Broadwell) (green)

[ISCC 2021]

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Switching off

Idea: adapt the set of active resources to the load

Issues:
- Does it reduce the life time of resources?
- How to switch resources on again?
- How much time does it take to switch?
- Switch off or sleep?
- Does the middleware consider the resources as dead?

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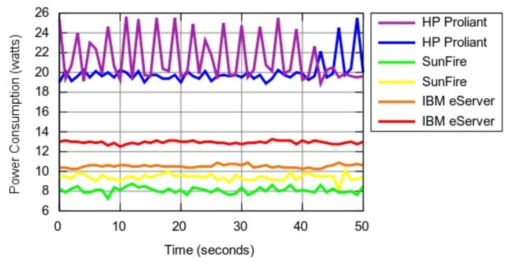
Does a switched off node consume energy?



"*Demystifying Energy Consumption in Grids and Clouds*", A.-C. Orgerie et al., WIPGC, 2010.

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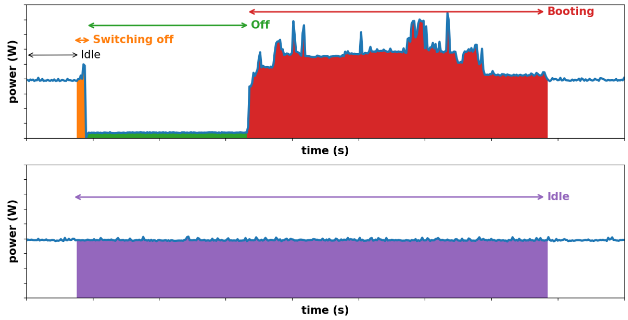
When can we switch off?



$$T_s = \frac{E_s - P_{OFF}(\delta_{ON\rightarrow OFF} + \delta_{OFF\rightarrow ON}) + E_{ON\rightarrow OFF} + E_{OFF\rightarrow ON}}{P_I - P_{OFF}}$$

"*Towards Energy Aware Reservation Infrastructure for Large-Scale Experimental Distributed Systems*", A.-C. Orgerie et al., Parallel Processing Letters, 2009.

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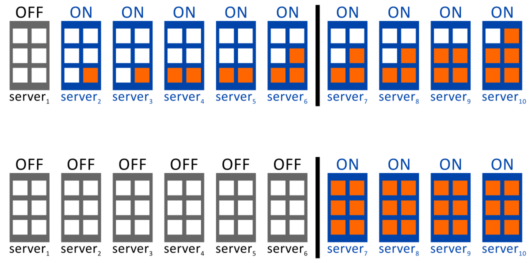
Let's consolidate the workload

Before Consolidation

After Consolidation



[Book chapter 2018]

Bin-packing problem.
Dynamic workload.

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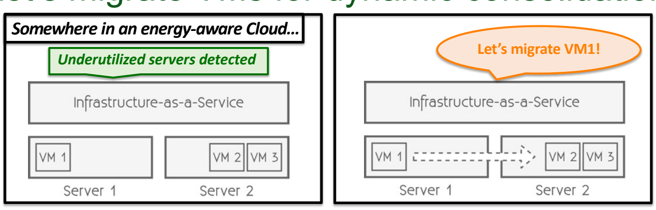
Let's migrate VMs for dynamic consolidation



[IC2E 2018]

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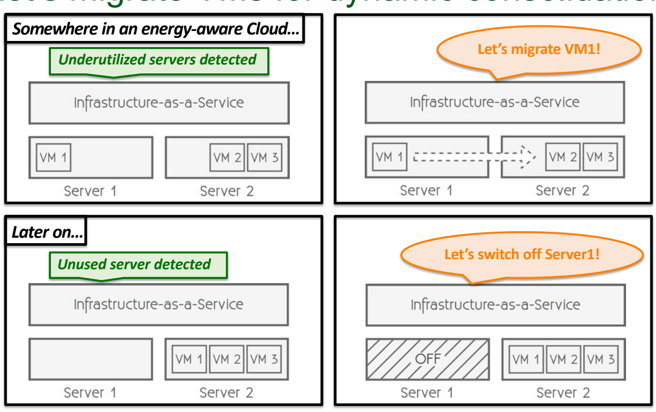
Let's migrate VMs for dynamic consolidation



[IC2E 2018]

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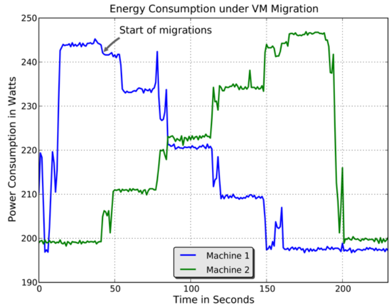
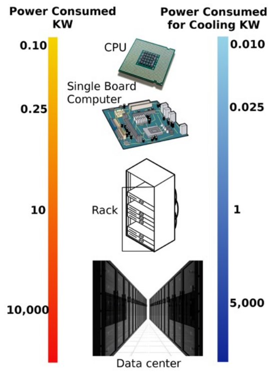
Exploiting live-migration capabilities

Idea: migrating virtual machines to consolidate the load on the fewer number of physical resources



"*Energy Aware Clouds*", A.-C. Orgerie et al., book chapter in *Grids, Clouds and Virtualization*, Springer, 2010.

Saving energy



Low power processors (big.LITTLE)

Multi-core architectures

Energy-efficient dedicated architectures (FPGA, **GPU**)

Dynamic Voltage Frequency Scaling

Workload consolidation techniques

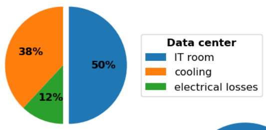
On/off policies

Hot spot management

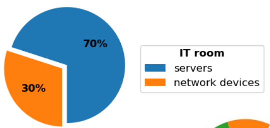
Workload peak reduction

Dynamic adaptation

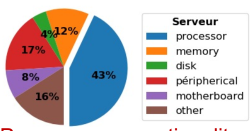
Wasted energy at all levels



Cooling
Power generators
Batteries
…



Unused servers
Overprovisioning
Redundancy
…

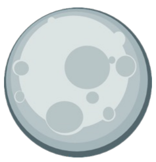


Power non-proportionality
Dark silicon
Unused components
…

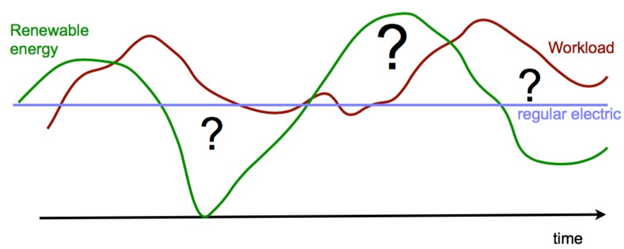
Greening data centers

Follow-the-* approaches

- Follow the moon: free cooling with air from outside during cool days, and on hot weather days, computing load is shifted to other data centers
- Follow the sun/wind: use renewable energy sources

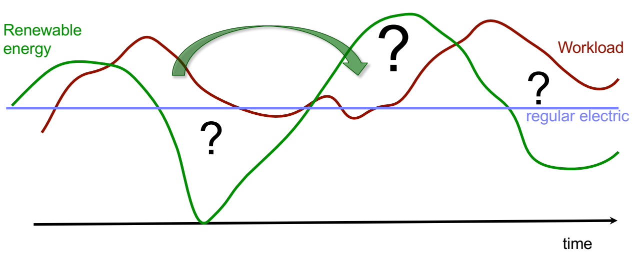


Problem

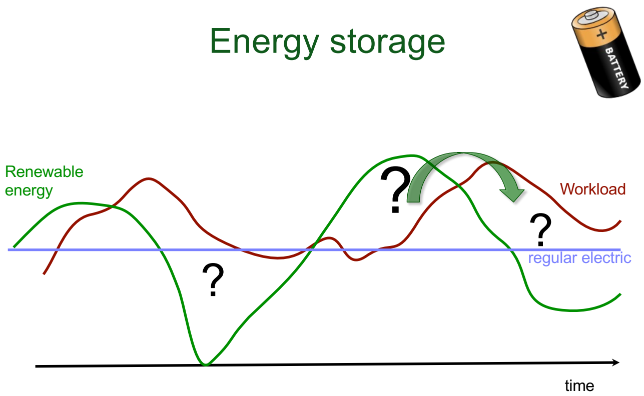


Courtesy of Jean-Marc Menaud

Opportunistic scheduling



Energy storage



Let's use multiple data centers

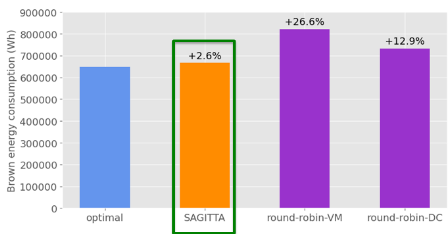
[SBAC-PAD 2018]

- Consumes energy on both locations during the migration
- Uses the telecommunication network (possible bottleneck)
- Needs to avoid oscillation effects (weather prediction)

Designing energy efficient algorithms

5 DCs with 20 homogeneous servers each, no migration

Optimal solution (dynamic programming algorithm) => 2 weeks of computation on 30 Grid'5000 servers



SAGITTA is close to the optimal solution.

[Chapter2018]

VM migration algorithm

1. **Pre-allocation**: incoming VM requests `Best-fit`

   [...] `Expected value`

2. **Migration**: moving running VMs between DCs with network constraints

   a. Evaluate energy costs (VM migrations) and gains (expected remaining green energy on DCs) `Expected value`

   b. Schedule the VM migrations between DCs `Best-fit` `Dichotomy`

3. **Consolidation**: packing VMs inside DCs

4. **Allocation**: actually send the commands to the servers

   a. Switch ON/OFF servers

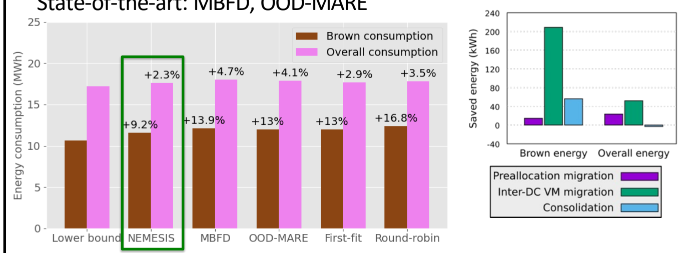
   b. Deploy and migrate the VMs

Energy-efficient algorithm dissection

9 DCs and 1,035 servers in total

Theoretical lower bound => best-fit on a single DC

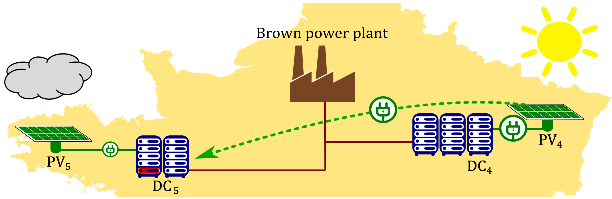
State-of-the-art: MBFD, OOD-MARE



Simulation tools allow for algorithm dissection

[SBAC-PAD2018]

Migrating energy?



[Cluster 2018, ISGT 2018]

Using **Smart Grids** capabilities:

- Increasing the share of renewables in the energy mix
- **Collective self-consumption**

Cost for using the electrical network (accounting for power losses, equipment aging, Grid services, etc.)

A real example

Apple's North Carolina iCloud data center

40 MW (max) of power

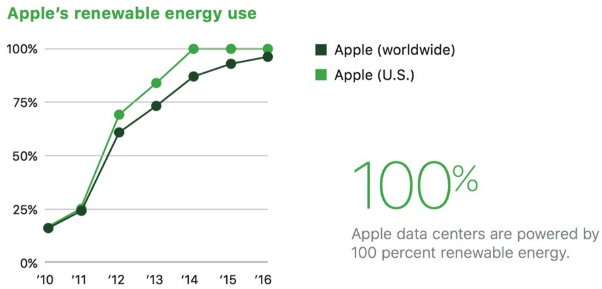
Apple Environmental Responsibility Report, 2017.

Renewable energy

- two 20 MW and one 18 MW solar arrays
- one 10 MW biogas fuel cells
- producing 244 million kWh annually
- daily on-site production: 60-100% of facility's consumption

Around 450 acres (1,800,000 m^2) needed for solar farms

Apple Environmental Responsibility Report 2016



In just six years, Apple's use of renewable energy to power its corporate facilities, retail stores, and data centers worldwide went from 16 percent in 2010 to 96 percent in 2016.

https://images.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2017.pdf

How is this possible?

The Truth About Apple's '100% Renewable' Energy Usage

Alex Epstein, Forbes, January 2016.

http://tinyurl.com/yc3r7c73

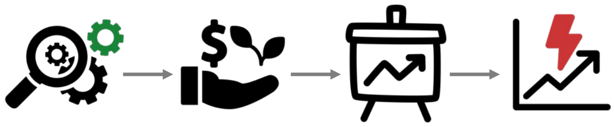
Apple pays off consumers and other companies to give it 'green credits' for its coal electricity usage

To go a bit further

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!

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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.)

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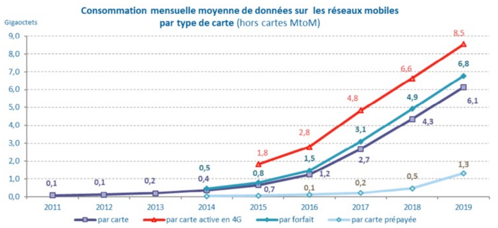
More and more traffic



[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)

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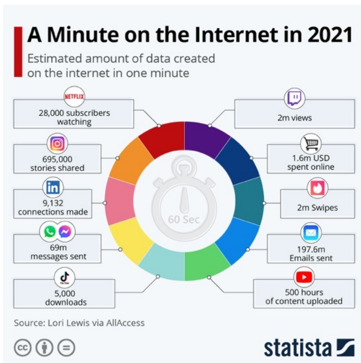
Can we save ICT…



… without changing users' habits?

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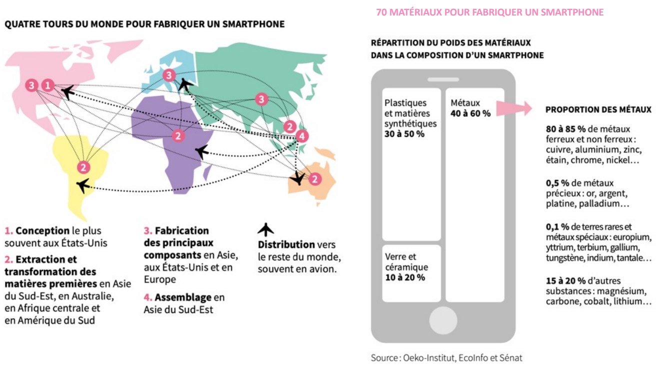
Things more and more indispensable



"Les impacts du smartphone", ADEME, 2019

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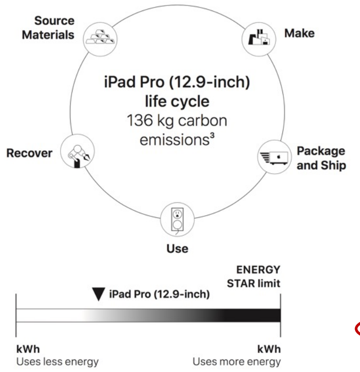
Life cycle of end devices



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.

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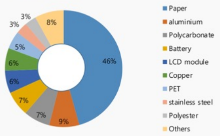
Numerous other environmental impacts

Product Features

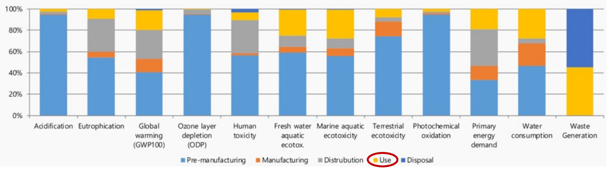
Model name	SM-N950U (Galaxy Note8)
Processor	Qualcomm 2.35GHz, 1.9GHz Octa-Core 64bit
Dimension	162.5 x 74.8 x 8.6 mm
Display	6.3" 2960 x 1440, 16M In-Cell Touch LCD
Battery	Li-Ion 3300 mAh
Camera	12 MP / 5MP
Wt.(g)	186.34g

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

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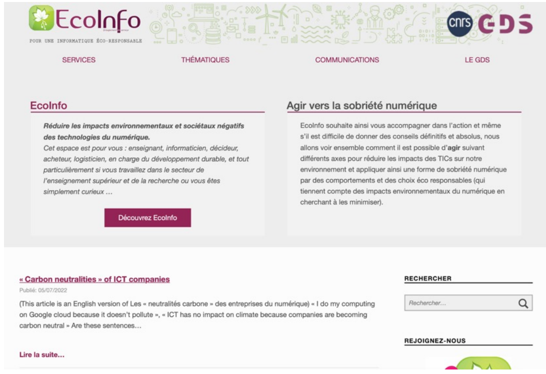
Studying environmental impacts of ICT



https://ecoinfo.cnrs.fr

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Opportunities

	Sobriety
To think differently	*Resilience*
To propose new things	*Low-tech*
To build differently	*Sustainable computing*
To design a sustainable future	*Computational sustainability*

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Thank you for your attention

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

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