ICT Within LIMITS is Bound to be Old-Fashioned by Design

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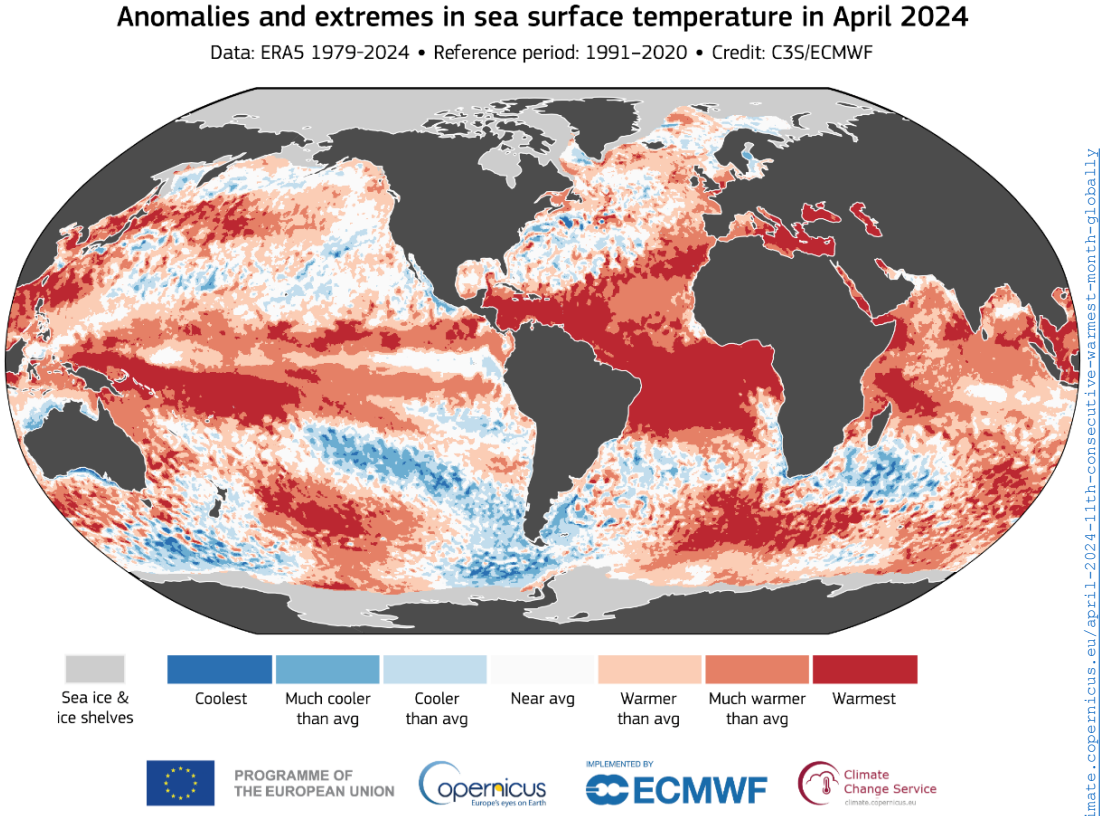
Outline

1. Context (climate change and their consequences)
2. ICT (no limits nor materiality)
3. ICT meets the earth's boundaries (and things go wrong)
4. What is to be done? (our proposal)
5. Conclusion

1 Context

Major environmental crisis

- **Climate change widespread, rapid and intensifying (IPCC)**
  - Extreme temperatures
  - Drought conditions
  - Heatwaves
  - Fires
  - Flooding
  - Glacier melting
  - Permafrost melting
  - …
- **Relative to 1850/1900**
  - +1,15 °C (world)
  - +1,7 °C (France)



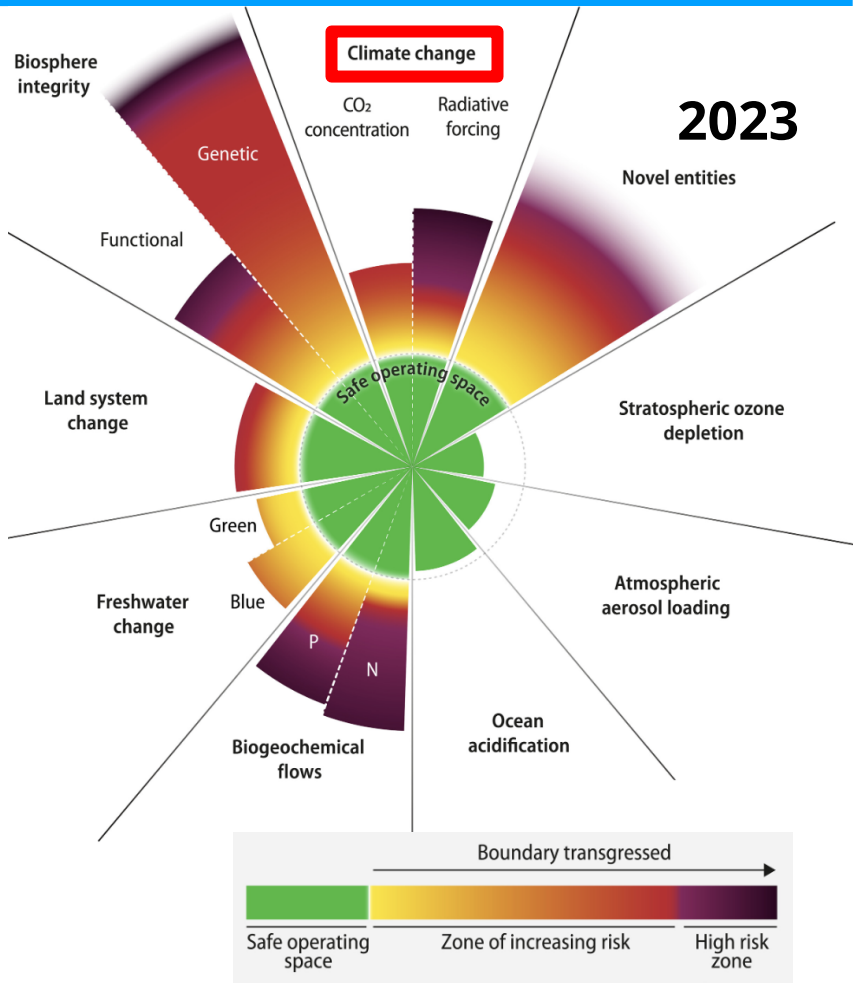
[…] April 2024 is the eleventh consecutive month being the warmest for the respective month of the year. […]

https://climate.copernicus.eu/april-2024-11th-consecutive-warmest-month-globally

Climate change isn't the whole story

- **Planetary boundaries**
  - "The **planetary boundaries** framework delineates the **biophysical and biochemical systems** and **processes** known to **regulate the state of the planet within ranges** that are historically known and scientifically likely to **maintain Earth system stability and life-support systems conducive to the human welfare** and societal development experienced during the Holocene."

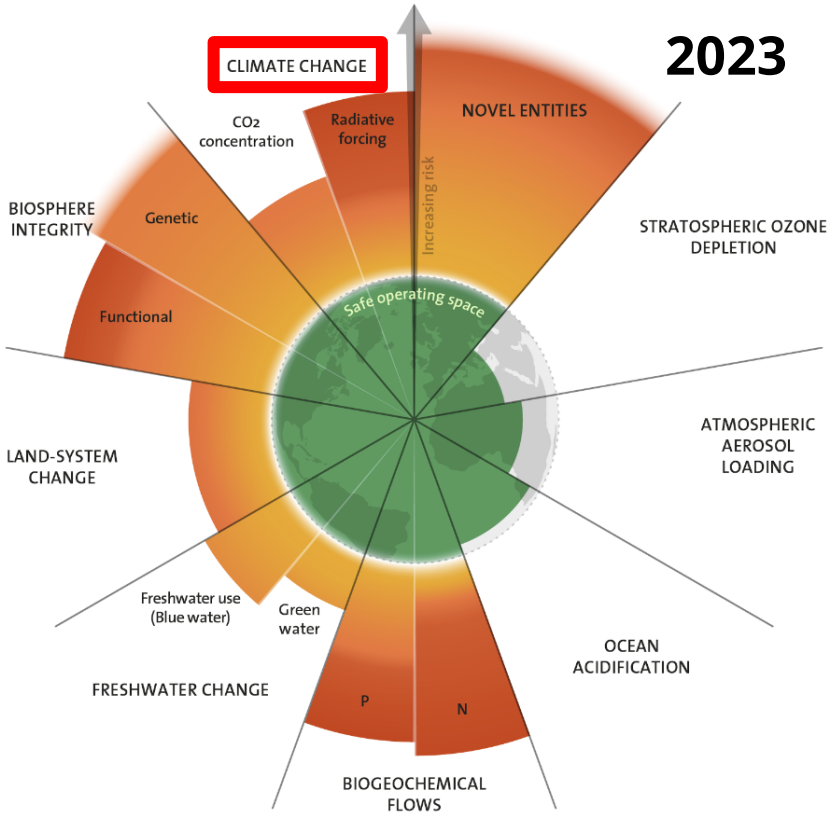
- **Regulation during > 3B years**
  - **Interactions between the geosphere and biosphere have controlled environmental conditions**
  - **Holocene state of earth (last 11 000 years) have been rather stable**



https://www.science.org/doi/10.1126/sciadv.adh2458

Climate change isn't the whole story

- **It's one of the 9 planetary boundaries…**
  - **Defined by a *control variable***
    - CO_2 concentration (ppm CO_2)
    - Radiative forcing measured on the top of the troposphere (18 km)
  - **Trois values**
    - Reference (pre-industrial society - 1750)
      - 280 ppm CO_2
      - 0W / m^2
    - A **boundary** corresponds to the **start of increasing risk**
      - 350 ppm CO_2 - 450 ppm CO_2
      - +1 et +2 degrees of global warming
      - +1.0W / m^2
    - **Current value**
      - 423 ppm CO_2 (november 2024)
      - +1.5 W / m^2



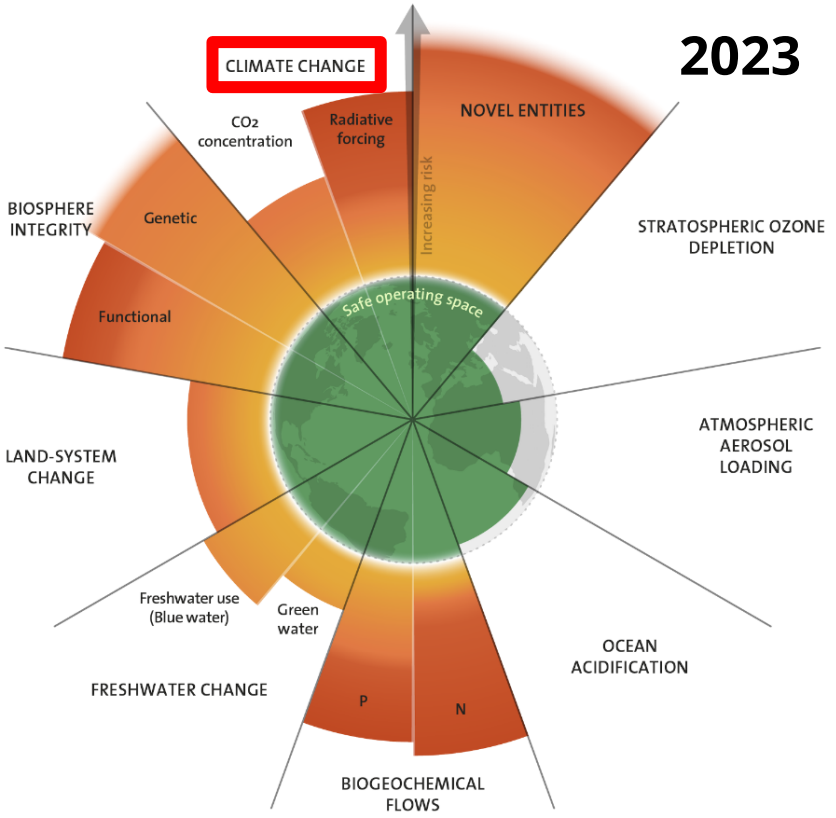
https://www.stockholmresilience.org/research/planetary-boundaries.html

https://www.science.org/doi/10.1126/sciadv.adh2458

Climate change isn't the whole story

- ...6 have already been crossed
  - 1. Climate change

- But also
  - 2. Novel entities
  - 3. Stratospheric ozone depletion
  - 4. Atmospheric aerosol loading
  - 5. Ocean acidification
  - 6. Biochemical flows (N/P)
  - 7. Freswater change
  - 8. Land-system change
  - 9. Biosphere integrity



https://www.stockholmresilience.org/research/planetary-boundaries.html

GHG production and rising temperature

❑ IPCC modelization (AR6 – 2021 – p20/21)

B.5.2 For every 1000 $GtCO_2$ emitted by human activity, global surface temperature rises by 0.45°C (best estimate, with a *likely* range from 0.27 to 0.63°C). The best estimates of the remaining carbon budgetsfrom the

[39] Net zero GHG emissions defined by the 100-year global warming potential. See footnote 9.

are 500 $GtCO_2$

beginning of 2020 are 500 $GtCO_2$ for a 50% likelihood of limiting global warming to 1.5°C and 1150 $GtCO_2$ for a 67% likelihood of limiting warming to 2°C[40]. The stronger the reductions in non-CO_2 emissions the lower the resulting temperatures are for a given remaining carbon budget or the larger remaining carbon budget for the same level of temperature change[41]. {3.3.1}

In 2021…

https://www.ipcc.ch/assessment-report/ar6/

GHG production and rising temperature

- **IPCC modelization(2021)**

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Approved Summary for Policymakers IPCC AR6 SYR

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https://www.ipcc.ch/assessment-report/ar6/

- **CO_2 remaining stocks (in 2025) to comply with the Paris agreement (SSP1-1.9) - +1,5 % with a 50 % likelyhood**
  - **2025: 130 Gt (exhausted in 3 years if CO_2 emissions stay at 2024 level)**
  - **2024: 200 Gt**
  - **2023: 275 Gt (+1,7 °C: 625 Gt, +2 °C: 1 050 Gt)**

https://esd.copernicus.org/articles/17/2641/2025/

Local Conclusion

- **Crossed Planetary Boundaries**
  - places us in a ***zone of uncertainty***
  - characterized by ***considerable fluctuations***
- **IPCC projections**
  - commit us to reducing our net GHG emissions
  - SSP1: net-zero in 2050 (and negative after)

    (even though we know that we won't be able to reach that target – see [Earth System Science Data - Indicators of Global Climate Change 2024: annual update of key indicators of the state of the climate system and human influence - 17, 2641–2680, 2025])

2 ICT

A technology without any limits

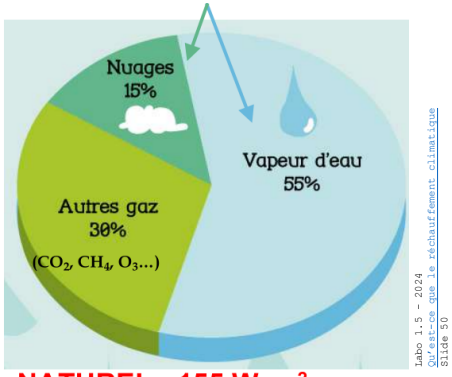
- Computation: G. Moore’s law (1965)
- Dennard's scaling law (1974) : power density remains constant
- Disks storage capacity : Kryder’s law (*Sci. Am. 2005*)
- Network effect: Metcalfe’s law
- Bandwidth tripling every 6 months: Gilder’s law
- State of the art of a connexion grows 50%/year: Nielsen’s law

- And yet [T. Pirson et al – 2022 - The Environmental Footprint of IC Production: Review, Analysis and Lessons from Historical Trends]
  - “Moreover, the trend towards more functionalities observed over the last decades reveals a clear rebound effect at the hardware level, absorbing or backfiring efficiency improvements captured by Moore’s Law“

A technology without any limits… but not without materiality

- **Unlimited computation/storage/use/communication**

- **Which is reflected in the imagination: "Cloud computing"**
  - **Without any materiality**
  - **On-demand unlimited resources (*hyperscale*)**
  - **No constraints**
  - **And yet, clouds account for 15% of the Earth's natural greenhouse effect**

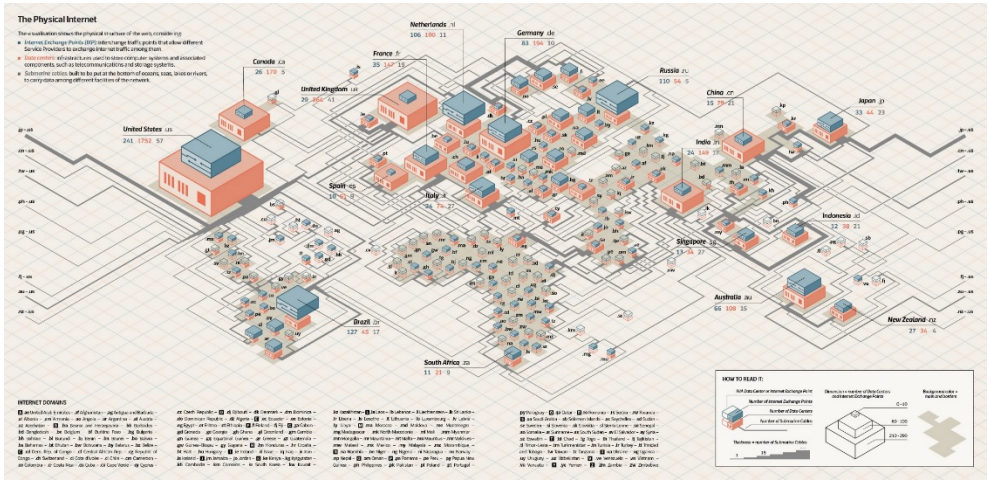


NATUREL : 155 W m^{-2}

Digital materialities

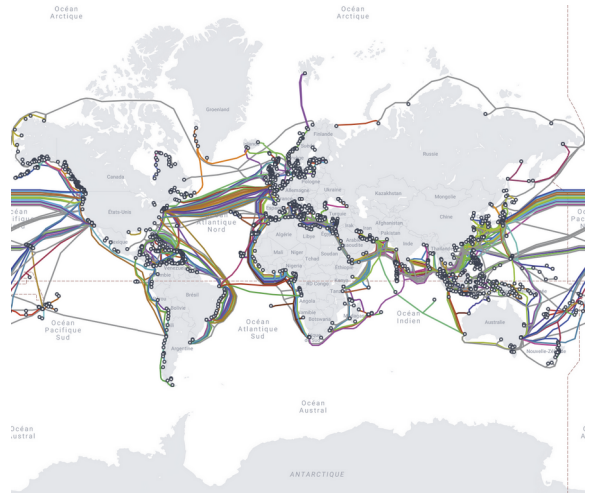
- **Some numbers**
  - **34 B equipments**
  - **4.1B users**
  - **5,5% of world electricity**
- **Three tiers point of view**
  - **Data centers**
    - **67 millions servers**
    - 1-1.3% of world electricity (IEA – 2022)
  - **User devices**
    - **3.5B smartphones**
    - > 3B screens
    - Between 10 et 30B IOT
  - **Network**
    - **1B of Internet boxes**
    - 10M base stations

Data from GreenIT2019 – Lean ICT 2018



https://densitydesign.github.io/teaching-dd15/course-re sults-esg1-group4/assets/img/Physical%20Internet%20CO R2Th..jpg

An uneven geography of networking devices

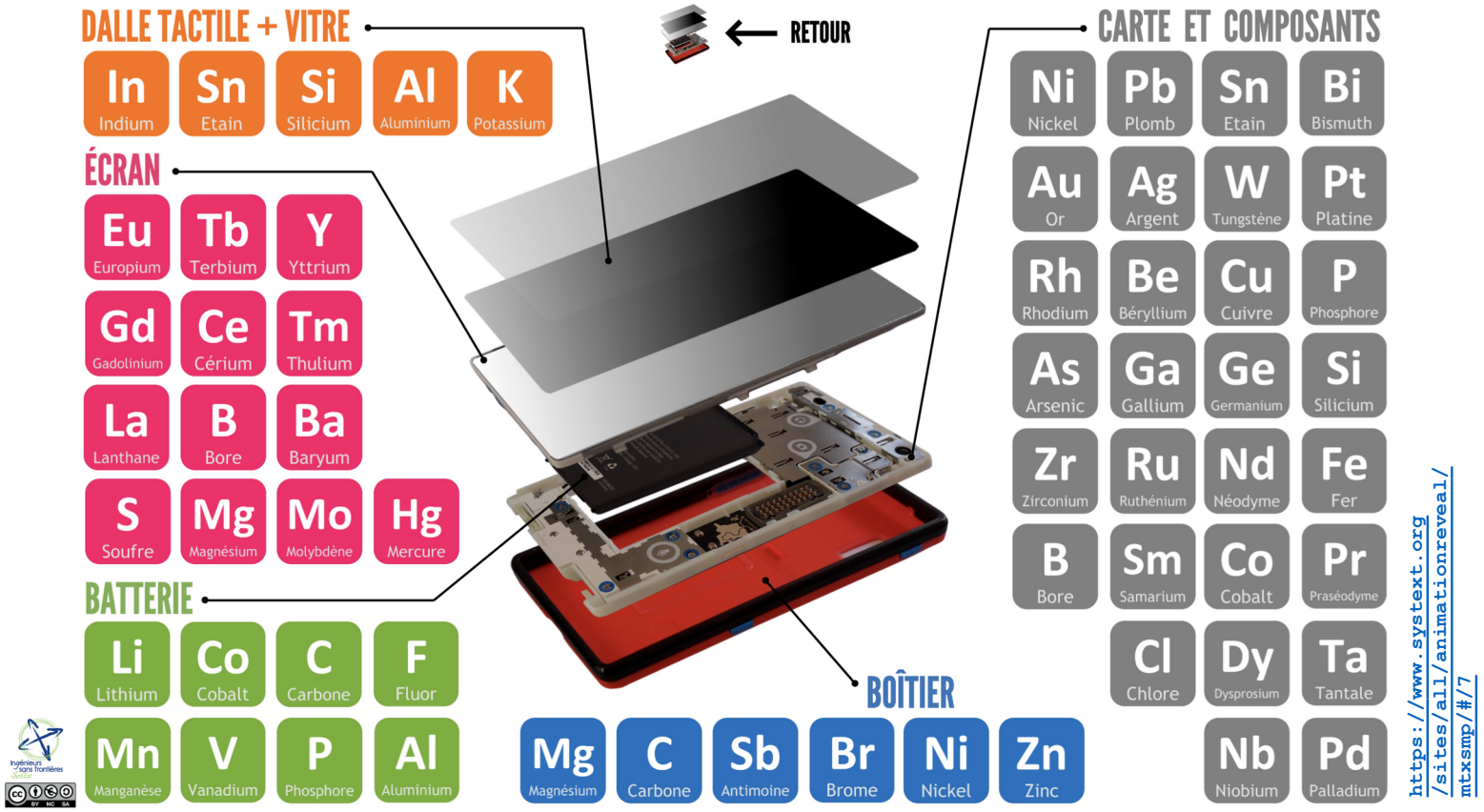


https://www2.telegeography.com/submarine-cable-faqs-fre quently-asked-questions

- **In 2024**
  - **1,4M km of cables**
  - **574 active cables**
  - **Of various length**
    - Starting from 131km (Ireland – UK)
    - to 20k km (Asia-America)

Very dense in materials

- **Elements found in a smartphone (66% of the periodic table of the elements)**

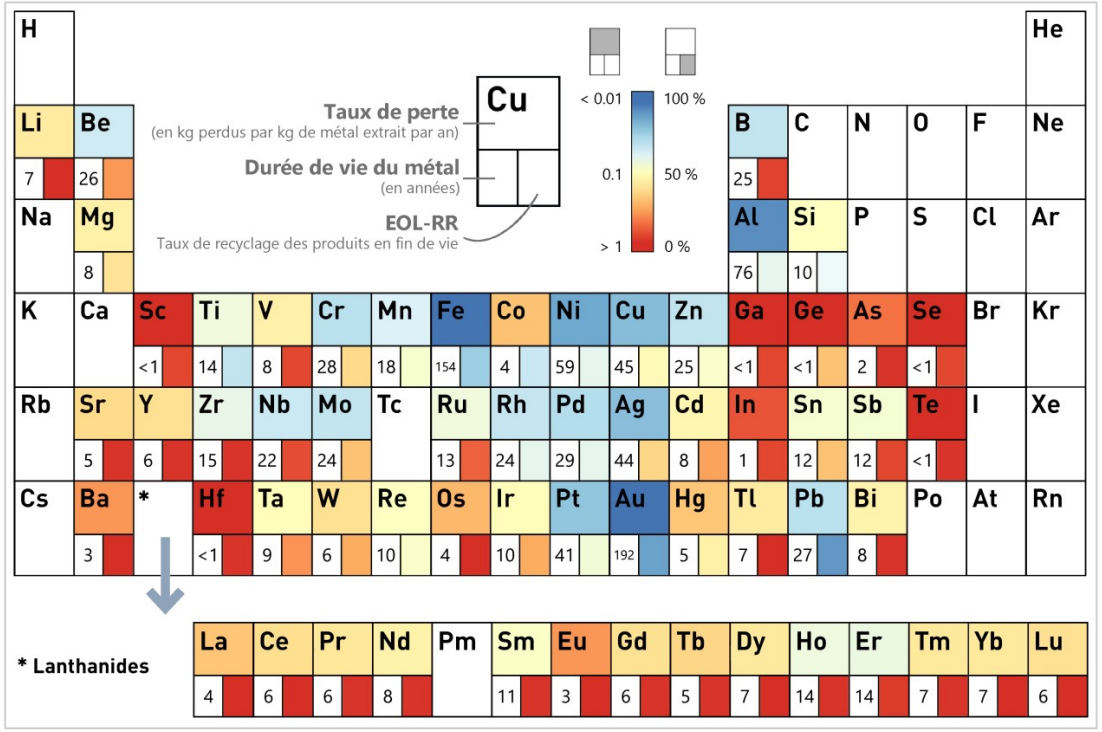


Hardly recyclable

- **Loss rate, service life and EOL-RR of 61 metals**

  [data from Charpentier, Poncelet *et al.* – 2022]

  - **Service life: average duration of use in the economy**
  - **Loss rate: rate at which extracted metal becomes unavailable for further use**



https://www.systext.org/sites/all/documents/RP_SystExt_Controverses-Mine_VOLET-2_Tome-3_Avril2024.pdf
page 107

Local conclusion

- **Digital technology in its infancy**
  - **Built without limits**
  - **Having a significant spatial/environmental/political impact**
  - **That became pervasive**
  - **Which crystallizes all the (dys-)functions of the capitalist economic system**

3 ICT and the Earth system

ICT impact is not only about GHG

- **Life cycle analysis takes many impacts into account (Cf. ReCiPe 2016 midpoint (H) methodology – 17 categories)**

Impact category	Abbreviations	Unit
Global warming	GW	kg CO_2 eq
Stratospheric ozone depletion	SOD	kg CFC11 eq
Ionizing radiation	IR	kg Co-60 eq
Ozone formation, Human health	OF	kg NOx eq
Fine particulate matter formation	FPMF	kg PM2.5 eq
Terrestrial acidification	TA	kg SO_2 eq
Freshwater eutrophication	FEut	kg P eq
Marine eutrophication	MEut	kg N-Eq
Terrestrial ecotoxicity	TE	kg 1,4-DCB eq
Freshwater ecotoxicity	FE	kg 1,4-DCB eq
Marine ecotoxicity	ME	kg 1,4-DCB eq
Human carcinogenic toxicity	HCT	kg 1,4-DCB eq
Human non-carcinogenic toxicity	HNCT	kg 1,4-DCB eq
Land use	LU	m^2a crop eq
Mineral resource scarcity	MRS	kg Cu eq
Fossil resource scarcity	FRS	kg oil eq
Water consumption	WC	m^3

Reminder: direct impact of ICT

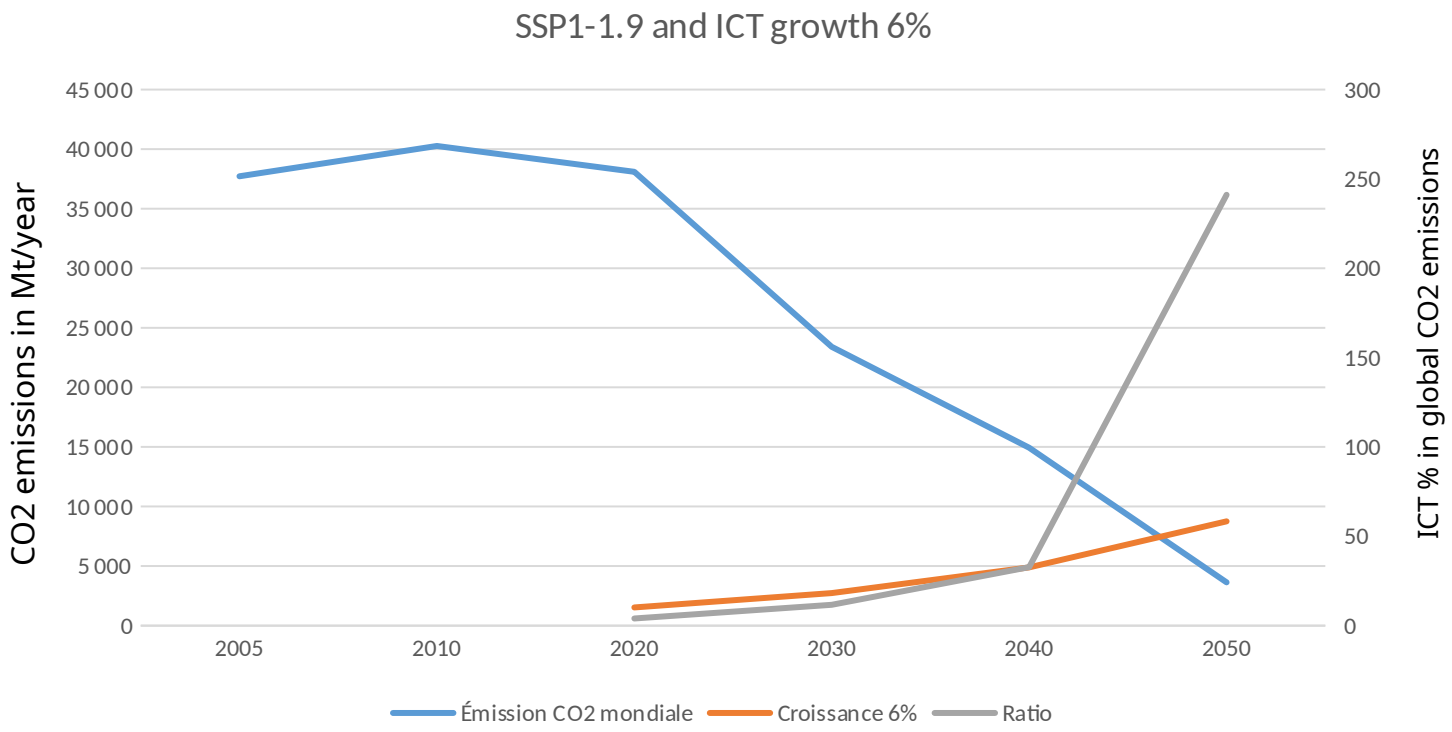
- **ICT share of global GHG**
  - **Between 2.1% and 3.9% of GHG [Freitag et al 2021]**
  - **Annual growth of 6-9% (based on 2015-2019 data)**
  - **So before** 

(2020 and 2022)
  - **Is it compatible with the targeted reductions?**

ICT share of GHG emission

Analysis suggested by D. Trystram, Y. Malot & G. Raffin (UGA/France)

❑ SSP1-1.9 scenario and minimal ICT growth (6%)

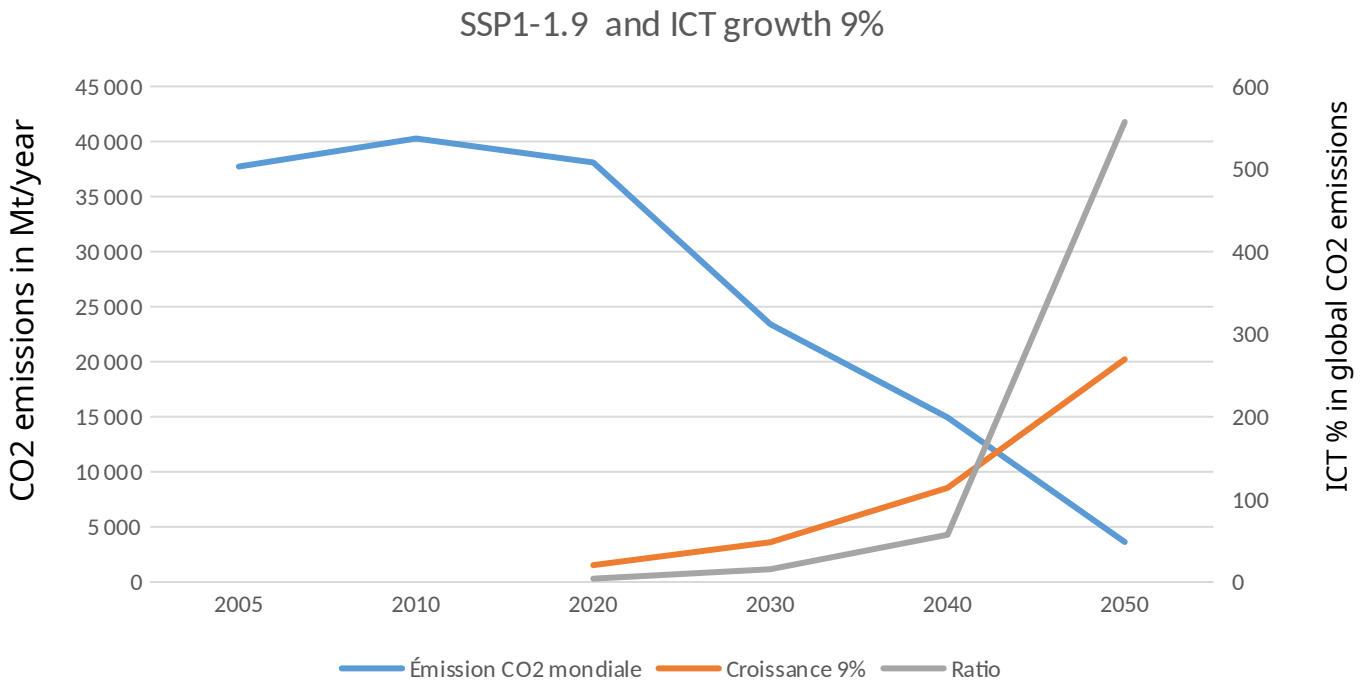


Left ordinate are MT of CO2 emission per year. Right ordinate are percentages for the grey curve.

ICT share of GHG emission

Analysis suggested by D. Trystram, Y. Malot & G. Raffin (UGA/France)

❑ SSP1-1.9 scenario and higher limit ICT growth (9%)



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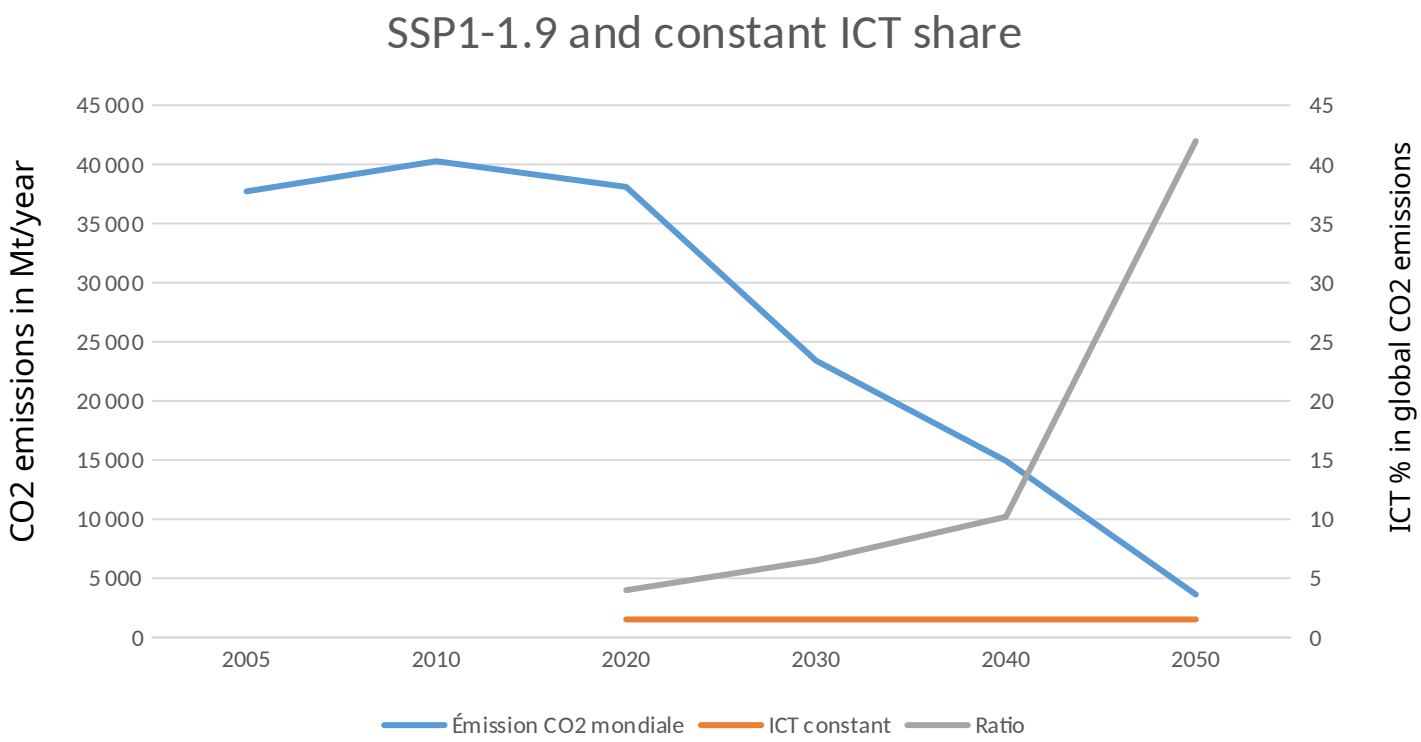
ICT share of GHG emission

Analysis suggested by D. Trystram, Y. Malot & G. Raffin (UGA/France)

❑ SSP1-1.9 scenario constant ICT share (6%)



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Local conclusion (1)

- **ICT**
  - **Without limits to growth (*whereas since 1972…*)**
  - **Inconsistent with the need to reduce emissions**

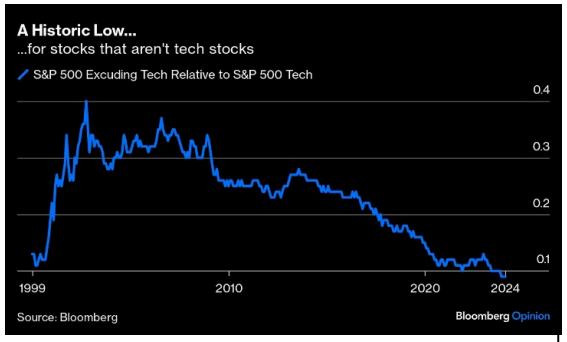
Local conclusion (2)

- **ICT**
  - **Without limits to growth (*whereas since 1972…*)**
  - **Inconsistent with the need to reduce emissions**
  - **But <u>essential</u> to the US economy**

https://www.macrotrends.net/2324/sp-500-historical-chart-data

SP500 (S&P, 80% of total market value)– 2012-2024

https://uncharteduncertainties.tomaspueyo.com/p/how-to-navigate-a-tech-world-dominated

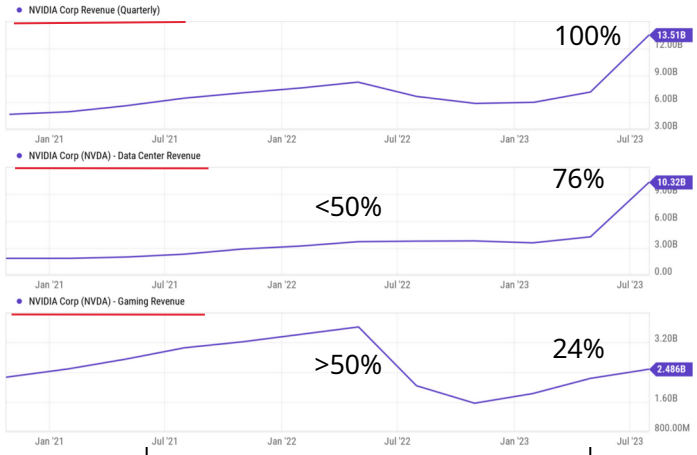


Oct, 16, 2024

https://companiesmarketcap.com/

	Name	Market Cap	Price	Today	Price (30 days)	Country
1	Apple AAPL	$3.524 T	$231.78	-0.89%		USA
2	NVIDIA NVDA	$3.329 T	$135.72	+3.13%		USA
3	Microsoft MSFT	$3.093 T	$416.12	-0.63%		USA
4	Alphabet (Google) GOOG	$2.042 T	$166.74	-0.10%		USA
5	Amazon AMZN	$1.961 T	$186.89	-0.43%		USA
6	Saudi Aramco 2222.SR	$1.746 T	$7.22	-0.18%		S. Arab
7	Meta Platforms (Facebook) META	$1.459 T	$576.79	-1.62%		USA

https://get.ycharts.com/resources/blog/the-rise-of-nvidia-in-5-charts/



4 What is to be done?

Burning Questions to Get Us Moving

Planetary boundaries and socio-technical systems

- **Crossing planetary boundaries**
  - places us in a *zone of uncertainty*
  - characterized by *considerable fluctuations*

- **What are the consequences for our technical systems?**
  - Technical systems have focused on *efficiency gains*
  - But « […] effectiveness and efficiency are the instruments of an optimization that locks us into a narrow path, and therefore inadequate if everything is constantly subject to change » (O. Hamant – Antidote au culte de la performance – 2023)
  - From now on, we should focus on from now on, *robustness* and *adaptability*

Planetary boundaries and socio-technical systems

- **Crossing planetary boundaries**
- **What are the consequences for our technical systems?**
- **ICT as *negative commons* and *zombie technology***

  [Héritage et fermeture – E. Bonnet, D. landivar et A. Monnin – Divergences – 2021]
  [“Negative commons” – A. Monnin – Études – Septembre 2021 – No 4285 – english version]
  [Technologie zombie - J. Halloy – dialogue avec N. Nova]

  - **To which we are bound (or *attached*)**
  - **Who binds us**
  - **Whose legacy (and closure) we must collectively manage**

	Resources	Sustainability	End of Life
Zombie technlogies	Finite (long-term exhaustion	Minimum durability in working order	Maximum life span as waste
Living Technologies	Renewable (strong sustainability)	Maximum durability in working orders	Minimum life span as waste

From A. Parmentier-Cajaiba and J. Mazza - Living technologies, a renewed perspective of Deeptech to foster climate and ecological transitions – accessed 3/12/204

A biologist's metaphor on robustness and adaptability

- **O. Hamant reminds us that the robustness of living organisms is the result of**
  - **Heterogeneity**
  - **Random processes**
  - **Slowness**
  - **Delays**
  - **Redundancies**
  - **Inconsistencies**
  - **Errors**
  - **Incompleteness**
  - **Sub-optimality**
  - ***Locality + interactions [me]***
  - ***Emergence [me]***
- **Paradigmatic example: photosynthesis**
  - **Appeared 3,8B years ago**
  - **Efficiency < 1% (is wasting 99% of solar energy)**

ICT in a trap

- **A double effect which combines**
  - **ICT growth inconsistent with the need to reduce emission**
  - **Crossed planetary boundaries producing *considerable fluctuations***

- **Combine robustness with reduction**
  - **By building on (1) limits and (2) savings resources**
  - **By considering a digital system as a (3) dynamical system**
  - **By building robustness by redundancy, self-adaptability and (2) simplicity**

Building on Limits (1)

- **Reintroducing limits**
  - **Time**
    - **Data circulation constrained by external resources** (energy from PV for example)
  - **Space**
    - **Relocate services** (local mesh WiFi, hierarchy of data access…)
  - **Discontinuity**
    - **Intermittent operation** (constrained by a resource)
  - **Computation**
    - **Can we/Should we compute everyhting?** Slow-down computations ? Pre-process and store already computed data?
  - **Resource**
    - **Think in term of supply (finite)** and not fluxes (infinite)

Building on Limits (1)

- **Reintroducing limits**
  - **Availability**
    - **Should a service be always available?**
  - **Acceleration**
    - **How to slow-down exchanges?**
  - **Exhaustivity**
    - **What does it mean to undigitize?** (willing or not)
  - **Politics**
    - How to deliberate? If **`Code is law`** / **`Law is code`**: requires a public control over code
  - **And what about the rebound effect *(direct and indirect)*?**

Building on Limits (1)

- **Reintroducing limits**
- **Thinking in terms of non-extensible systems (but rather shrinkable) and identify anti-limits**
- **Considering constraints:**

{*intermittent*, *quotas*, *supply*}
x
{*energy*, *communication*, *memory*, *computation*}

- **Experimenting alternative systems and *already available material resources***

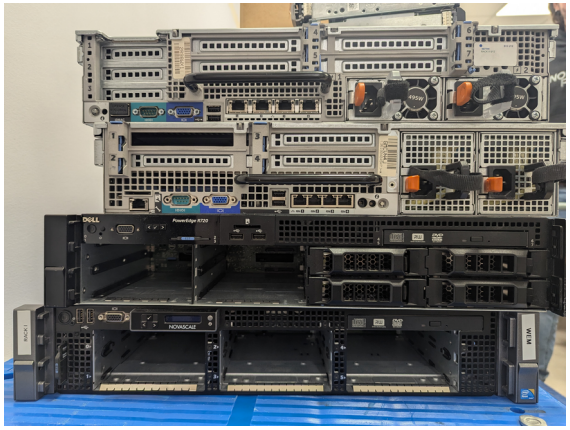
Saving resources and simplicity (2)

- **Considering an approach that uses (already) available resources**
  - **University as an *urban mine* (server, computers, routers, smarphones…)**
    - Not considering the extraction of rare metals from ICT
    - Considering the extraction of working functionalities (computing/communication/…): higher abstract level
  - **Computing with (what is considered) electronic waste (WEEE) or EOL electronics**

Some WEEE at some University's dept – photo taken in 2024

Saving resources and simplicity (2)

- And we do have a LOT of these WEEE (here from the IT at University)



DELL PowerEdge R720 server - 2012

Overland Storage NEO 2000e - 2013

Lenovo ThinkStation S20 model 4157 servers - 2009

DELL PowerEdge 1950 server - 2009

Novascale R460 F3 - 2012

Nvidia Quadro FX 580 - 2009

Saving resources and simplicity (2)

- **Consider an approach that uses (already) available resources**
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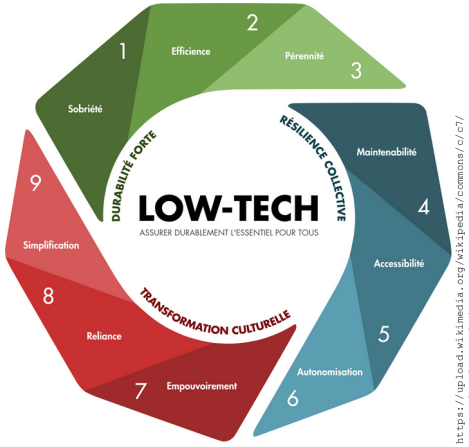
  - **Computing with WEEE**

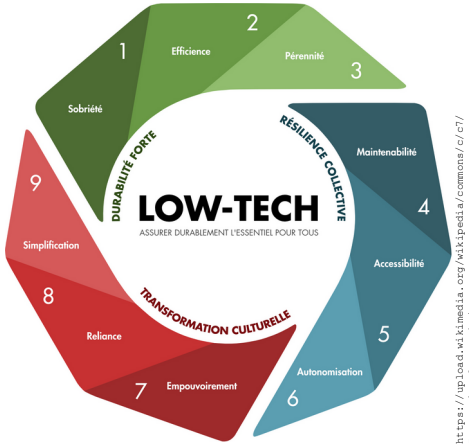


https://upload.wikimedia.org/wikipedia/commons/c/c7/Innovation_low-tech.jpg

- **Close to the notion of *low-tech***
  - **Sustainability**
    - Sustainable (and standardization / modularization)
    - Low environmental impact (**reduced consumption of resources**)
    - **Low resources required**
      - Removal of unnecessary functions
      - Use of locally abundant available resources
  - **Autonomization**
    - Autonomy of use
    - **Reducing interdepencies**

Saving resources and simplicity (2)

- **Consider an approach that uses (already) available resources**
  - **University as an urban mine**
  - **Computing with WEEE**

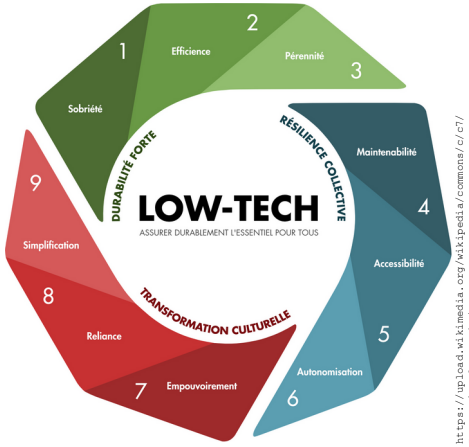


https://upload.wikimedia.org/wikipedia/commons/c/c7/Innovation_low-tech.jpg

- **Close to the notion of *low-tech***
  - **Locality**
    - **Reducing resource pressure** (transportation / autonomy / ...)
  - **Accessibility**
    - Understandability (individual and collective reappropriation)
    - Simplicity (control the entire chain – required for resilience, **robustness** and accessibility)
    - *Empowerment* of the users (being an agent in conception and use)
    - Sophistication (from the object to the agents and their approach)
    - **Cost-efficient** (facilitates deployment - network effects - **increased longevity**)

Saving resources and simplicity (2)

- **Consider an approach that uses (already) available resources**
  - **University as an urban mine**
  - **Computing with WEEE**



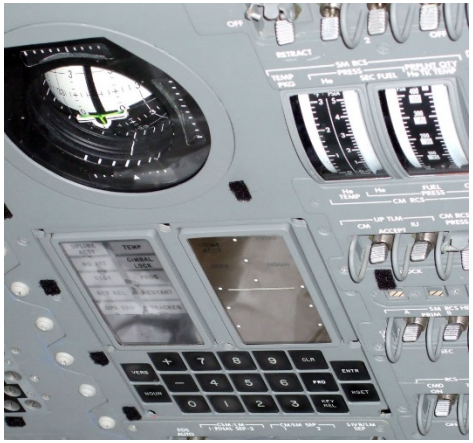
https://upload.wikimedia.org/wikipedia/commons/c/c7/Innovation_low-tech.jpg

- **Close to the notion of *low-tech***

- **Promote innovation by *removal* and not by addition: *substractive innovation: SIRIUS project***

Saving resources and simplicity (2)

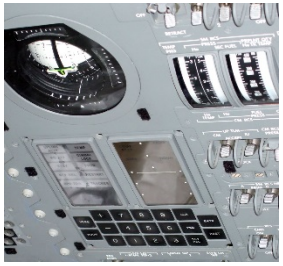
- **Shifting the viewpoint – a concrete example**
  - **Law : « To have an ~~efficient~~ robust program, you need a low-performance hardware architecture »**
  - **Paradigmatic example: Apollo 11 mission (21/07/1969)**
    - Apollo Guidance Computer
      - 72 Ko (36k of 16 bits words) of ROM (prog. + OS)
      - 4ko (2k of 16 bits words) of RAM
      - Frequency: 85 kHz
      - Power consumption: 55 W / 32 kg
      - Logics: 2800 double-NOR-3 gates
      - Source code : https://github.com/chrislgarry/Apollo-11/



https://fr.wikipedia.org/wiki/Apollo_11#/media/Fichier:Dsky.jpg

Saving resources and simplicity (2)

- **Shifting the viewpoint – a concrete example**
  - **Law : « To have an ~~efficient~~ robust program, you need a low-performance hardware architecture »**
  - **Paradigmatic example: Apollo 11 mission (21/07/1969)**
    - Apollo Guidance Computer
      - 72 Ko ROM / **4ko RAM** / 85 kHz / **5600 NOR-3 gates**
    - Apple IPhone 1 (2007)
      - **128 Mo RAM**
      - 4, 8 ou 16 Go of storage flash memory
      - CPU ARM RISC @ 620 MHz
      - About **50M transistors**
        (in 2024: 10B to 50B transistors)
    - Ratios
      - 32 000 (RAM)
      - 8900 (transistors)



https://fr.wikipedia.org/wiki/Apollo_11#/media/Fichier:Dsky.jpg

https://en.wikipedia.org/wiki/IPhone_(1st_generation)#cite_note-Processor-4

Saving resources and simplicity (2)

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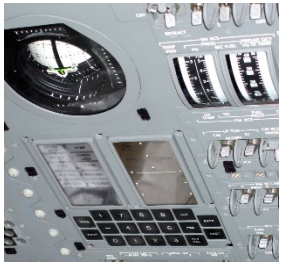
  - **Computing with WEEE**



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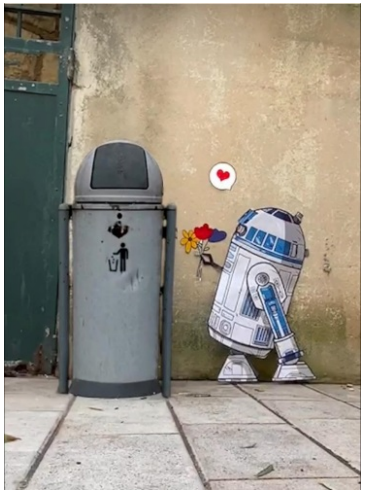

https://en.wikipedia.org/wiki/IPhone_(1st_generation)#cite_note-4

Saving resources and simplicity (2)

- Computing with WEEE
  - Collecting even more WEEE!

EUROPEAN WEEK FOR WASTE REDUCTION

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SEMAINE EUROPÉENNE DE LA RÉDUCTION DES DÉCHETS

UPEC
Connaissance - Action

COLLECTE DE SMARTPHONES

Mardi 19 novembre - 9h à 13h – Site St Simon

Saving resources and simplicity (2)

- **Computing with WEEE**
  - **Hardware – urban mine in effect**
    - Collecting WEEE from the University
      - from the IT (**lots** of available hardware, even more with W10 -> W11)
      - From the various departments (known and forgottent/lost hardware)
      - From the users
    - Checking the hardware, its capabilities (upgrade if possible, disassemble if needed to extract the computing device) and install news OS
      - Easy for regular PC
      - Moderate/Hard for heterogeneous smartphones
      - Old hardware not able to run current softwares
  - **Collect PV, energy storage system (batteries, supercapacitors…) and build an energy storage system**
  - **If nothing can be done: dispose to WEEE collectors for *recycling***

LENOVO S20 - Intel Xeon X3503 - (2009)

Keeping the computing part of a DELL AIO

Saving resources and simplicity (2)

- **Computing with WEEE**
  - **Hardware**
  - **Software**
    - Building a cluster and trying to **unify** heterogeneity
      - Easy if Linux on all machines
      - Harder if *ad-hoc* exotic hardware is considered
    - Many possible directions (lots of work done in that area)
      - Following the *Berkeley Open Infrastructure for Network Computing* approach
      - Following a Kubernetes/Docker/virtual machine approach
      - Following a Garage approach for storage(Amazon S3 compatible API developped by french researchers)
      - Following a standalone app with redundancy approach
    - Failures (of energy and/or computing devices): adding and removal of unreliable computing devices

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slow-tech.fr

Saving resources and simplicity (2)

- **Computing with WEEE**
  - **Hardware**
  - **Software**
  - **Proof of concept**
    - Evaluate and challenge the cluster itself
      - on IT real apps (student projects, mail server, file server, ad-hoc app, machine learning/AI…)
      - intermittent operation of the infrastructure
    - LCA to evaluate the impact reduction using WEEE vs. new hardware at IT
    - Change the users' (from IT to students and staff/faculty) point of view on waste
    - Rehabilitating *maintenance* and care towards *things* [Denis & Pontille – 2022]

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Computation as a dynamical system (3)

- **A software**
  - **Globally specified from high-level guidelines**
  - **Local computing for robustness**
  - **With sensors, effectors and feedback loops**

- **Built with anti-limits in mind**
  - **Static and limited resources**
  - **No global control (locality)**
  - **Developed in a simple, high-level and robust language (SML or alike)**

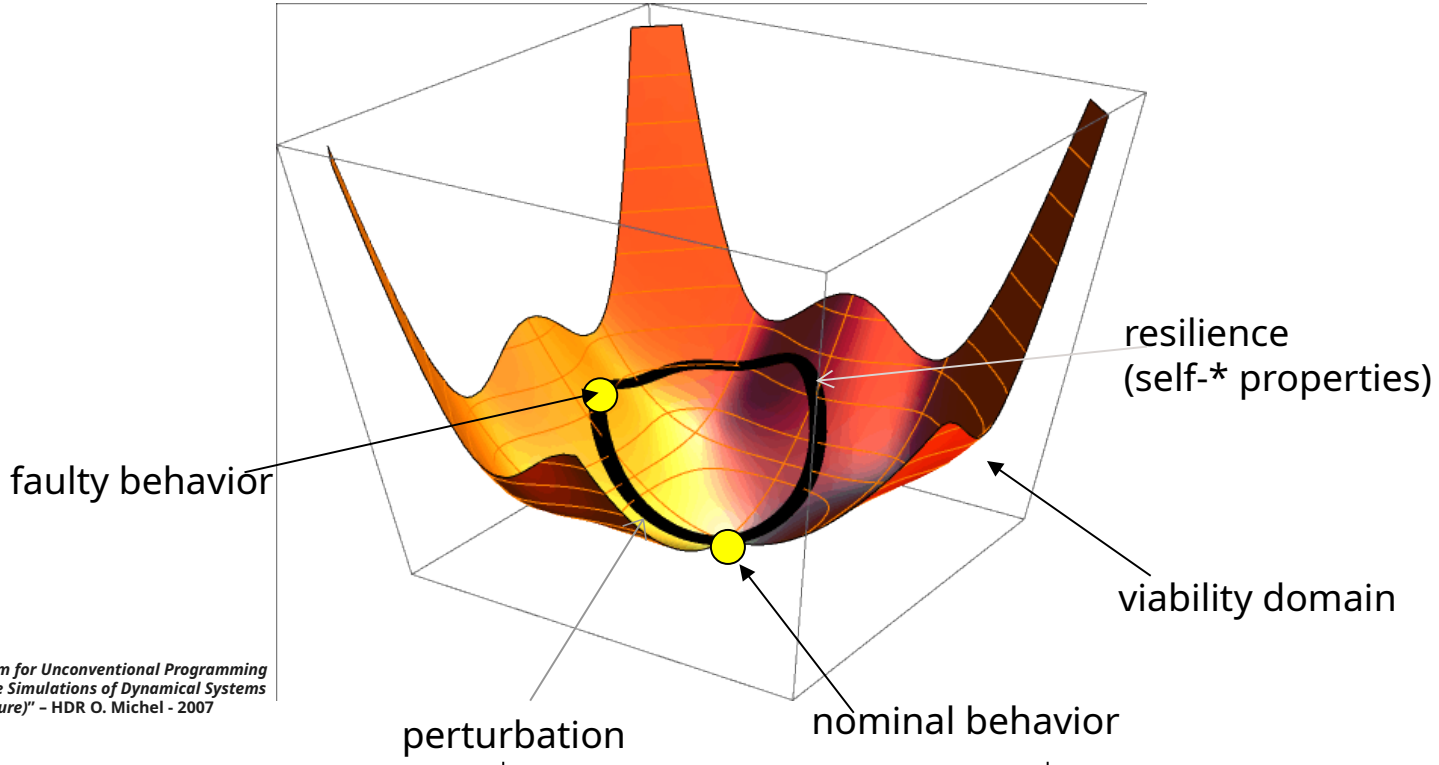
- **Whose behavior is the emergence of local interactions (*multi-agent style*)**

Computation as a dynamical system (3)

Software = dynamical system

Nominal behaviour = stable state

Auto-* = returning to stable state after perturbation

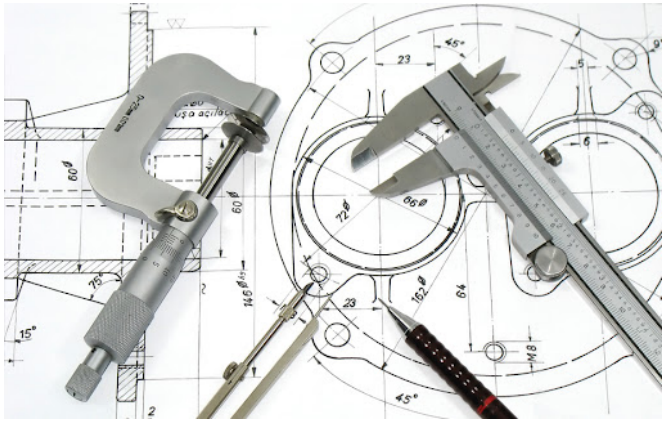


In *"There's Plenty of Room for Unconventional Programming Languages* or *Declarative Simulations of Dynamical Systems (with a Dynamical Structure)"* – HDR O. Michel - 2007

5 Conclusion

An Old-Fashioned Project By Design

- **Numerous challenges**
  - **At the technical level**
    - Unreliable hardware
    - Hardware heterogeneity
    - Handling of variable energy sources
    - Adaptable and autonomous system
    - **Keeping the software stack as simple as possible**



http://geniadesign.ca/services_item/resolution-technique/

  - **At the sociotechnical level**
    - Massive availability of WEEE
    - Conduct a meaningful Life Cycle Assessment
    - Change IT department practices
    - Avoid rebound effect
    - **Change the viewpoint on WEEE**
    - Developing an ambitious and efficient maintenance policy

https://decidim.u-pec.fr/processes/CCB2023

ICT within boundaries

- **A plea for research within planetary boundaries**
  - **Taking seriously the notion of limit in IT**
  - **Using LCA to assess its impact**
  - ***Not increasing the crossed environmental boundaries***
  - **Exploring neglected trajectories…**
  - **…valuing *robustness* and *adaptability* over *efficiency***
  - **…changing the way we look at waste**
  - **…questioning our imaginary, our ways of living and working**
  - **…politicizing this socio-technical system, a *zombie negative commons***

[Jean-François Millet – Des glaneuses – 1857 – Musée d'Orsay]

Reverse Panel Questions

A few questions

- **If a university can be considered an *urban mine*, should we imagine (and how) setting up maintenance and repair services for these devices in our institutions, in order to extend their lifespan as much as possible?**

- **If ICT is a *negative commons*, then we have a collective responsibility to gradually de-attach ourselves from it. How can we manage this de-attachment, and what can we re-attach ourselves to as a substitute? Do you think we can make our institutions work with a reduced digital environment, and at what cost?**

- **Given that hard decisions have to be made (like renouncing the latest technological innovations) not to cross planetary boundaries, what do you think of organizing *deliberative democratic processes like citizens' assemblies*?**
  (ref below if the question is written and given beforehand?)