Teaching Computers and the Environment: Between modesty and ambition

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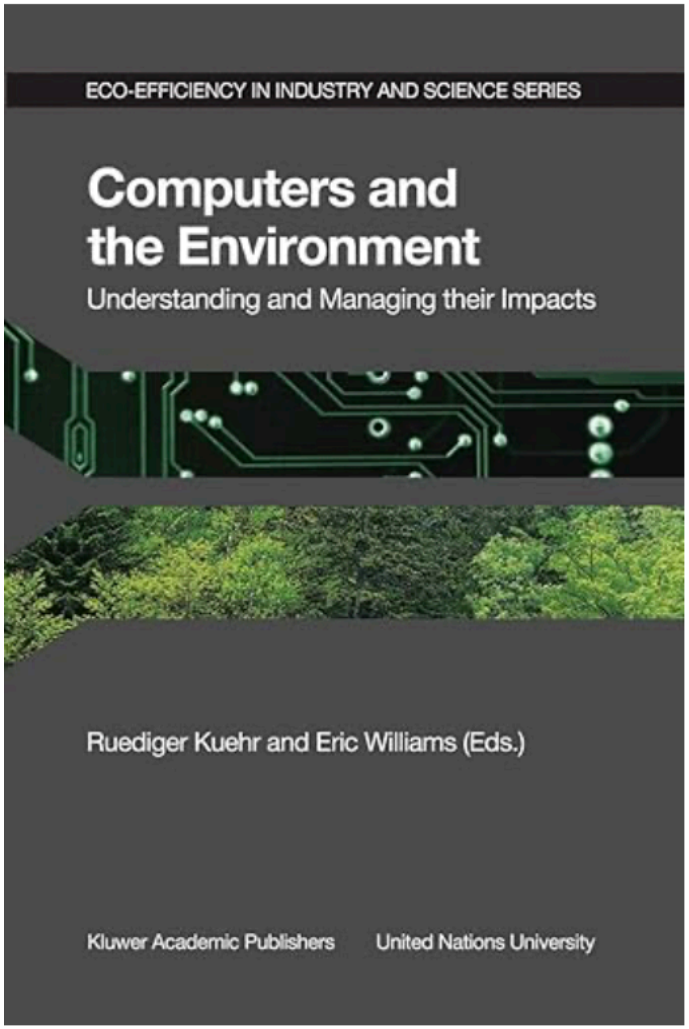
EcoInfo UMR IRISA istic Informatique Électronique Université de Rennes

Plan

- Introduction
- Observed obstacles to teaching Computers and the Environment (CE)
- A range of possible contents according to context

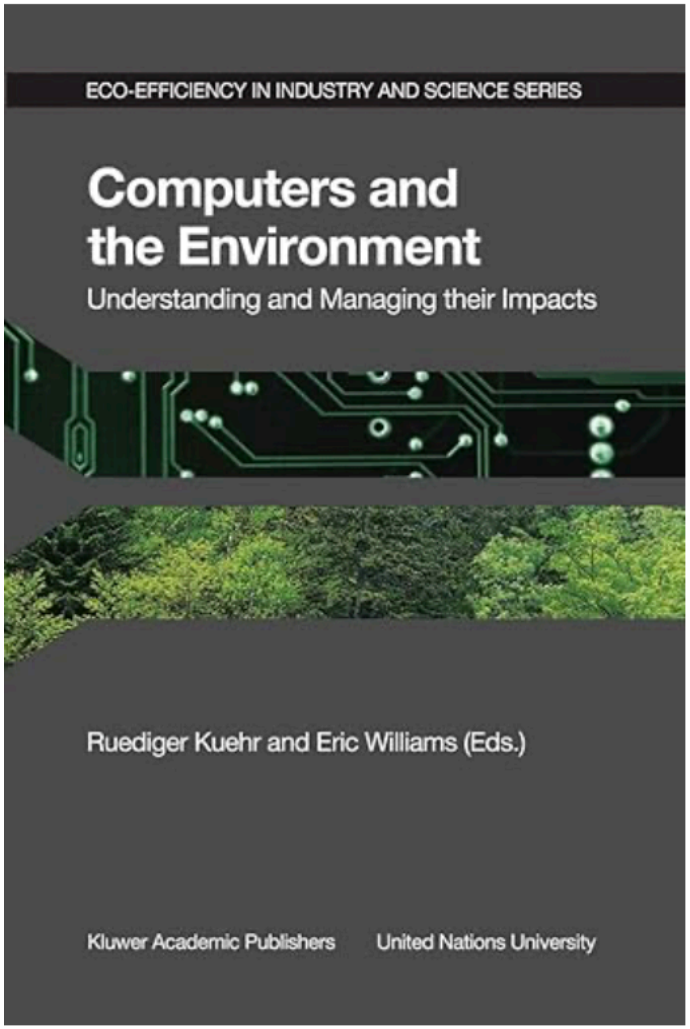
Introduction

Why Computers and the Environment ?



- A great old book (2003)
- Most data outdated
- Most questions still open
- DON't misuse it

A severe misuse



- "Environmental impacts in the production of personal computers", by Eric Williams
- Page 65-68: **producing a PC consumes 240 kg of fossil fuels, 22 kg of chemicals, and 1.5 m^3 of water**
- Data from late 1990 to early 2000

A severe misuse

Search: PC consumes 240 kg of fossil fuels, 22 kg of chemicals, and 1.5 m3 of water

Answers:

- **9 mai 2023** — Carte de visite virtuelle > https://cartlyapp.com > How Can ...
- **2019** - torvius.com > https://torvius.com › e-waste-the-...
- M Kaya · **2016** — Manufacturing of a computer and monitor requires 240 kg fossil fuels, **2.2 kg** chemicals, 1.5 tons of water. ...
- **20 oct. 2023** — Global E-waste Statistics > emew Corporation > https://blog.emew.com › global-e-...
- **15 févr. 2022** — GoodPlanet mag > https://www.goodplanet.info › actu-fon...
- **21 janv. 2018** — **France Info** > https://www.francetvinfo.fr › internet › ecol...
- **18 mai 2018 – ADEME** > La fabrication d'un ordinateur nécessite 240**K**g de combustible fossile, 22**K**g de produits chimiques et 1,5 t d'eau.
- ...

Who am I?

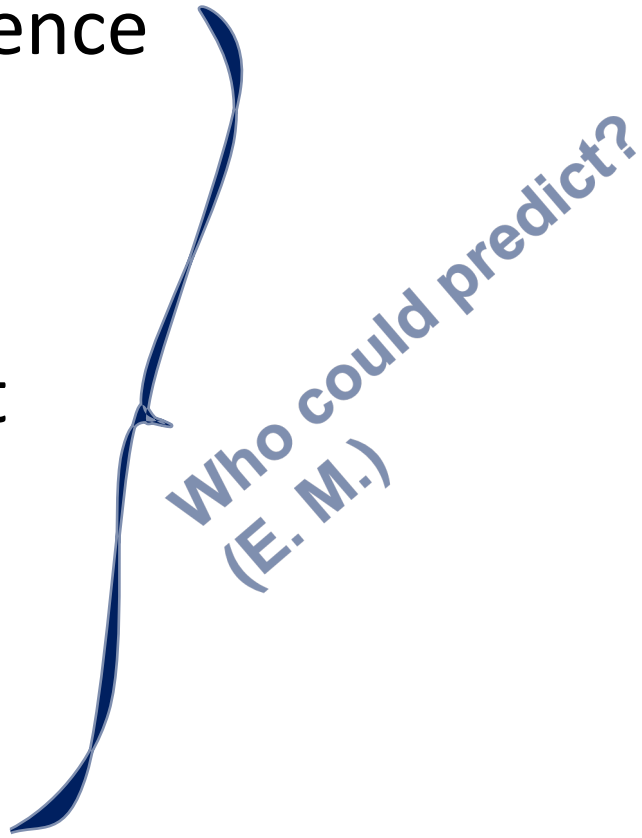
- **15 years** a full-time researcher at INRIA
- **25 years** a researcher-teacher at University of Rennes
- Deeply interested in **limits to computing**
  - logic expressivity
  - computability
  - algorithmic complexity
  - **energy ?**

Energy limits to computing

- Discovered works by
  - Richard Feynman
  - Charles Bennett
  - Rolf Landauer
- But also
  - Christopher Lutz on Janus
- All in the 1960-70s
- All on **reversible computing**

Discovery of other limits as a citizen

- Stockholm conference
- Meadows report
- Oil shocks
- Brundtland report
- IPCC report
- Kyoto protocol
- Rio Earth submit
- **Planet limits**



Freedom and responsibility
Responsibility and freedom

- 1999, moved to University of Rennes
- Immediately, became immersed in Bachelor and Master degrees
- Soon, became a **full-tenured** professor
- Rapidly, became **head of teaching department**

Responsibility and freedom!

Started teaching Computers and the Environment

- Very often **embedded** in something else
- At university and other institutions
- **Struggling** for an official status at university

Teaching CE

- At bachelor level (**embedded** in an Introduction to Computer Systems course)

  was head of Teaching dept

- In the university Engineering school (**embedded** in an Innovation course)

  was head of the Eng. school

Teaching CE

- In a neighbouring Engineering school (**embedded** in a Risk management course)
- In another Engineering school (**1st official CE course !**)
- In the Doctoral school

started a conflict with the school which wanted it be proposed to CS students only, while I wanted it to be proposed more largely

Teaching CE

- As an elective course at Bachelor level

  was head of Bachelor level

- As an academic minor at Bachelor level

  was still head of Bachelor level,
  but failed to make it a major

- In student projects
  - Software
    - lowcost solutions for **live scoring**

      with the sport dept

      tennis, long-distance running, athletics
    - digital humanities

      explore environmental questions in La Nature

      ex. reception of Svante Arrhenius prediction of climate change in 1896
  - Hardware and system
    - demonstrators for **energy consumption**

Teaching
Computers and the Environment

- A struggle with colleagues and the institutions
- A struggle to imagining an academic content

Observed obstacles to teaching Computers and the Environment

Rhetoric obstacles

- It's an **opinion**, not a science

  no room for opinions in the academy

- Computer has a **globally positive impact**
  - progress of science,
    including environmental sciences
  - education, information, transparency
  - dematerialization
  - optimization, computer-aided X

  nothing to worry about

Logistic obstacles

- No room: no time slot, or no credit

  was true for OOP, web techs, ...,
  and even for CS! World changes!

- No resource: manpower or money

  reassign resources

- **No legitimacy**: we were not taught these subject

  nobody has!
  was the same for CS in the 60-70s

A bootstrap theory

- We love cycles
  - **natural cycles**: tide, water flow, carbon flow, sexual reproduction, ...
  - **social cycles**: nationality acts, teaching, PhDs teach future PhDs, CS PhDs teach future CS PhDs,
- Never the same, always the same

  movement and stability
- We always forget the **genesis of cycles**

A bootstrap theory

- Even philosophers love cycles
  - **Thomas Kuhn**,
    The Structure of Scientific **Revolutions**
  - but the book is mostly about normal science, ie. science between revolutions
  - at least he gives a name to **science before science**: pre-paradigm science or immature science

A bootstrap theory

- Cycles allow us to think the future, but only one kind of future

  follow-up to present

- We are **locked up** into cycles

A bootstrap theory

- We are not trained to think the emergence of cycles
- We are not taught to...
- However, CS has a name for it

Bootstrap!

The bootstrap of CS teaching

- Today CS teachers
  teach future CS specialists,
  among them future CS teacher
- They are all legitimate because they have been, will be, taught by CS specialists
- But first CS specialists have not been taught by CS specialists

I was not ☺

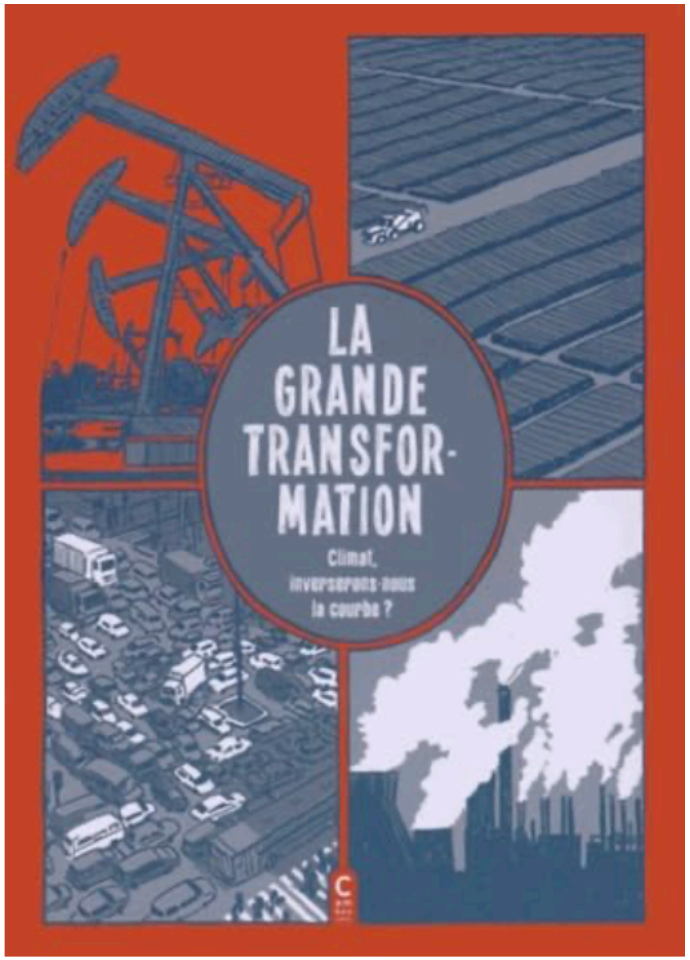
The bootstrap of CE teaching

- We must admit that we are opening a new cycle
- All we can do is **bootstrap**
- Teach something we have not been taught
- We should be used to it, but we are not used to such major changes

The volontarist bootstrap of CE teaching

- Open the bootstrap
  - call for **good will**
  - **give room** to it in teaching programs
  - **invest** while it is time
- Create new institutions around new values
  - **Clayton Christensen** (Harvard BS)
- **Reassign** resources
  - do not dream of new resources

The volontarist bootstrap of transition institutions



- La grande transformation (2015)
- Jörg Hartmann, Alexandra Hamann
- Many specialized institutions in Germany, Austria and the Netherland

A range of possible contents according to context

Many contextual parameters

- **Student level**: from 1st bachelor year to PhD students
- **Course size**: from a few hours to 40 hours
- **Group size**: from a dozen to more than 300
- Objective: from observation to action

My opinions on objectives

- **Macroscopic** over microscopic
- **Top-down** over bottom-up
- **Size order** over absolute values

That is, while there is value in the items on the right, we value the items on the left more. [The Agile Manifesto]

– especially at the beginning (bachelor)

– can be reversed with higher grades

My opinions on objectives

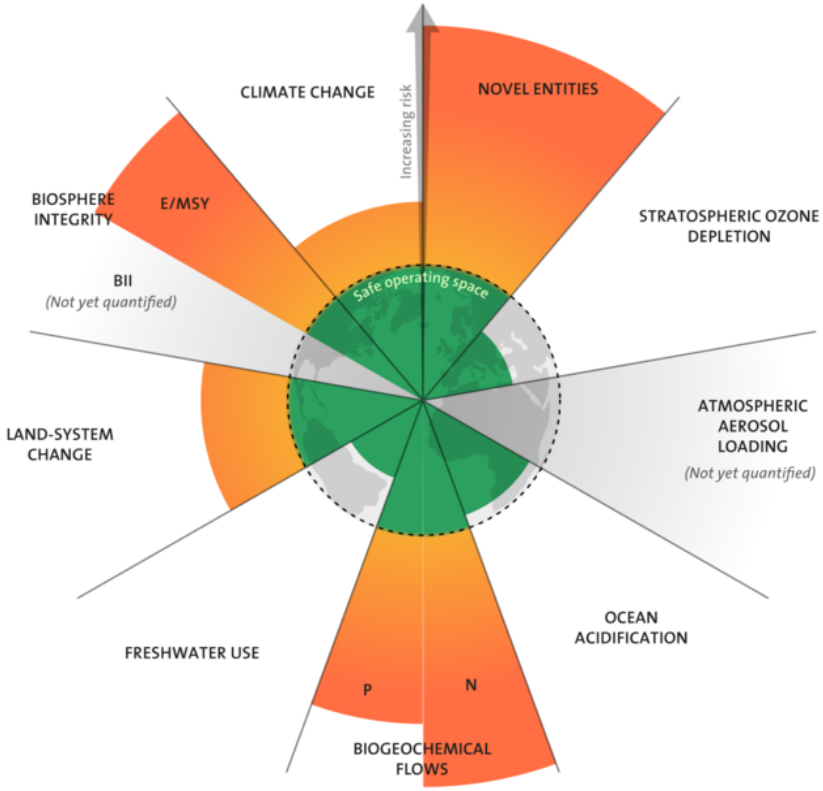
- Give autonomy for **self-documentation**
  - admit that in a bootstrap phase, there is no well established corpus
  - read physics, chemistry, demography, economy, ...
  - **learn to read!**
- Relearn basics
  - elementary physics, unit systems
  - high-school geography, ...

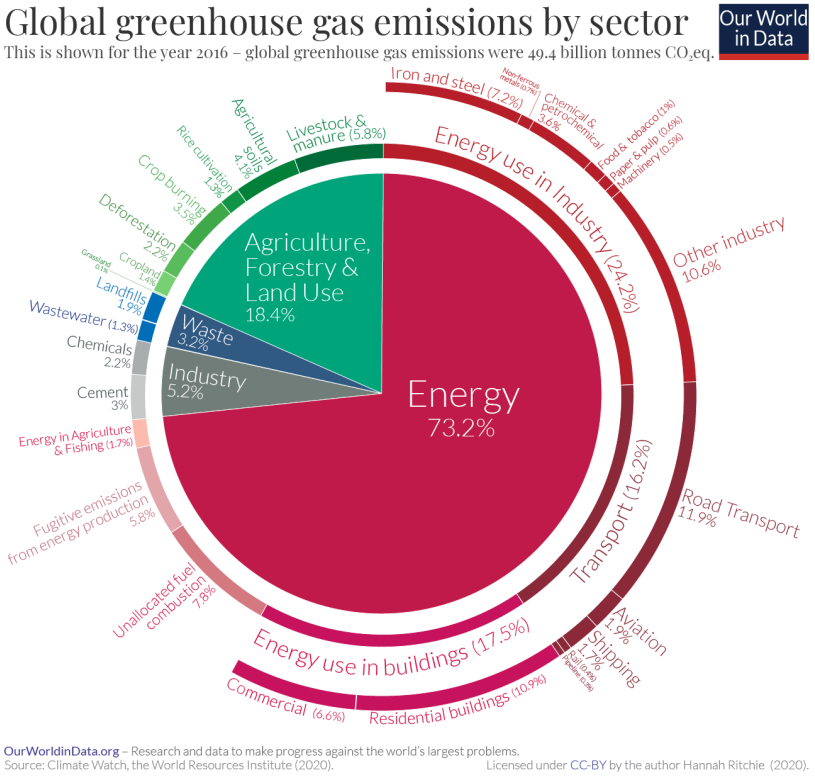
Document samples

Amérique du Nord	0,4 --
Europe	0,7 ++
Amérique C & S.	0,6 --
Asie sauf Chine et Inde	1,9 --
Chine	1,4 ++
Inde	1,4 ++
Afrique	1,4 ++
Planète	**8 10^9 hab.**

Amérique du Nord	6,7
Europe	8
Amérique C & S.	3,2
Asie sauf Chine et Inde	6
Chine	12,7
Inde	3,4
Afrique	5,7
Planète	**46 $MtCO_2e$**

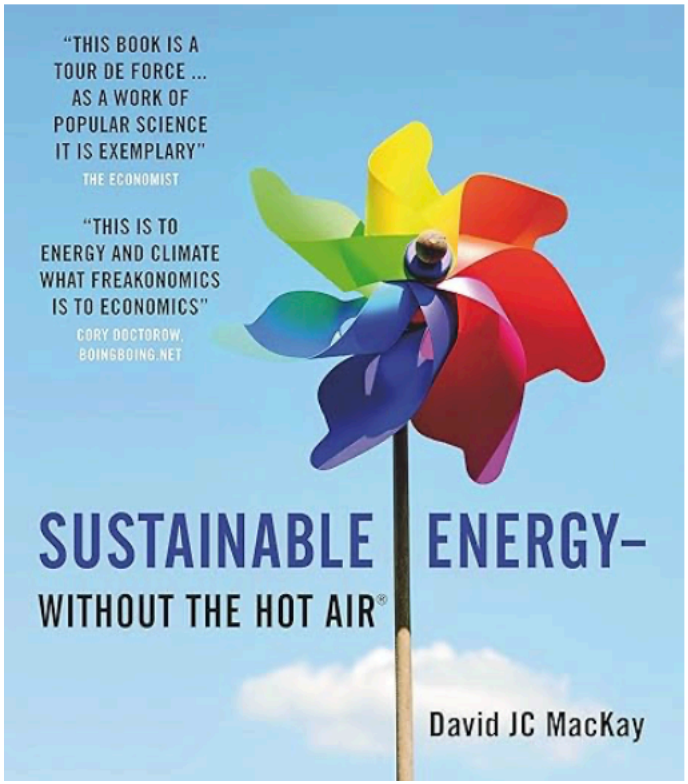
Document samples

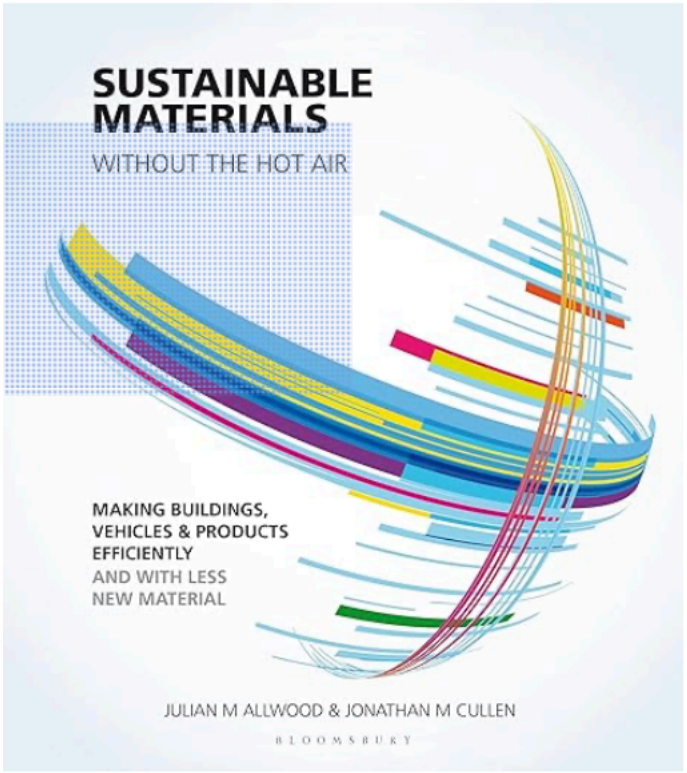




Diversify sources

- Sustainable X, UIT Cambridge

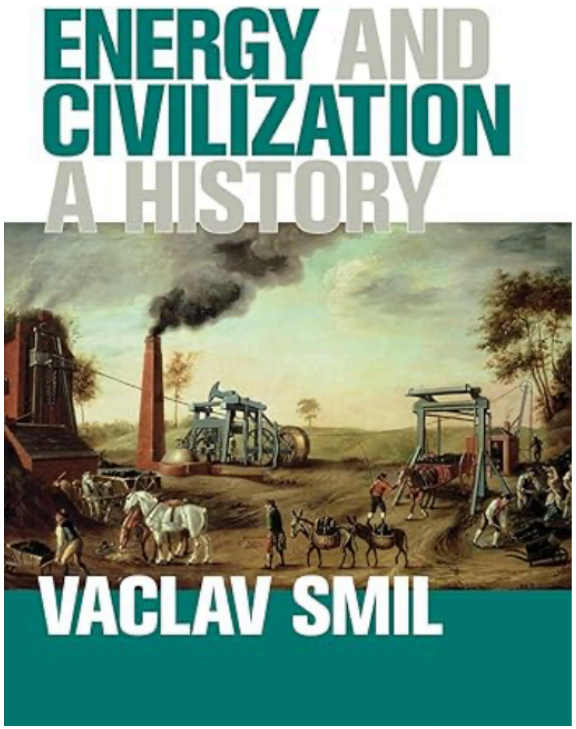


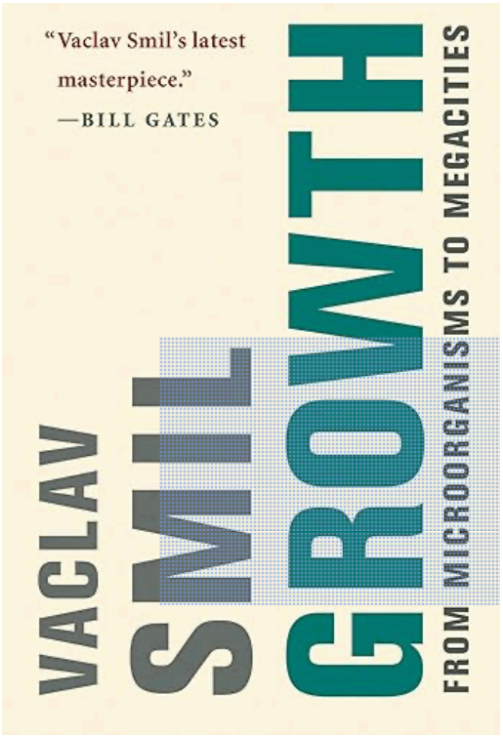


https://www.uit.co.uk/without-the-hot-air-series.html

Diversify sources

- Vaclav Smil, MIT Press

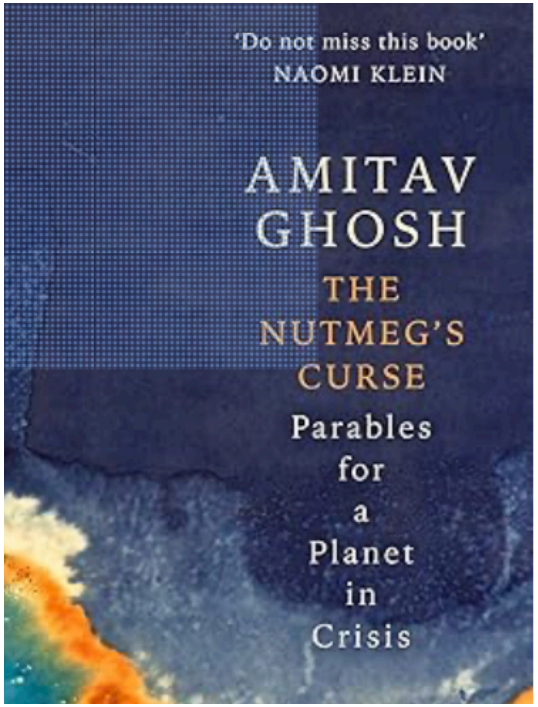


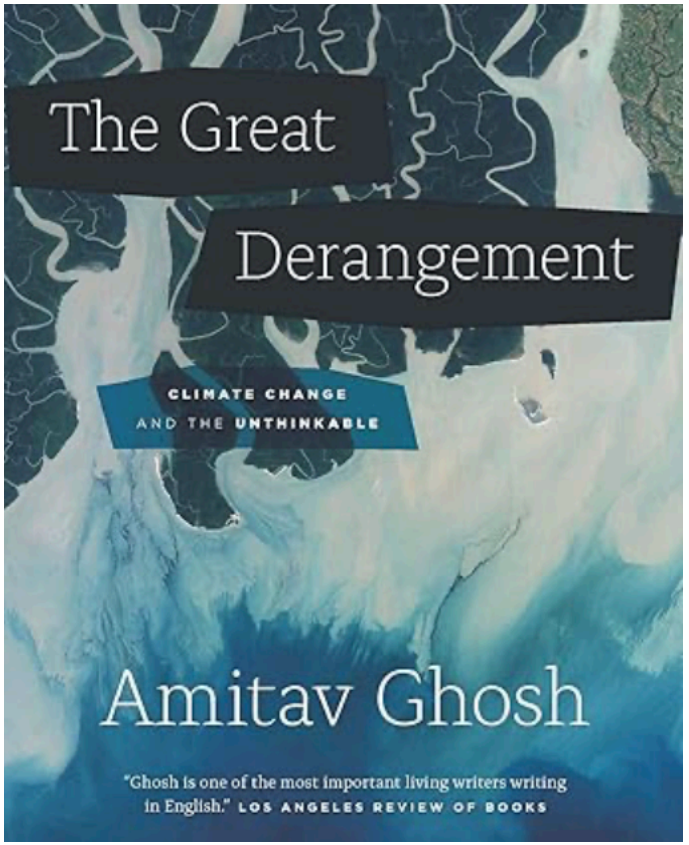


https://mitpress.mit.edu/author/vaclav-smil-2228/

Diversify sources

- Amitav Ghosh





https://news.rice.edu/news/2021/amitav-ghosh-dangerous-delusions-created-our-climate-crisis

1st year bachelor
Principles of computer systems

- Macroscopic measures of computer systems
  - storage, information
  - **natural resources**, **energy**
- Responds an **un-expressed expectation** by the students
- 300 students / ~ 4 h / observation

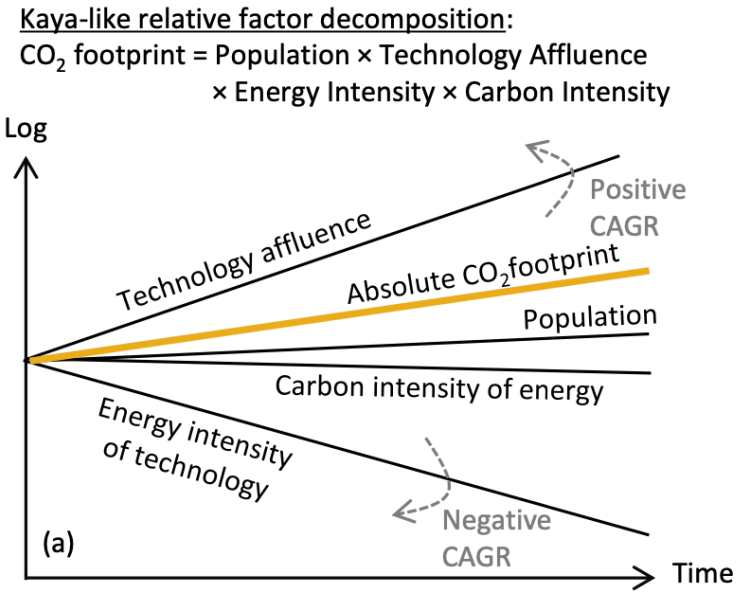
2nd year bachelor
Minor module on CE

- Overview observation ⟶ action
  - SDG, planetary limits, LCA, best pratices, regulations, sufficiency
- **Readings**
  - Bol et al. 2021, Gupta et al. 2020, RSE report TSMC, UNU e-Waste monitor, Solar Lowtech magazine...
- ~ 25 students / ~ 40 h / observation ⟶ action

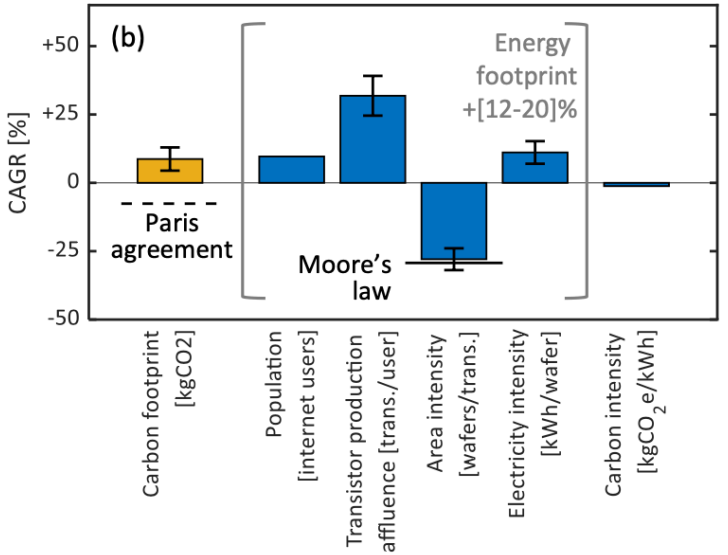
Bol et al. *Moore's Law and ICT Innovation in the Anthropocene.* IEEE Design, Automation and Test in Europe, 2021.
Gupta et al. *Chasing Carbon: The Elusive Environmental Footprint of Computing.* IEEE Micro, vol. 42, no. 4, 1 July-Aug. 2022

Document sample from Bol2021

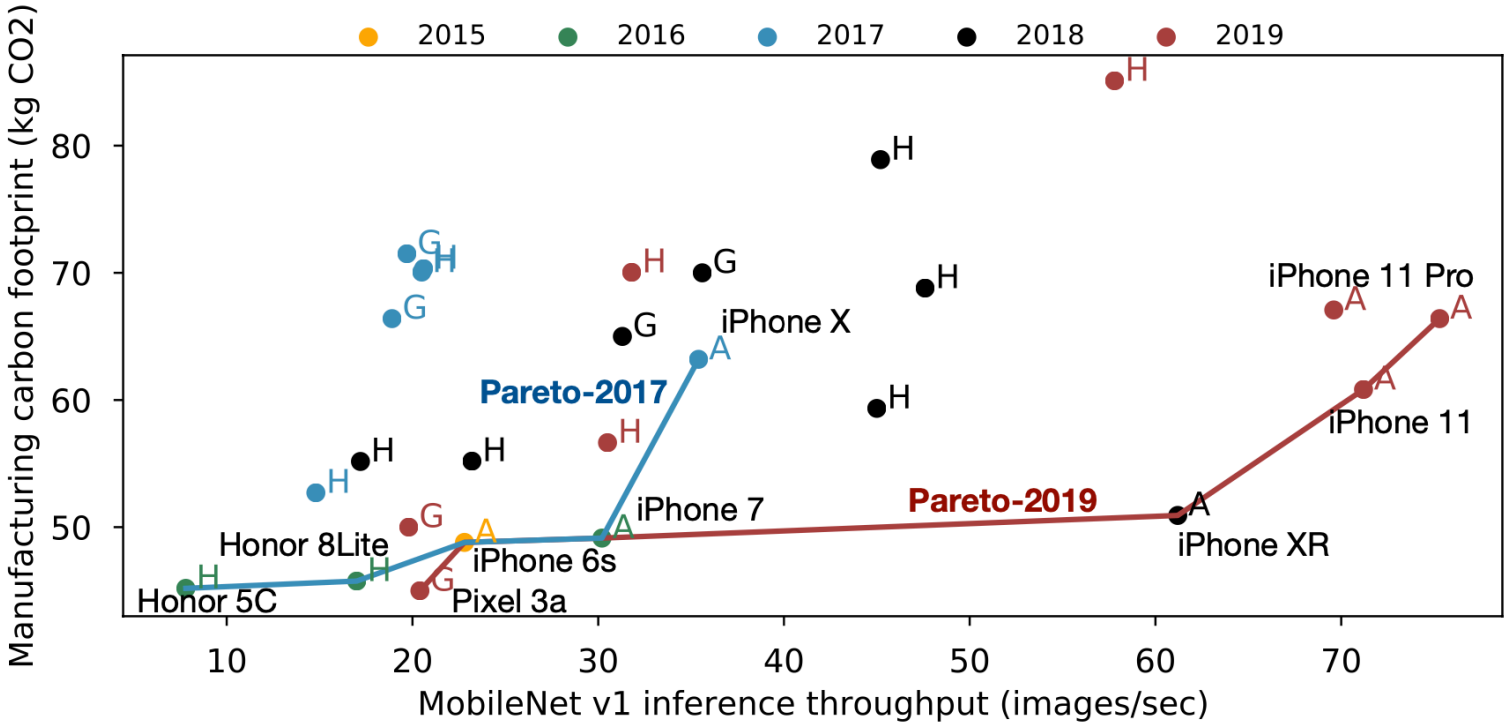
Bol et al. *Moore's Law and ICT Innovation in the Anthropocene*. IEEE Design, Automation and Test in Europe, 2021.



$$CO_2e = Users \times \frac{Transistors}{User} \times \frac{Wafers}{Transistor} \times \frac{kWh}{Wafer} \times \frac{CO_2e}{kWh}$$



Document sample from Gupta2022

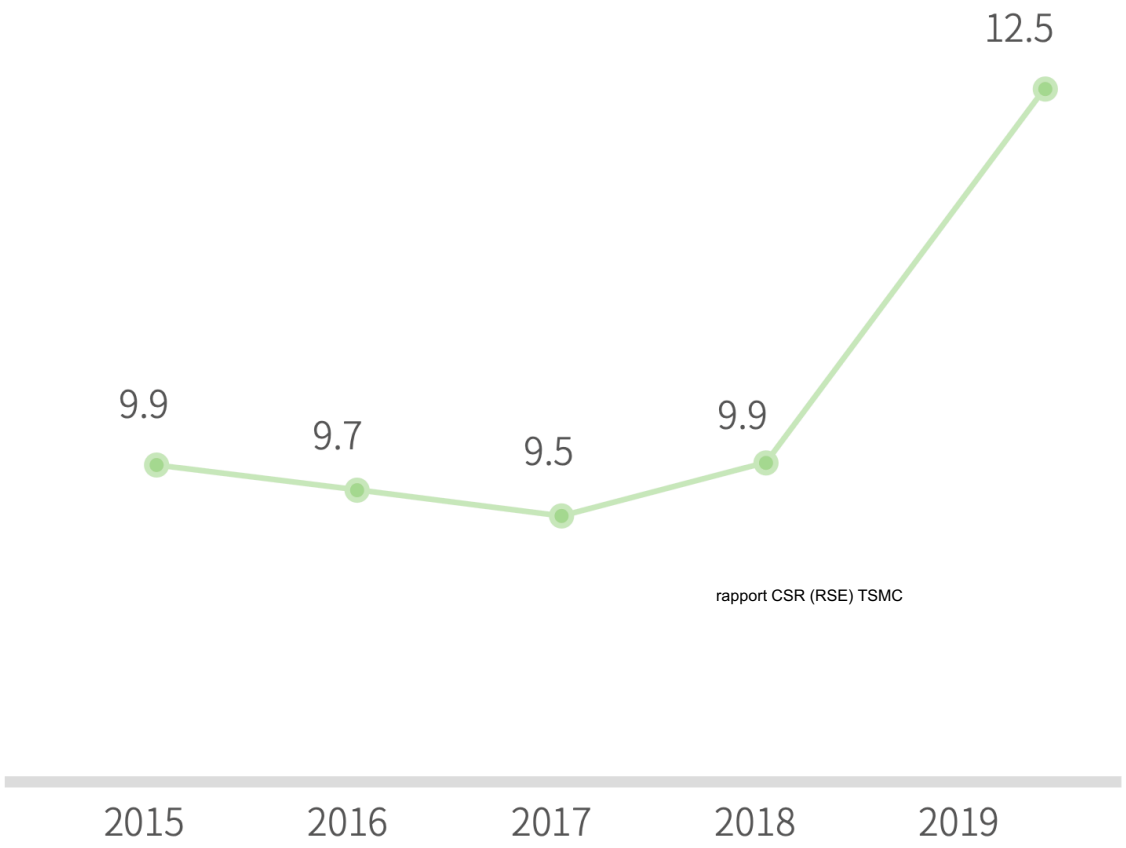


Gupta et al. *Chasing Carbon: The Elusive Environmental Footprint of Computing*. IEEE Micro, vol. 42, no. 4, 1 July-Aug. 2022

Document sample from TSMC CSR report

Power Consumption per Unit of Production

Unit: kWh/8-inch equivalent wafer mask layer



School of Environmental Engineering

- CE for non computer students
  - LCA, regulations, sufficiency
  - **readings**
  - CSR in the computer industry, change management, SDG, ...
- ~ 15 students / ~ 20 h / observation ⟶ action

Doctoral school

- CE for CS ans non-CS student
  - LCA of computer systems, regulation, sufficiency
  - **readings**
  - energy of computation, Landauer limit, reversible computing, energy complexity, …
- ~ 15 students / ~ 15 h / concepts ⟶ research

A note on readings

- To **read and explain** to others

  not that easy

☞ a progressive approach

A note on readings – step 1

- Several groups read the same (simple) text
  - discover the variety of interpretations and restitutions of the same text:
    a form of responsibility
  - also discover the danger of a too casual reading:
    miss something important
  - finally, discover **active listening**

A note on readings – steps 2 and 3

- Several groups read different parts of the same text

  (~ **surveying/arpentage** principle)

  grow expectations on what others will do

- Each member of several groups read different parts of several related texts

  more active listening

Open questions

- Practical works
  - to **model** : requires simplified frameworks, but expressive enough

    pyWorld3?

  - to **measure** : requires measurable systems

    pyJoule for software?

  - **LCA** : requires simplified frameworks

    UC Davis approach?

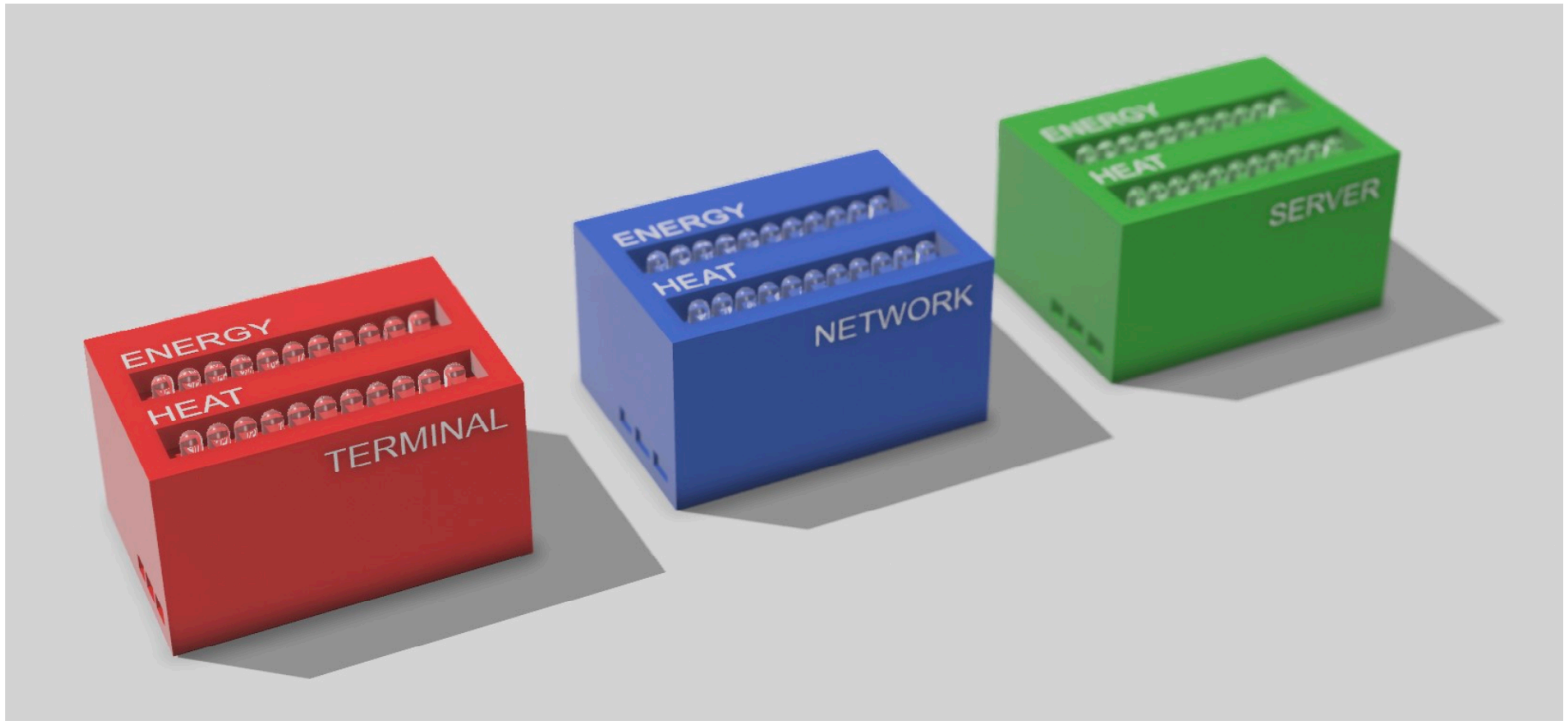
A note on our technical plateform

~ 300 workstations connected to a distant shared file system, and dispersed in 4 shared buildings

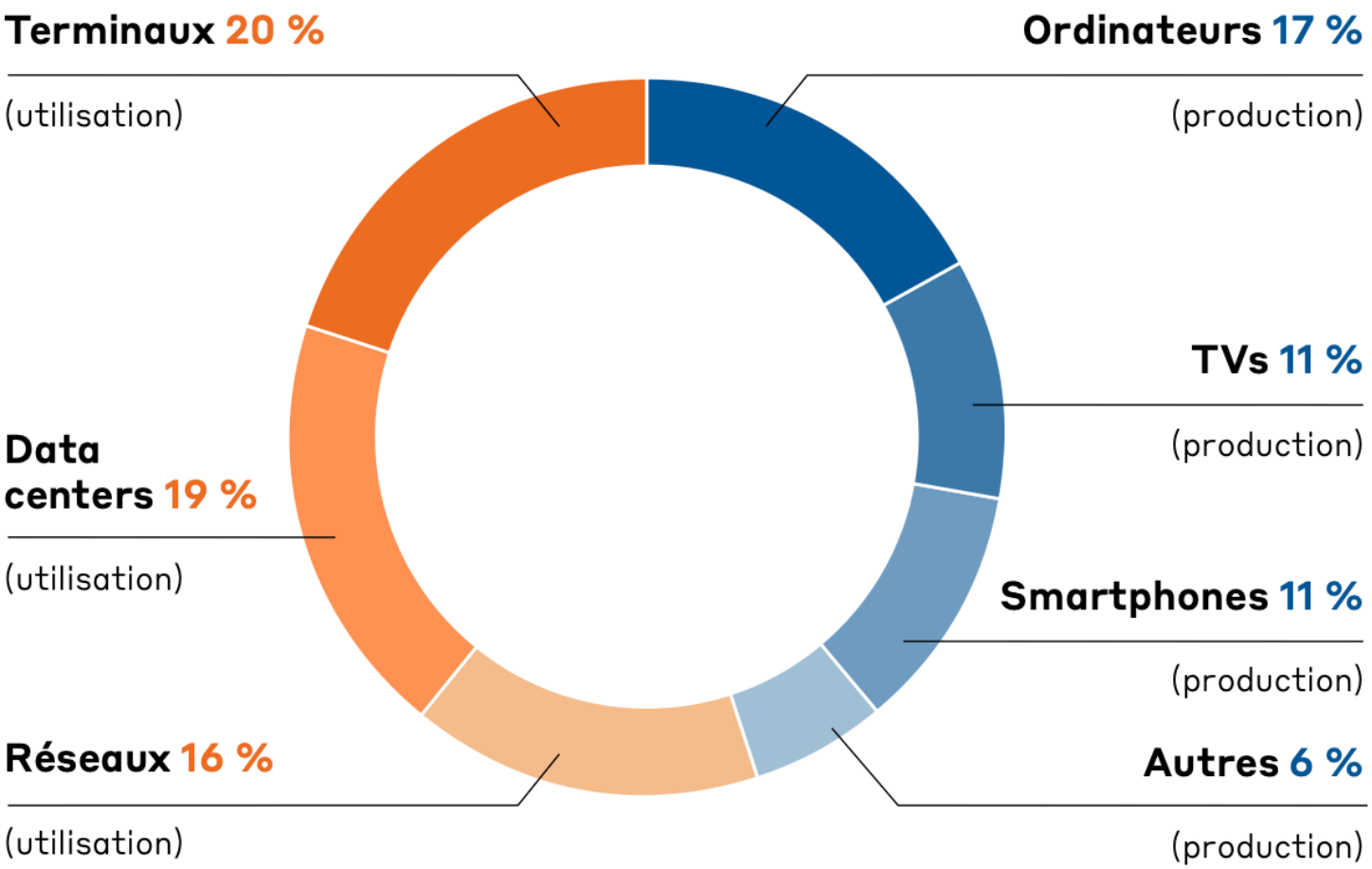
- distant data
- local computation
- also serve as remote machines for SSH accesses
- all wires, power and data, are hidden
- no alignment with power network

DemoJ: an energy consumption demonstrator

A student project



The context of DemoJ



The concept of DemoJ

- Each box assumes a role:
  Terminal, **Network** or **Server**
- They all display their **power consumption** and their **processor temperature**
- Public can participate with role **Terminal**
- They execute scenarios
  - download a small/large file
  - execute a client/server web application
  - chat with an LLM robot

A dummy demo - streaming

- Stream video of different qualities
- Observations
  - hardly noticeable except VHQ videos
  - number of Terminal lowers noticeable threshold
- Streaming procedures work at a **fixed rate**, they do not really stress the system

A dummy demo – math computing

- Compute with unbounded numbers
  primality test, naïve Fibonacci, ...
- A web application
  client side or server side
- Observations
  – as expected, client side or server side

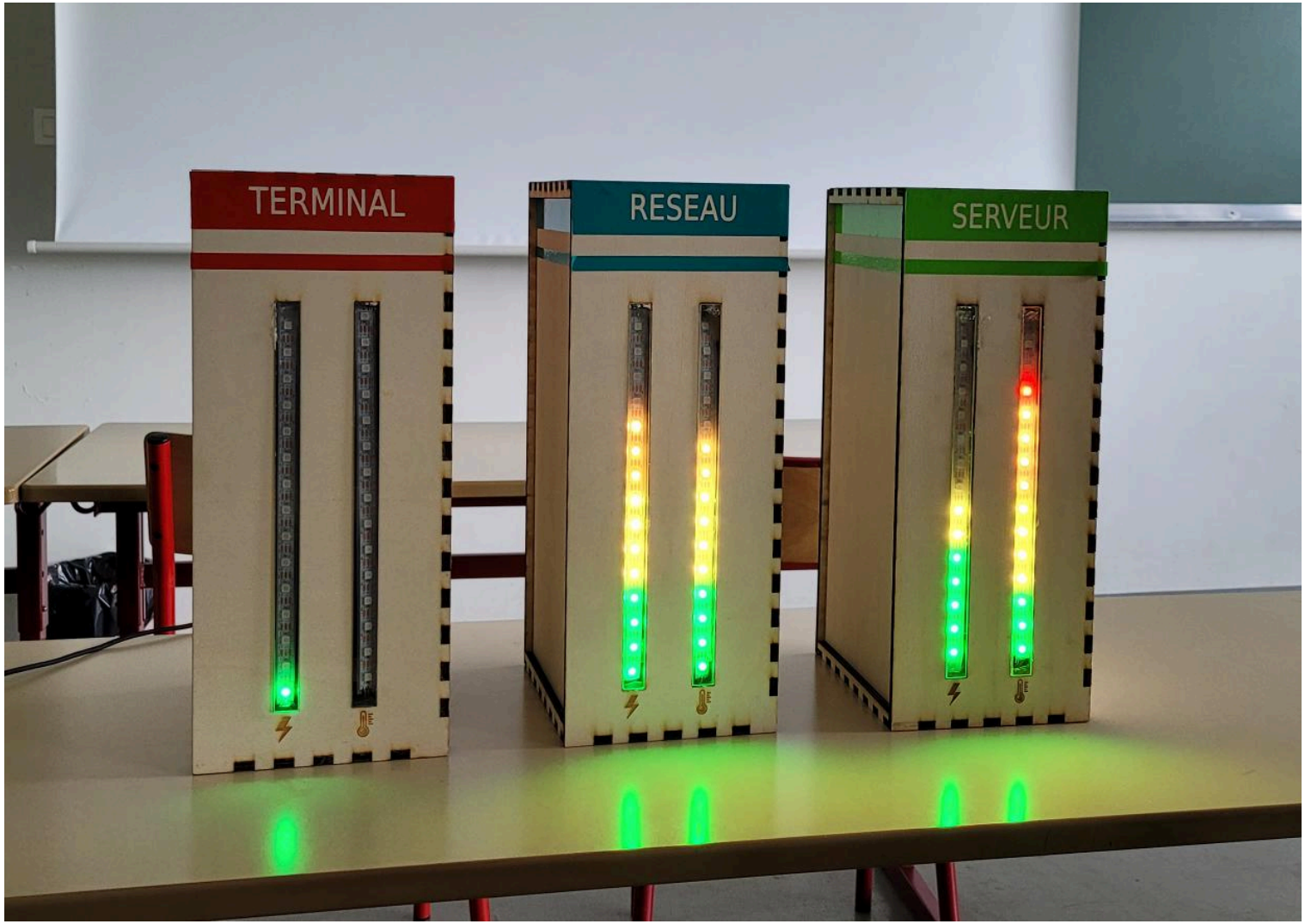
A dummy demo – LLM chatbot

- Chat with an LLM
  a small LLM, to fit in the memory
- Observations
  - phase 1: load the LLM in memory, takes a long time, but no energy or temperature stress
  - phase 2: answer a question, takes a very long time, and stresses the network!

DemoJ: final design

- Three 50×15×15 cm boxes
  powered by a Raspberry Pi 4
- **Fan off, heatsink on**
  otherwise temperature curve
  always high or always low
- Run off-grid (data and energy)
  can run in parks or in bars
- The network box creates a wifi hotspot

DemoJ: final design



DemoJ as a working group

- 12 students × ~ 100 h

2 never came

3 did nothing

2 on external design and documentation

3 on lower layers: electronics and system

2 on higher layers: applications and scenarios

DemoJ – in real life

- Used during a Bachelor level course
- Presented to
  Collectif Numérique Responsable

an industrial working group in Rennes
on Responsible IT

- Was socially very interesting

Students realised real people
spoke the same language
they have learned during the project

Ongoing project: DemoJcpu

- An energy consumption demonstrator
  again?
- To expose dependence of energy consumption on clock frequency and temperature
- **Static** consumption
  grows with computation time
- **Dynamic** consumption
  grows with clock frequency

DemoJcpu

- Where is the optimum?
- What does the computer do when computation is over?

On and ACTIVE

On and IDLE

Off

- …

Conclusion

- In favor of voluntarist ***bootstrap***

  try things

- Consider CE teaching as a **real academic stuff**

...it takes **resources** in the academic programs

time

teachers

credits

...

Conclusion

- Accept that transition is chaotic

...help exists

How to Integrate Environmental Challenges in Computing Curricula? SIGCSE (1) 2022

- Can be a great occasion to explore different teaching practices

Conclusion

- Learn by **doing**
- Learn by **teaching**

docendo dicimus