Digital technologies :
Environmental issues, rebound effects

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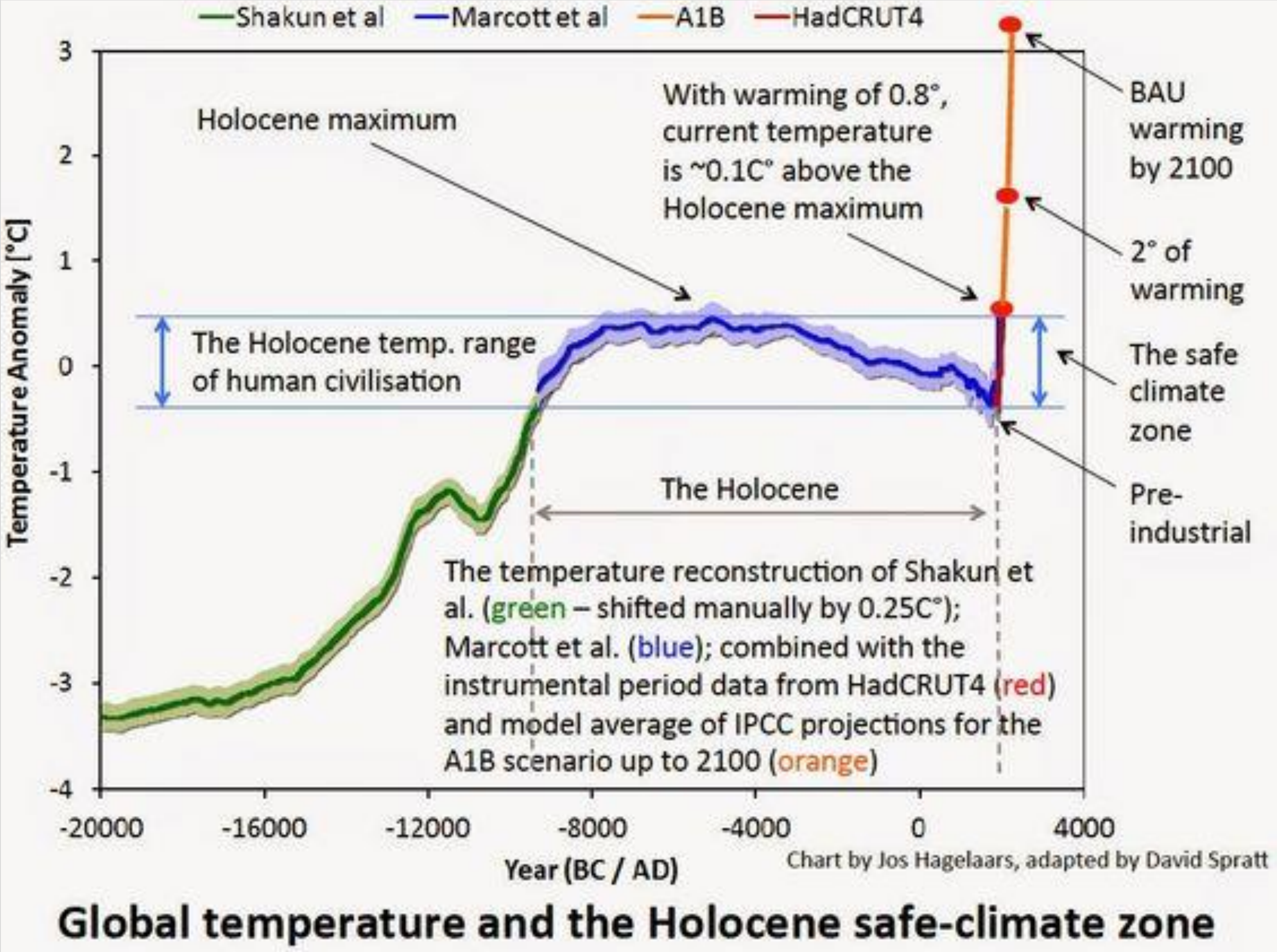
The context

[Becoming resilient in a world exposed to unprecedented systemic risk](#)

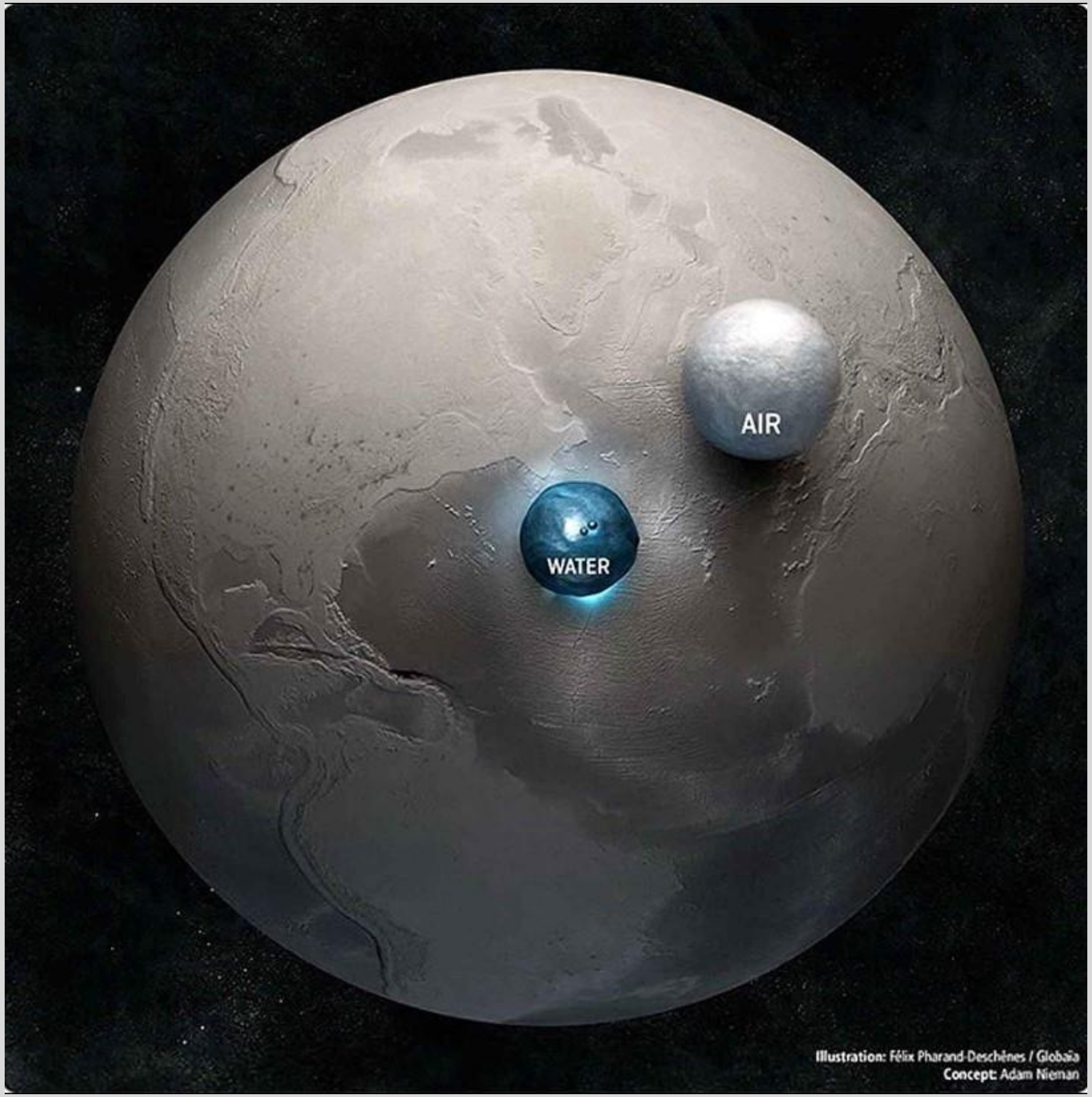
Arthur Keller

The context



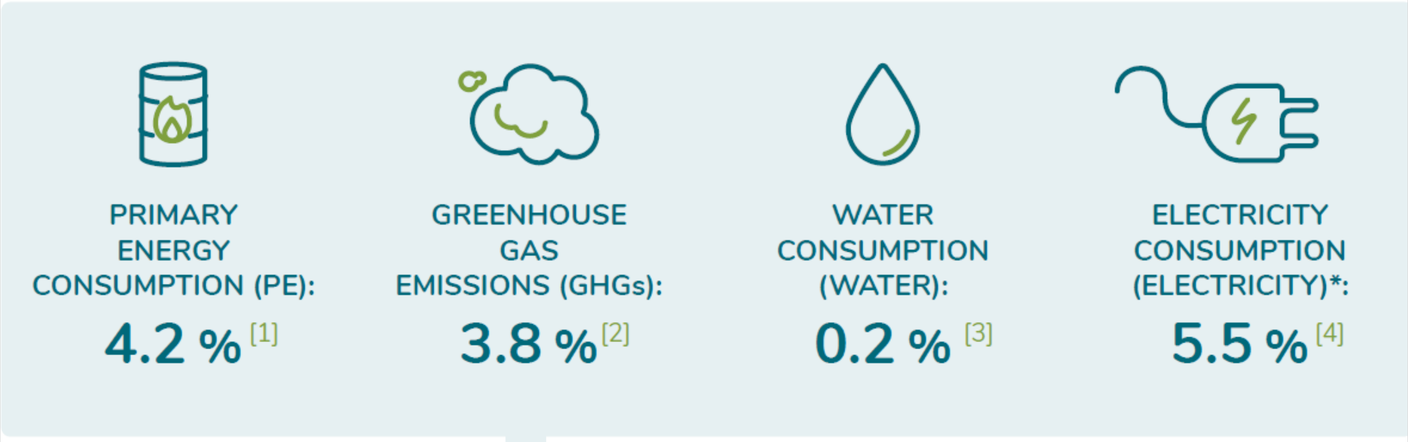
Adapted from Jos Hagelaars, David Spratt

The context


AIR
WATER
Illustration: Félix Pharand-Deschênes / Globaïa
Concept: Adam Nieman

ICT and environmental issues

Environmental footprint of digital technologies



5.5 %
(2025)

GreenIT, « Environmental footprint of the digital world » 2019

ICT and environmental issues

Environmental footprint of digital technologies

%	Energy	GHG	Water	Elec.	ADP
User equipment	60%	63%	83%	44%	75%
Network	23%	22%	9%	32%	16%
Data centres	17%	15%	7%	24%	8%

Abiotic Depletion Potential

Mostly manufacturing

Decreasing impact

1. **Manufacturing of user equipment;**
2. **Power consumption of user equipment;**
3. Power consumption of the network;
4. Power consumption of data centres;
5. Manufacturing of network equipment;
6. Manufacturing of equipment hosted by data centres (servers, etc.).

Use devices as long as possible !!!

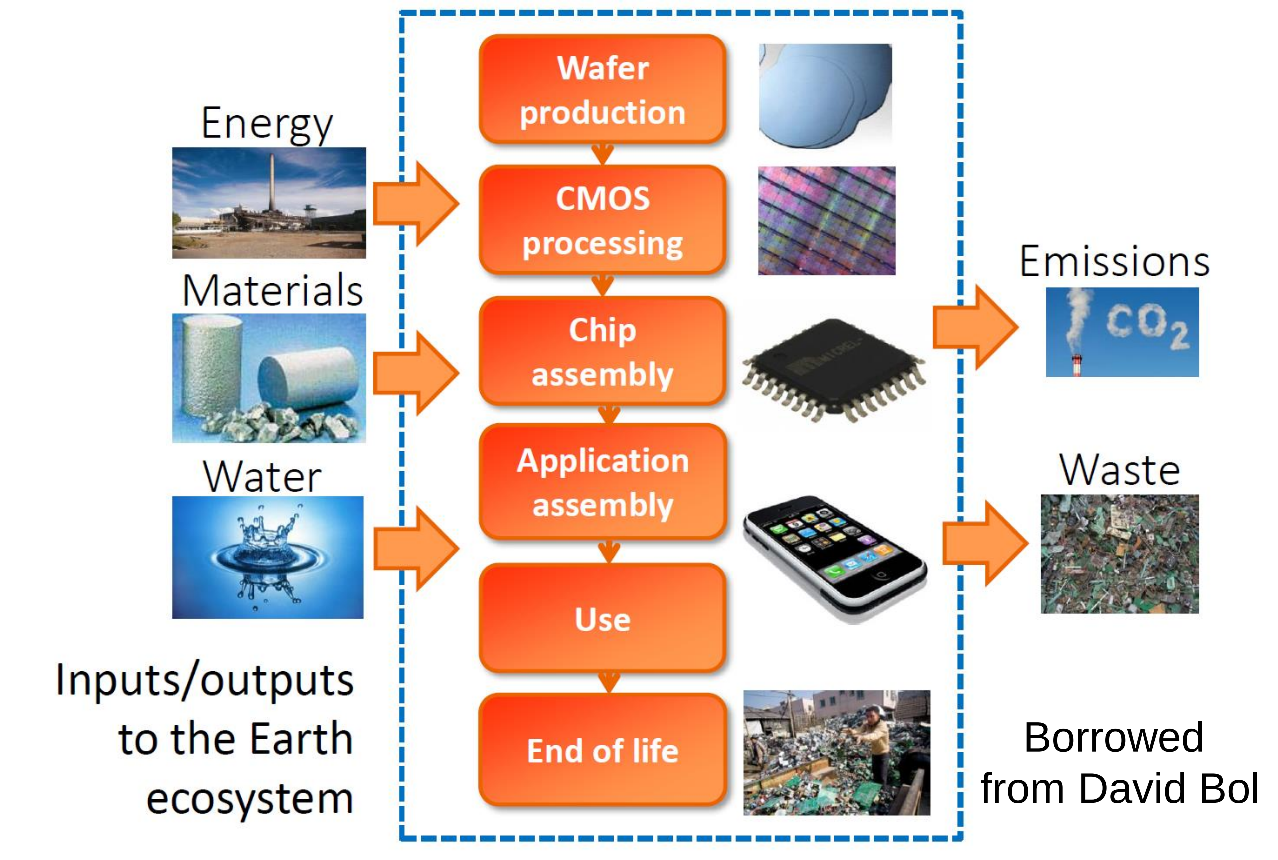
…obsolescence (technical, technological, cultural…)

Before Gen-AI !!!

GreenIT, « Environmental footprint of the digital world » 2019

ICT and environmental issues

Environmental impact not restricted to CO_2 emissions !!!



ICT and environmental issues

Environmental impact not restricted to CO_2 emissions !!!

EDITORS' PICK

No Water No Microchips: What Is Happening In Taiwan?

Emanuela Barbiroglio Senior Contributor

I write about sustainability

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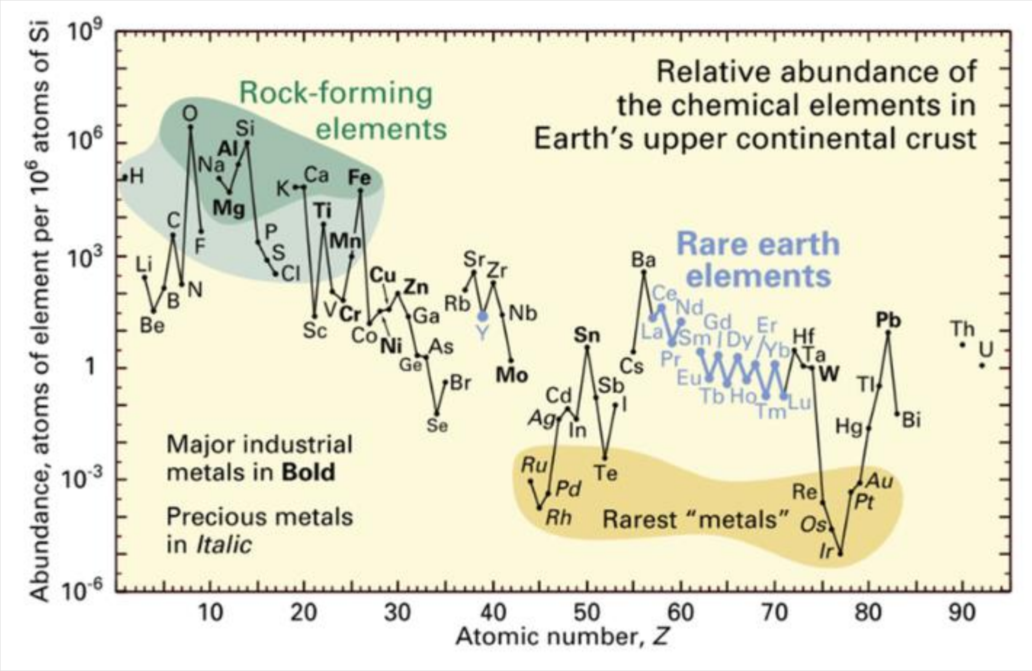
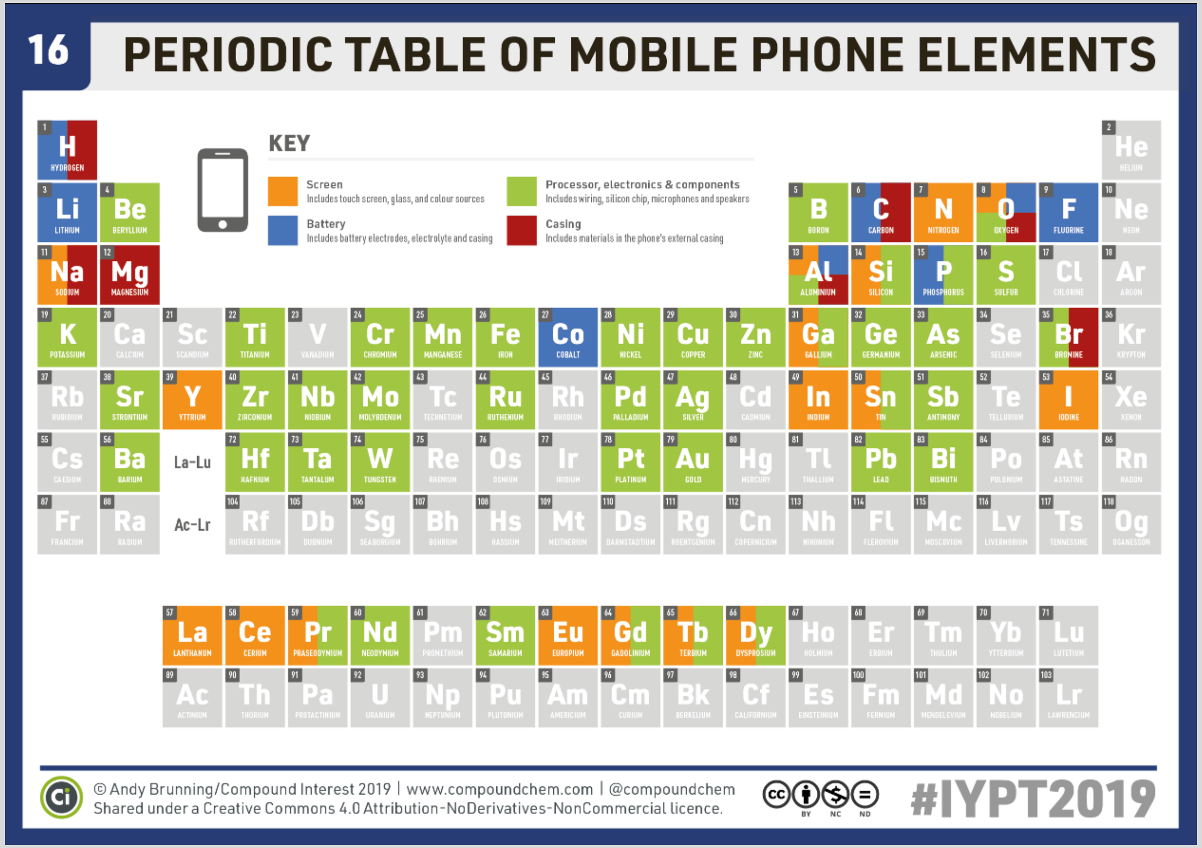
May 31, 2021, 05:09pm EDT

TSMC needs 150 000 m^3 water each day, up by 70 % between 2015 and 2019
2021 : water restrictions due to 20 % decrease in rainfall

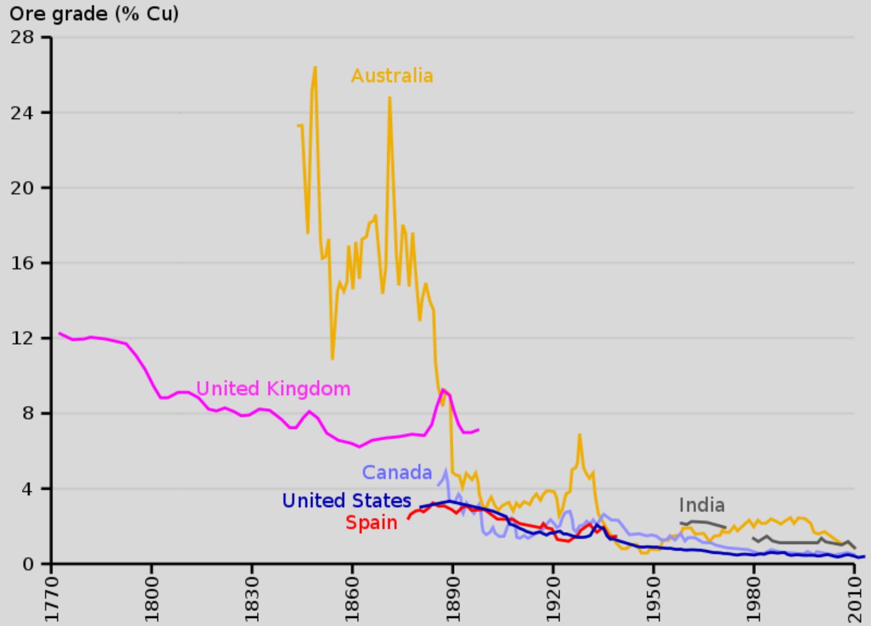
ICT and environmental issues : metals





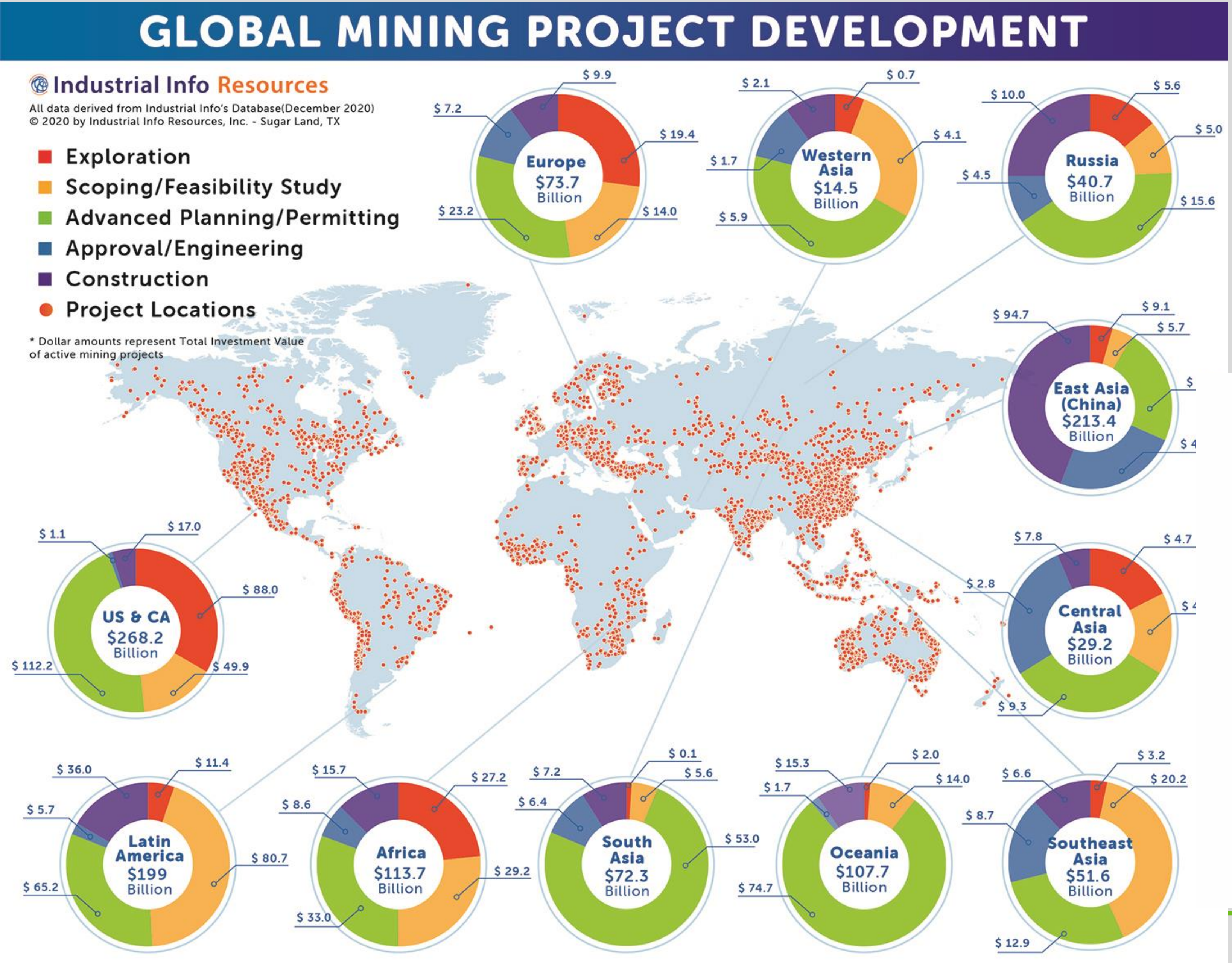
56 elements !!!

ICT and environmental issues : metals

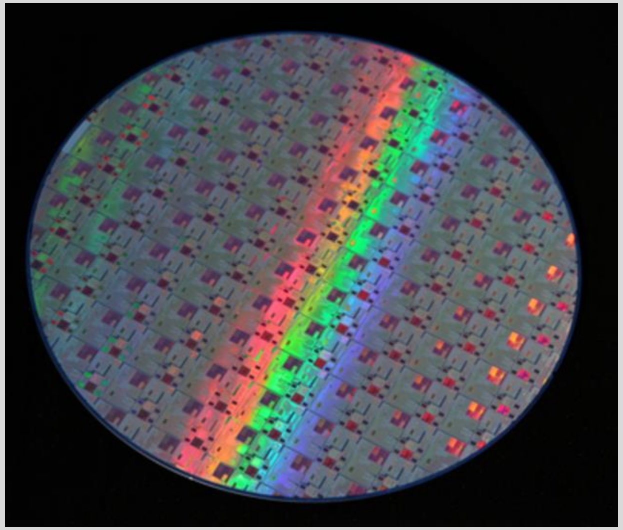


8 kg/capita.year

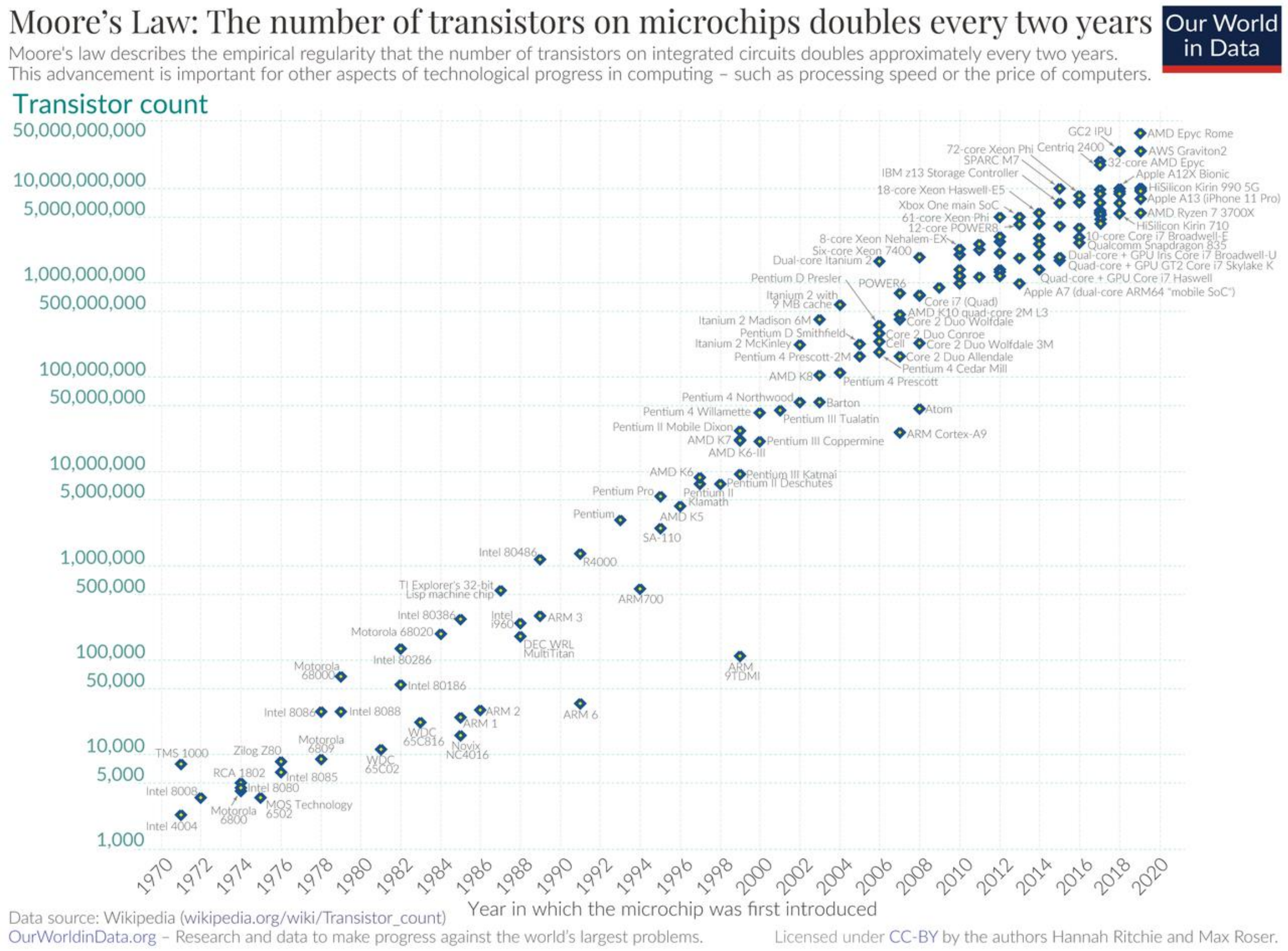
ICT and environmental issues : metals



The "miracle" of microelectronics



© ST Microelectronics



Fair enough, what about energy consumption ???

Microelectronics and energy efficiency

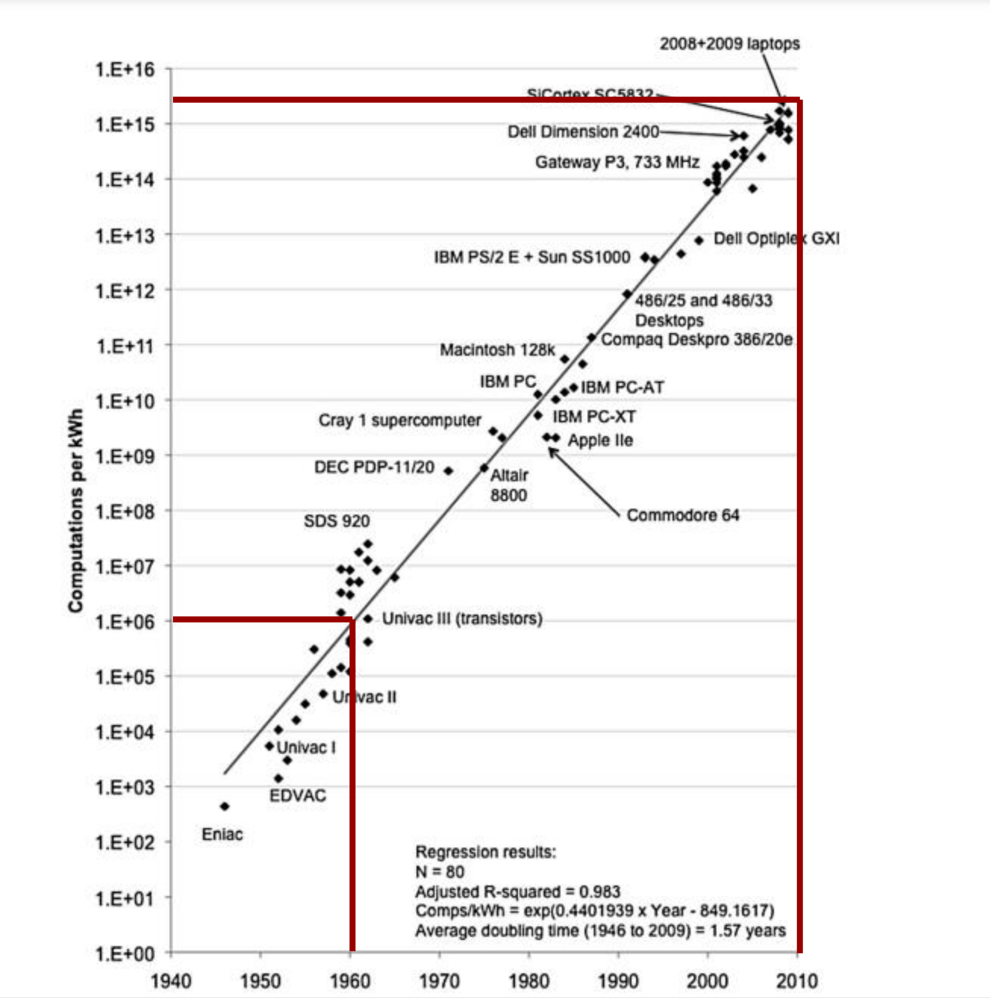
Koomey's law

⇒ Energetic efficiency doubling every 1.6 yrs

⇒ **10^9 increase** 1960 - 2010

⇒ Yet the GHG (Green House Gas) emissions linked to ICT increase (~ **4 %** in 2019, ~ 5.5 % in 2025….)

Energy efficiency => Energy savings ???



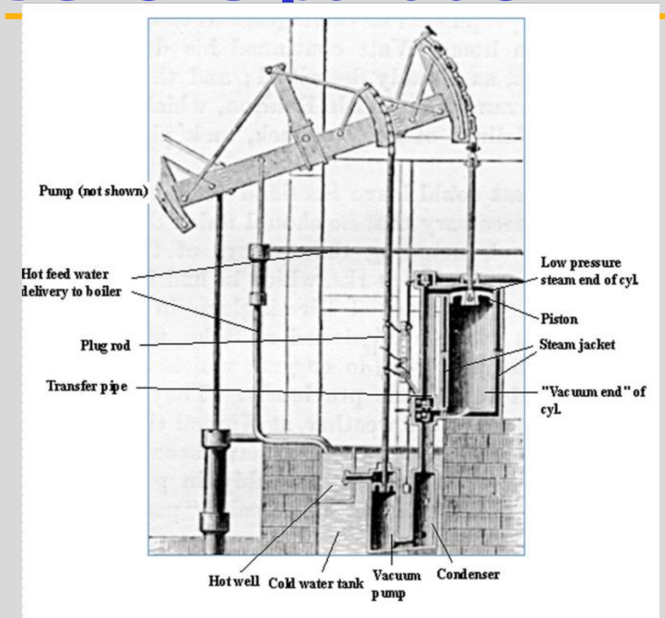
J. G. Koomey et al.,
IEEE Annals of the History of Computing, **33,** 46 (2011)

=> **Rebound effects** (cf *Jevons paradox*)

S.W. Jevons "The Coal Question: an Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines." 1865

Jevons paradox

1776



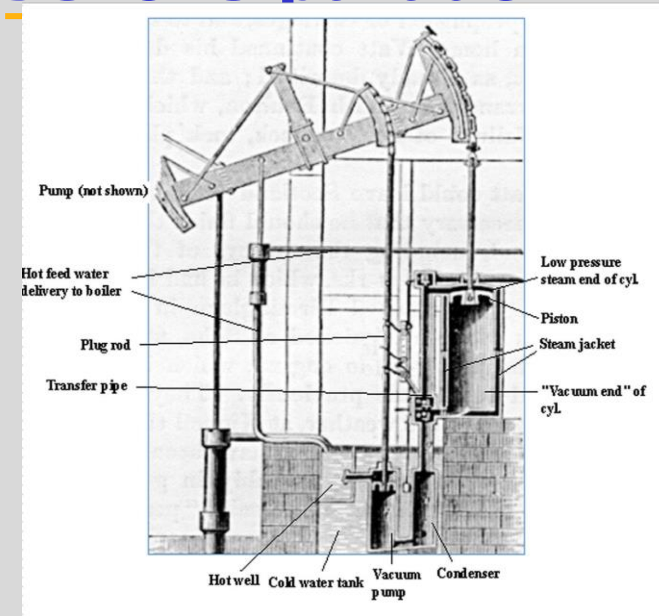
Watt steam engine => more efficient

More and more efficient machines → Less coal for a given work → Will our coal reserves last longer ?

S. W. Jevons : « The coal question, : an Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines. » (1865)

Jevons paradox

1776

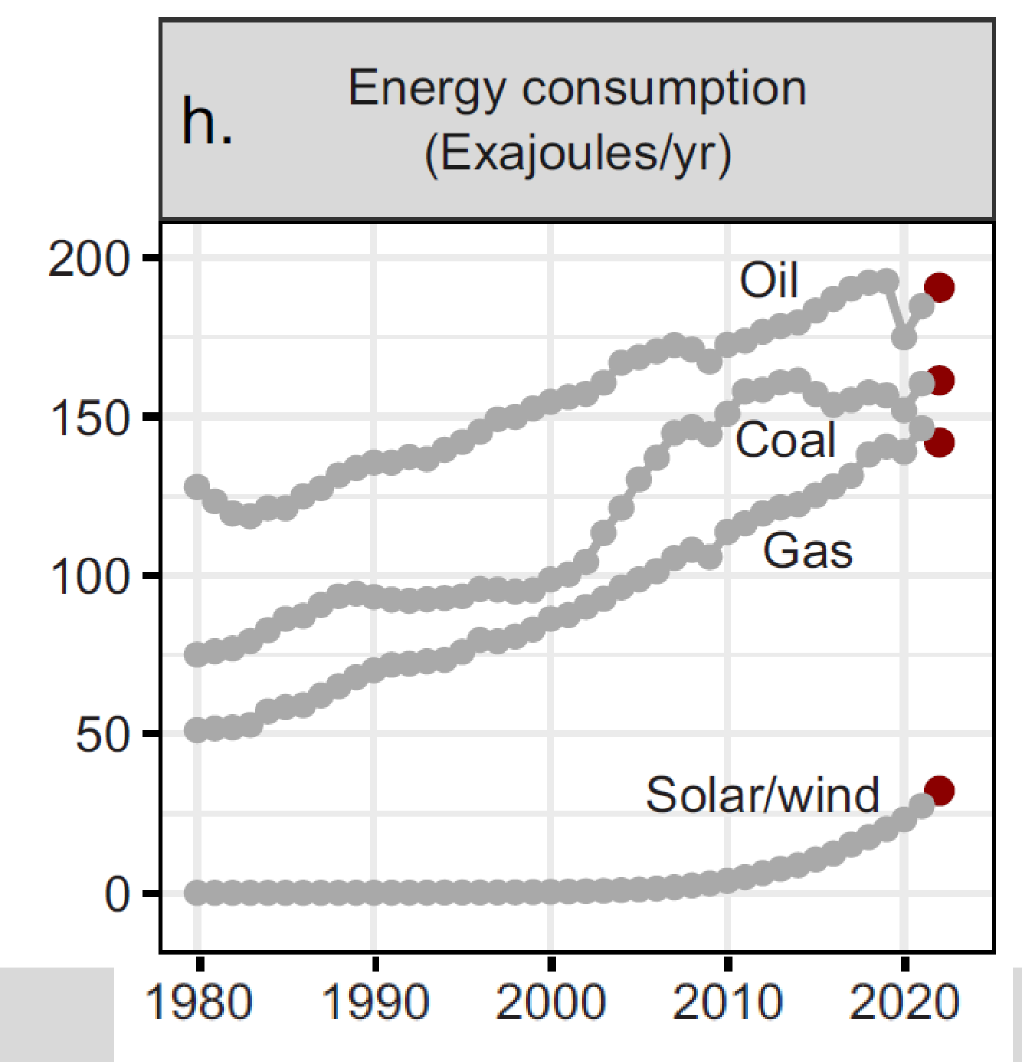


Watt steam engine => more efficient

“It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption.
The very contrary is the truth.”

S. W. Jevons : « The coal question, : an Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines. » (1865)

Coal consumption…



W.J. Ripple *et al.* "The 2023 state of the climate report: Entering uncharted territory", Bioscience **0** p 1 (2023)

Rebound effect : a short introduction

Defining the rebound effect :

- *Improvements in the technical efficiency of energy use that has a smaller energy-saving effect than predicted by engineers*

D.J. Khazoom "Economic implications of mandated efficiency standards for household appliances" , Energy J. **1** 21 (1980)

Energy consumption

Energy per unit

Units consumed

$$C = \mu N$$

Technological innovation

$$C = (g\mu)(aN)$$

Technological efficiency gain

"Behavioral" consumption change

Rebound effect

$$R = \frac{g(a-1)}{1-g}$$

Jevons paradox

R=0 : full technological gain

0 < R < 1 : usual case

1 < R : back-fire

Rebound effect : a short introduction

Typical example : car consumption

8 l/100 km => 6 l/100 km

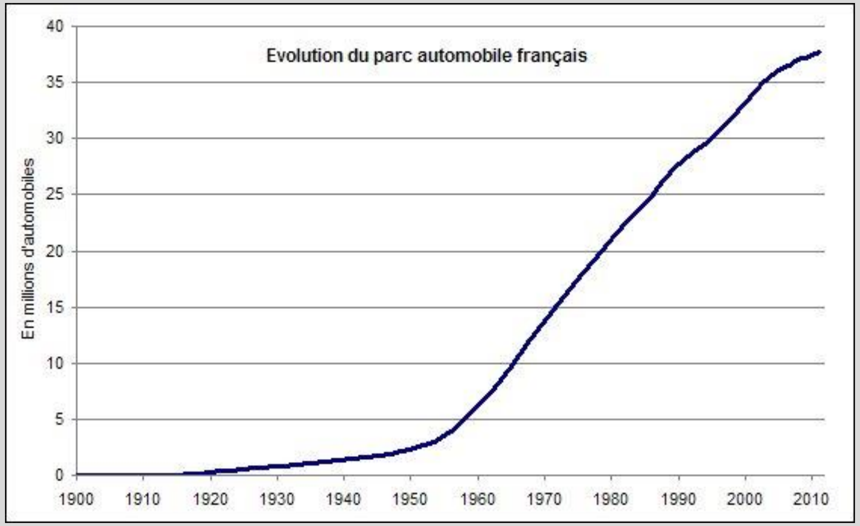
Direct rebound effect : - more driving (can even backfire !)

Indirect rebound effect : - less fuel consumption but transfer to other energy intensive consumption
- overall increase in car sales

Frontier effect : - more cars/distance => more roads, more malls etc…

570 kg, 8.2 l/100 km
1963

1300 kg, 5.2 l/100 km
2019



Rebound effects and semiconductor technologies

Energy efficiency gains come with other benefits :

Microelectronics : faster clock rates

Datacom : faster bit-rate

LEDs : - Much more flexibility for lighting
- Display back-lighting
- Micro-displays for AR/VR

Large R&D & equipment investments + low marginal cost

Production volume is an economical necessity, *so are the various rebound effects*

Pervasive technologies => large frontier/induction effects

=> Consumption enablers + Socio-economical transformations

The power and curse of the roadmaps

Why are roadmaps needed ?

- Complex supply chains => coordination needed between actors (+ standardization)
- Large investments => visibility (also on regulation side) + market forecast

Who decides ?

- Industrial stakeholders, sometimes governmental institutions
- Profoundly affects our economies and societies, hardly democratically debated (internet, smartphone, 5G, AI…)

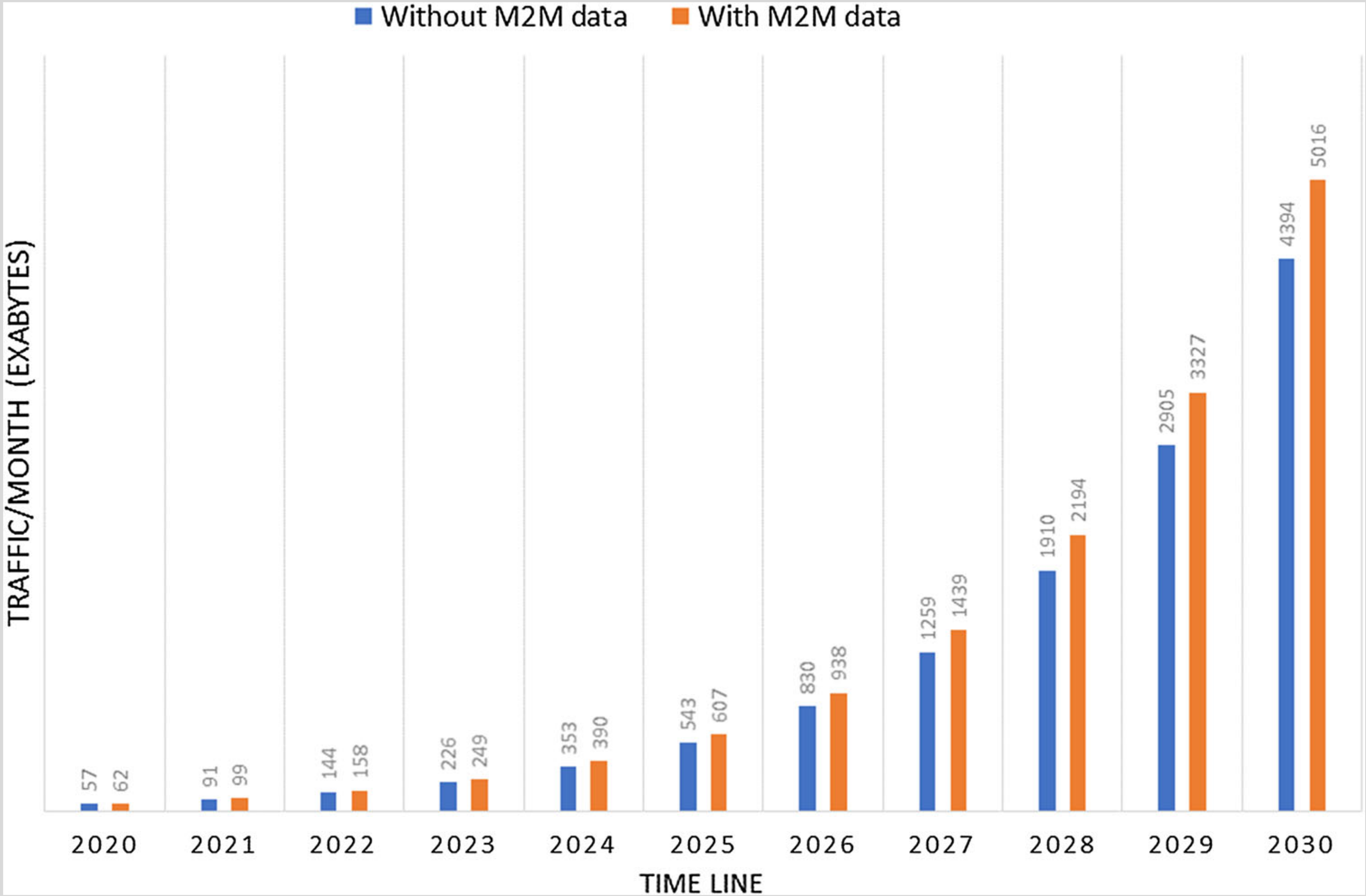
From the viewpoint of research

- Take the deployment roadmap as a « given » => any technological efficiency gain considered as an energy saving

OR

- Question the roadmap ? Anticipate ? Regulate ?

The power and curse of the roadmaps

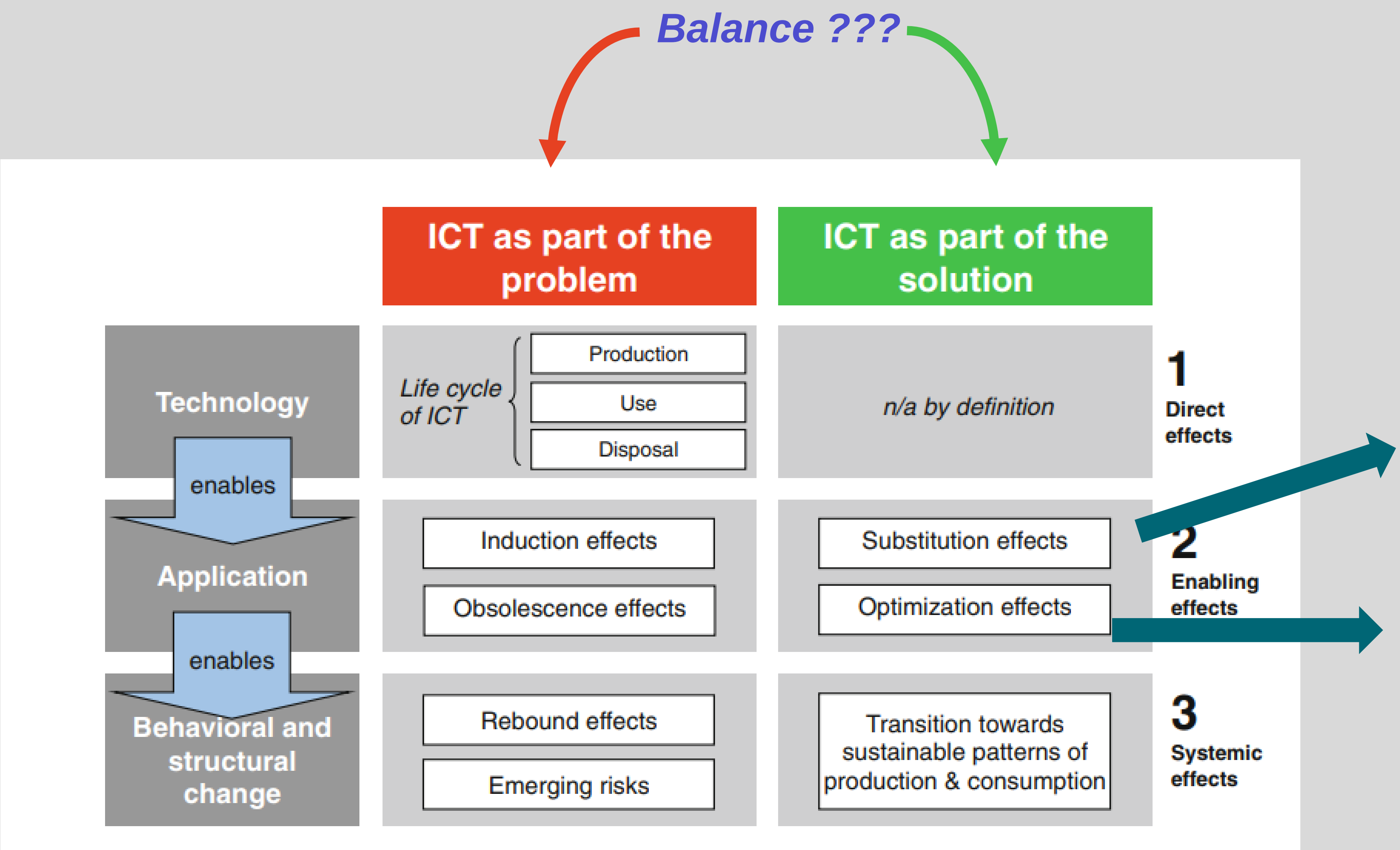


Exponential increase
(doubles every 1.7 years)

A linear efficiency improvement
yields an exponential energy saving !

S. Rajoria and K. Mishra "A brief survey on 6G communications"
Wireless Networks **28** 2901 (2022)
Report ITU-R "IMT traffic estimates for the years 2020 to 2030” 2015

ICT and environmental issues



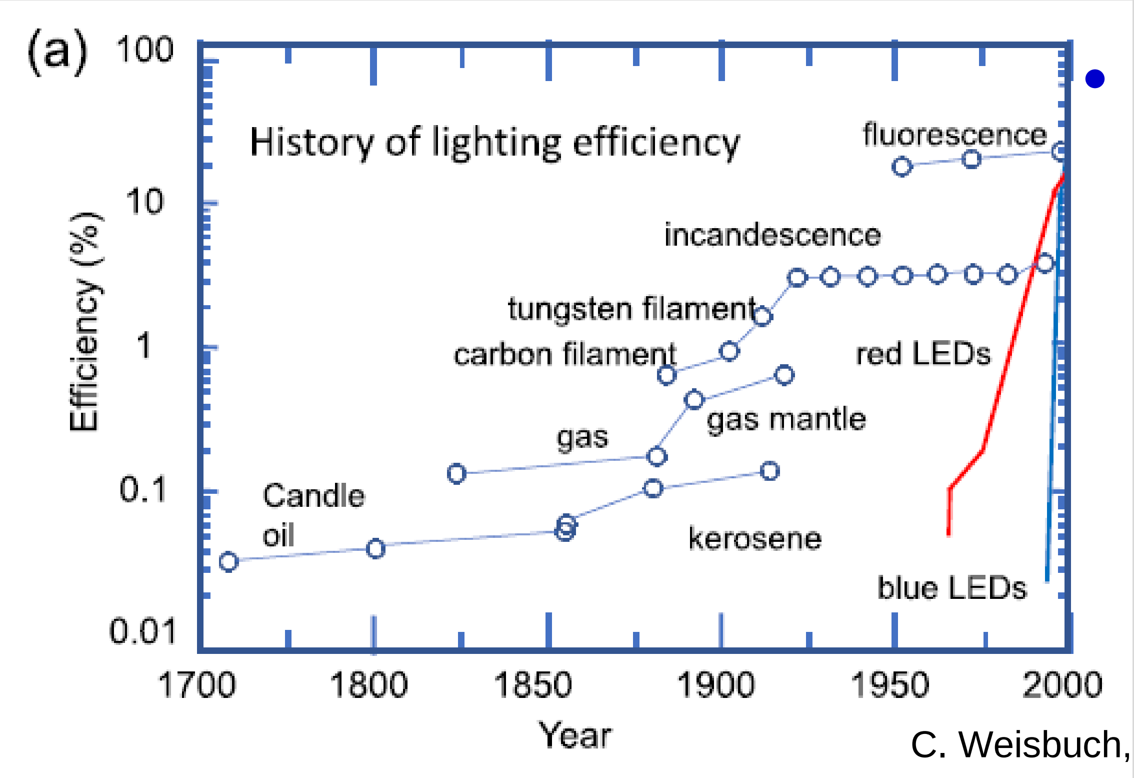
e.g. videoconference instead of traveling

Industrial processes
« Smart » buildings

L. M. Hilty *et al.* in *ICT Innovations for Sustainability*, Springer, 2015

The issue of visible / white LEDs

- The LED is a technology with various use cases
- The most sought application is general lighting
- Lighting is "essential" for mankind (400 000 yrs of usage !)
- LEDs are the most energy efficient lighting devices



C. Weisbuch, C. R. Physique **19** 89 (2018)

2014 : Nobel prize for for the invention of efficient blue light-emitting diodes which has enabled bright and ***energy-saving*** white light sources

Rebound effects and LED lighting : ex-post studies

Surprisingly few articles !!!


ledlighting.com

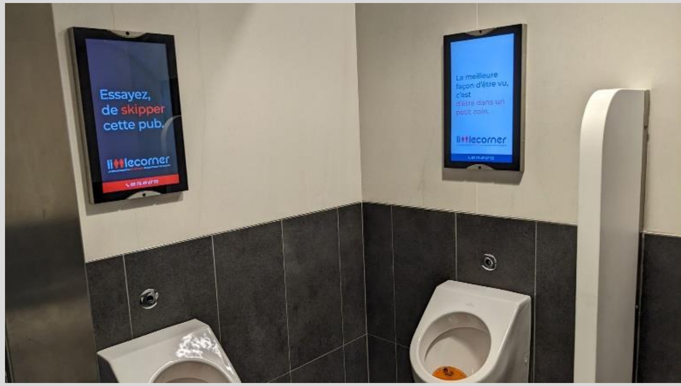

carlstahl-architektur.com

Possible LED lighting rebound effects :

- Lights less switched off
- More lighting fixtures overall
- More lighting due to expanded technological possibilities (colored lighting, architectural lighting…)

LEDs as a global technology

- Replacement + increased sales of various displays (TVs, PC screens….)
- LEDs for the automotive industry



LEDs for lighting

Has the LED technology for lighting resulted in energy savings ?

⇒ **Probably yes**, how much : ????   We have no idea !!!

⇒ Developing countries : *increase in lighting fixtures* for general lighting

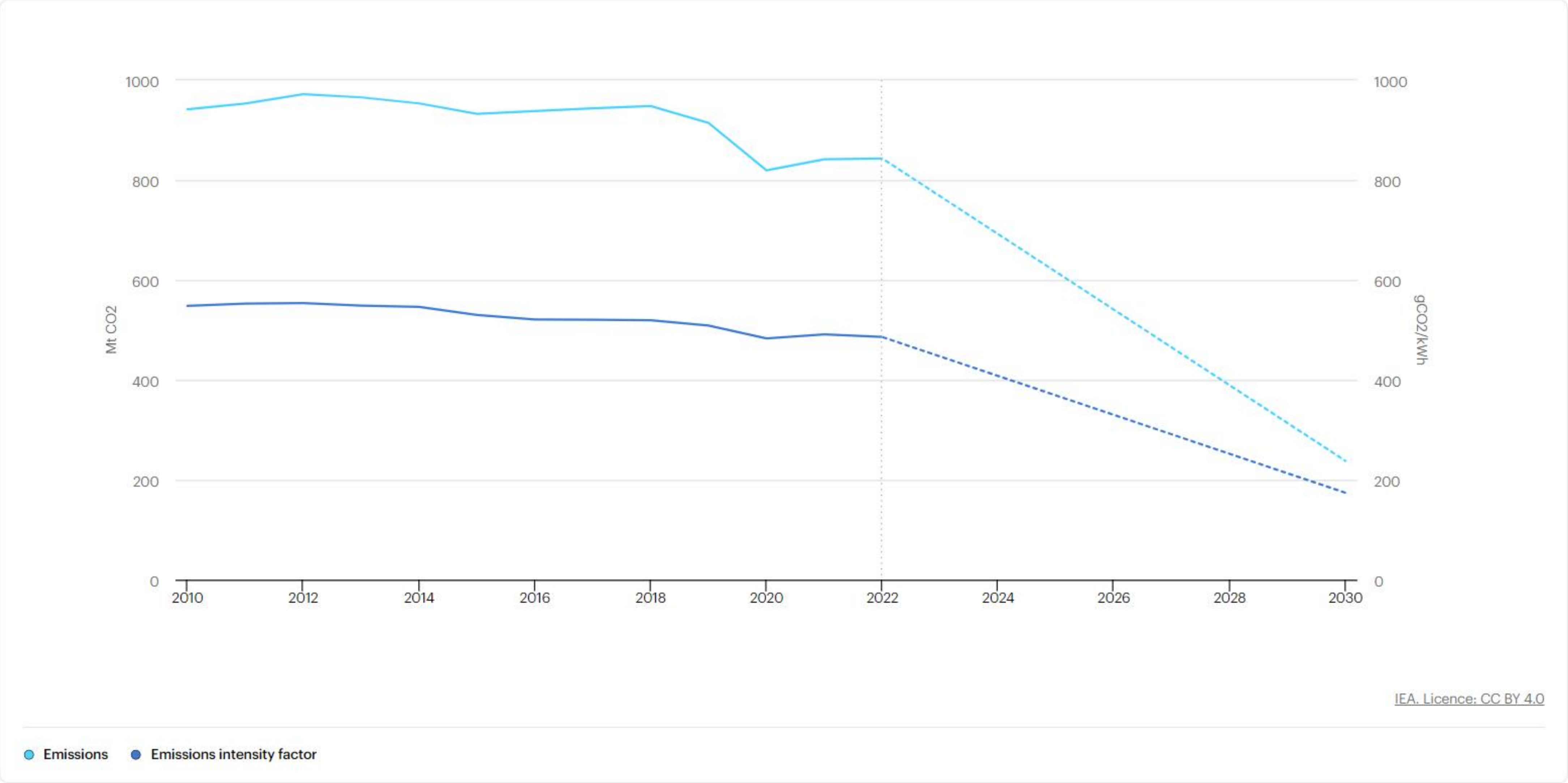
⇒ Developed countries : *new lighting behaviors* due to LED peculiarities

⇒ Decorative/architectural lighting, colored lighting…

Note : since the IL ban and switch to CFLs and then LEDs, no measurable inflexion in electricity consumption in Europe / USA

Conclusion : do we have an answer ?

Has the LED technology for lighting resulted in energy savings ?



https://www.iea.org/energy-system/buildings/lighting

Conclusion : visible LED technology and energy

Other applications of visible LEDs contributing to the rebound effect

Present

- *LEDs for large displays* => more displays in public areas + TV replacement
  => *Most carbon impact at manufacturing stage*

Future

- *Microdisplays for AR / VR*
  ⇒ All ingredients for *major rebound effects*
    ⇒ Totally new use-cases
    ⇒ Very large diffusion expected
    ⇒ Rapid technological upgrades leading to frequent replacements
    ⇒ Very large frontier effects : will require more data transmission and storage

Apple Vision Pro
3500 US$ (2024)
3 screens
12 cameras

Conclusion : what do I make out of that ?

- *Go beyond simple ideas on the real-world impact of technology*

Energy efficiency does not imply energy savings !!!

"Dematerialization", "cloud", "virtual" => misleading
=> ICT is quite "material" (terminals, data centers, telecom infrastructures…)

Environmental impacts of ICT are diverse (CO_2, pollution, abiotic depletion…)
=> Beware of impact transfer !

More systemic (vs silo) thinking + culture

Humbly accept that the "energetic transition" *is not mainly a technical issue to be solved*

- Be cautious concerning claims about the environmental impact of technology

It is largely a question of usage => difficult to assess !

~~Green technology~~

At most : state that a new technology has a ***potential*** for energy savings

Questions worth asking

On a topic supposed to be important (LEDs and energy savings), why don't we have more ex-post studies ?

=> We don't know how to measure ?
=> We don't care ?
=> We don't want to know ?

Would the business model of replacing every lamp in OECD countries by 25 000 hours lifetime LEDs make sense ?

~20 years, 3 hours a day

Neutrality and impartiality

Impartiality : grounds to accept a result / hypothesis

=> « pure science », the way it is done in a particular context

Neutrality : related to the implications, consequences of a choice/decision

=> You expect judges to be impartial, but their decisions are not neutral !

By definition, research, teaching should ideally be impartial

Are science, research, teaching etc… neutral ???

Credit : S. Ruphy, "S'engager par le choix de ses sujets de recherche : enjeux épistémologiques et politiques« Séminaire d'Alembert 2023

The neutrality paradoxical injunction

- Researchers have a strong incentive to brag about the socio-economical implications and potential use-cases of their research
  => *Responsibility* for the possible outcomes of their research

- Fundamental research is often justified by unexpected applications of « blue sky science » (iconical example : the laser)
  => *Irresponsibility* for the possible outcomes of their research

Examples of non-neutrality

In public research

- Funding particular fields of science (corollary : not funding particular fields of science)

- Making (or not) a partnership with an industrial

- Making (optimistic) statements about potential applications and socio-economical consequences

- Teaching a lecture on « Technology and society » at a summer school !

More generally in technology

- The build-up of industrial roadmaps and corresponding investments

The paradox of fundamental research

- Strong incentive to brag about positive socio-economical consequences and vertuous usage cases of our research
  $\Rightarrow$ *Responsibility* concerning the consequences of the research

- Fundamental research is often justified by the possibility of unexpected applications (iconic example : the laser)
  $\Rightarrow$ *Irresponsibility* concerning the consequences of the research

The technological promise

"Creating a horizon of expectation where the new technology appears as a necessity“

“Promoters strive to demonstrate that the new technology is the solution of important societal problems, thus translating it into an obligatory passage point.”

P.-B. Joly and C. Le Renard "The past futures of techno-scientific promises", *Sci. Public Policy* **48** 900 (2021)

The global context : Social control of technology/Governance of science

Collingridge dilemma :

"Attempting to control a technology is difficult…because during its early stages, when it can be controlled, not enough can be known about its harmful social consequences to warrant controlling its development; but by the time these consequences are apparent, control has become costly and slow” (“The social control of technology”, 1980)

=> How does this question the discourses about potential impacts of our research ?

Claims about the impacts of innovation...

It is not in our hands => we have no idea !

The grant system pushes us to make over-optimistic claims about our research's impact

Techno-scientific promises have been around for a long time

=> Who is accountable ?

=> Does it act as a disincentive to socio-economical transformations ?

=> Can it have an impact on the credibility of the scientific community ?

We tend to be rigorous in the practice of our research (integrity) but quite biased and sloppy when discussing its impacts (ethics issue ?)