Environmental impacts of electronics and the role of open source hardware
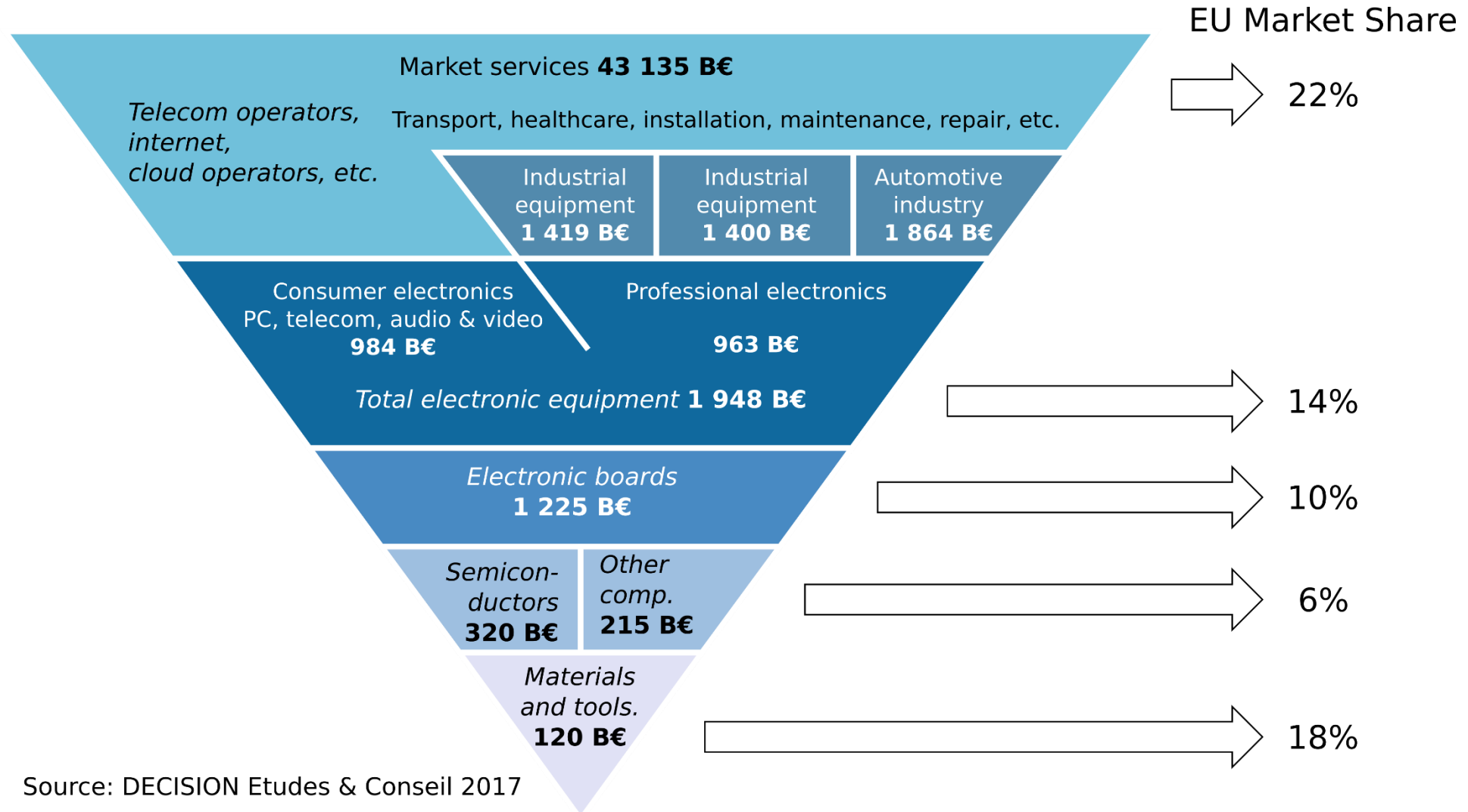
FSiC 2023

Maxime Pelcat, INSA Rennes, Univ Rennes, IETR, UMR CNRS 6164

Scope

- What is the electronics market?

- How do electronics affect environment? (focus on climate)

- How can we act?

- How will open source hardware help?

Electronics market and Europe (in 2017)

EU Market Share

Market services **43 135 B€**

Telecom operators, internet, cloud operators, etc.

Transport, healthcare, installation, maintenance, repair, etc.

Industrial equipment **1 419 B€**	Industrial equipment **1 400 B€**	Automotive industry **1 864 B€**

22%

Consumer electronics
PC, telecom, audio & video
984 B€

Professional electronics

963 B€

Total electronic equipment **1 948 B€**

14%

Electronic boards
1 225 B€

10%

Semicon-
ductors
320 B€

Other
comp.
215 B€

6%

Materials
and tools.
120 B€

18%

Source: DECISION Etudes & Conseil 2017

3

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.

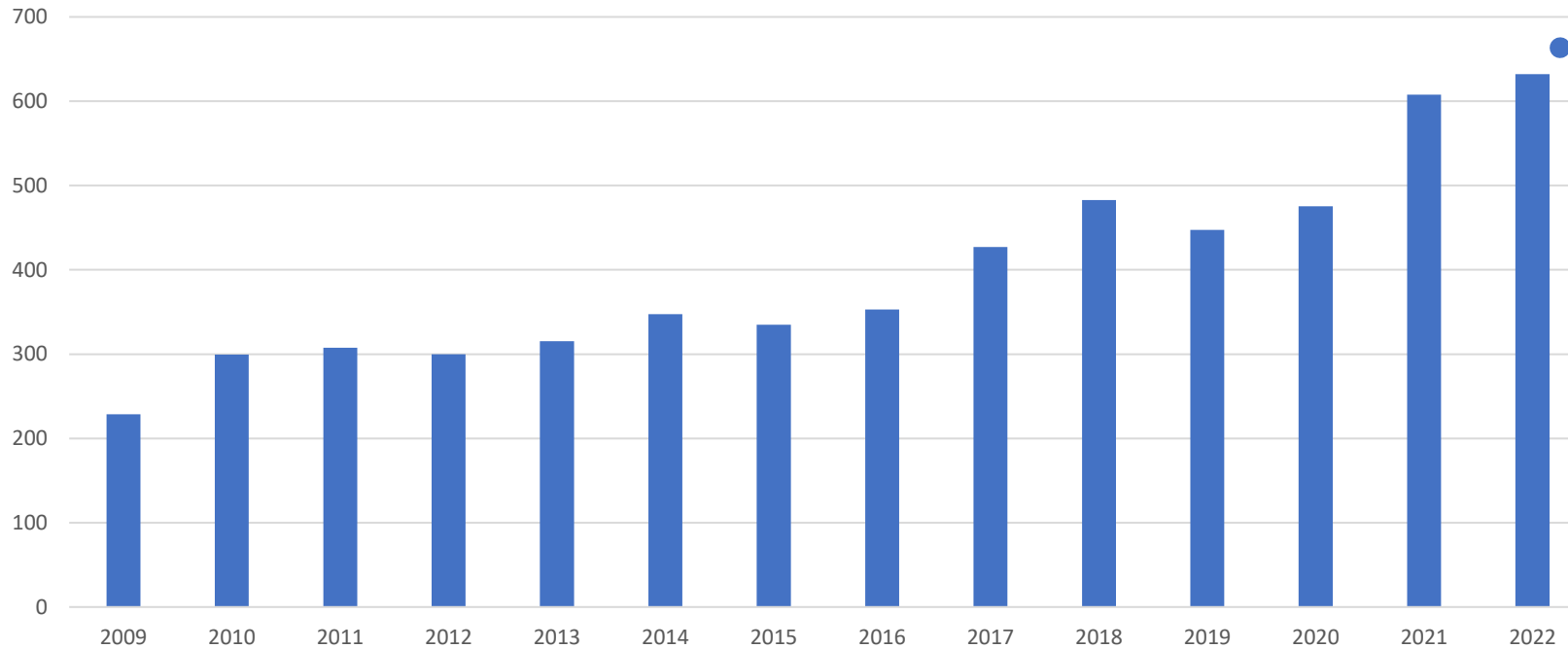a. Global net anthropogenic GHG emissions 1990–2019 [5]
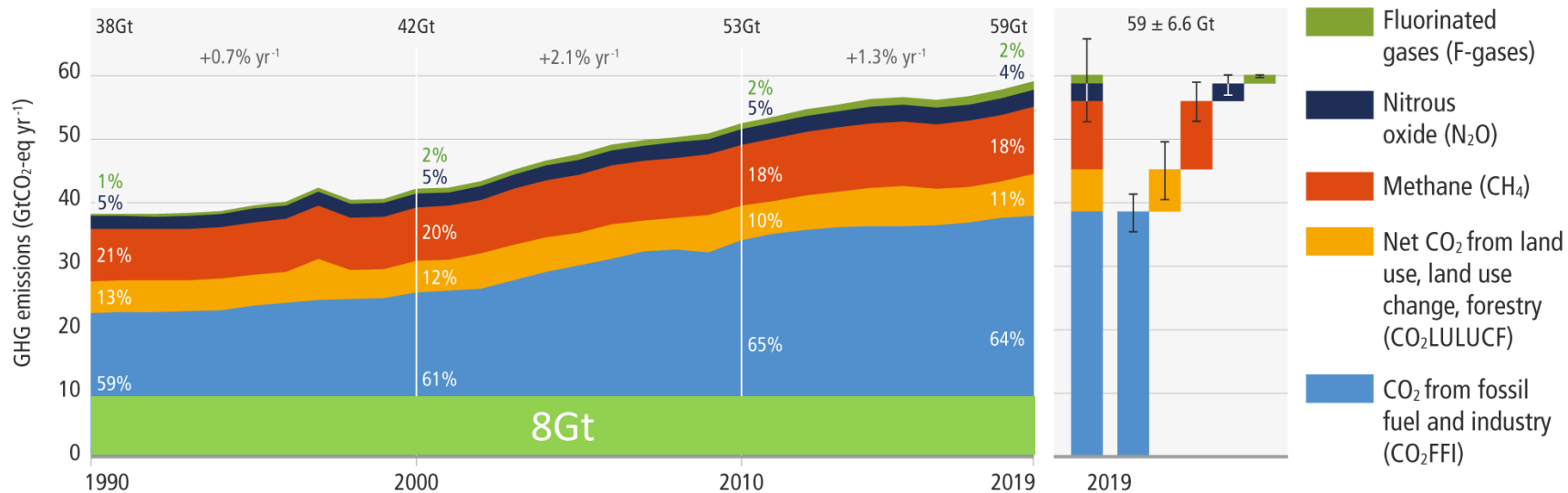
The Closing Window: Climate crisis calls for rapid transformation of societies, UN environment program 2022

Semiconductor revenue

1 trillion $

Semiconductor revenues (B$)

2030

5

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…

- More largely, production optimization and earth observation heavily rely on EEEs
  - Precision farming, earth observation satellites…

CC 3.0 ChristofferRiemer

CC SA Kritzolina

6

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
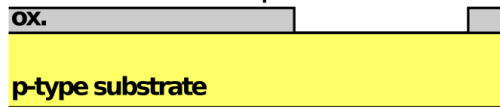 - Emits e-wastes that pollute water and soils (54Mt waste in 2019)

Global E-waste Monitor 2020, UN, ITU
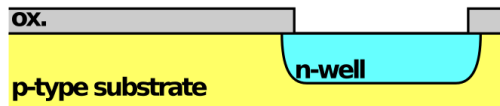
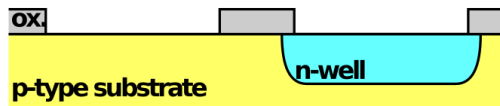# Semiconductors and GHG emissions
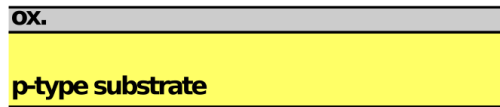
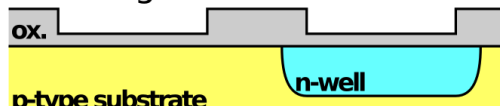1. Grow field oxide
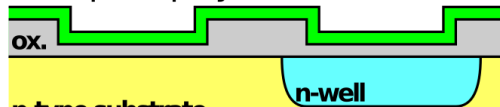2. Etch oxide for pMOSFET
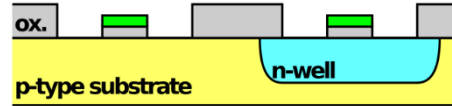3. Diffuse n-well
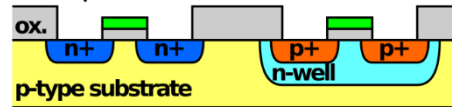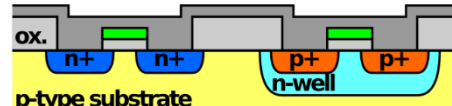4. Etch oxide for nMOSFET
5. Grow gate oxide
6. Deposit polysilicon
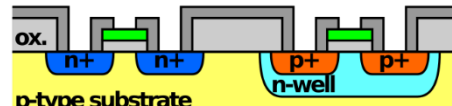7. Etch polysilicon and oxide
8. Implant sources and drains
9. Grow nitride
10. Etch nitride
11. Deposit metal
12. Etch metal
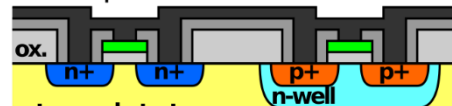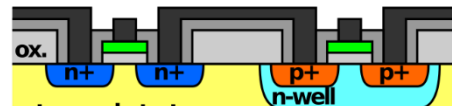
- Scope 1 emissions: F-gases
  - F-gases are used for cleaning and etching, as well as for heat pumps and refrigerants
  - 1kg of SF6 $\Leftrightarrow$ 23 tons of CO_2

    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 CO_2e/kWh to 1kg CO_2e/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
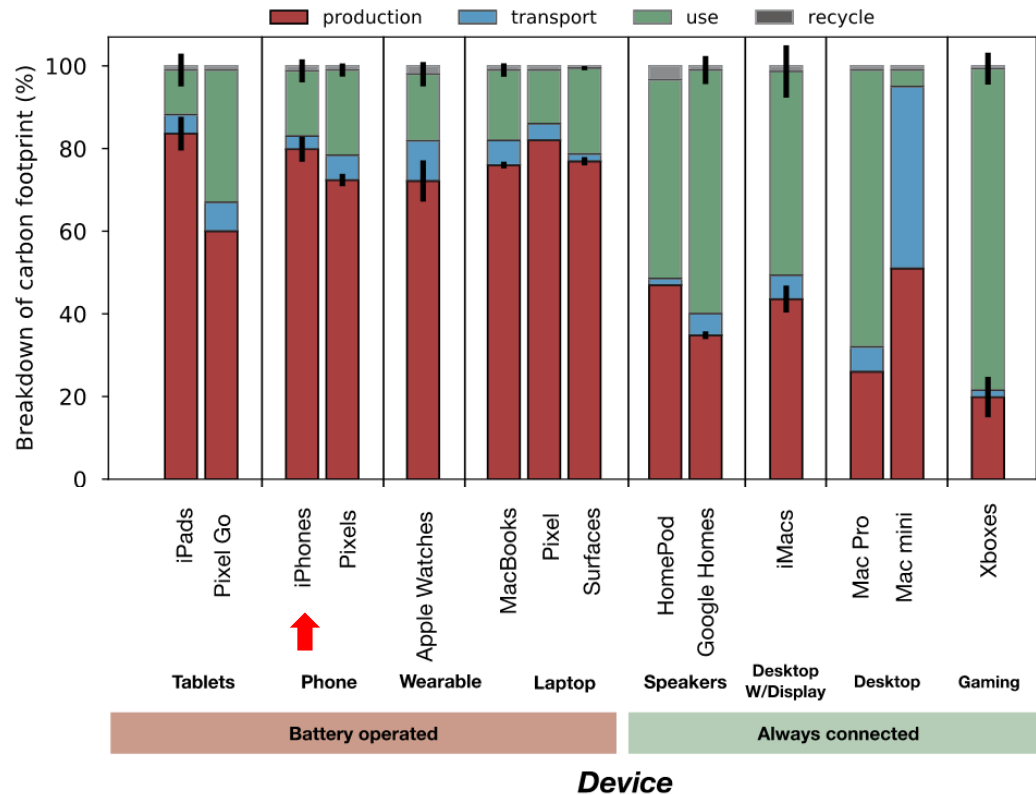
Gupta, U., Kim, Y. G., Lee, S., Tse, J., Lee, H. H. S., Wei, G. Y., ... & Wu, C. J. (2022). Chasing carbon: The elusive environmental footprint of computing. IEEE Micro.

Semiconductors and GHG emissions

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

Smartphone production relative impact

Legend: IC, PCB, Display, Battery, Casing, Assembly, Other
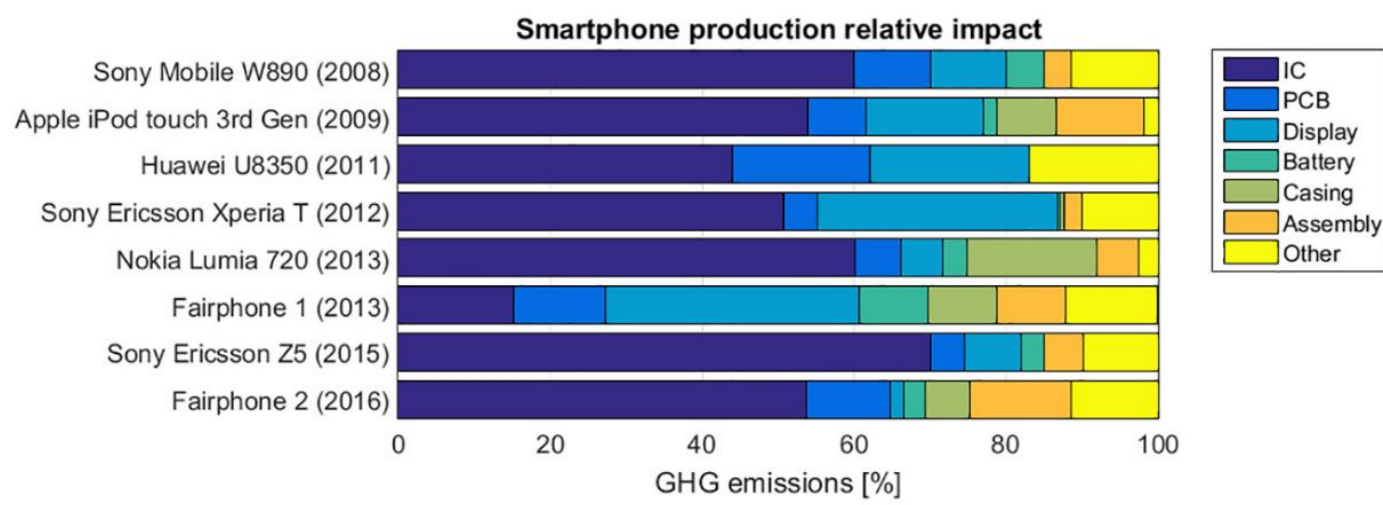
X-axis: GHG emissions [%], 0 to 100

Rows: Sony Mobile W890 (2008), Apple iPod touch 3rd Gen (2009), Huawei U8350 (2011), Sony Ericsson Xperia T (2012), Nokia Lumia 720 (2013), Fairphone 1 (2013), Sony Ericsson Z5 (2015), Fairphone 2 (2016)

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

- The manufacture of integrated circuits emitted 76Mt CO2eq in 2021, an increase of 13% compared to 2020

Year	Semiconductor Market with Foundries		
	Scope 1	Scope 2	Total
2020	$26.84 \; MtCO_2e$	$40.96 \; MtCO_2e$	$67.8 \; MtCO_2e$
2021	$30.56 \; MtCO_2e$	$45.93 \; MtCO_2e$	$76.5 \; MtCO_2e$

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

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.

13

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, reparable, reconfigurable, repurposable chip technologies

- We need to **understand the consequences of our design decisions**

15

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.

16

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 (taxes and quotas)

- Read, write, and talk on the subject

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

How will open source hardware help?

- Carbon footprint reduction requires
  - **Transparency**
  - **Acting fast**
  - **Sharing information**

- Electronics carbon footprint reduction requires **expertise on**
  - **Chip design**
  - **PCB design**
  - **ICT infrastructure design**

18

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.
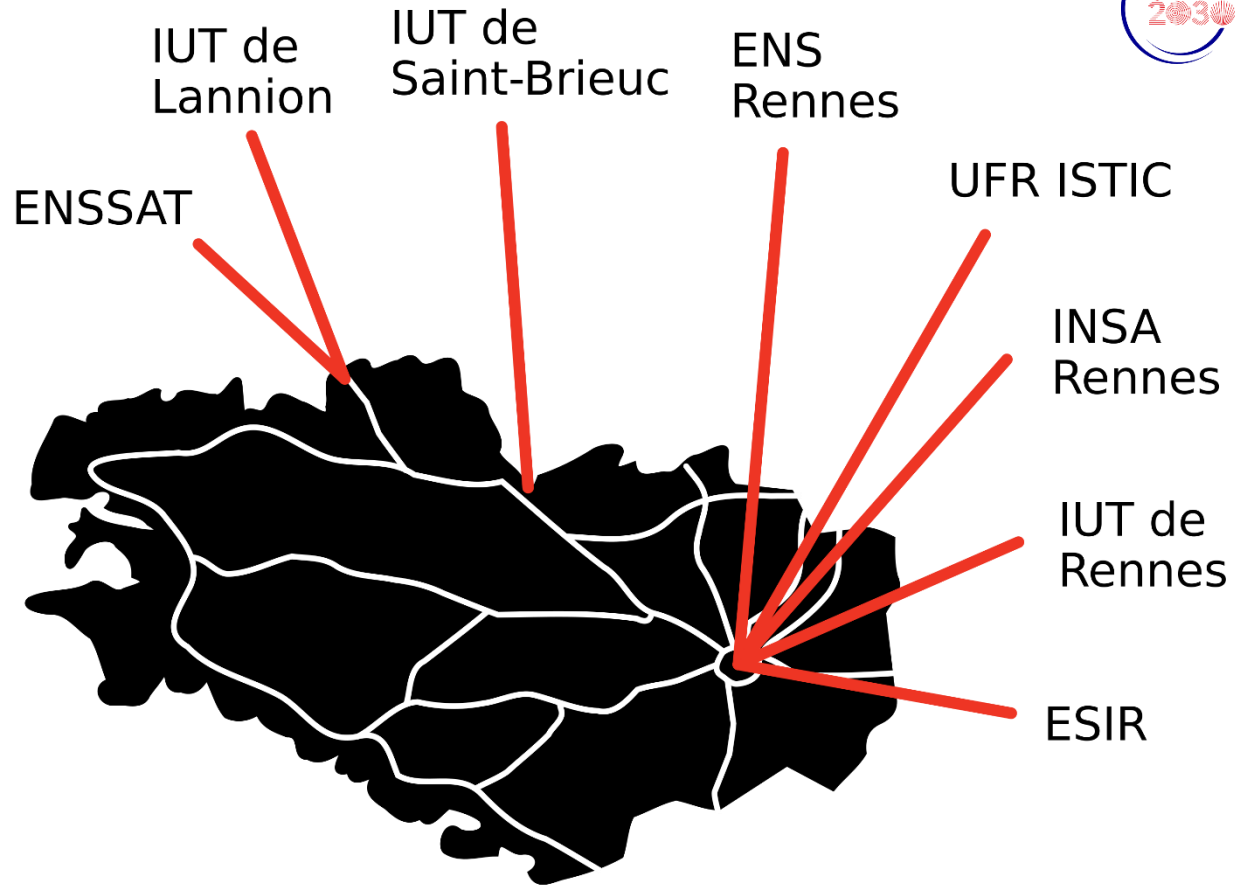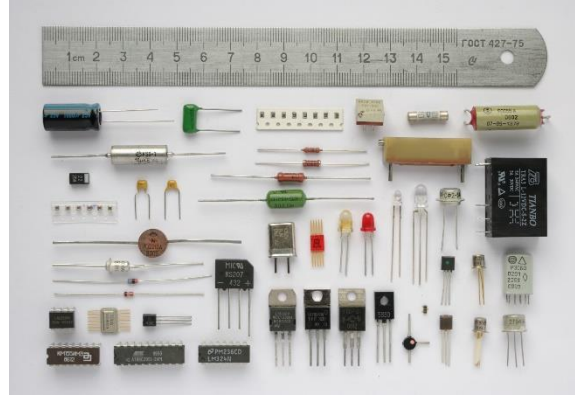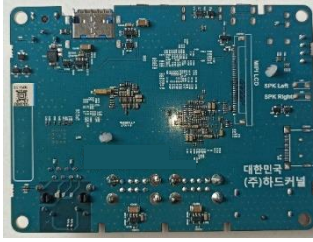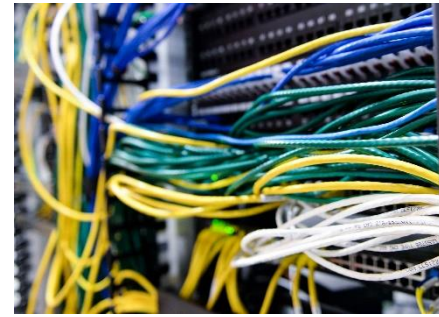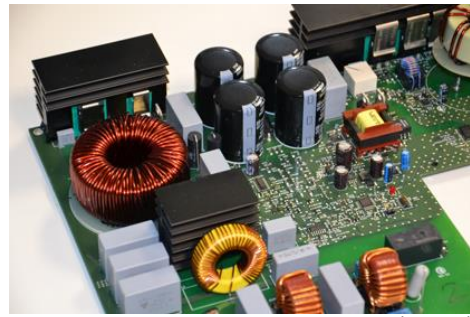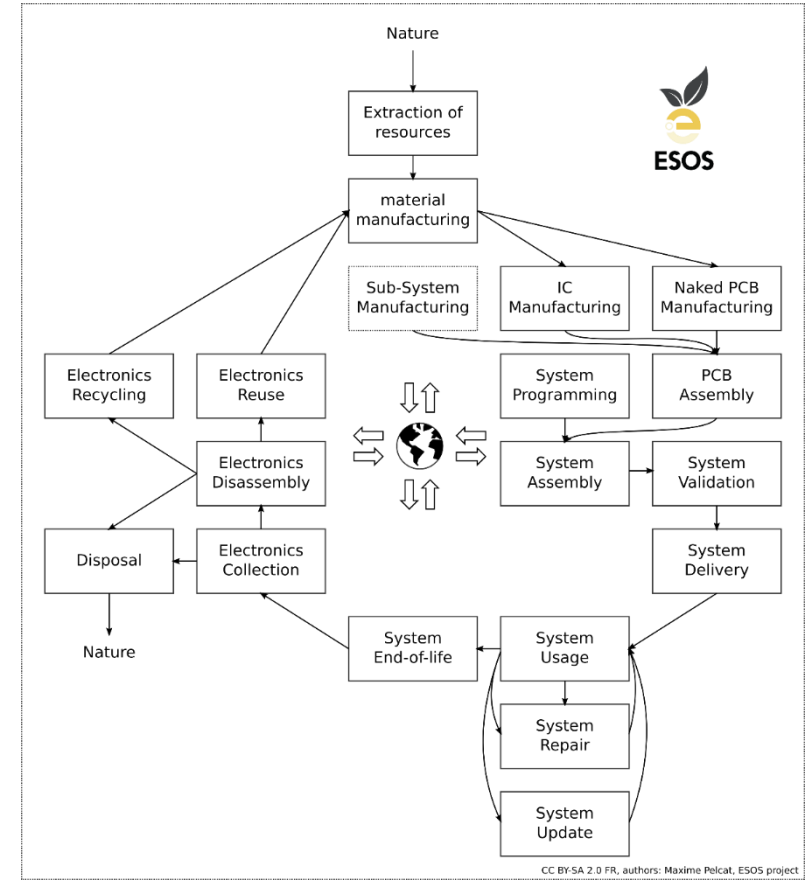
ESOS – 7 actions

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

- **Looking for partners!**

IUT de Lannion

IUT de Saint-Brieuc

ENS Rennes

UFR ISTIC

ENSSAT

INSA Rennes

IUT de Rennes

ESIR

CC SA Angels Pinyol

CC-SA Project Kei

CC BY-SA 2.0 FR, authors: Maxime Pelcat, ESOS project

Thanks