

Sustainable Electronics: Challenges, Opportunities, and Instruments

Journée « Robotique et Société » 27-11-2023 – GDR Robotique
Maxime Pelcat, INSA Rennes, Univ Rennes, IETR, UMR CNRS 6164



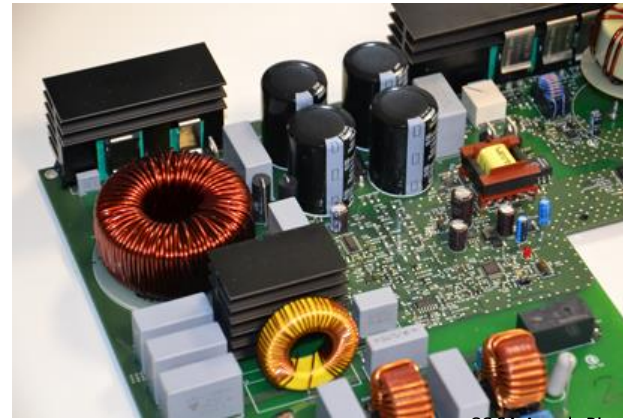
Scope

- What is the electronics market?
- How does electronics affect sustainability? (focus on environment and climate)
- How can we act?

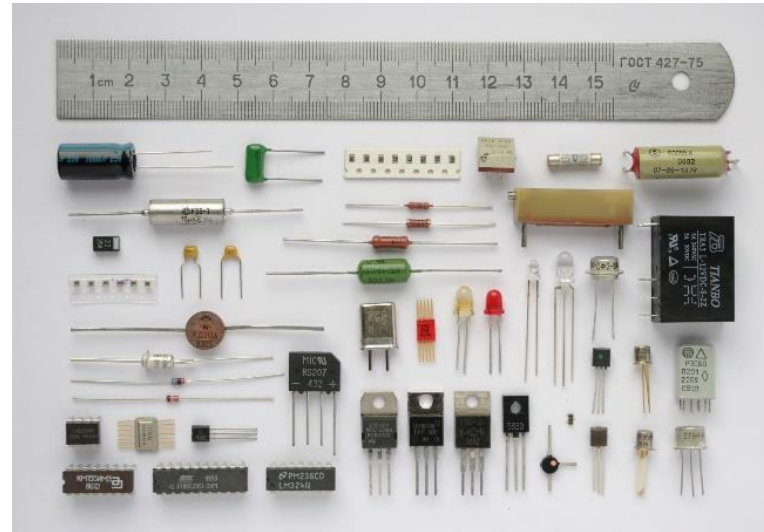


Electronics Market

Electronic Devices



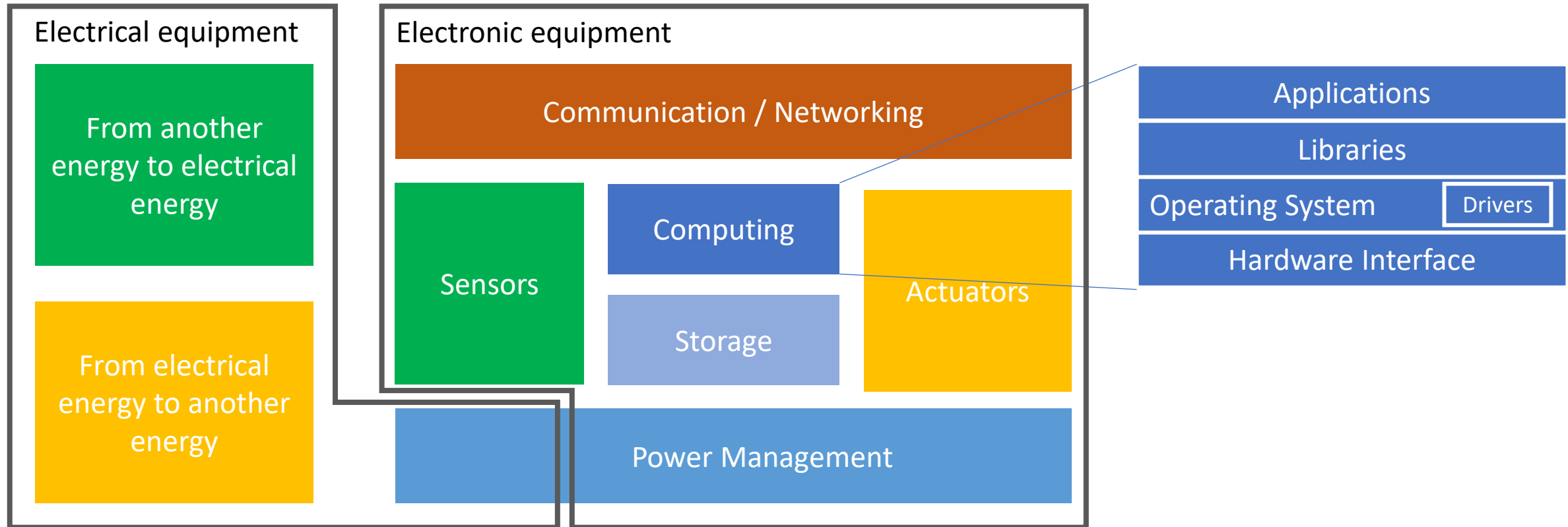
CC SA Angels Pinyol



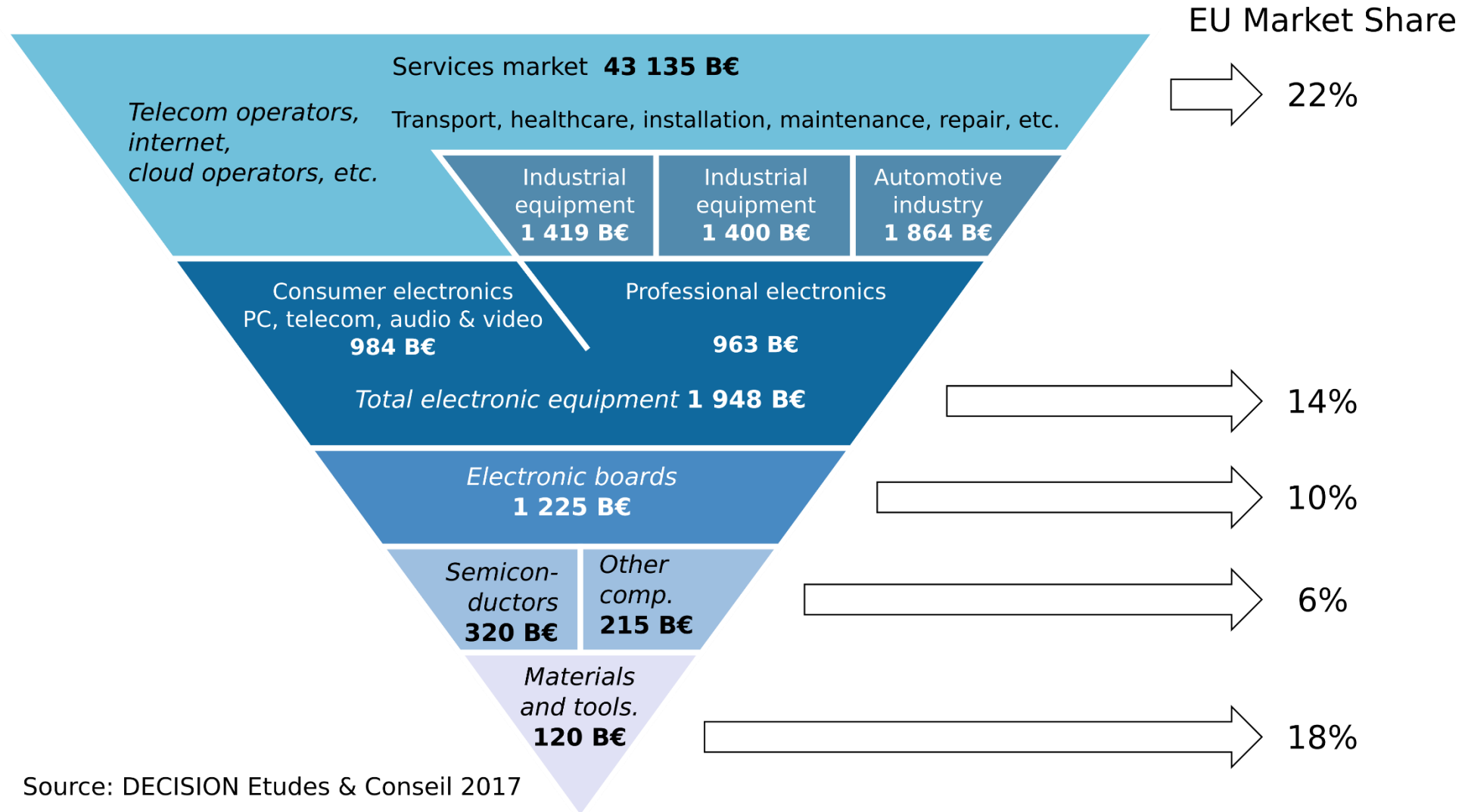
CC-SA Project Kei



Electronic and Electrical Equipment



Electronics market and Europe (in 2017)



Electrical and Electronic Equipments



Air purifier	Drill	iPod	Radiator	Washing machine
Air conditioner	Dvd player	Iron	Radio	Watch
Alarm clock	Earphones	Juicer	Reading lamp	Water pumps
Backup charger	Electric frying pan	Kettle	Refrigerator	Water purifier
Bread maker	Electric grill	Kitchen scale	Remote control	Wall fan
Banknote counter	Electric guitar	Hair straightening machine	Rice cooker	Water heater
Blender	Electric pencil sharpener	Laser printer	Safe	Webcam
Bluetooth speaker	Electric razor	Lawn mower	Robotic vacuum cleaner	Wifi modem
Bulb	Exhaust fan	Lift	Sandwich maker	
Calculator	External hard drive	Meat grinder	Scale	
Car toy	Fan	Microphone	Scanner	
Ceiling fan	Facial cleansing machine	Microwave	Sewing machine	
Chandelier	Fax	Mixer	Smart television	
Clock	Fish tank	Monitor	Smartphone	
Clothes dryer	Floor lamp	Mosquito racket	Speakers	
Coffee maker	Game controller	Mouse	Tablet	
Computer	Garage	Mp3 player	Television	
Copier	Grandfather clock	Oil-free fryer	Timer	
Curling iron	Hair dryer	Piano	Toaster	
Digital camera	Headset	Oven	Torch	
Dishwasher	Inkjet printer	Plotter	USB drive	
Doorbell camera		Pressure cooker	Vacuum cleaner	
		Printer	Walkie-talkie	
		Projector		

List from 7esl.com

Electrical and Electronic Equipments

Air purifier	Drill	iPod	Radiator	Washing machine
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ICT main devices

List from 7esl.com

Electrical and Electronic Equipments

... and

xG Base stations

Cars

Boats

Planes

Trains

Tramways

Busses

Windmills

Power plants

Satellites

Rockets

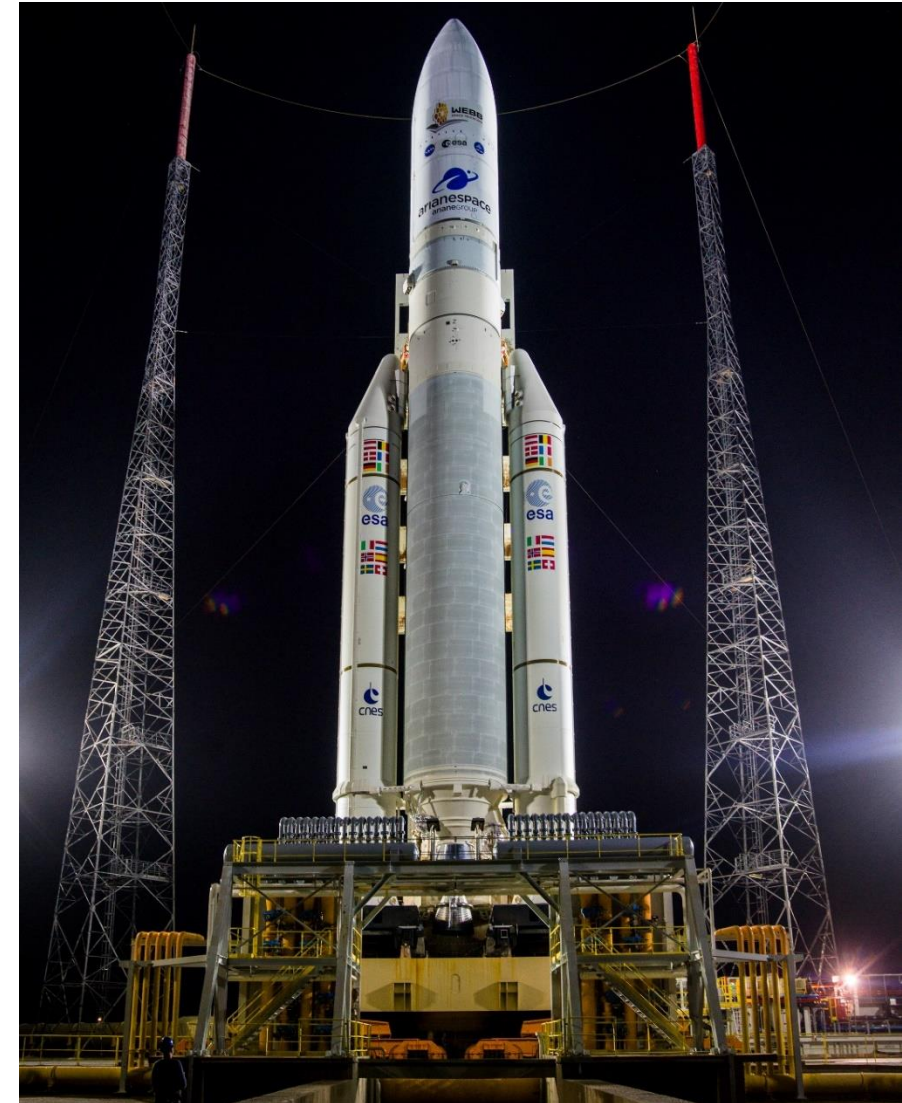
Supercomputers

Data centers

...



CC-BY-SA Aynamankajan



CC-BY NASA's James Webb Space Telescope from Greenbelt, MD, USA

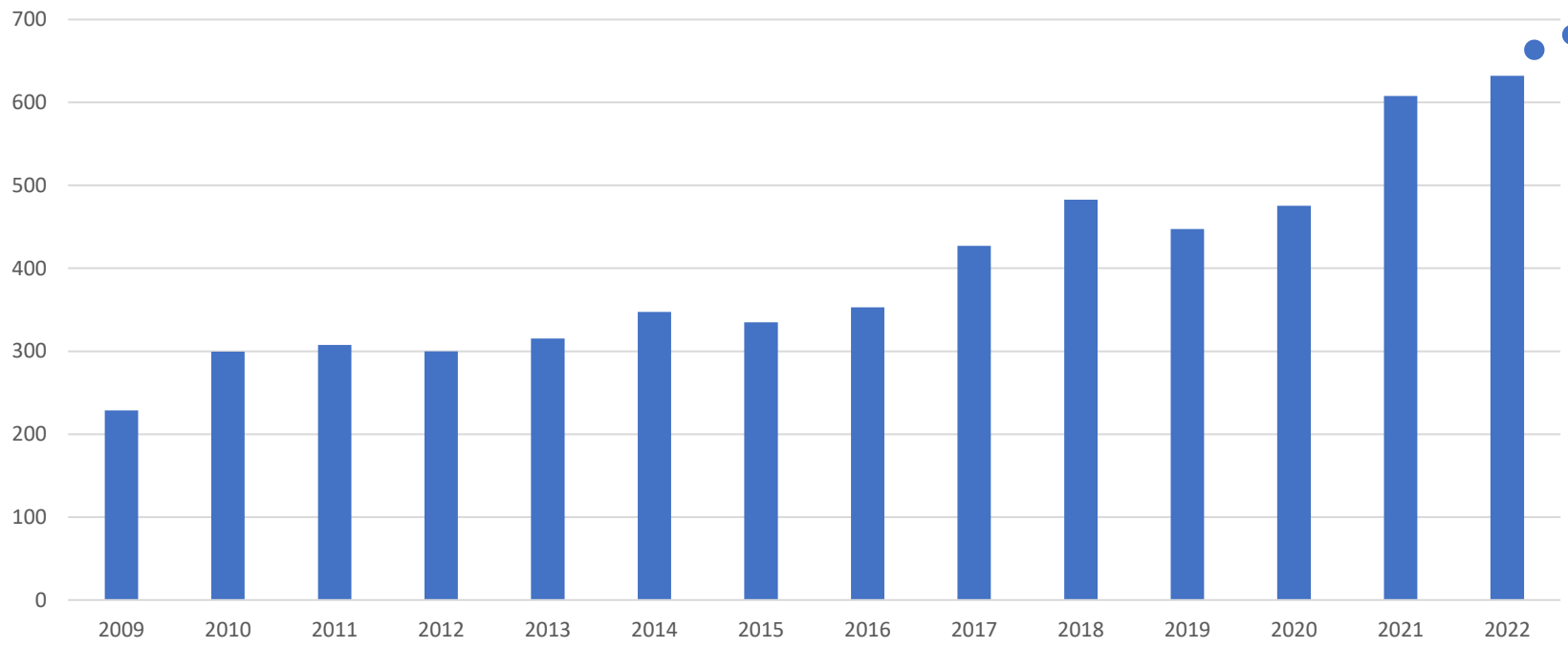
Semiconductor industry revenue



1 trillion \$



Semiconductor revenues (B\$)



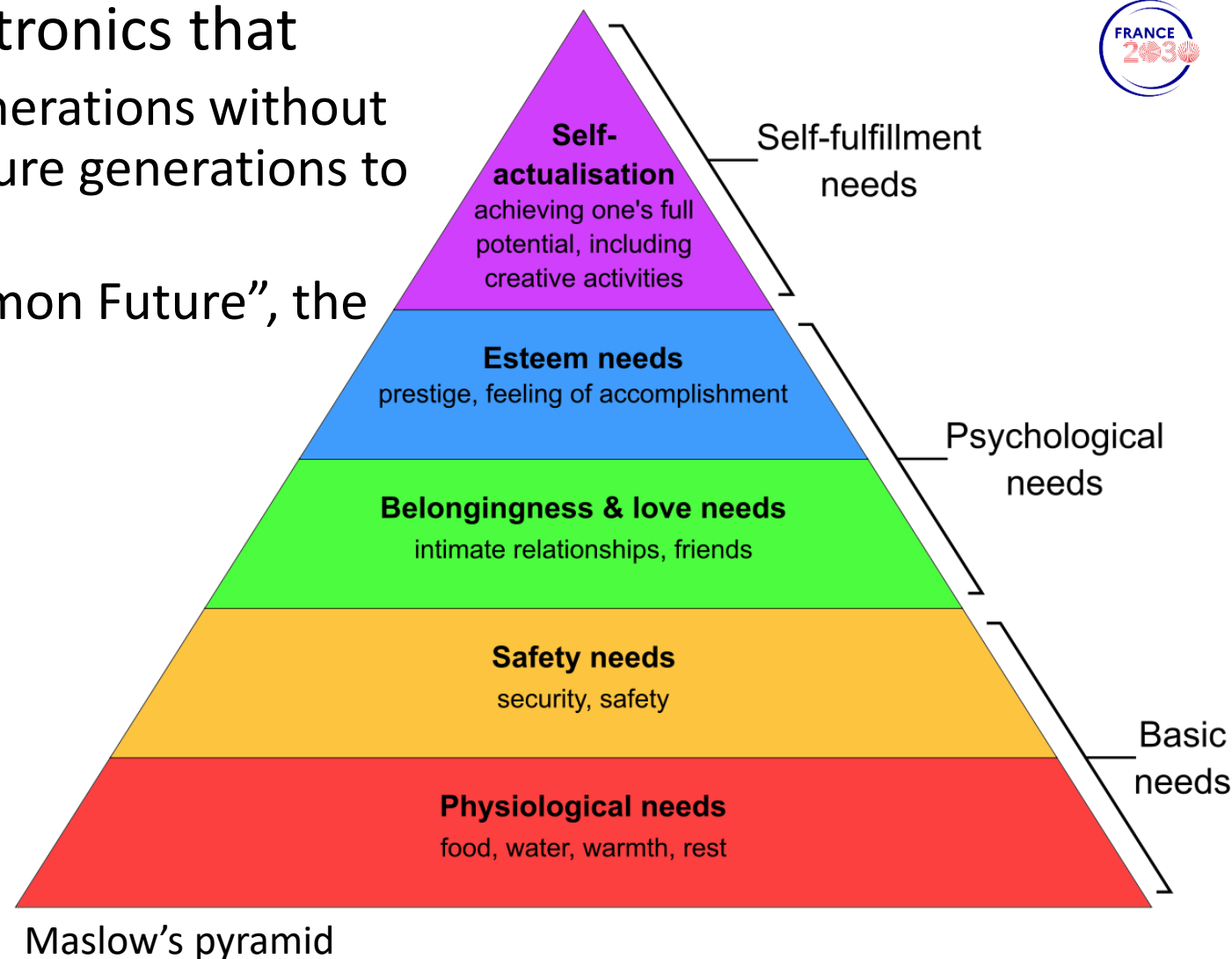
2030

Numbers: Statista

Electronics and Sustainability

What is sustainable electronics?

- Sustainable electronics is electronics that
 - meets the needs of present generations without compromising the ability of future generations to meet their own needs.
 - Brundtland report – “Our Common Future”, the United Nations, 1987
- 3 pillars
 - Environmental
 - Social
 - Economic

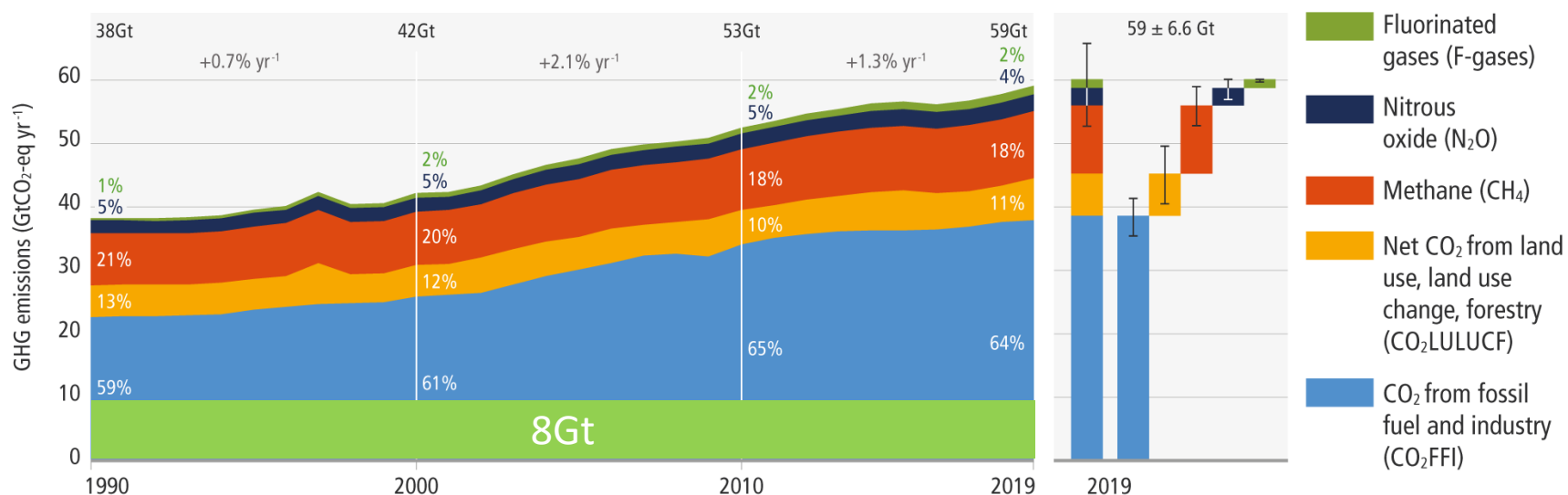


Human carbon impact

- Human GHG emissions reach 60Gt/year
- To respect the 1.5°C scenario of the Paris Agreement, emissions must reach 8Gt/year by 2050, i.e. **a reduction of ~7× by 2050**

Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.

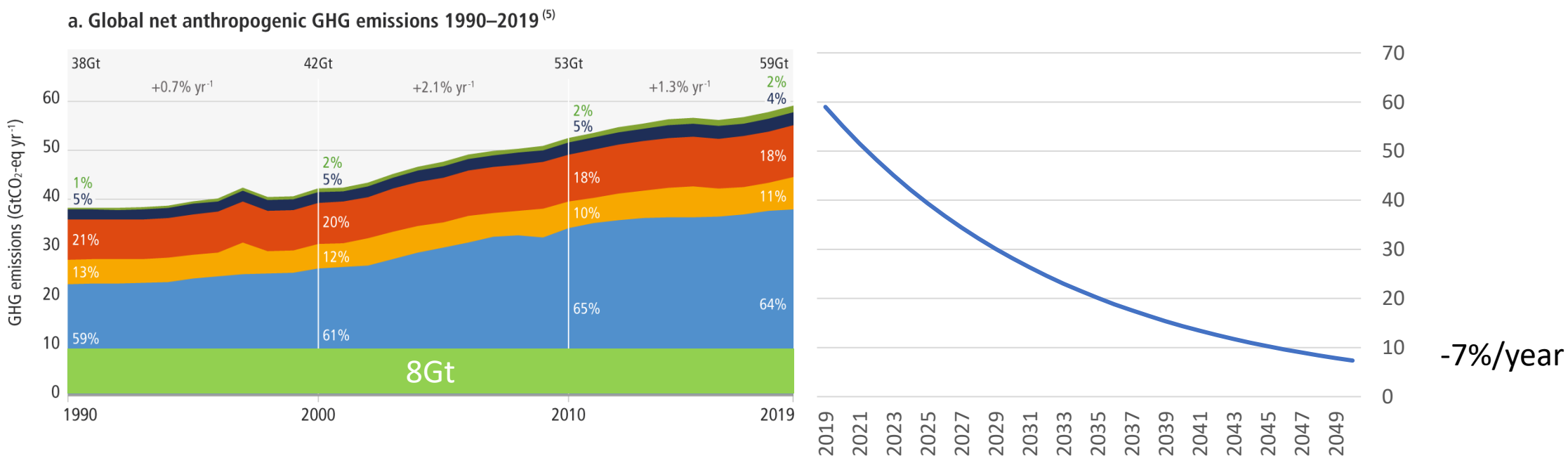
a. Global net anthropogenic GHG emissions 1990–2019 ⁽⁵⁾



The Closing Window: Climate crisis calls for rapid transformation of societies, UN environment program 2022

Human carbon impact

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Semiconductors and GHG emissions

- The manufacture of integrated circuits has emitted 76Mt CO₂eq in 2021 (only scopes 1 and 2), an **increase of 13% from 2020 to 2021.**

Year	Semiconductor Market with Foundries		
	Scope 1	Scope 2	Total
2020	26.84 MtCO ₂ e	40.96 MtCO ₂ e	67.8 MtCO ₂ e
2021	30.56 MtCO ₂ e	45.93 MtCO ₂ e	76.5 MtCO ₂ e

Maxime Pelcat. GHG emissions of semiconductor manufacturing in 2021. Research Report. 2023. (hal-04112708)

How do EEE help sustainability?

- All energy transitions/shifts heavily employ electronics and electrical equipments (EEE)
 - Electric cars, renewable energies from windmills, solar panel, heat pumps...
- Energy optimization heavily relies on EEEs
 - Smart grids, smart buildings, smart cities...



CC 3.0 ChristofferRiemer



CC SA Krizolina



How do EEE hinder sustainability?

(focusing on environmental impacts)

- Production of EEEs
 - Requires rare material (abiotic resource depletion)
 - Emits greenhouse gases
 - Requires much water
- Usage of EEEs
 - Requires energy
- End-of-life of EEEs
 - Emits e-wastes that pollute water and soils

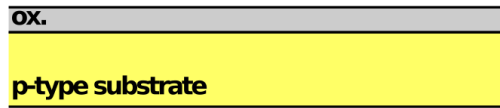


Author: Laconicon

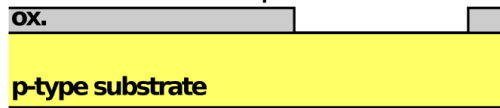


Semiconductors and GHG emissions

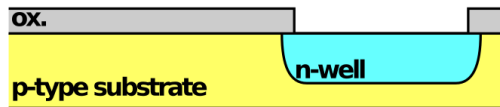
1. Grow field oxide



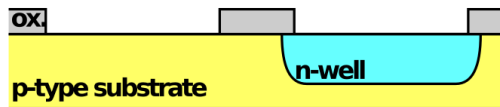
2. Etch oxide for pMOSFET



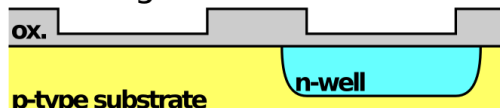
3. Diffuse n-well



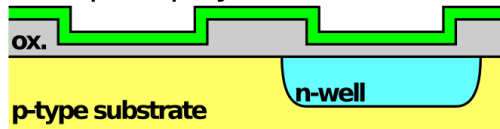
4. Etch oxide for nMOSFET



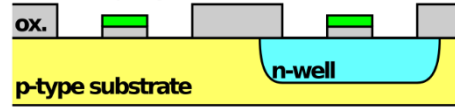
5. Grow gate oxide



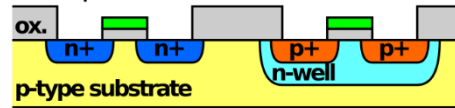
6. Deposit polysilicon



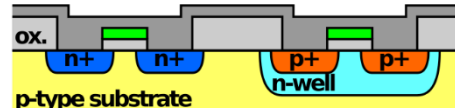
7. Etch polysilicon and oxide



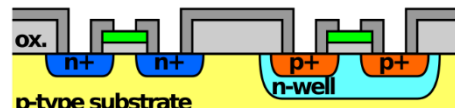
8. Implant sources and drains



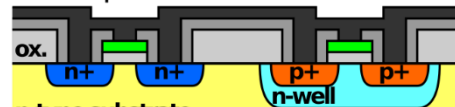
9. Grow nitride



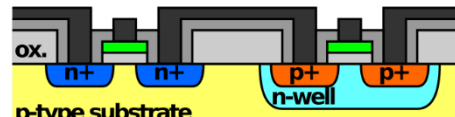
10. Etch nitride



11. Deposit metal



12. Etch metal



• Scope 1 emissions: F-gases

- F-gases are used for cleaning and etching, as well as for heat pumps and refrigerants
- 1kg of SF₆ ⇔ 23 tons of CO₂

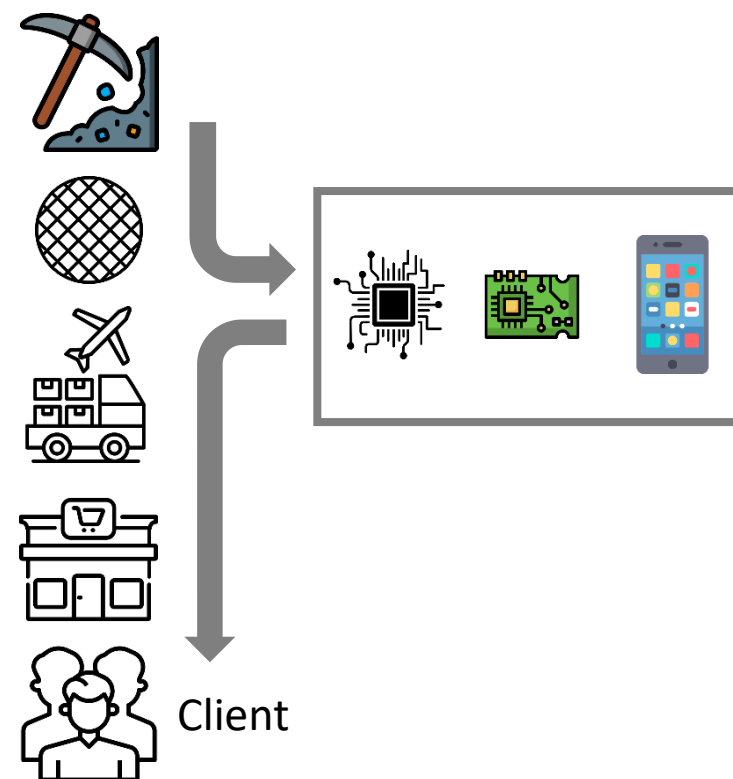
Bartos, S. C., & Burton, C. S. (2002). PFC, HFC, NF3, and SF6 emissions from semiconductor manufacturing. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 1-13.

• Scope 2 emissions: electricity

- From 60g CO₂e/kWh to 1kg CO₂e/kWh

Semiconductors and GHG emissions

- Scope 3 **upstream** emissions
 - Mining materials
 - Smelting
 - Refining
- Scope 3 **downstream** emissions
 - Transporting products
 - Using products
 - End-of-life

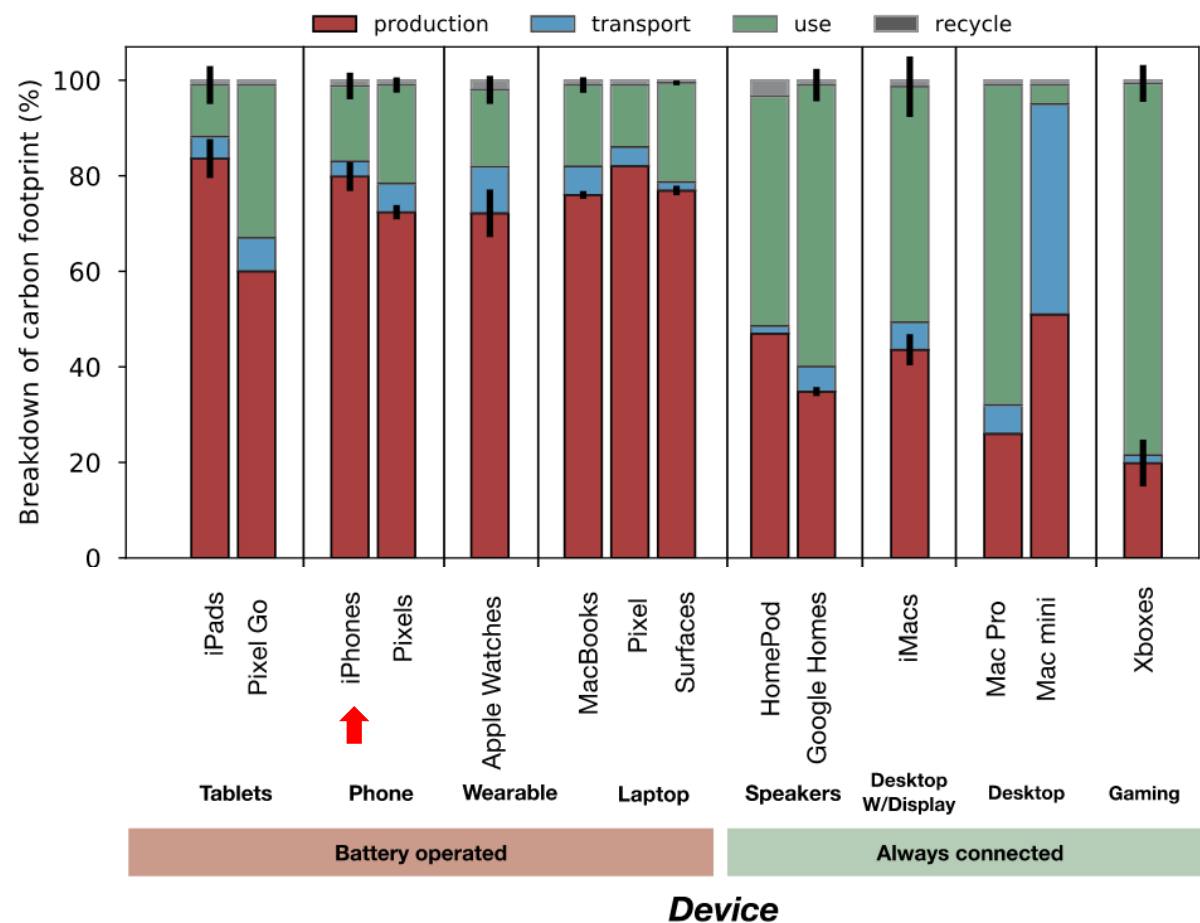


- Impacts of electronics are increasingly well understood

Greenhouse Gas Protocol, World Resources Institute, Revised edition, 2015

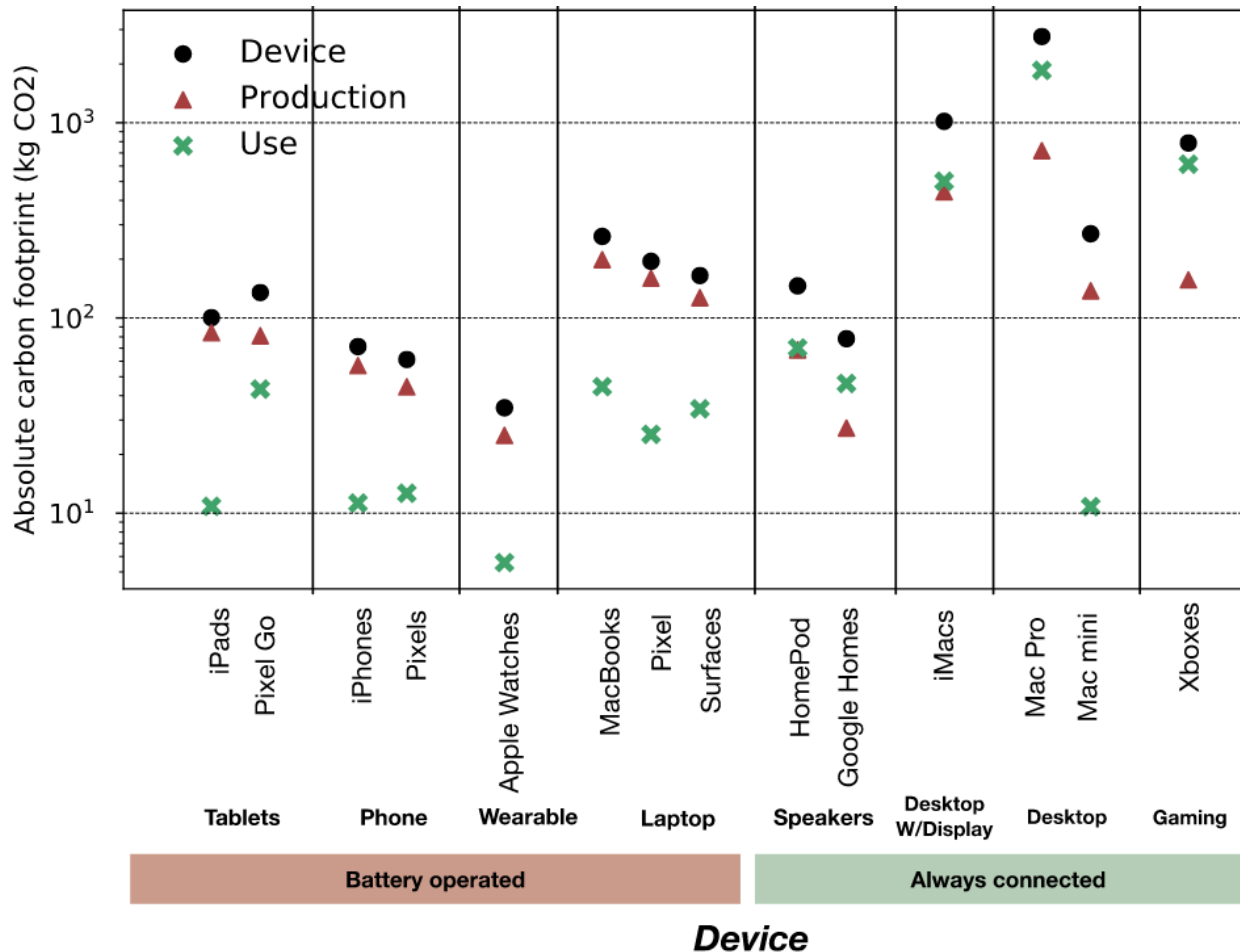
Semiconductors and GHG emissions

- 85% of a cell phone's GHG emissions come from manufacturing



Gupta, U., Kim, Y. G., Lee, S., Tse, J., Lee, H. H. S., Wei, G. Y., ... & Wu, C. J. (2022). Chasing carbon: The elusive environmental footprint of computing. IEEE Micro.

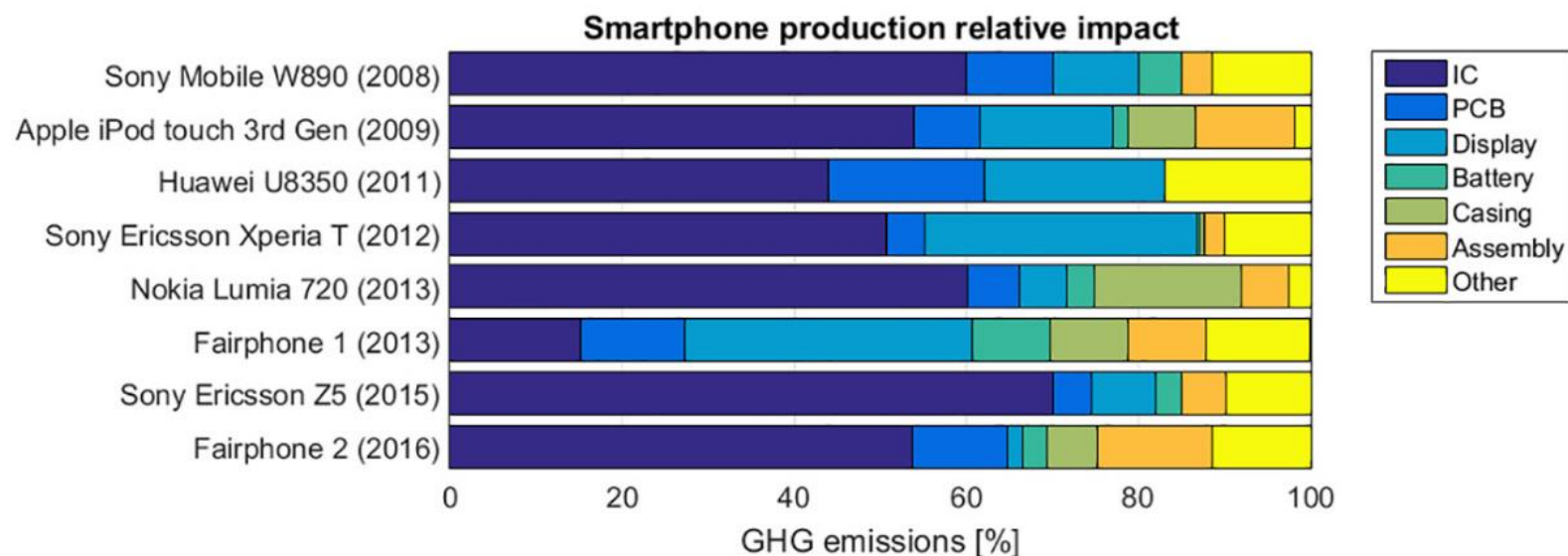
Absolute carbon emissions of devices



Gupta, U., Kim, Y. G., Lee, S., Tse, J., Lee, H. H. S., Wei, G. Y., ... & Wu, C. J. (2022). Chasing carbon: The elusive environmental footprint of computing. IEEE Micro.

Semiconductors and GHG emissions

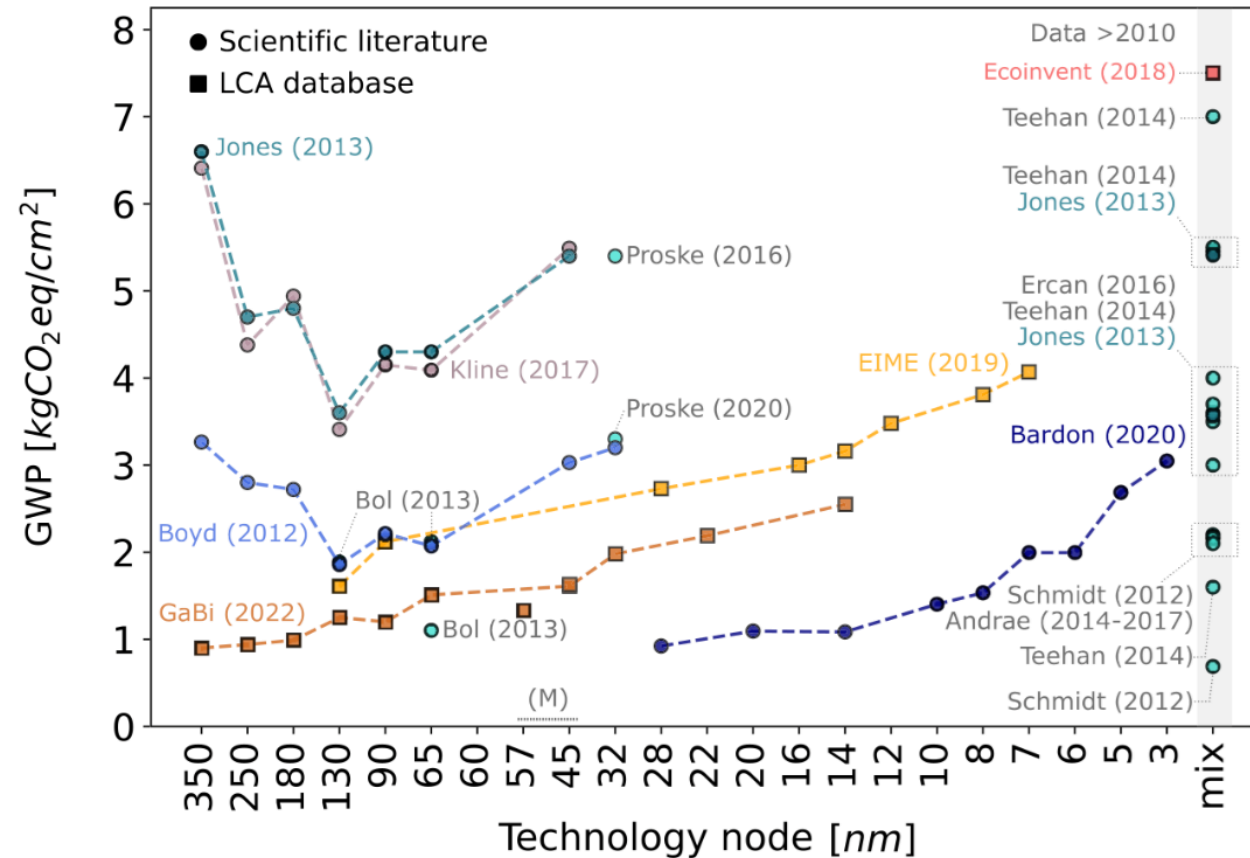
- The manufacture of integrated circuits is the primary cause of cell phone emissions



Louis-Philippe, P. V. C., Jacquemotte, Q. E., & Hilty, L. M. (2020). Sources of variation in life cycle assessments of smartphones and tablet computers. Environmental Impact Assessment Review, 84

Semiconductors and GHG emissions

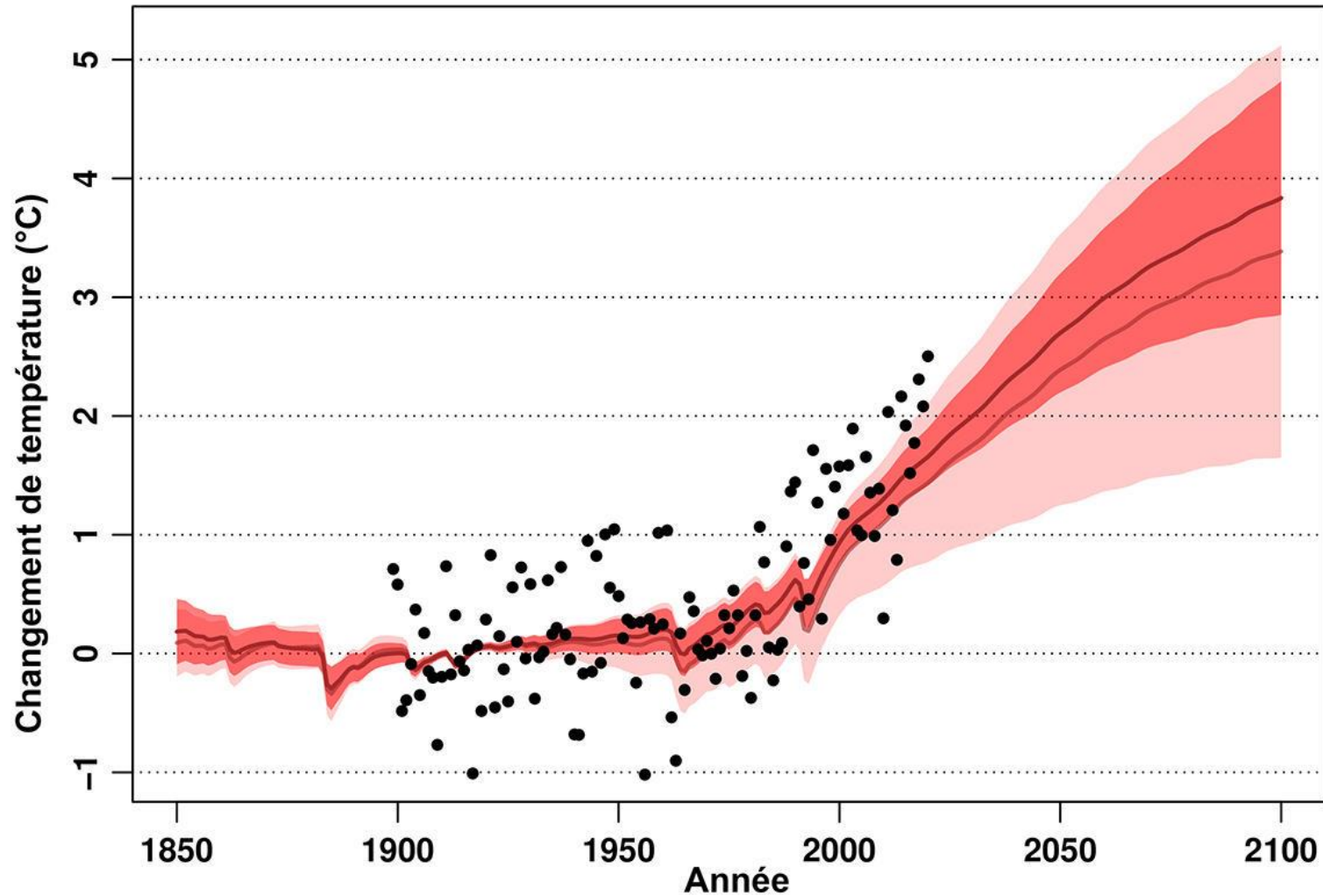
- Product lifecycle analysis is a complex science, requiring a detailed understanding of the scope and assumptions involved



Pirson, T., Delhaye, T. P., Pip, A., Le Brun, G., Raskin, J. P., & Bol, D. (2022). The environmental footprint of IC production: Review, analysis and lessons from historical trends. IEEE Transactions on Semiconductor Manufacturing.

How can we act?

Global Warming, in France



Aurélien Ribes et al. 2022, « Earth Syst. Dynam. », 13, 1397-1415 (CC BY-4.0)

Prediction for an intermediate scenario in which carbon emissions neither increase nor decrease drastically

From Local Decisions to Global Impacts

Global Warming



Causality established and quantified by GIEC

Human greenhouse gas emissions

Communication

Transport

Healthcare

Defense

Industry

Energy

Agriculture

...

From Local Decisions to Global Impacts

Global Warming



Causality established and quantified by GIEC

Human greenhouse gas emissions



Causality to be established and quantified by domain experts

Communication

Transport

Healthcare

Defense

Industry

Energy

Agriculture

...

Some solutions – Research needed!

- Life cycle analysis
- 3R: Repair, Reuse, Recycle
- New fabrication technologies
 - PCB, IC, other components
- Better energy management



How can we act?

- Mobile phones have a lifetime of 2.5 years, high-end processors 4.5 years
- To be a leader in future chips, EU shall **invest in novel lengthened lifetime chips and systems**
 - upgradeable, repairable, reconfigurable, repurposable chip technologies
- We need to **understand the consequences of our design decisions**

How can we act (as system architects)?

- Gather reliable, scientific numbers on electronics impacts, and evaluate their reliability
 - Life Cycle Analysis (LCAs)
- **Attributional LCA:** aims to describe the environmentally relevant physical flows to and from a life cycle
- **Consequential LCA:** LCA aiming to describe how environmentally relevant flows will change in response to possible decisions

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., ... & Suh, S. (2009). Recent developments in life cycle assessment. Journal of environmental management, 91(1), 1-21.

How can we act (as system architects)?

- Propose new technologies for repairable, reusable, reconfigurable, repurposable systems
- Assess the real impact of these new technologies in the field
- Help and foster the setup of novel regulations (incentives, taxes and quotas)
- Read, write, and talk on the subject
- Train more professionals

Ashby, M. F. (2022). Materials and sustainable development. Butterworth-Heinemann.

How to act

- Carbon footprint reduction requires
 - **Transparency**
 - **Acting fast**
 - **Sharing information**
 - **Open source communities** (hardware and software) are key assets

- Electronics carbon footprint reduction requires
 - **True commitment to the goal**
 - **Technical competences**
 - **Research**

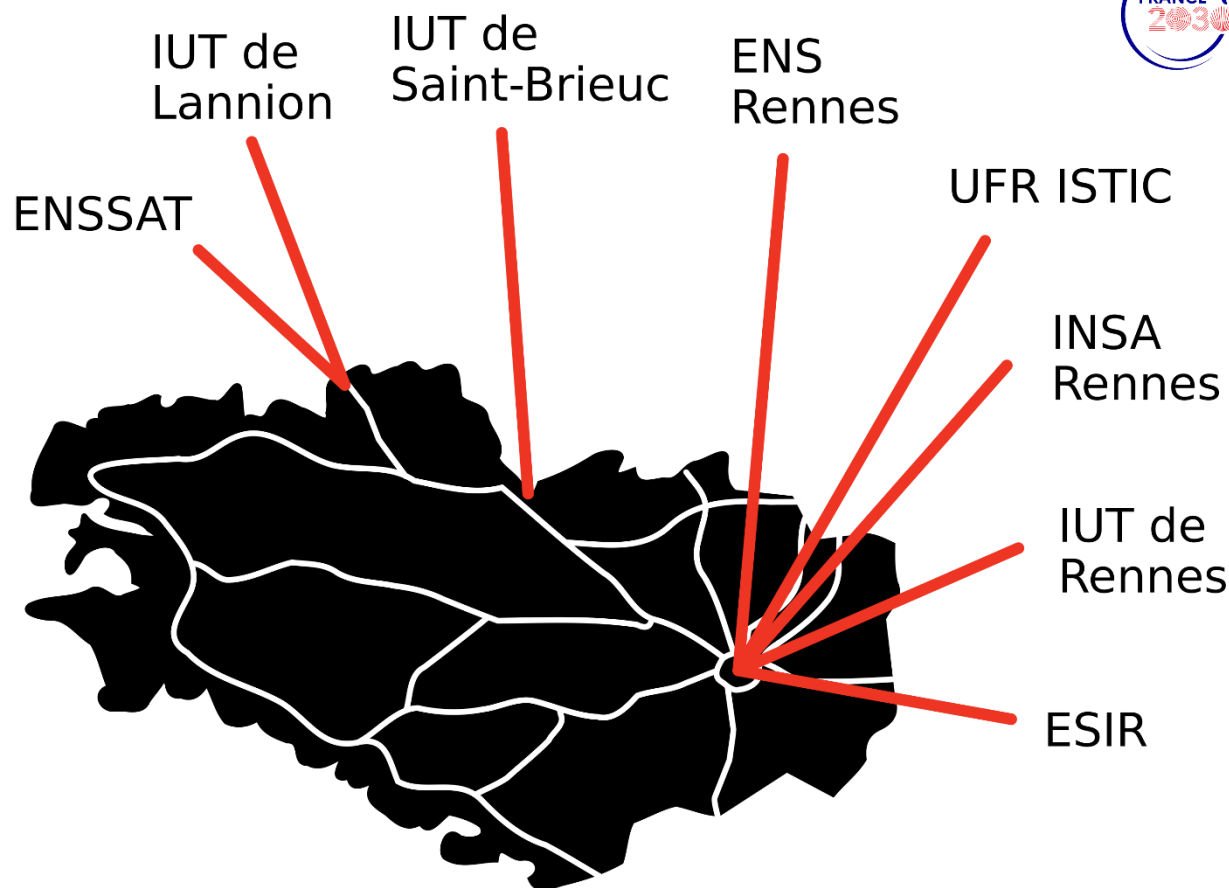
The ESOS project

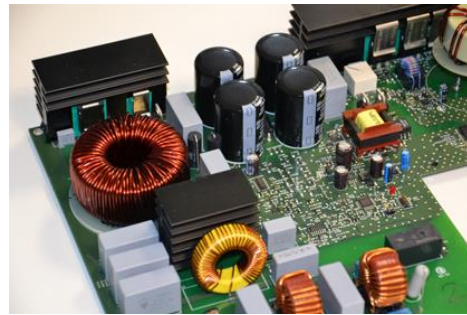
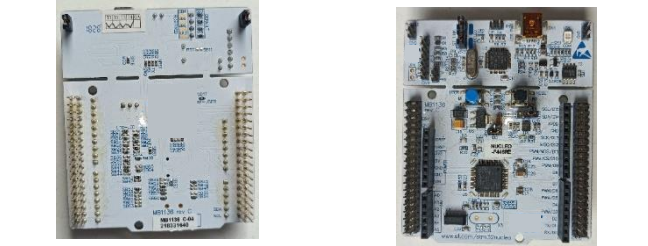
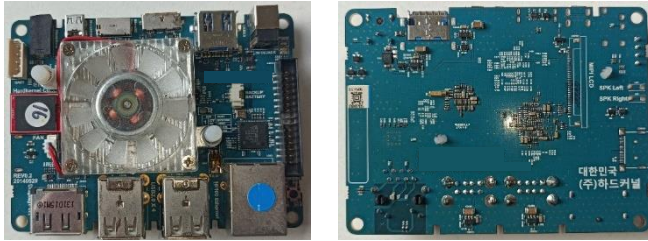
- **Electronics: Sustainable, Open and Sovereign**
- 2023-2028, 6.3M€, funded by France2030
 - **Sustainable:** meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.
 - **Open:** a decentralized development model that publicly distributes the source code for open collaboration and peer production, known as "the open-source method."
 - **Sovereign:** the quality of a state being free and independent, determined solely by its own will within the limits of the higher principle of law, and in accordance with the collective purpose it is called to achieve.

ESOS – 7 actions

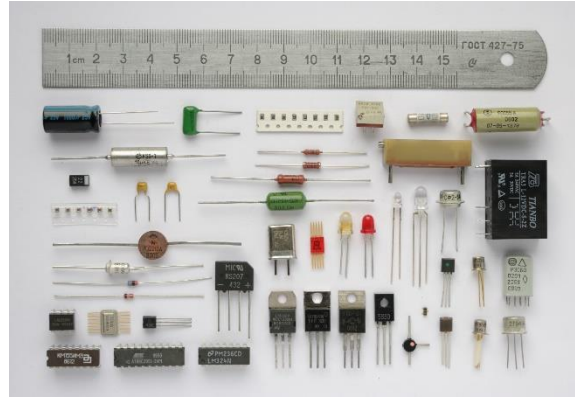
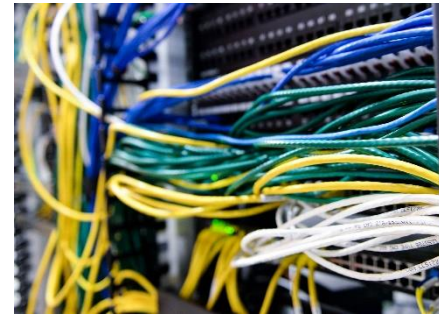
- Attract pupils to electronics
- Train students to ESOS
 - Licence, master, doctorate
- Train professionals to ESOS
- Create **open teaching material**
- <https://esos.insa-rennes.fr>

- **30 industrial partners**
- **Open to collaborations!**



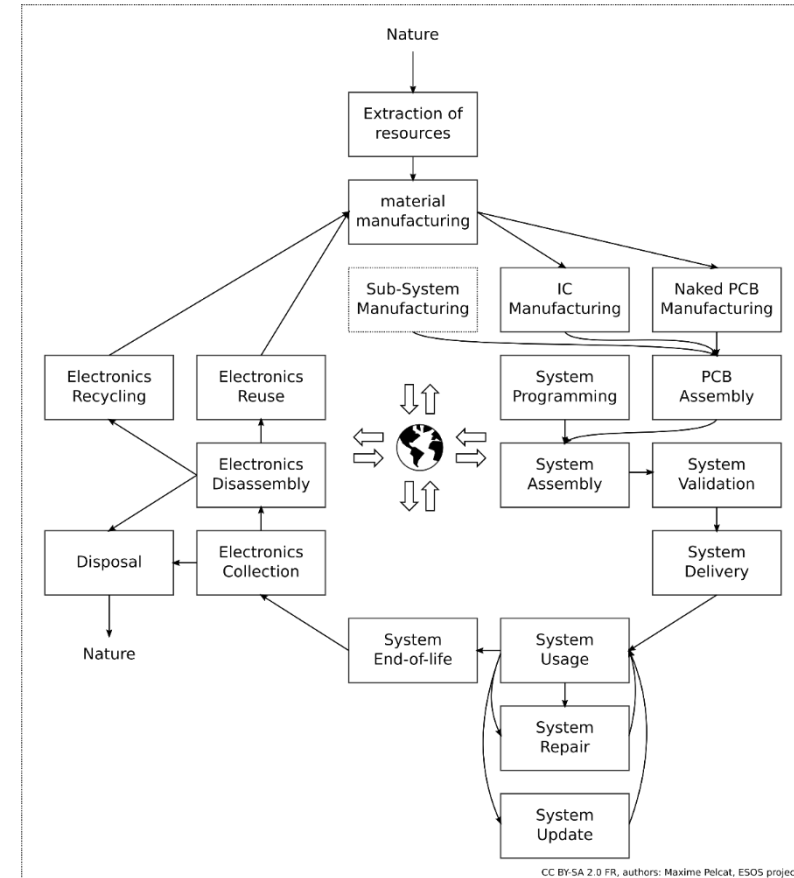


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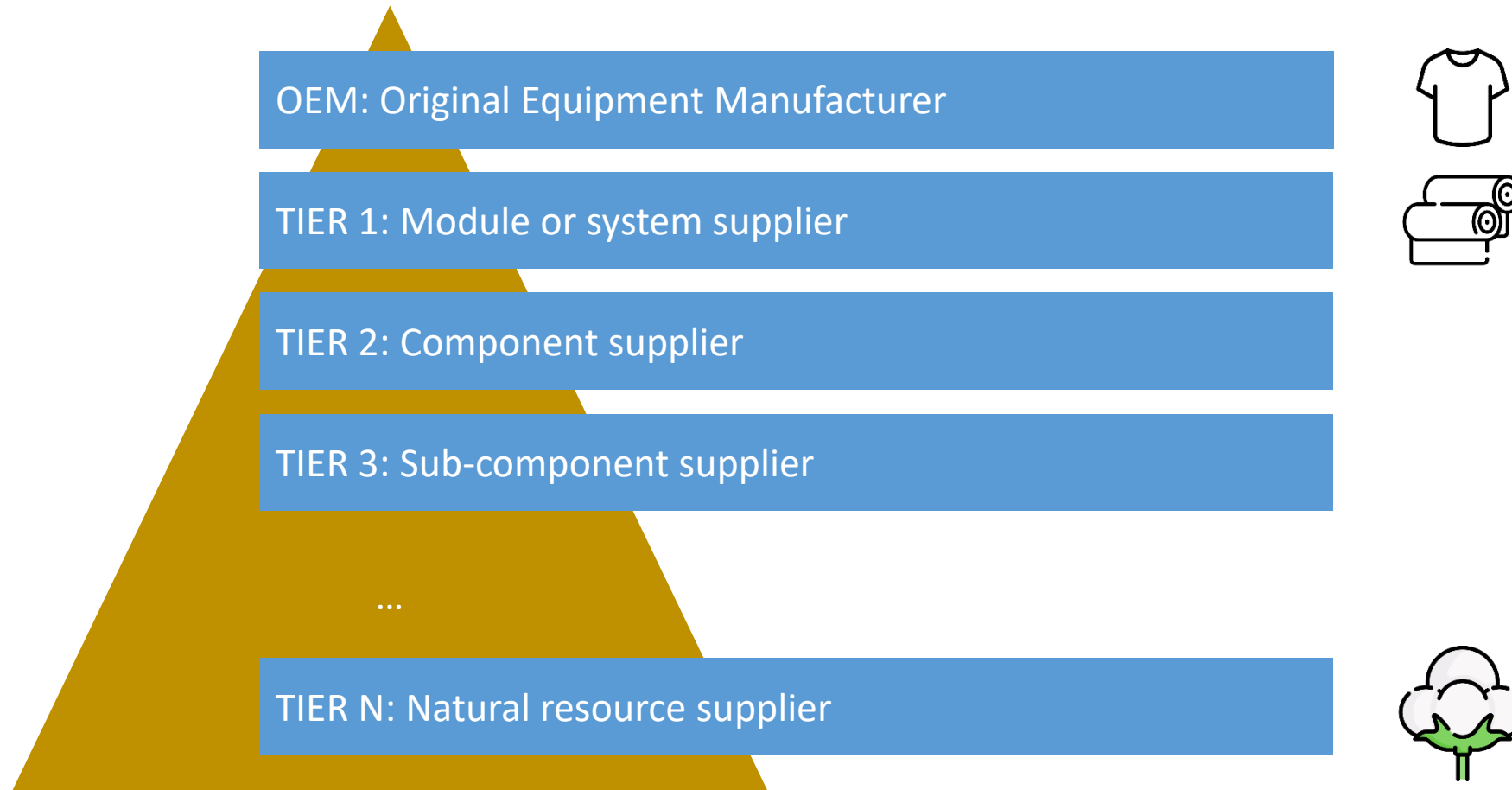
Thanks



Additional Slides

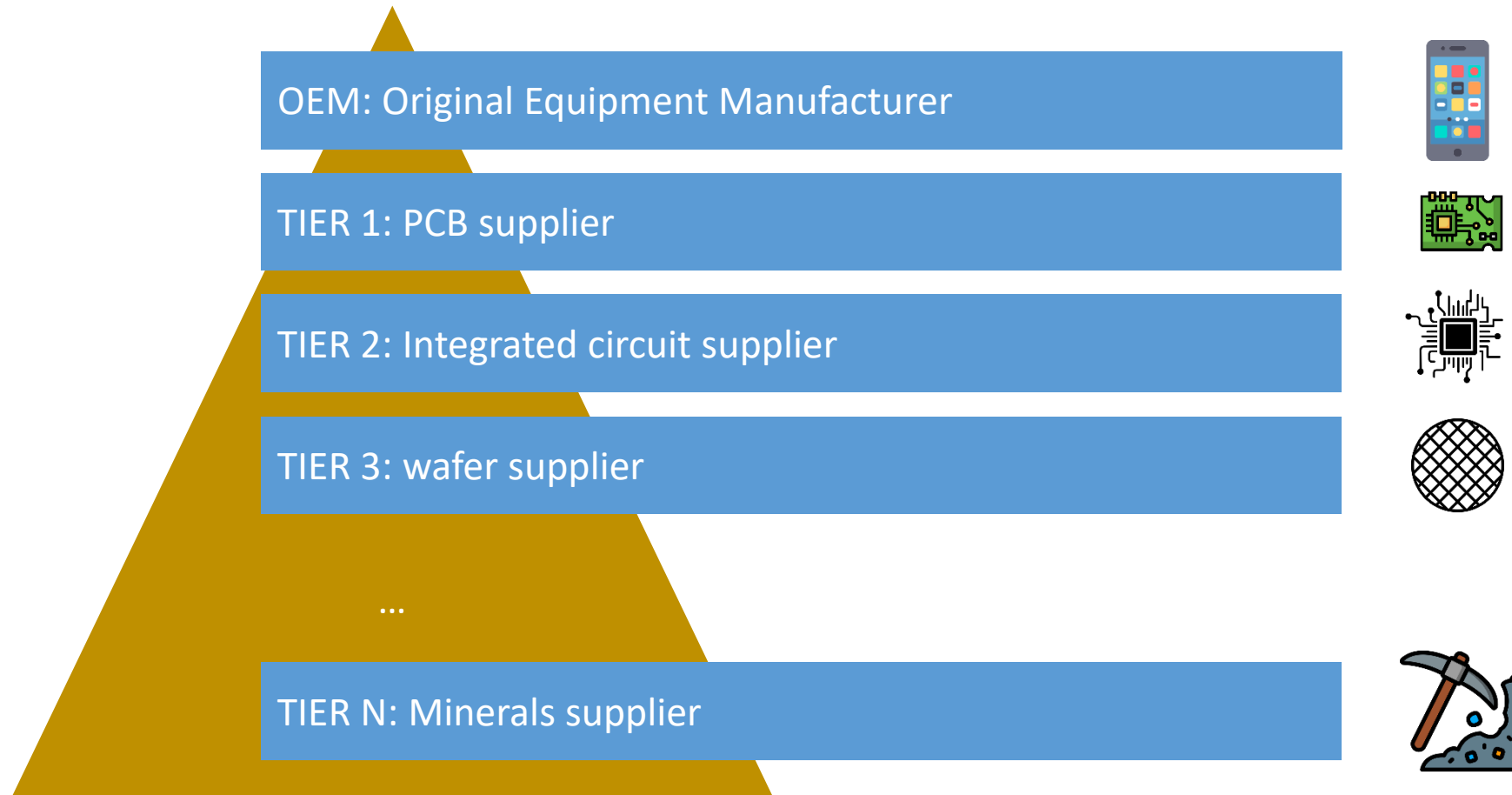
Supply chain (in general)

- Industry employs a supply chain pyramid with Tiers

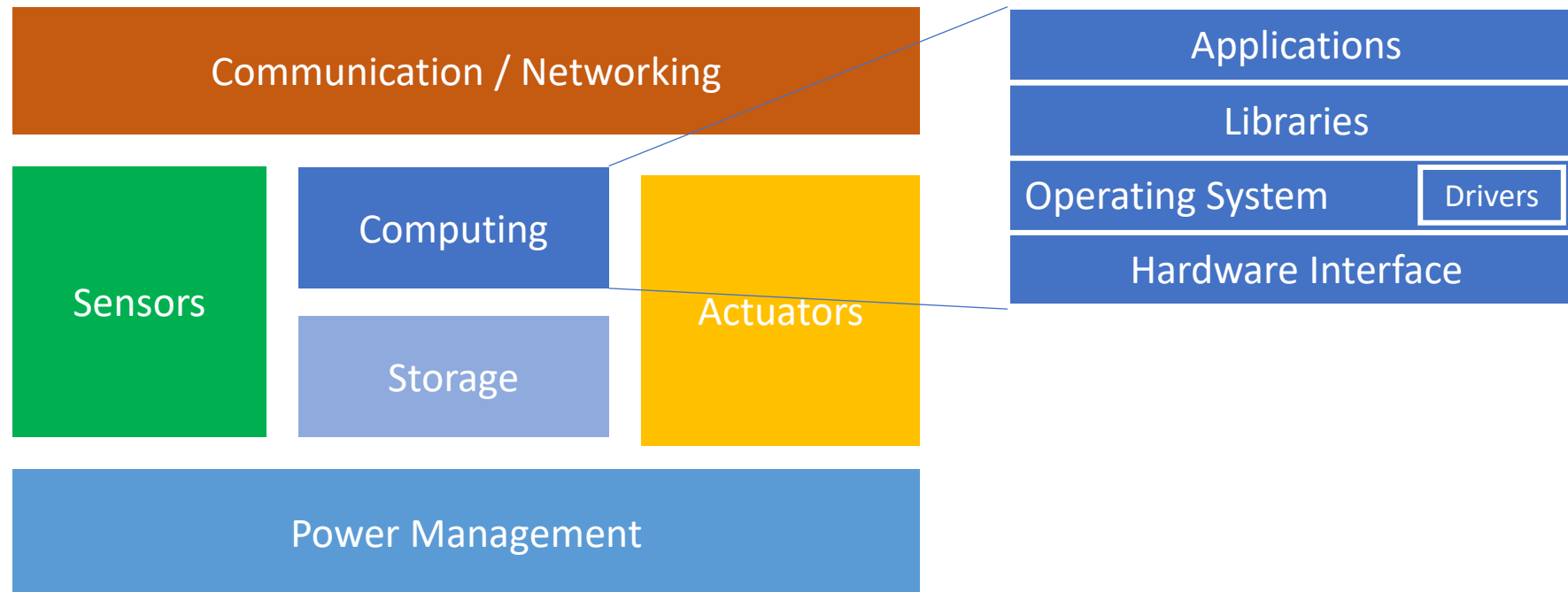


• The electronics industry supply chain

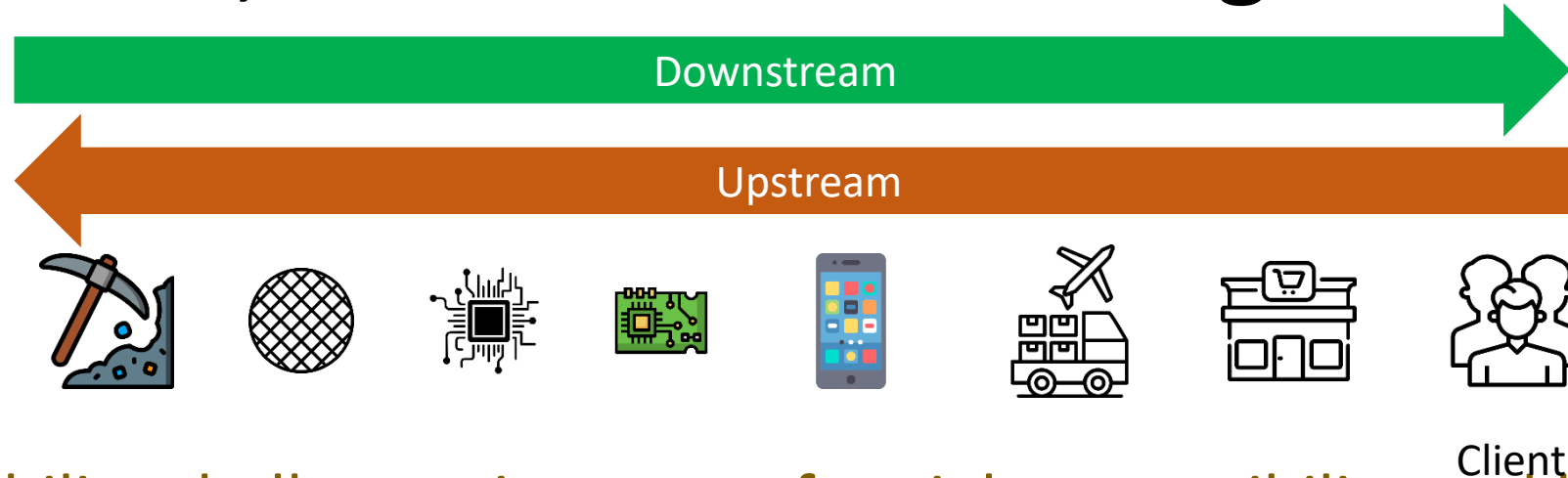
Industry employs a supply chain pyramid with Tiers



Structure of an embedded system



Electronics, ethics and human rights



- Sustainability challenges in terms of social responsibility and human rights include:
 - Social standards for employees
 - Impacts on local communities
 - Impact on society