Green ICT

Anne-Cécile Orgerie

Lecture, Telecom SudParis
8th October 2021

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

I. Introduction to (not) green ICT
   A. General context
   B. Green computing history

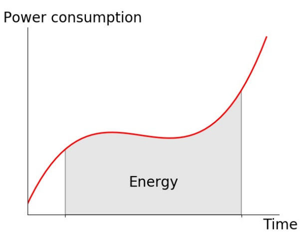
II. Trails to green ICT from my research point of view
   A. Data center level
   B. Measuring energy consumption of servers
   C. Saving energy
   D. Greening data centers

III. Concluding remarks

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

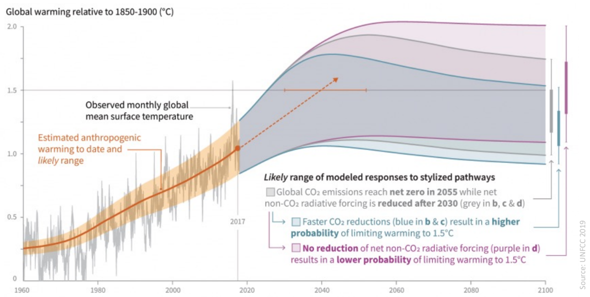


ICT impact ?

- What is ICT carbon impact in comparison with global impact?
- What is carbon impact?
- Which part of the lifecyle of an ICT product has more carbon impact?

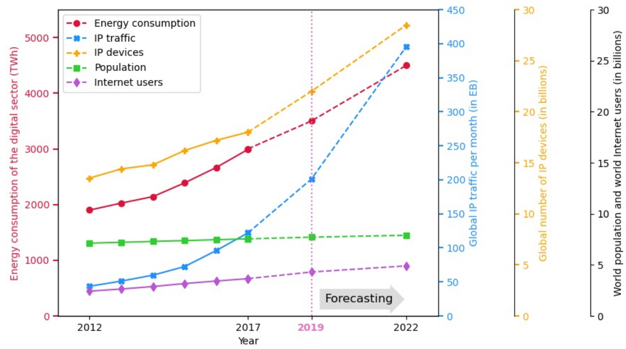
https://app.klaxoon.com/join/JXKBVEY

Paris Agreement: 1.5° C



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

ICT energy consumption

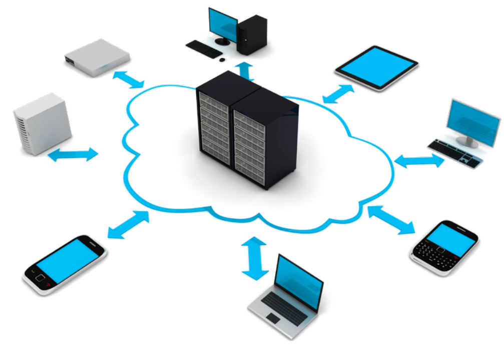


Estimation in 2019: ICT energy consumption grows by **9%** each year.

Rapport Lean ICT : Pour une sobriété Numérique, 2018, https://theshiftproject.org
Cisco Visual Networking Index: Forecast and Methodology [2013—2019].
World Population: Past, Present, and Future *https://www. worldometers.info/world-population* 2019.
International Telecommunication Union, *Measuring the Information Society Report*, 2018.

Computing in the 21st century?

The Cloud

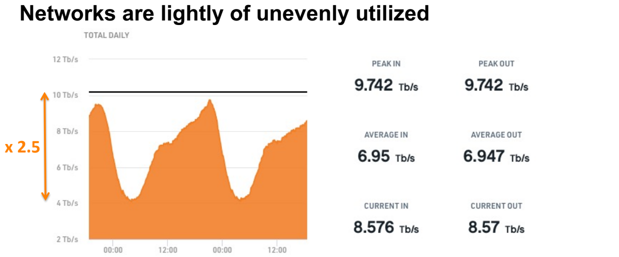


Resource waste

Servers are used 6% on average.

Source: *Revolutionizing Data Center Energy Efficiency*, McKinsey, July **2008**.

Networks are lightly of unevenly utilized



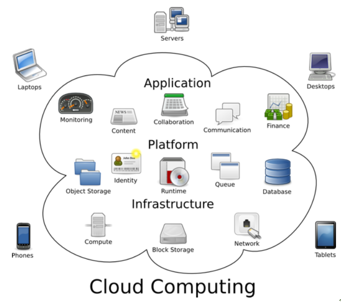
Daily aggregated traffic on AMS-IX(Amsterdam Internet eXchange Point), October 2021.

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



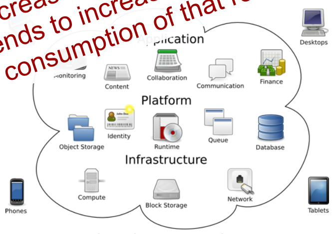
Cloud computing in 1 slide

Cloud computing: access through networks to on-de... self-service, configurable, shared computin...

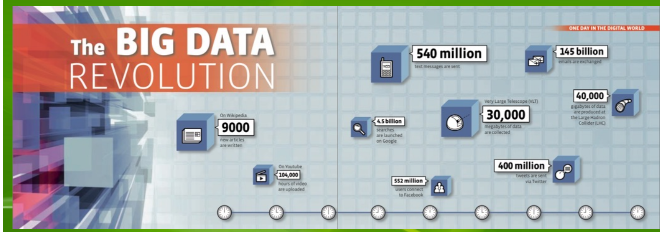
- Mutualization of services
- ...
- ... of data

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



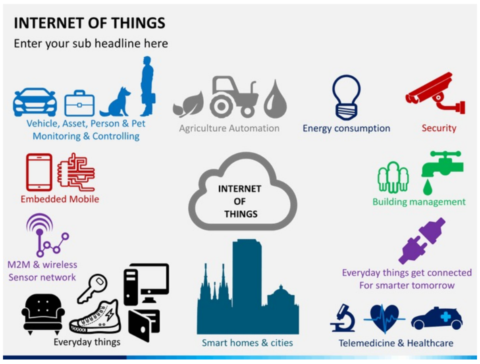
Can we save ICT…



"The Big Data revolution", CNRS Ineternational Magazine, 2013.

… without changing users' habits

Practical Internet of Things

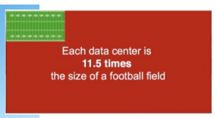


http://www.supinfo.com/articles/single/4235-internet-of-things

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

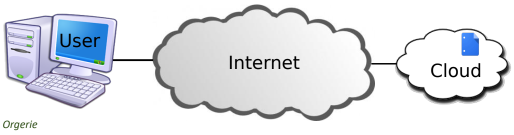
Roubaix site in 2011:
~ 10,000 servers

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

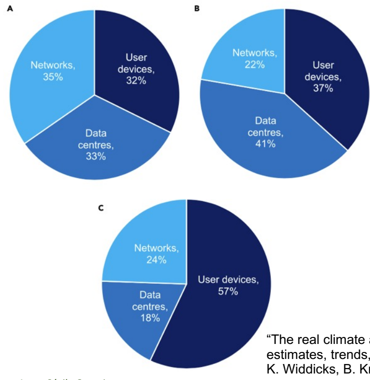
Tests: every 2-3 weeks

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

Inside the cloud



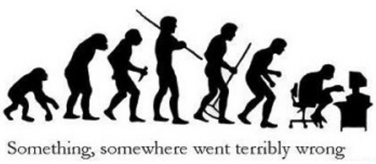
Distribution of ICT energy consumption



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.

Green computing history



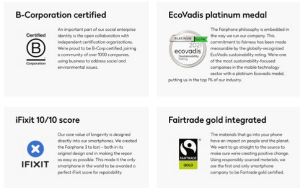
First eco-labels

- 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

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

Fairphone



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

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

Data center level

Let's reduce the heat

- Water-based cooling

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

Let's reduce the heat

- Oil-based cooling

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

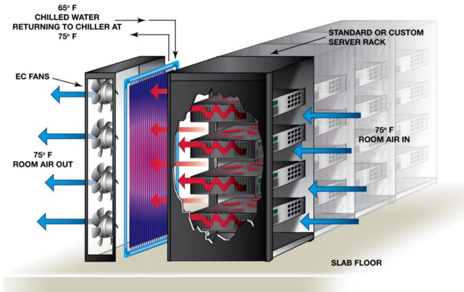
Let's reduce the heat

- 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!

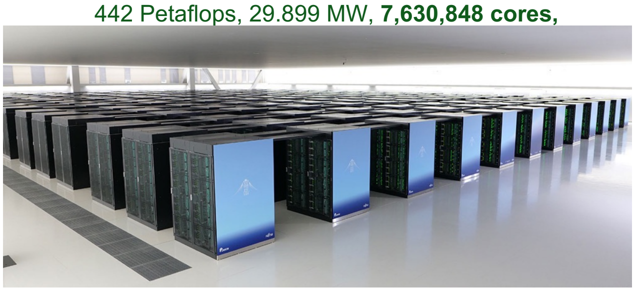
Water tanks capacity:
900,000 liters

Google data center in South Carolina, US

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

N° 1: Fugaku (TOP500 June 2021)

442 Petaflops, 29.899 MW, **7,630,848 cores,**



https://spectrum.ieee.org/tech-talk/computing/hardware/japans-fugaku-supercomputer-is-first-in-the-world-to-simultaneously-top-all-high-performance-benchmarks

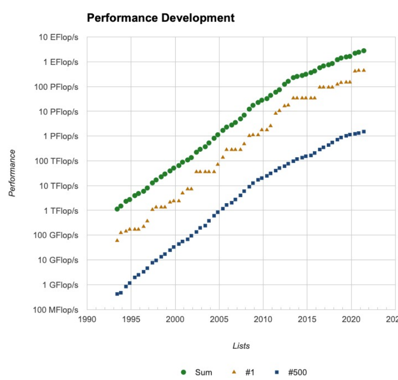
Typical applications:
- Artificial intelligence
- Disaster-prevention simulations
- …

Top500

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu RIKEN Center for Computational Science Japan	7,630,848	442,010.0	537,212.0	29,899
2	**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	148,600.0	200,794.9	10,096
3	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	1,572,480	94,640.0	125,712.0	7,438
4	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
5	**Perlmutter** - HPE Cray EX235n, AMD EPYC 7763 64C 2.45GHz, NVIDIA A100 SXM4 40 GB, Slingshot-10, HPE DOE/SC/LBNL/NERSC United States	706,304	64,590.0	89,794.5	2,528

http://www.top500.org, Top500 list, June 2021.

Performance development



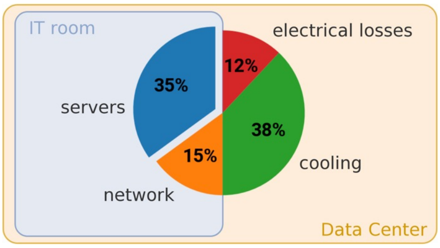
https://www.top500.org/statistics/perfdevel/

The Green500

Rank	TOP500 Rank	System	Cores	Rmax (TFlop/s)	Power (kW)	Power Efficiency (GFlops/watts)
1	335	**MN-3** - MN-Core Server, Xeon Platinum 8260M 24C 2.4GHz, Preferred Networks MN-Core, MN-Core DirectConnect, Preferred Networks Preferred Networks Japan	1,664	1,822.4	61	29.700
2	22	**HiPerGator AI** - NVIDIA DGX A100, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Infiniband HDR, Nvidia University of Florida United States	138,880	17,200.0	583	29.521
3	100	**Wilkes-3** - PowerEdge XE8545, AMD EPYC 7763 64C 2.45GHz, NVIDIA A100 80GB, Infiniband HDR200 dual rail, Dell EMC University of Cambridge United Kingdom	44,800	4,124.0	147	28.144
4	36	**MeluXina - Accelerator Module** - BullSequana XH2000, AMD EPYC 7452 32C 2.35GHz, NVIDIA A100 40GB, Mellanox HDR InfiniBand/ParTec ParaStation ClusterSuite, Atos LuxProvide Luxembourg	99,200	10,520.0	390	26.957
5	214	**NVIDIA DGX SuperPOD** - NVIDIA DGX A100, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Mellanox HDR Infiniband, Nvidia NVIDIA Corporation United States	19,840	2,356.0	90	26.195

https://www.top500.org/green500/, Green500 list, June 2021.

How to measure energy efficiency?



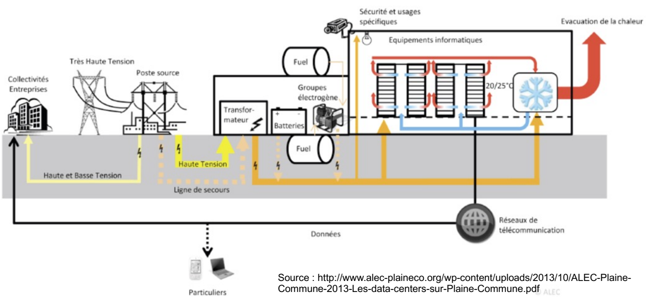
Courtesy of David Guyon

PUE: Power usage effectiveness

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

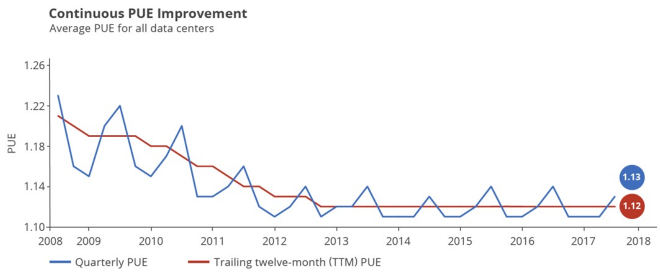
"*Green Grid Data Center Power Efficiency Metrics: PUE and DCIE*", Green Grid White Paper, 2008.

Overall data center view



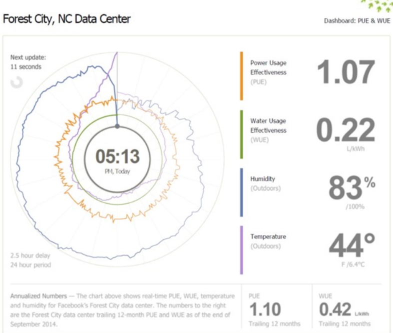
Source : http://www.alec-plaineco.org/wp-content/uploads/2013/10/ALEC-Plaine-Commune-2013-Les-data-centers-sur-Plaine-Commune.pdf

PUE as a selling point: Google case



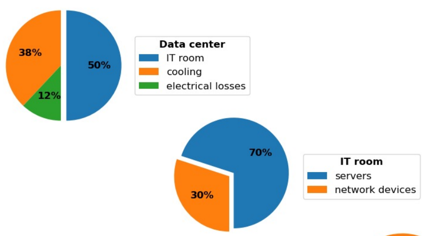
https://www.google.fr/about/datacenters/

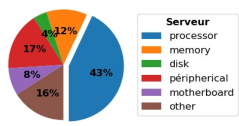
Facebook live dashboard



https://www.facebook.com/ForestCityDataCenter/app_288655784601722

Wasted energy

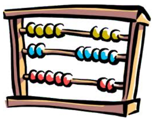




D. Kliazovich, P. Bouvry, and S. U. Khan, "GreenCloud: A Packet-level Simulator of Energy- aware Cloud Computing Data Centers", The Journal of Supercomputing, vol. 62, no. 3, pp. 1263–1283, 2012

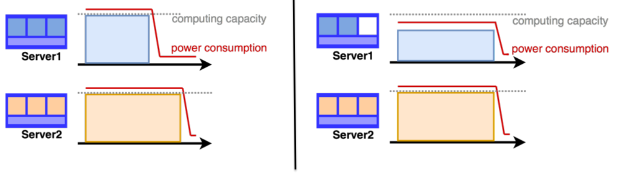
Courtesy of David Guyon

Measuring energy consumption of servers



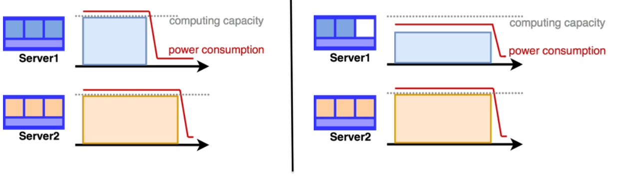
Energy efficiency: business as usual?

Computing faster? *Computing slower?*

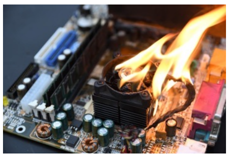


Energy efficiency: business as usual?

Computing faster? *Computing slower?*



Temperature matters.



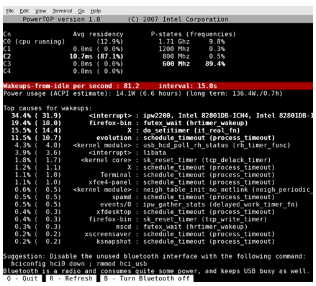
Understanding energy consumption

- Mandatory to optimize the energy consumption of a resource or an application
- Mandatory to simulate or emulate energy consumption
- Other usages:
  - monitoring,
  - forecasting,
  - accounting...

Grid'5000

How to measure energy consumption?

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



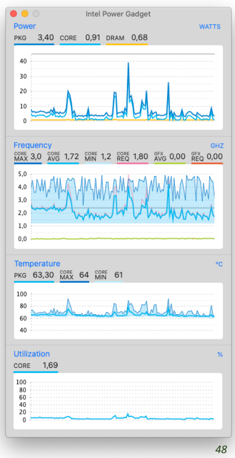
Less Watts. Saving Power with Linux on Intel® Platforms

http://lesswatts.org/projects/powertop/

"*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



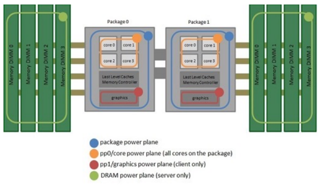
Without wattmeters

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.

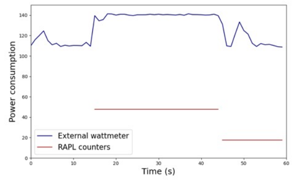
Hardware counters

Intel's RAPL (Running Average Power Limit) interface




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

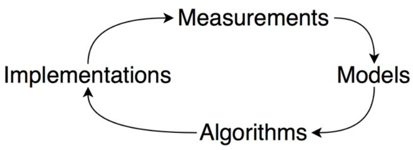
Warning: RAPL counters ignore a **large part** of the power consumption of servers.



Energy consumption: a complex phenomenon

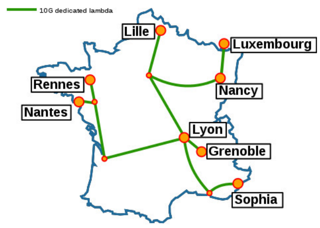
Need for **wattmeters** and sound experimental campaigns

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



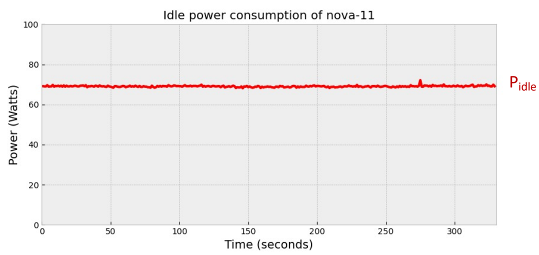
With an example: Grid'5000

- 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

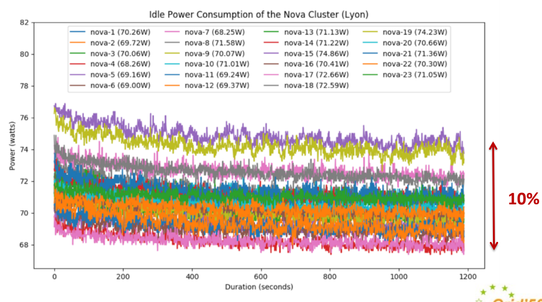
Idle server consumes nothing or little.



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

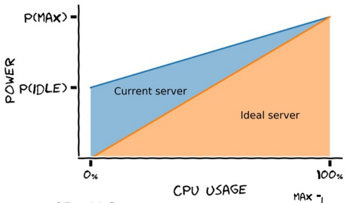
Wrong idea #2

This server model consumes that amount of power.

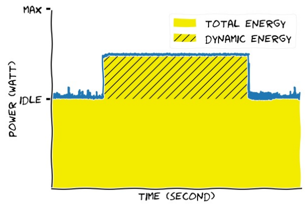


10% difference in idle and more at maximal consumption.

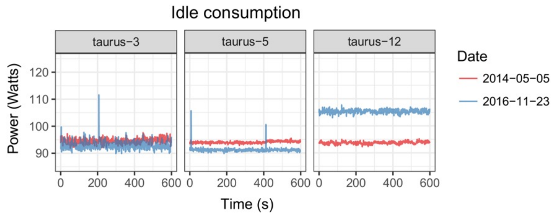
Ideal server vs. current server



Courtesy of David Guyon



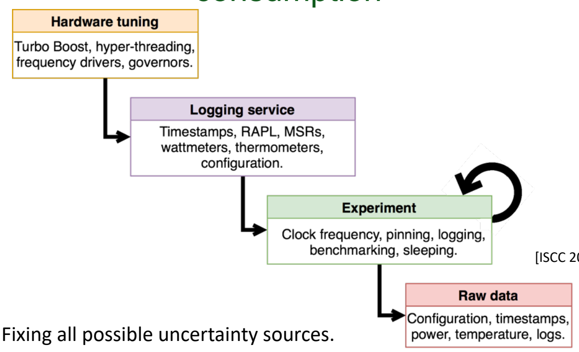
Reproducibility?



[Cluster 2017]

Idle power consumption varies over time.

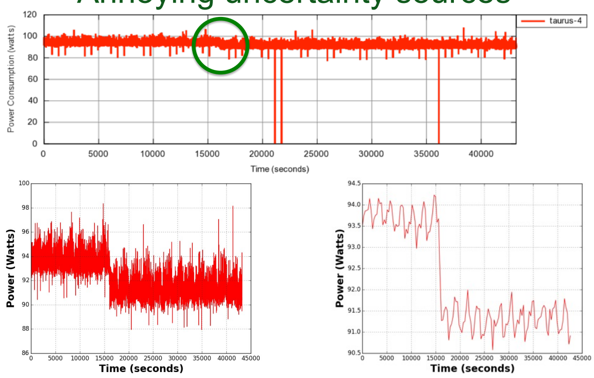
Methodology for measuring server consumption



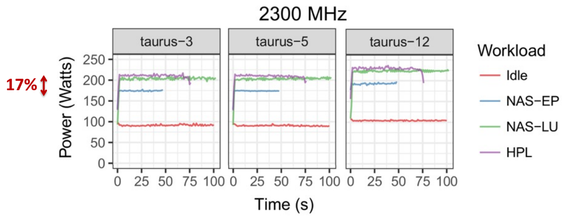
[ISCC 2021]

Fixing all possible uncertainty sources.

Annoying uncertainty sources



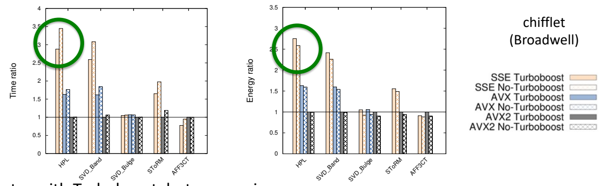
100% CPU utilization?



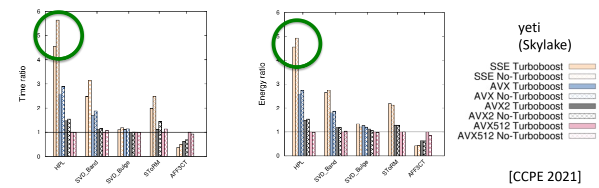
[Cluster 2017]

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

Faster or slower? … It depends.



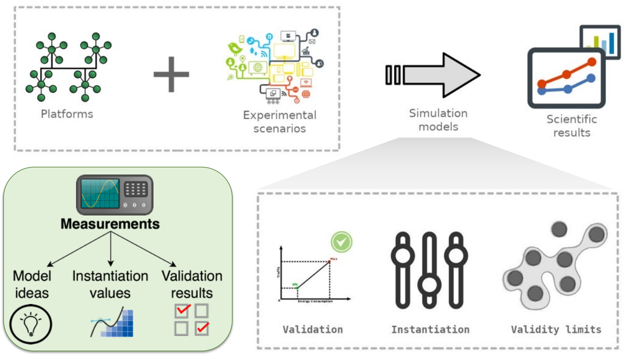
Faster with Turboboost, but consuming more energy.



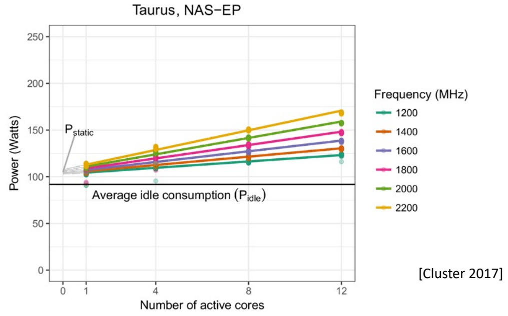
[CCPE 2021]

Faster with Turboboost, and comsuming less energy.

Simulating energy consumption



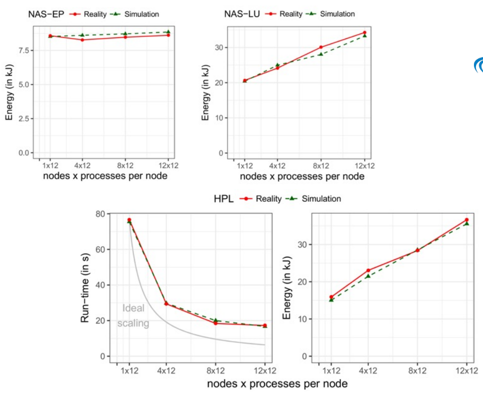
Server profiling



[Cluster 2017]

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

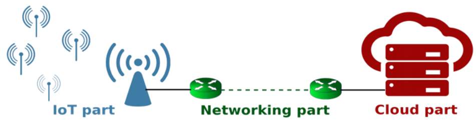
Simulating server clusters



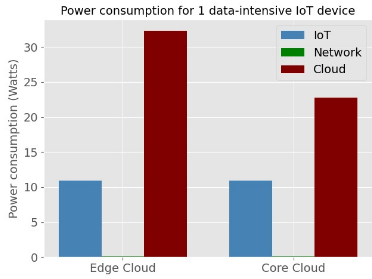
[Cluster 2017]

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

Power consumption of IoT



[FGCS 2018]

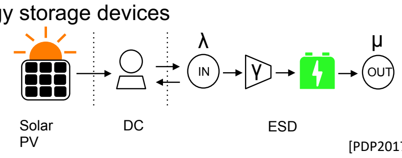


Tradeoff between:
- Performance
- Application accuracy
- Energy consumption

It depends.

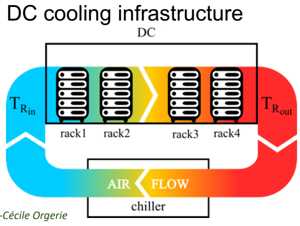
Other simulation models

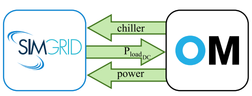
- Energy storage devices



[PDP2017]

- DC cooling infrastructure





[PADS 2018]

Models and simulation tools for what?

Capacity and energy planing

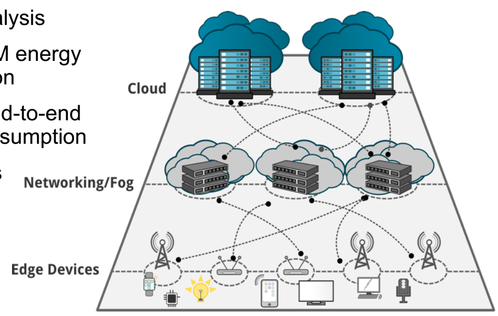
What-if scenarios

Algorithm analysis

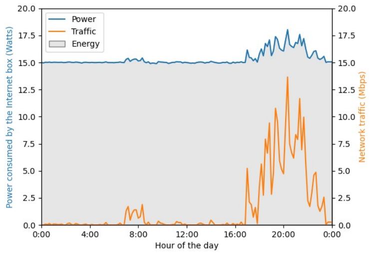
Estimating VM energy consumption

Estimating end-to-end energy consumption

Closing doors



Energy cost of an Internet box?

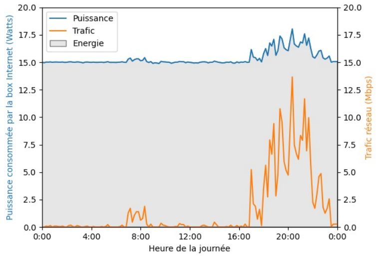


Energy cost in Joules/bit:

$$\text{cost} = \frac{energy}{data\_volume}$$

- When the box is idle, it consumes15 Watts
- At 8am, 15.15 Watts and 0.65 Mbps
- At 8pm, 16.05 Watts and 4.75 Mbps
- At max, 25 Watts and 60 Mbps

Efficiency of an Internet box



Efficiency metrics	Conditions	µJoules/bit
Instantaneous dynamic cost	At 8am, 0.15 Watts 0.65 Mbps	**0.23**
Instantaneous overall cost	At 8am, 15.15 Watts 0.65 Mbps	**23.3**
	At 8pm, 16.05 Watts 4.75 Mbps	**3.38**
Dayly overall cost	On average, 15.35 Watts 1.55 Mbps	**9.9**
Overall minimal cost	At max, 25 Watts 60 Mbps	**0.42**

Two orders of magnitude

Internet energy intensity

Estimates for the energy demand of Internet transmissions.

Study	Method	System boundary			Data for	Energy intensity
		Networking equipment	Optical fibers	End devices		
Koomey et al. (2004)	Top-down	X	X	X	2000	<136 kWh/GB
Taylor and Koomey (2008)	Top-down	X	X	X	2006	8.8–24.3 kWh/GB
Weber et al. (2010)	Top-down	X	X	X	2008	7 kWh/GB
Pickavet et al. (2008)	Top-down	X	X		2008	1.8 kWh/GB[a]
Lanzisera et al. (2012)	Top-down	X			2008	0.39 kWh/GB[a]
Baliga et al. (2007)	Model-based	X	X		2007	0.7–2.1 kWh/GB[a]
Baliga et al. (2009)	Model-based	X	X		2008	>0.179 kWh/GB
Baliga et al. (2011)	Model-based	X	X		2011 (?)	0.006 kWh/GB
Schien et al. (2012)	Bottom-up	X	X		2009	0.057 kWh/GB[a]
Coroama et al. (2013)	Bottom-up	X	X		2009	<0.2 kWh/GB

[a] Calculated by the authors based on the results provided in the cited study.

"Estimates published over the last decade diverge by up to four orders of magnitude — from 0.0064 kilowatt-hours per gigabyte (kWh/GB) to 136 kWh/GB."

"Assessing Internet energy intensity: A review of methods and results", V. Coroama, L. Hilty, Environmental Impact Assessment Review, 2014.

Saving energy

big.LITTLE architecture

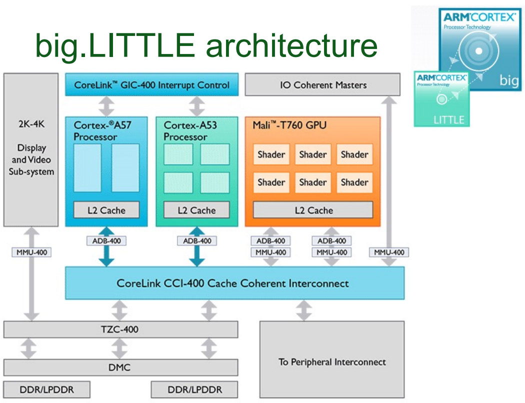
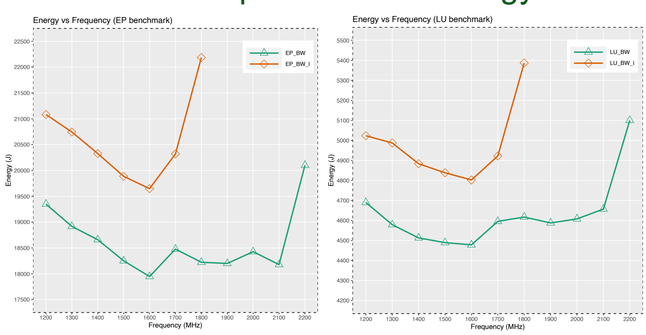


Fig. 3: Block diagram of a big.LITTLE System on Chip design representation

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

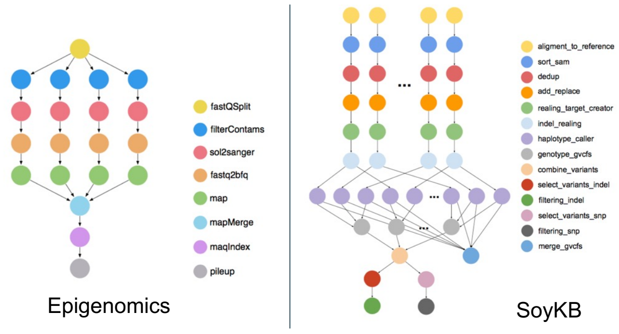
CPU frequencies and energy



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

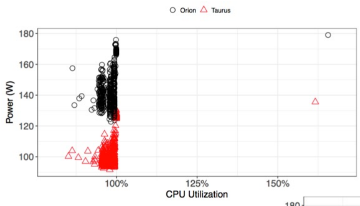
[ISCC 2021]

Bioinformatics applications



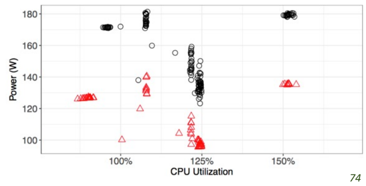
https://pegasus.isi.edu

Task power consumption vs. CPU utilization



- **Taurus**: 2 Intel Xeon E5-2630 (12 cores), 32 GB RAM, 600 GB HDD
- **Orion**: 2 Intel Xeon E5-2630 (12 cores), 32 GB RAM, 600 GB HDD, *Nvidia Tesla M2075*

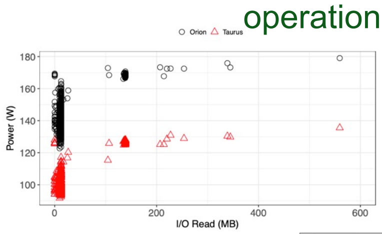
SoyKB



Grid'5000

[ICCS 2019]

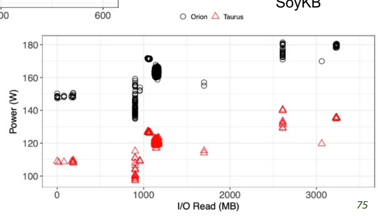
Task power consumption vs. I/O operations



- **Taurus**: 2 Intel Xeon E5-2630 (12 cores), 32 GB RAM, 600 GB HDD
- **Orion**: 2 Intel Xeon E5-2630 (12 cores), 32 GB RAM, 600 GB HDD, *Nvidia Tesla M2075*

Epigenomics

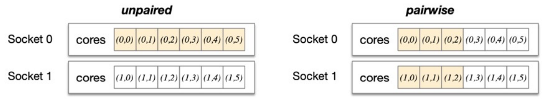
SoyKB

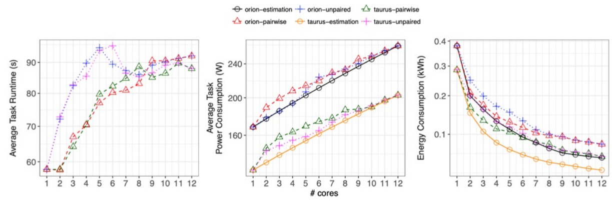


Grid'5000

[ICCS 2019]

Process placement onto cores





[JOCS 2020]

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

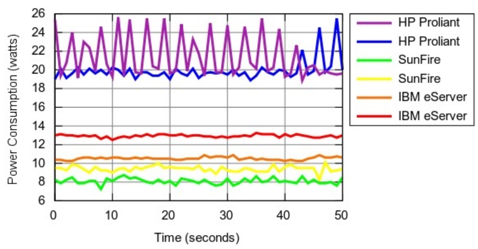
Switching off

Idea: adapt the set of active resources to the load

Issues:

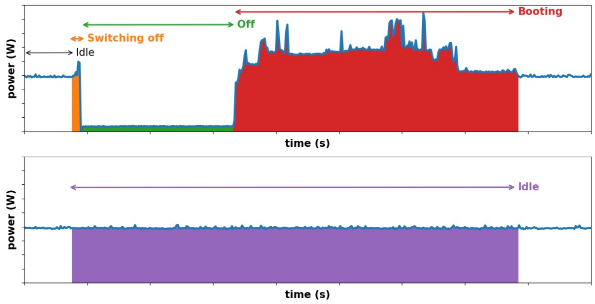
- Does it reduce the life time of resources?
- How to switch resources on again?
- How much time does it take to switch?
- Switch off or sleep?
- Does the middleware consider the resources as dead?

Does a switched off node consume energy?



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

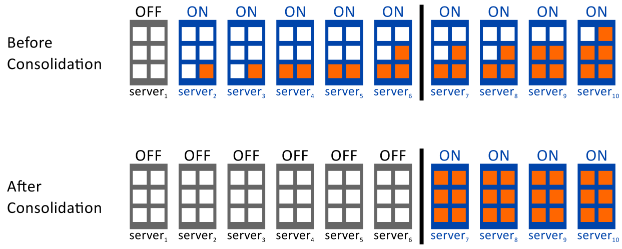
When can we switch off?



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

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

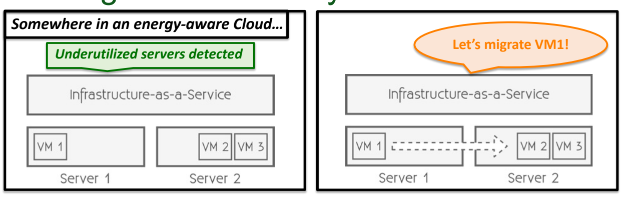
Let's consolidate the workload



[Book chapter 2018]

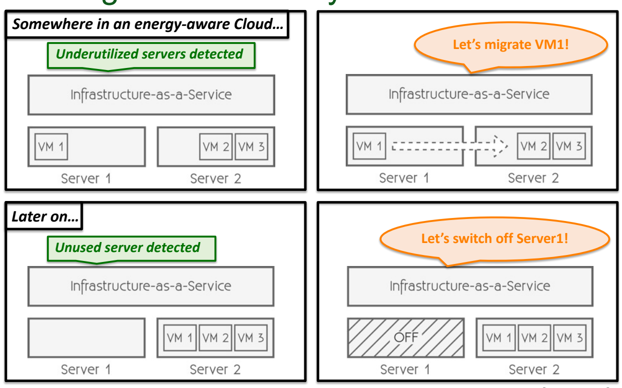
Bin-packing problem.
Dynamic workload.

Let's migrate VMs for dynamic consolidation



[IC2E 2018]

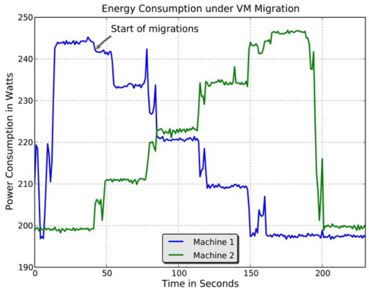
Let's migrate VMs for dynamic consolidation



[IC2E 2018]

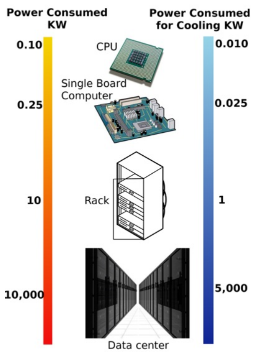
Exploiting live-migration capabilities

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



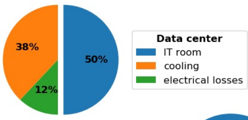
"*Energy Aware Clouds*", A.-C. Orgerie et al., book chapter in *Grids, Clouds and Virtualization*, Springer, 2010.

Saving energy

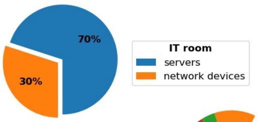


- Low power processors (big.LITTLE)
- **Multi-core architectures**
- Energy-efficient dedicated architectures (FPGA, **GPU**)
- **Dynamic Voltage Frequency Scaling**
- **Workload consolidation techniques**
- **On/off policies**
- Hot spot management
- **Workload peak reduction**
- **Dynamic adaptation**

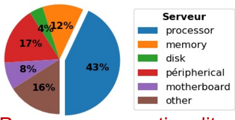
Wasted energy at all levels



Cooling
Power generators
Batteries
…



Unused servers
Overprovisioning
Redundancy
…

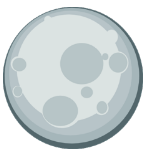


Power non-proportionality
Dark silicon
Unused components
…

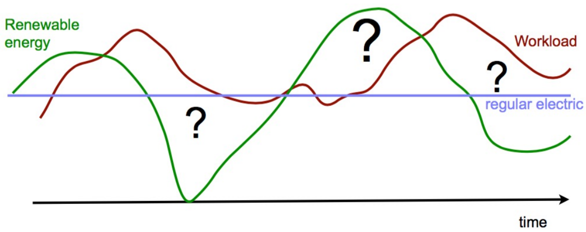
Greening data centers

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

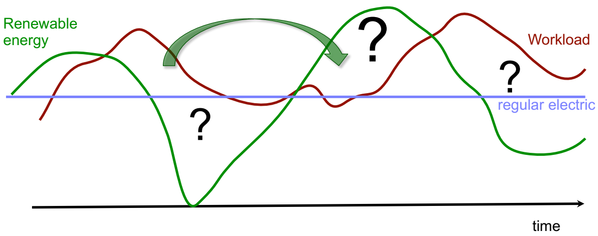


Problem

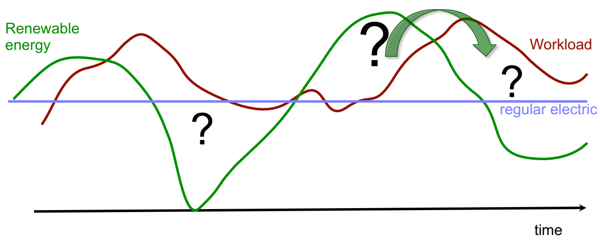


Courtesy of Jean-Marc Menaud

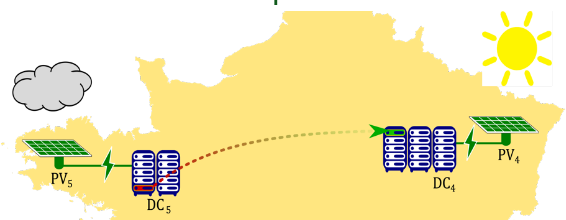
Opportunistic scheduling



Energy storage



Let's use multiple data centers



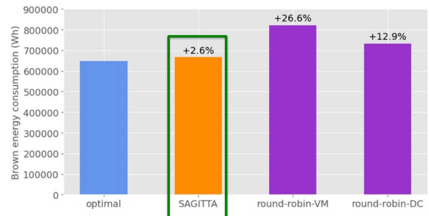
[SBAC-PAD 2018]

- 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`

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

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

   a. Switch ON/OFF servers

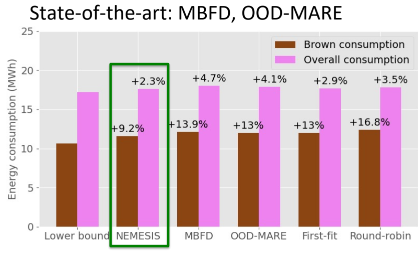
   b. Deploy and migrate the VMs

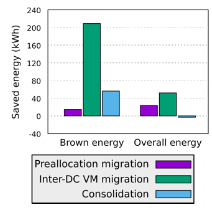
Energy-efficient algorithm dissection

9 DCs and 1,035 servers in total

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

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

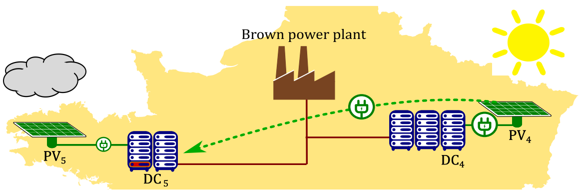




Simulation tools allow for algorithm dissection

[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

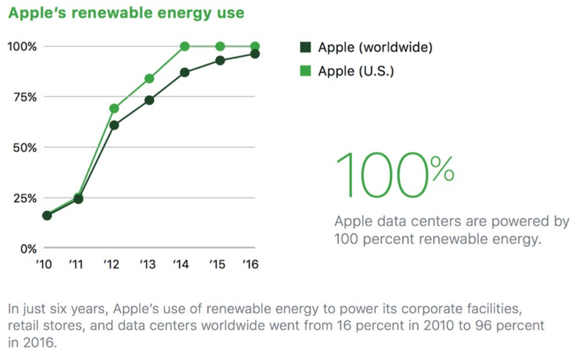
40 MW (max) of power

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



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

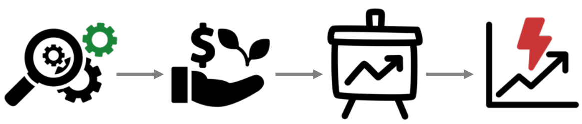
Apple pays off consumers and other companies to give it 'green credits' for its coal electricity usage

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, smart buildings, etc.
- **Green ICT**
  - Reduction of the ICT's environmental footprint
  - E.g. energy-aware data centers

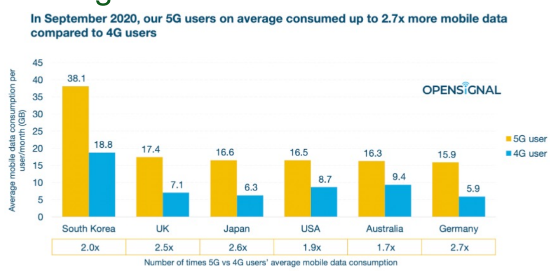
Increasing energy efficiency ≠ reducing consumption



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

Beware of rebound effects!

Larger networks ⟹ more traffic



Source: https://www.opensignal.com/2020/10/21/5g-users-on-average-consume-up-to-27x-more-mobile-data-compared-to-4g-users

Higher bandwidths, higher data volumes,
which impacts on infrastructures?

The (in)dispensable weather toaster

In 2017: 5 connected devices / person
20 billion devices worldwide.

Forrester Research, "*Connected devices forecast, 2012 to 2017*", white paper, 2013.

The smart frying pan

Assisteo, Tefal, 2017.

In 2017: 5 connected devices / person
20 billion devices worldwide.

Forrester Research, "*Connected devices forecast, 2012 to 2017*", white paper, 2013.

Questioning promises and uses

The Korea Herald

More than half a million 5G network users returned to 4G: report

By Shim Woo-hyun — Published : Oct 7, 2020 - 17:24 Updated : Oct 7, 2020 - 17:24

The number of 5G network **users who returned to 4G** network services has surpassed half a million -- 562,656 users who downgraded from their 5G subscriptions -- accounts for **6.5 percent of the total 5G network subscribers in South Korea**, according to the report by Rep. Hong Jung-min, who belongs to the Science, ICT, Broadcasting and Communications Committee at the National Assembly.

The lawmaker pointed out that many 5G users have gone back to the lower-speed network service as the **high-priced** new network system failed to offer quality **connection** and **coverage**.

Complete life-cycle

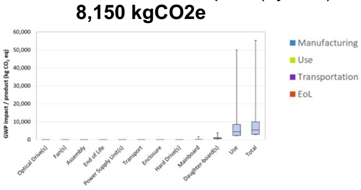
- 1.4 billion smartphones sold in 2015.
- Average life duration of first-hand smartphones < 2 years in 2015.

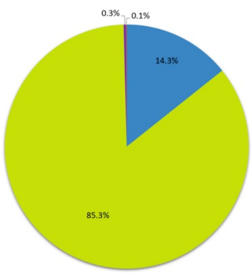
A. Scarsella, W. Stofega, "Worldwide Smartphone Forecast Update , 2015-2019", IDC report, 2015.

Full life cycle of servers

Dell PowerEdge R430 (Nova cluster)

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



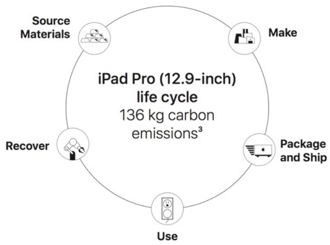


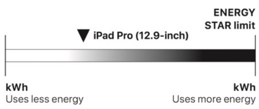
Assumptions for calculating product carbon footprint:

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

Source: Dell PowerEdge R430 carbon footprint, 2019.

Life cycle of end devices



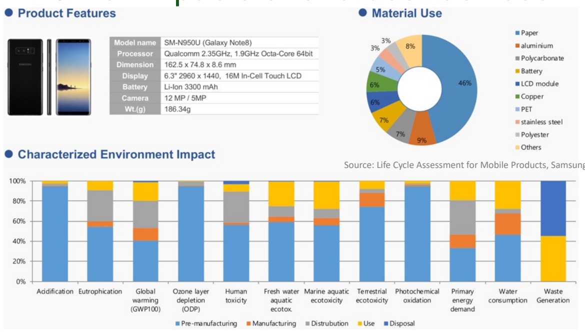


iPad Pro (12.9-inch) life cycle carbon emissions

83% Production
11% Transport
6% Use — *4 years of use*
<1% End-of-life processing

Source: Product environmental report, Apple, 2018.

Other impacts of end-user devices

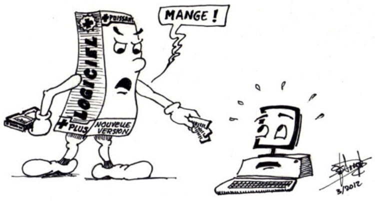


Source: Life Cycle Assessment for Mobile Products, Samsung, 2018.

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

User = person responsible

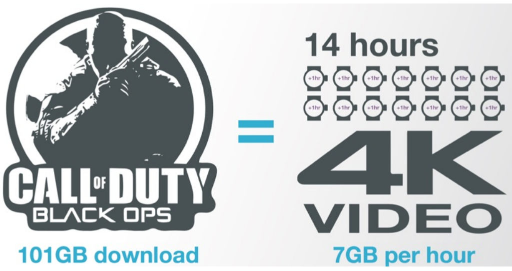


- Bloatware
- Obsolescence

In 2014, on average, 35 applications installed per smartphone, among which: 11 are used every week and 12 are never used.

Harris Interactive, 2015

Video games



Video games purshased on download
Do not fit on DVD any more (nor on floppy disk)
Network-hungry

[Source : Sandvine, The Global Internet Phenomena Report, 2018.]

What else?

What you can do

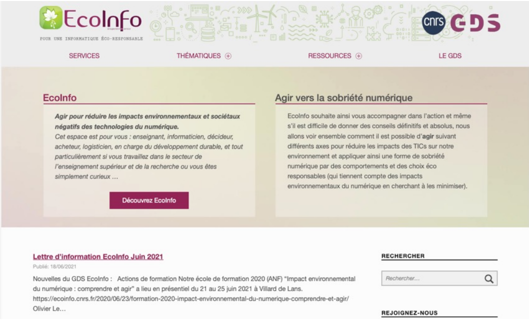
Completely switch off unused devices
Remove unused applications
Erase useless (old) emails, photos, etc.
Be careful when coding (image size, active loops, etc.)
Look at eco-labels when buying new equipment
Keep devices longer if they are still working
Avoid capability overlap
Stay energy-aware…

Opportunities

To think differently
To propose new things
To build differently
To design a sustainable future

Sobriety
Resilience
Low-tech
Sustainable computing
Computational sustainability

Studying environmental impacts of ICT



https://ecoinfo.cnrs.fr

Thank you for your attention

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