cnrs GDR Groupement de recherche
SOC² System On Chip - Systèmes embarqués et Objets Connectés

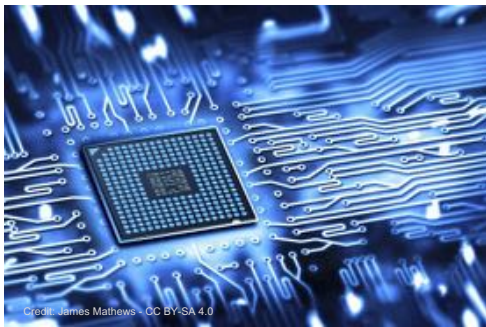
FRANCE 2030

ESOS

SUSTAINABLE ELECTRONICS: CHALLENGES, AND OPPORTUNITIES OF OPEN-SOURCE HARDWARE

GREENDAYS2023 @ LYON

Maxime PELCAT,
IETR, INSA Rennes
2023



INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES RENNES · rennes · UIMM · Novatech Industries · Université de Rennes · IETR

WHAT IS SUSTAINABLE ELECTRONICS?

What is electronics?

- **Electronic devices**
  - **Collins dictionary: *Electronics is the technology of using transistors and silicon chips, especially in devices such as radios, televisions, and computers.***
- **Electrical devices**
  - ***Electrical devices functionally rely on electric energy (AC or DC) to drive their core parts (electric motors, transformers, rechargeable batteries…).***
- **Both: EEE: Electrical and Electronic Equipments**

Electrical and Electronic Equipments

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

List from 7esl.com

Electrical and Electronic Equipments

Main EEE devices of digital society

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

List from 7esl.com

And Other Electrical and Electronic Equipments

And

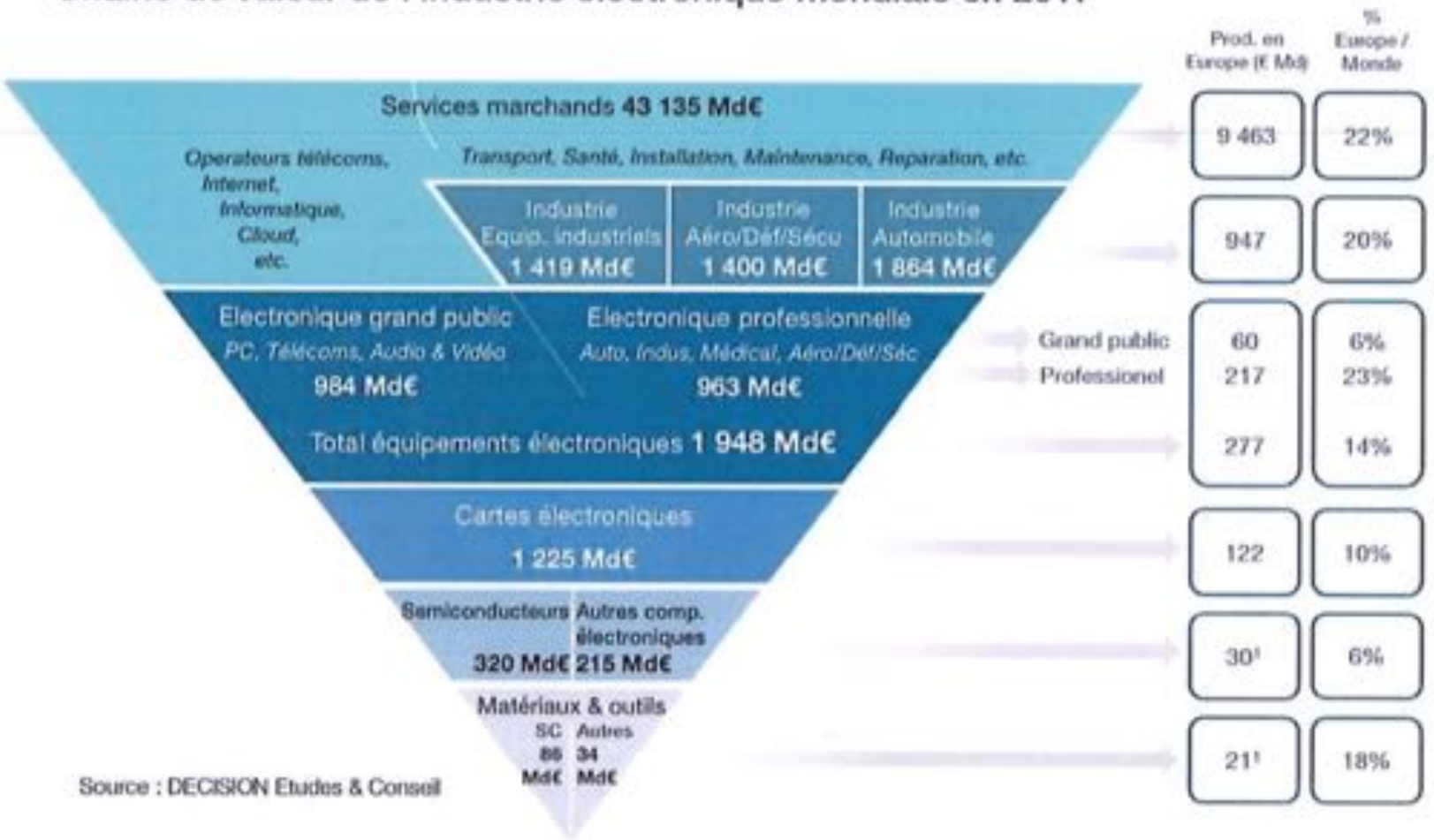
xG Base stations
Cars
Boats
Planes
Trains
Tramways
Busses
Windmills
Power plants
Satellites
Rockets
Supercomputers
Data centers
…

CC-BY-SA Aynamankajan

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

Concentrating on Electronics

Chaîne de valeur de l'industrie électronique mondiale en 2017



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**

- **What are the needs of current generation?**

- **How do we compromise the needs of future generations?**

Presentation Outline

- **Electronics and Sustainability Challenges**
  - How is electronics designed and built?
  - Sustainability impacts, and focus on global warming

- **How to act on electronics sustainability?**
  - Low energy, life cycle analysis, product extended lifetimes
  - Role of open source hardware

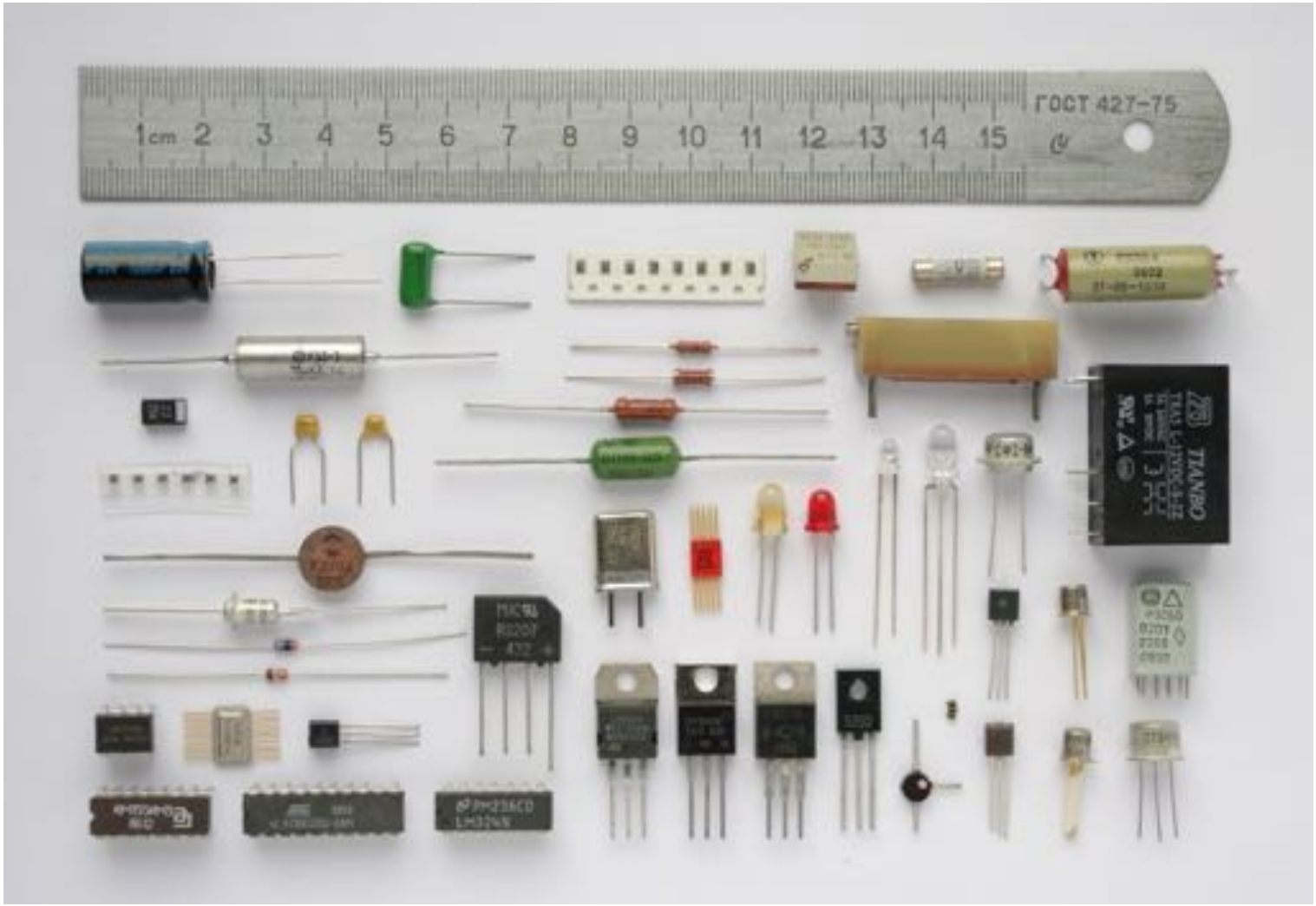
HOW IS ELECTRONICS DESIGNED AND BUILT?

Examples: Printed Circuit Boards





Examples: Electronics Components



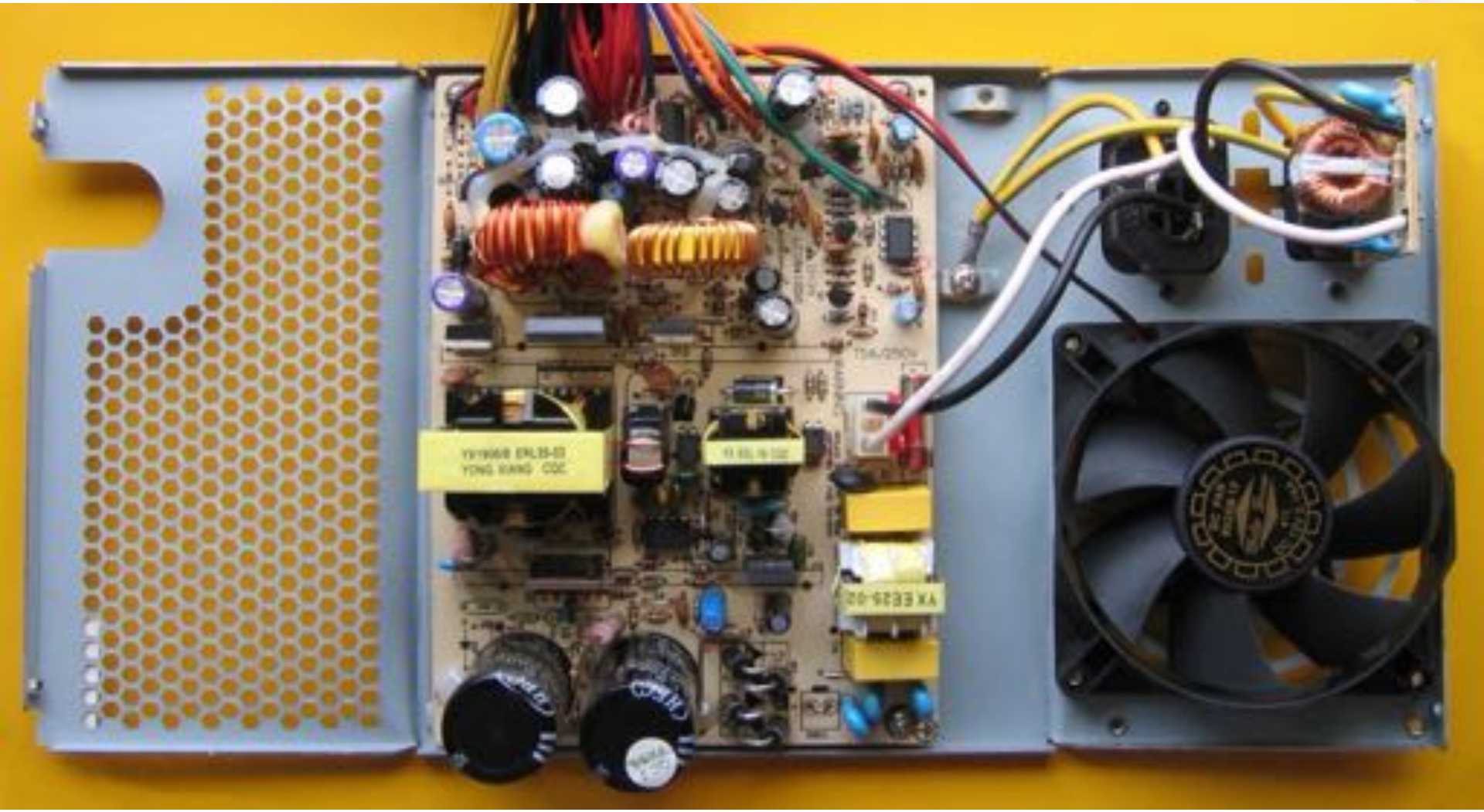
Examples: Communication and Storage

Examples: Smartphones

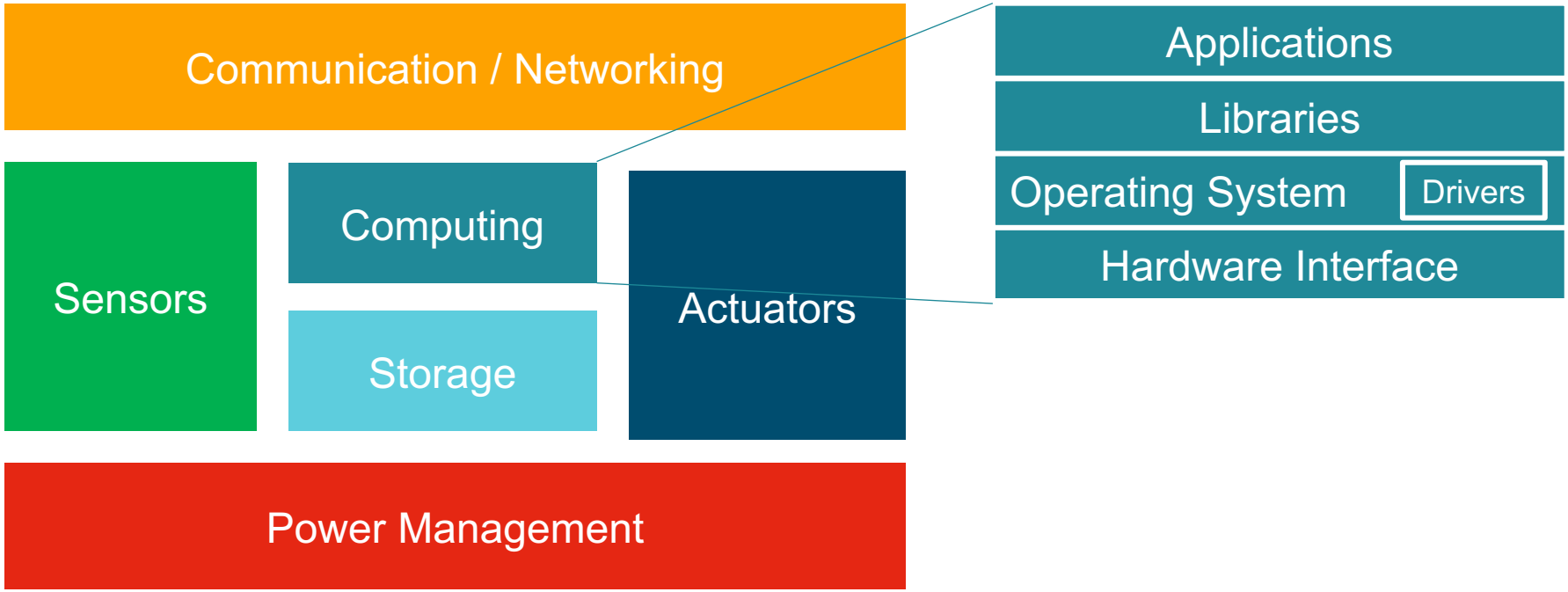
CC BY-SA Vera de Kok

Examples: Servers

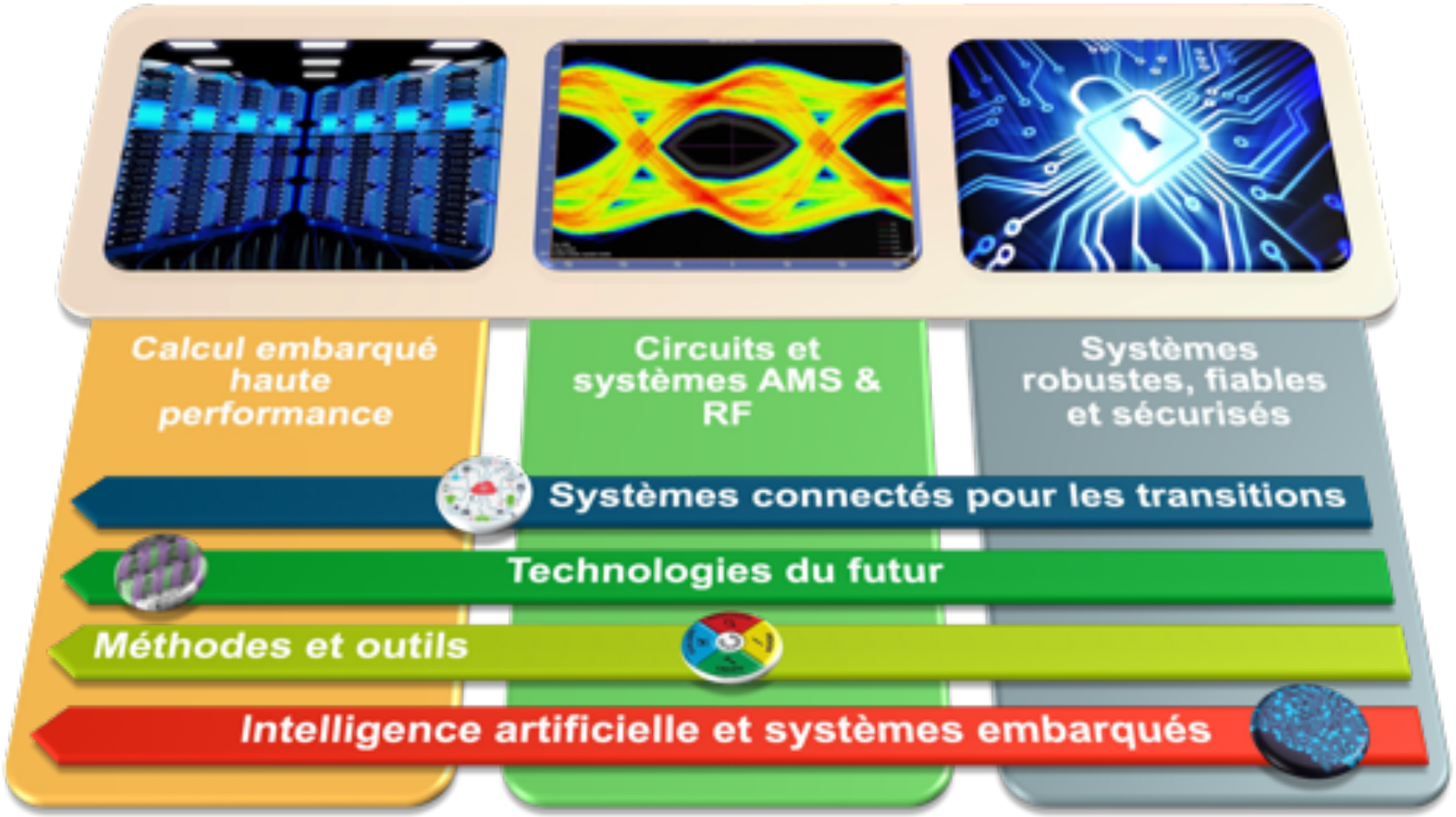
Examples: Power Supply



Structure of an embedded system

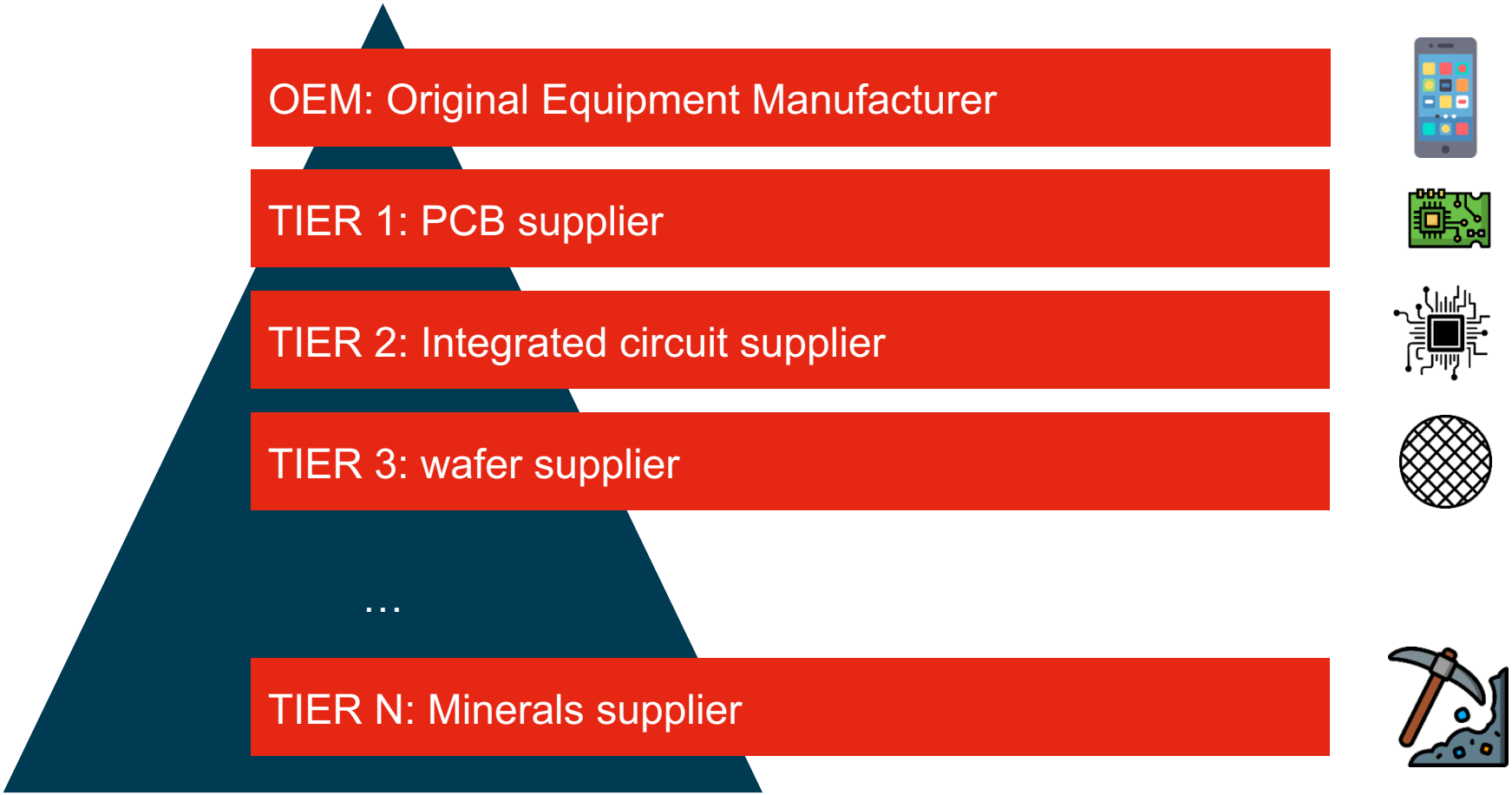


Systems-on-a-Chip – Systèmes et Objets Connectés



The electronics industry supply chain

- **Industry employs a supply chain pyramid with Tiers**



ELECTRONICS AND SUSTAINABILITY CHALLENGES

Understanding sustainability

- **UN - 17 sustainable development goals for 2030**

How do EEE help sustainability?

- All energy transitions/shifts heavily employ EEEs
  - Electric cars, renewable energies from windmills, solar panel, heat pumps…
- Energy reduction 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

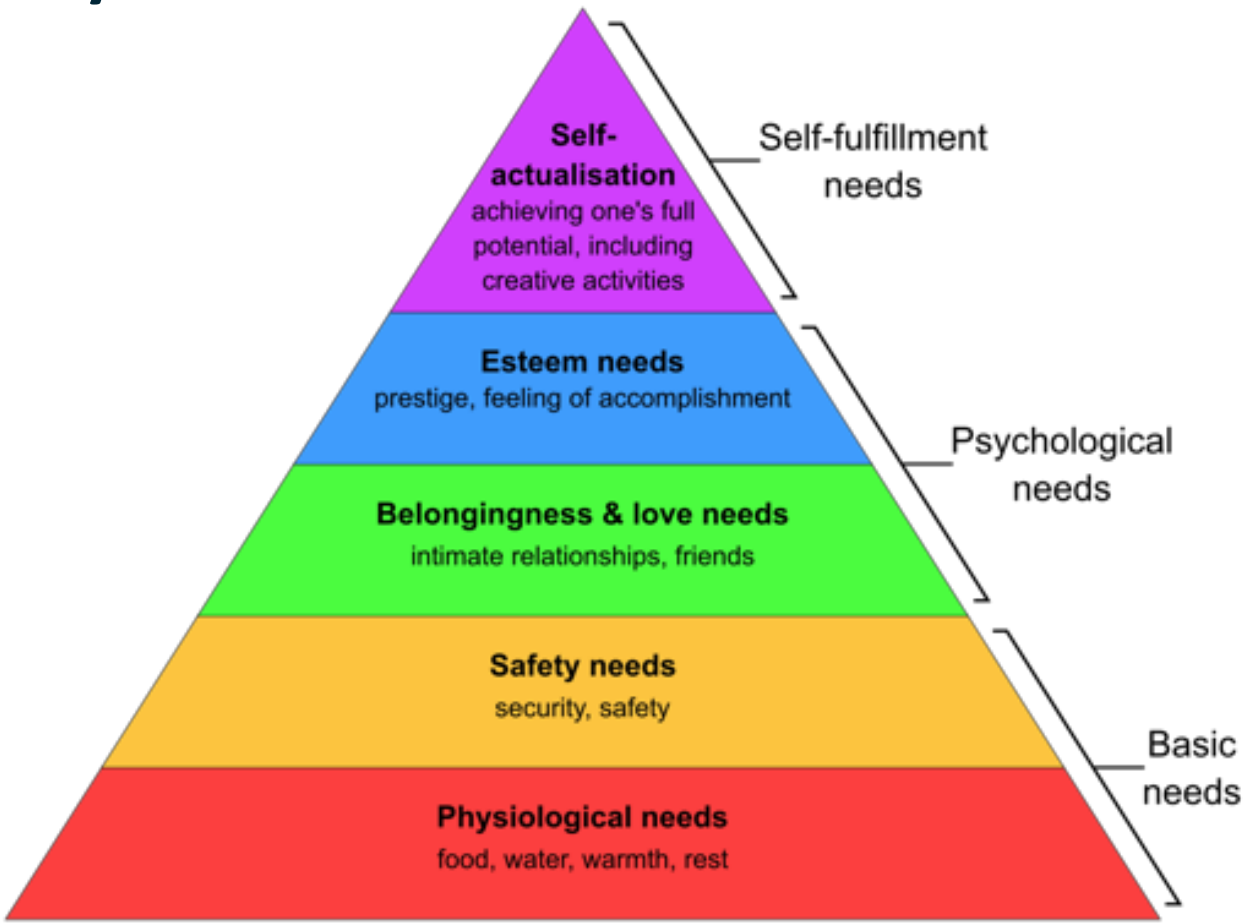
How do EEE hinder sustainability?

(focusing on environmental impacts)

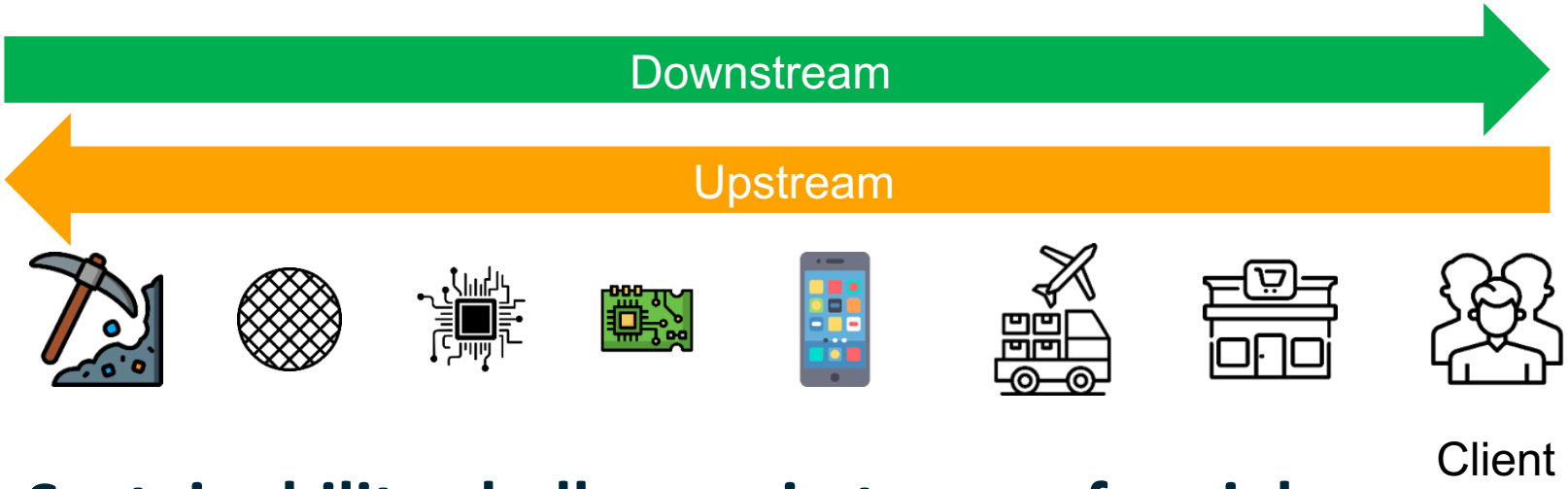
- **Production of EEEs**
  - Requires rare material (abiotic resource depletion)
  - Emits greenhouse gases
  - Requires much water
- **Usage of EEEs**
  - Requires energy
- **End-of-life of EEEs**
  - Emits e-wastes that pollute water and soils

+/- Impacts of electronics

- **Electronics has + and – effects at all levels of the Maslow's hierarchy of needs**



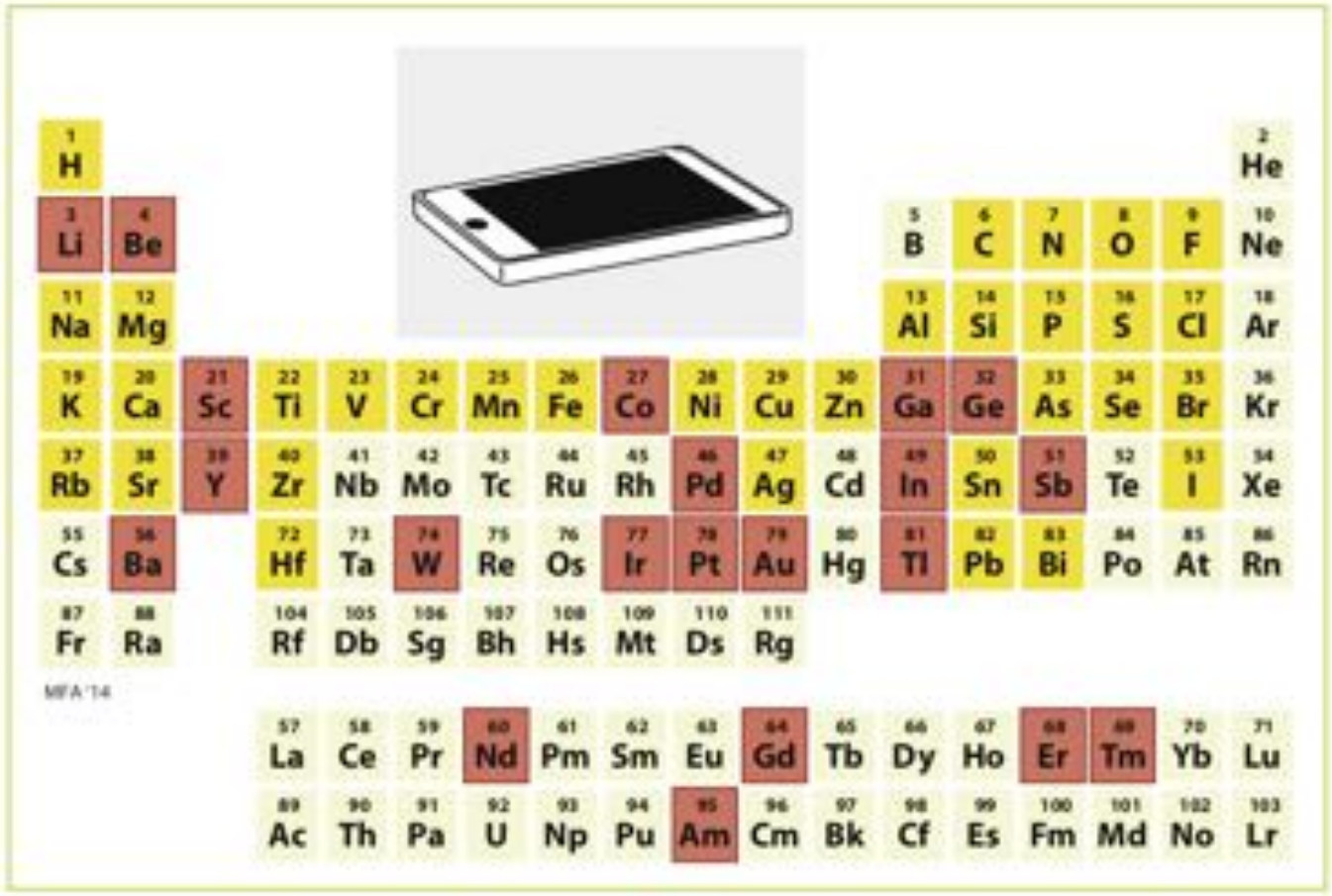
Electronics, ethics and human rights



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

Abiotic resources usage

- **Smartphones: 55 elements employed**



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

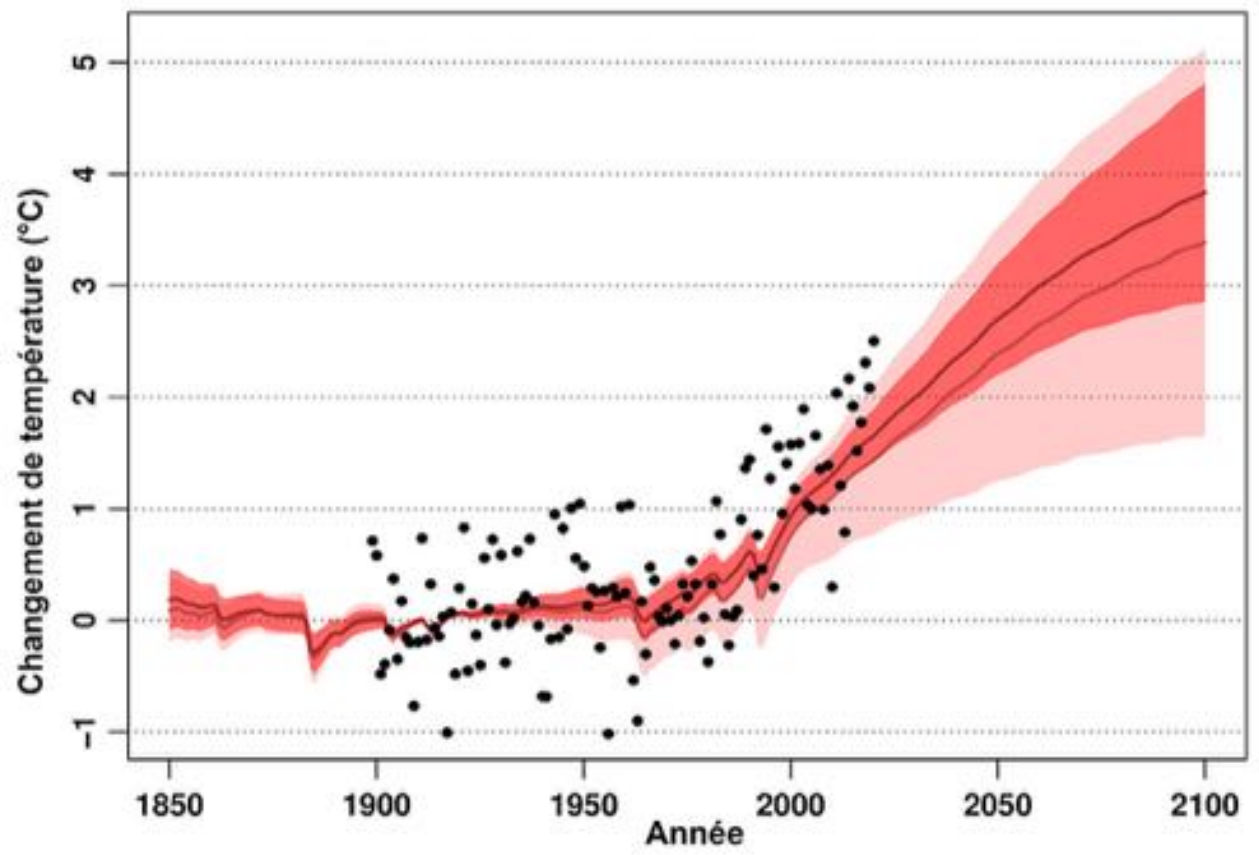
E-Waste

- **E-waste**
  - **One of the fastest-growing waste categories, growing at a rate of 3–5% per year → includes *product housing***
  - **In 2016, 44.7 million tons of e-waste were generated in the world , 6.1 kg per person; in 2019: 53.6 million tons**
  - **“Only 17.4 per cent of 2019’s e-waste was collected and recycled.” Global E-waste Monitor 2020**

Ilankoon, I. M. S. K., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018). E-waste in the international context–A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Management, 82, 258-275.

FOCUS ON GLOBAL WARMING

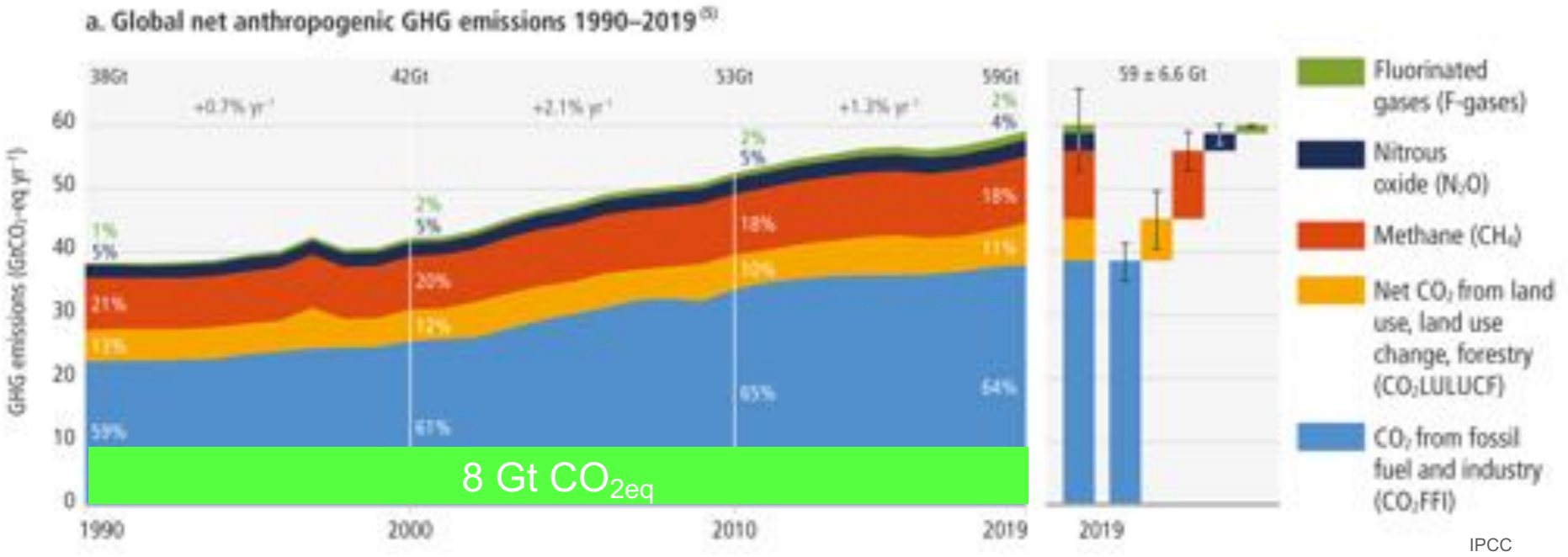
Global Warming, in France



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

Goal on global warming

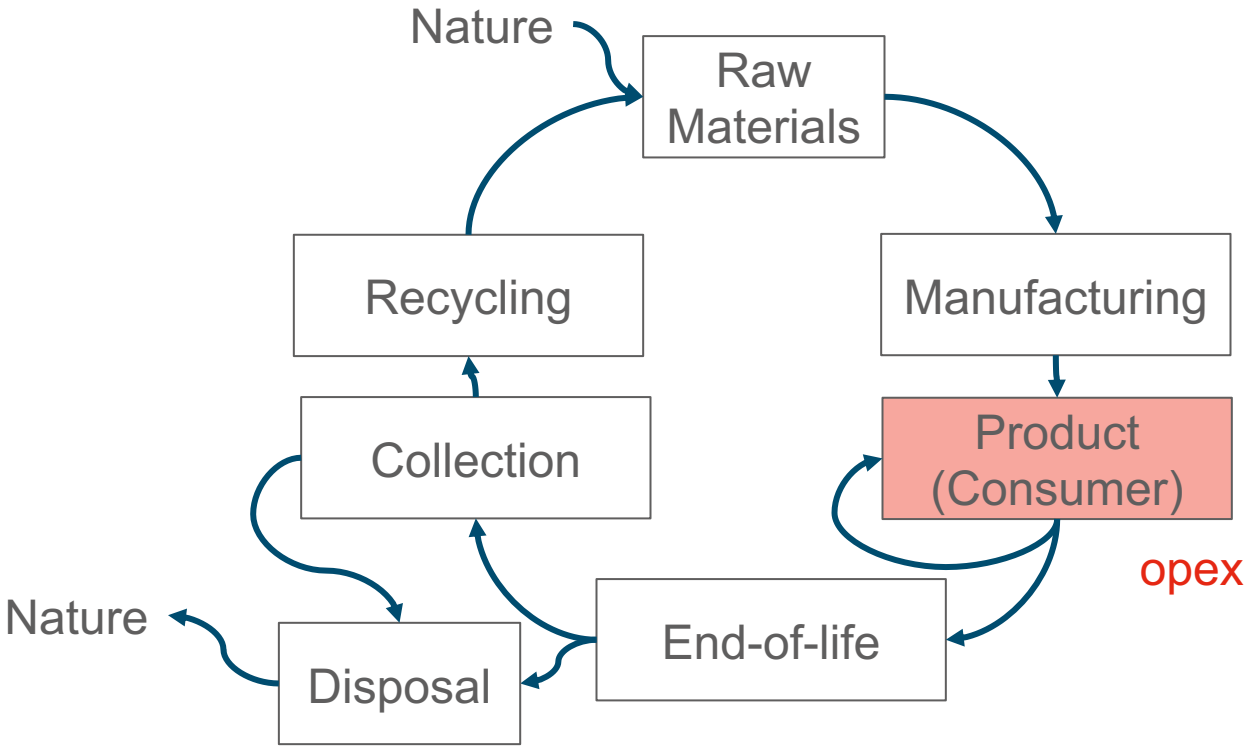
Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.



- **IPCC 1.5°C Scenario (66% chance in 2100 with no or limited overshoot): 8 $GtCO_2e$ in 2050 (gain of ~7×)**

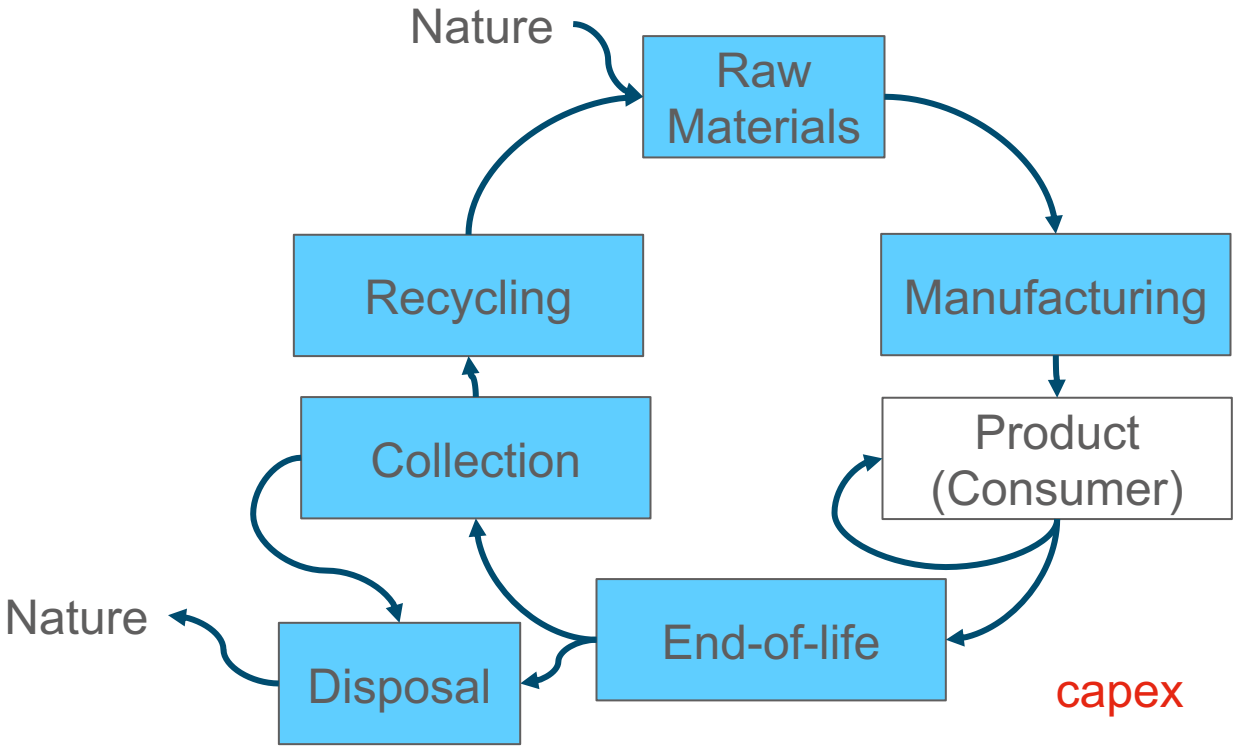
The Closing Window:Climate crisis calls for rapid transformation of societies
UN environment programme 2022

Electronics Life Cycle (LC)



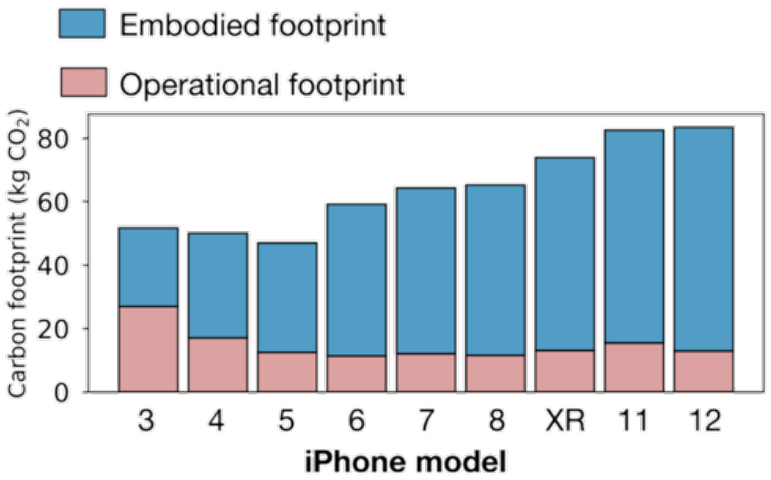
Gupta, U., Kim, Y. G., Lee, S., Tse, J., Lee, H. H. S., Wei, G. Y., ... & Wu, C. J. (2022). Chasing carbon: The elusive environmental footprint of computing. IEEE Micro, 42(4), 37-47.

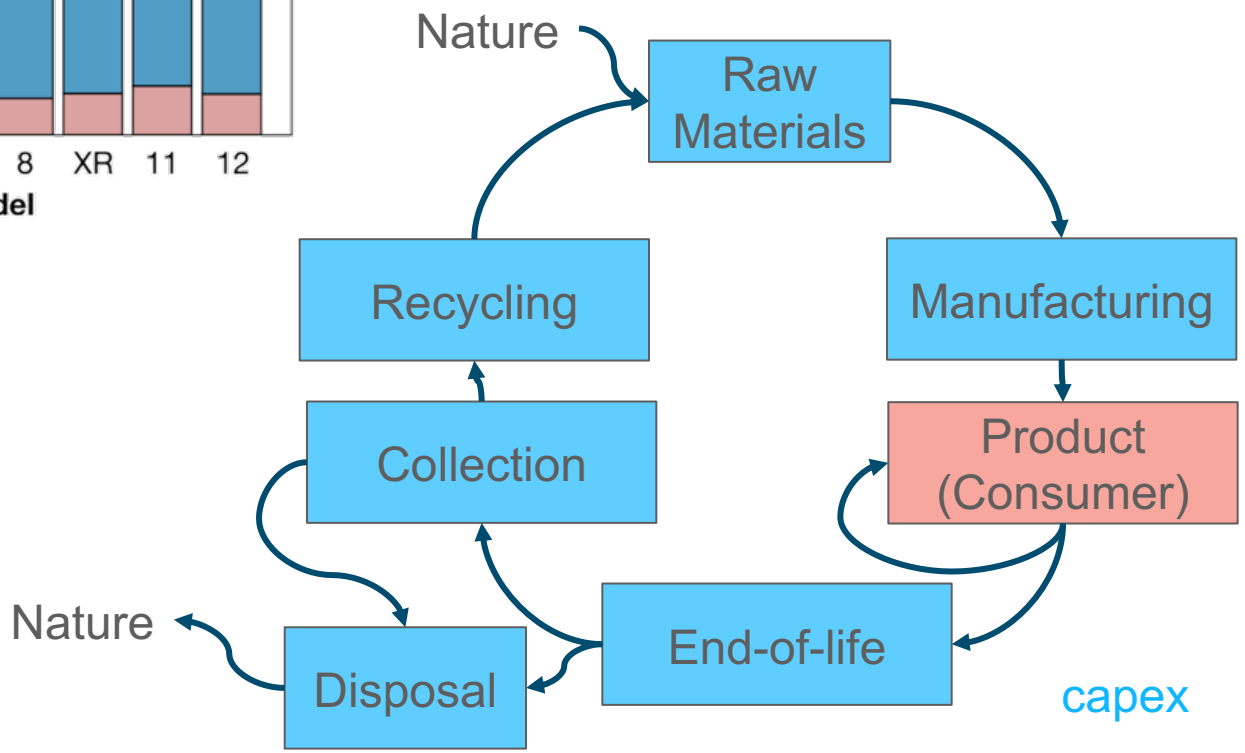
Electronics LC is strongly impacted by capex



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, 42(4), 37-47.

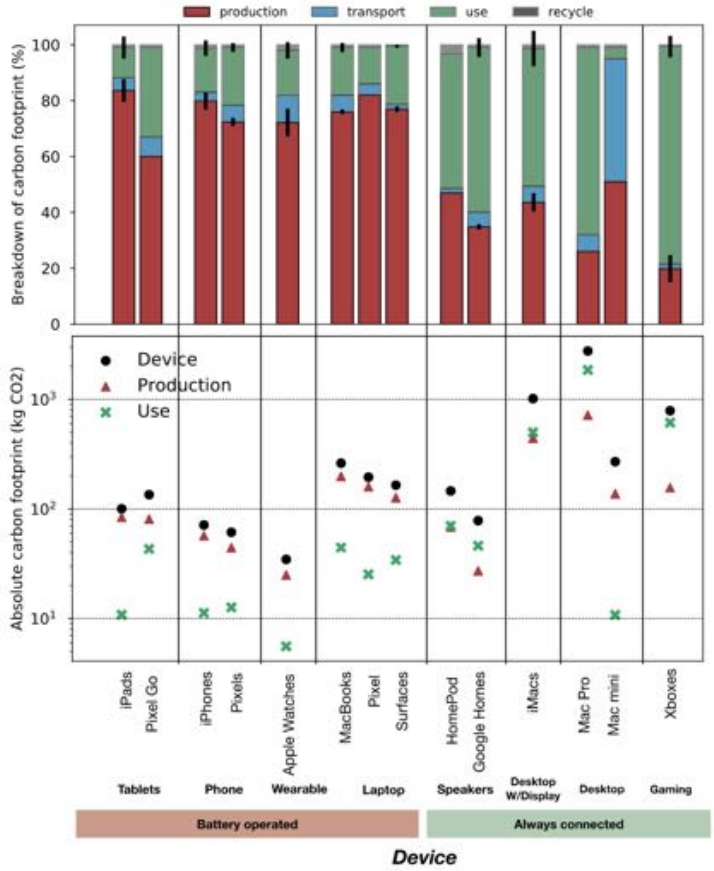
Electronics LC is strongly impacted by capex

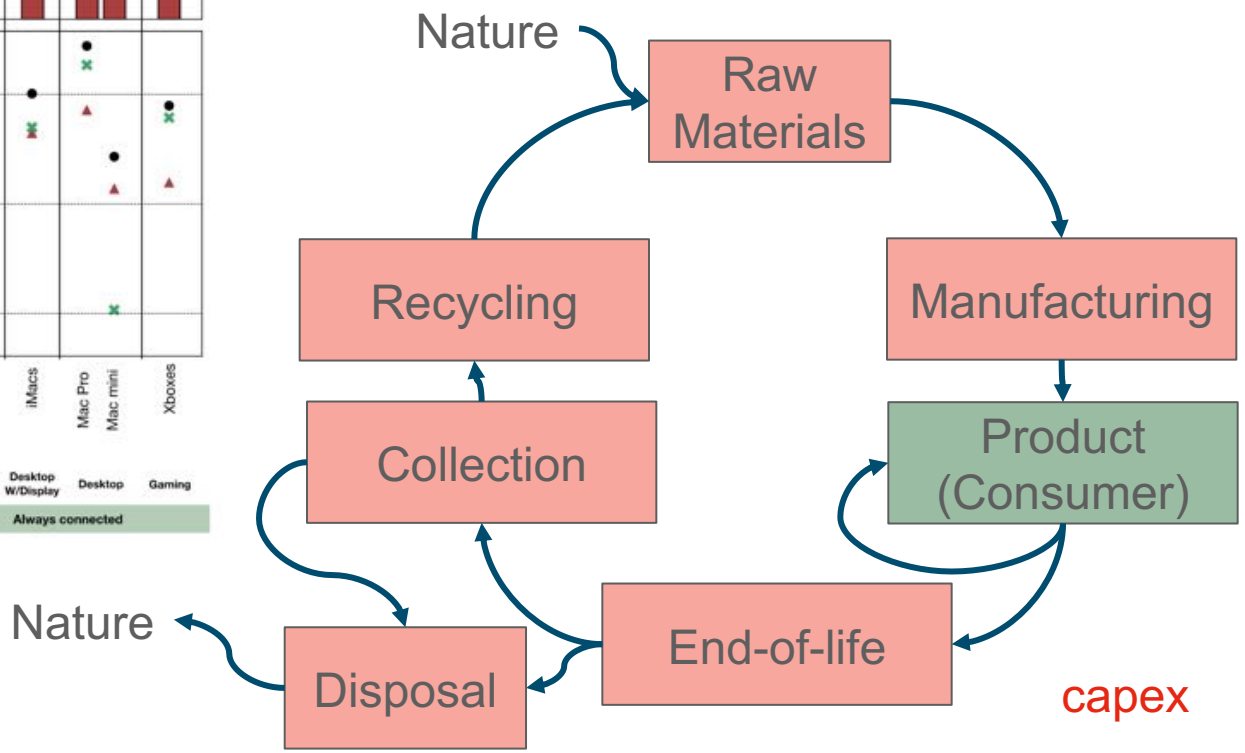




Gupta, U., Kim, Y. G., Lee, S., Tse, J., Lee, H. H. S., Wei, G. Y., ... & Wu, C. J. (2022). Chasing carbon: The elusive environmental footprint of computing. IEEE Micro, 42(4), 37-47.

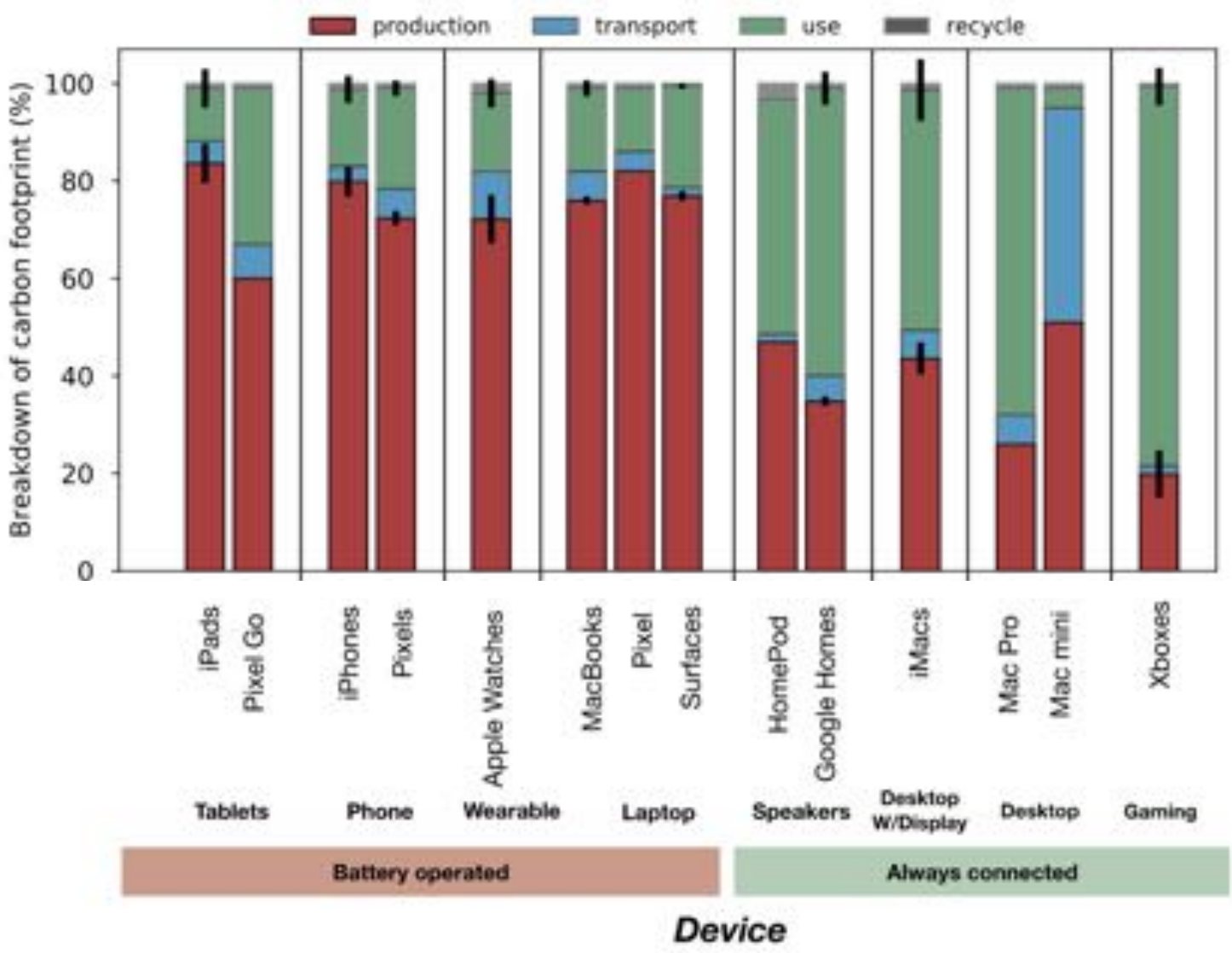
Electronics LC is strongly impacted by capex





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, 42(4), 37-47.

Electronics LC is strongly impacted by capex

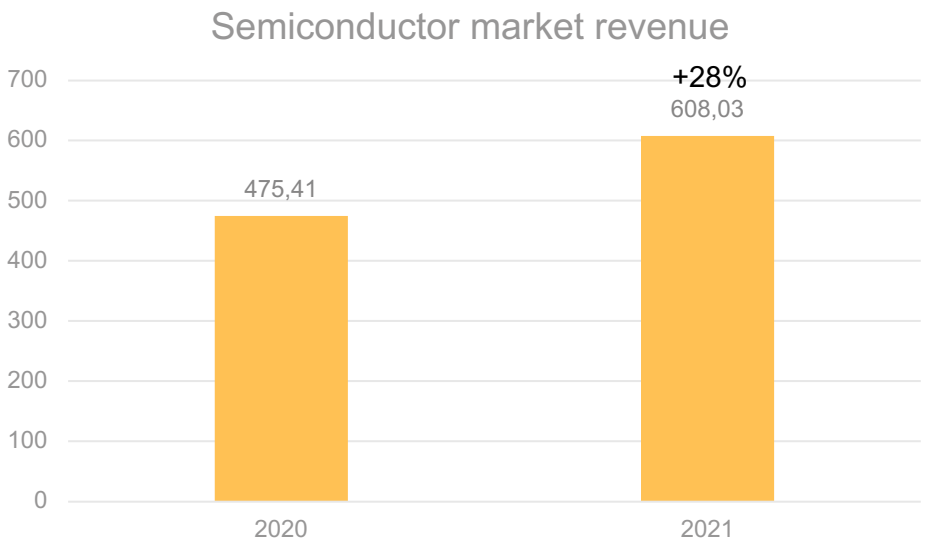


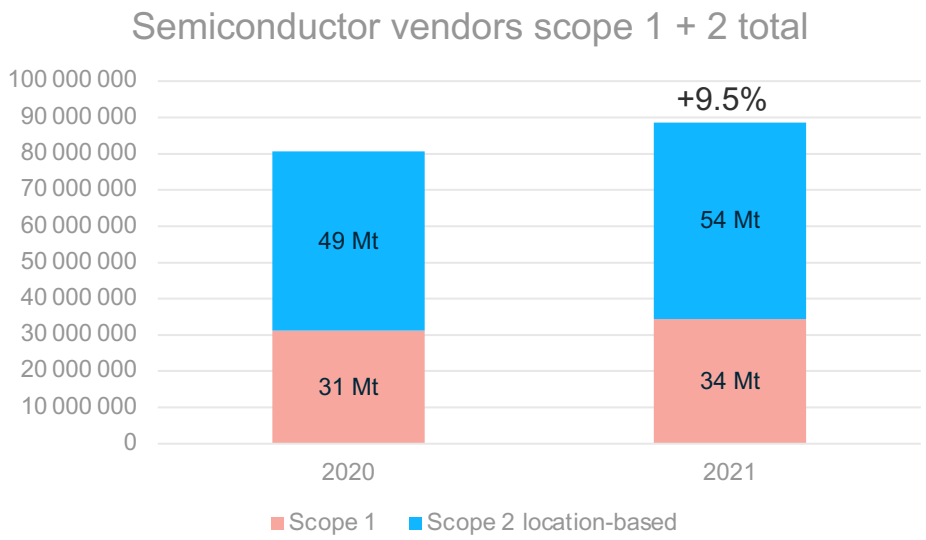
Carbon accounting

- **Greenhouse Gas Protocol and ISO 14064**
  - **Employing an accounting method for carbon emission tracking (in tons of CO_2 equivalent) to avoid double counting**
  - **Scope 1: GHG direct emissions from activity**
  - **Scope 2: GHG emissions from energy consumption**
  - **Scope 3: Indirect emissions from value chain (up and downstream)**

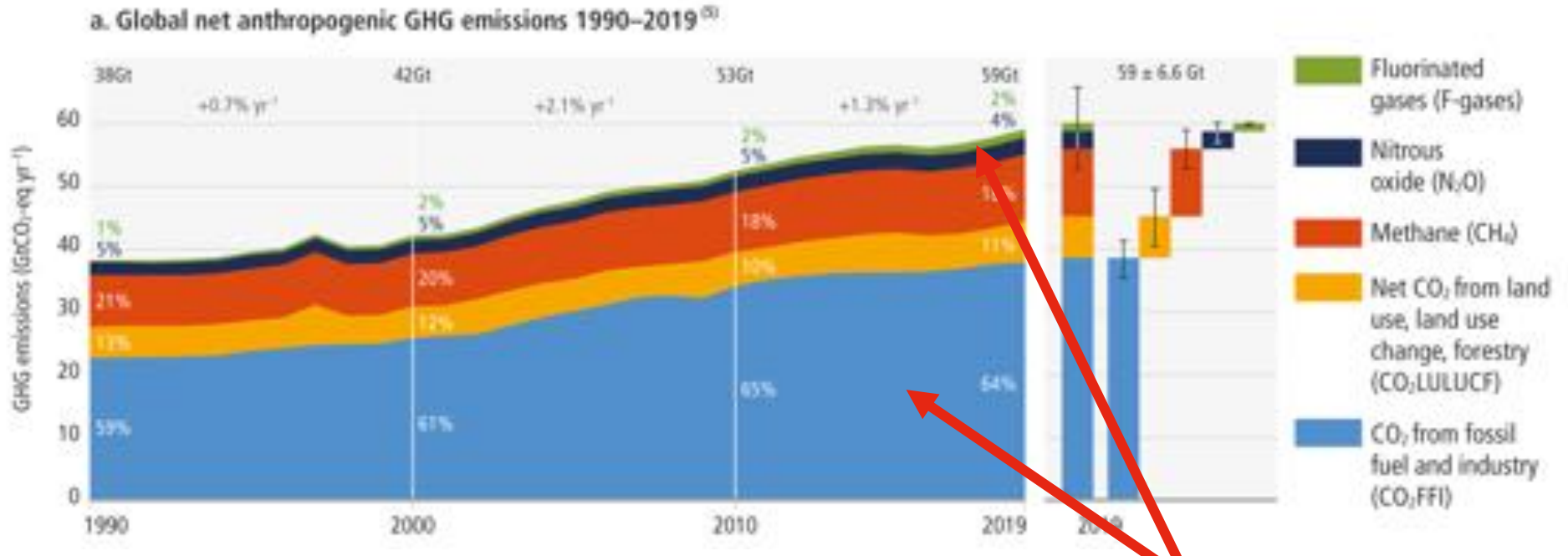
Semiconductor GHG accounting

- **Scope 1+2 of semiconductors: 88Mt CO_2eq in 2021**
  - **+9.5% GHG emission from 2020**
  - **For +28% revenue**
  - **Efficiency has improved**
  - **Sustainability has not**





Where is semiconductor industry in global GHG emissions?



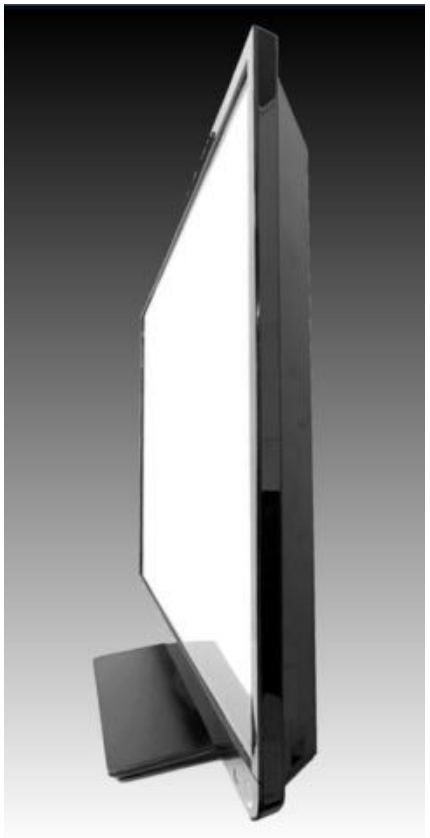
88 Mt CO_2eq
0,15% of total

- **Global ICT impact is estimated up to 4%***
  - **55% from cloud and network infrastructure:**
  - **45% from manufacturing devices**

* Climat : l'insoutenable usage de la vidéo en ligne, the Shift Project, 2019

Where are the %s total GHG of ICT?

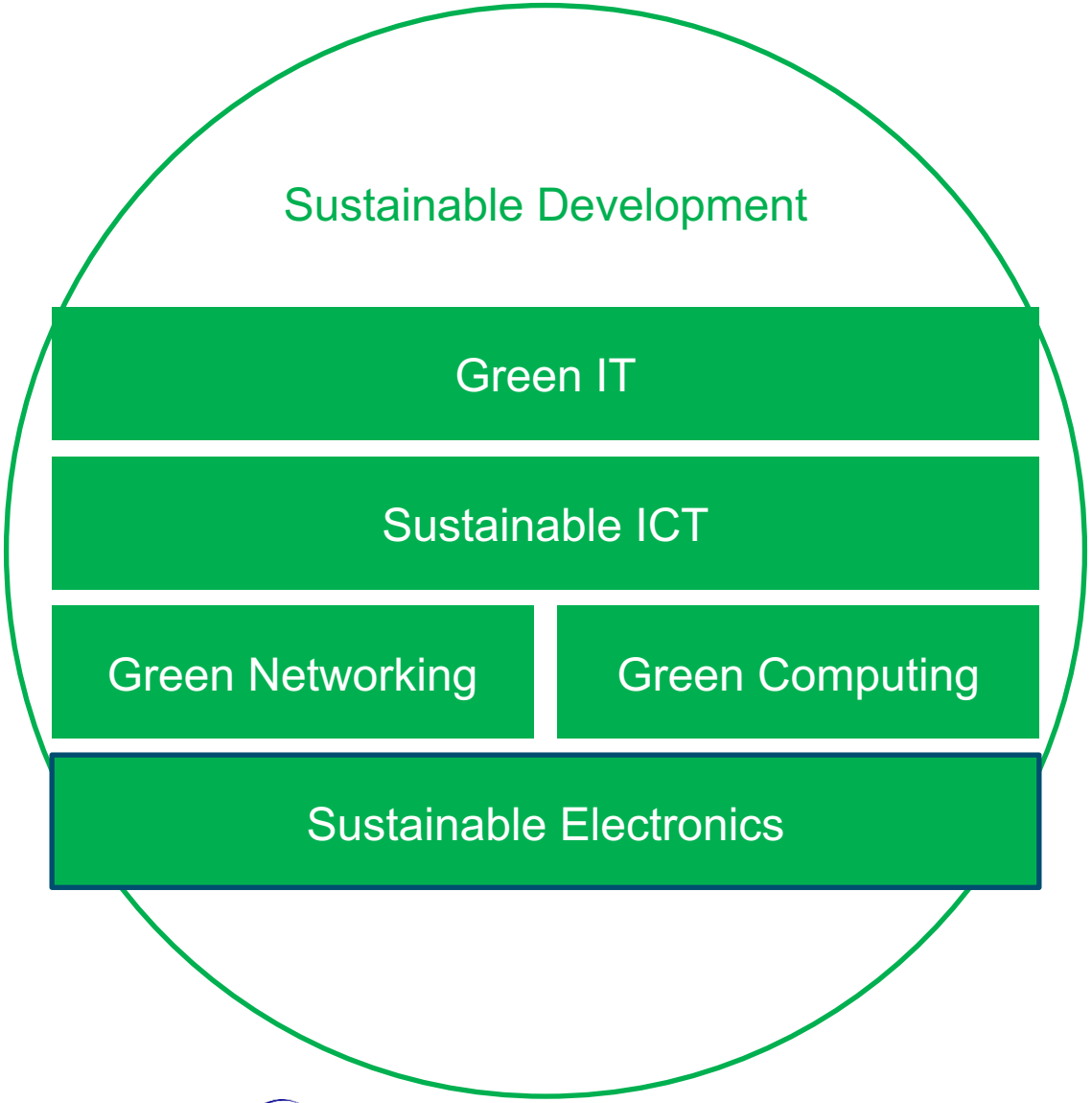
- Mines, smelters and refiners (scope 3 upstream)
- Cloud computing facilities (scope 3 downstream)
  - Including buildings, wiring…
- Electronics cooling systems
- Backbone fiber optics
  - Including fiber optic connection work
- Photonics and underwater cables
- Satellites
- Screens ~ 30Mt CO_2e fab. in 2021
- Batteries
- …



CC-SA Project Kei

HOW TO ACT ON ELECTRONICS SUSTAINABILITY?

Actions towards Electronics Sustainability



Where can electronics and computer science engineers act?

- **Collect and report the environmental footprint of electronics design decisions**
- **Build products:**
  - **With low energy consumption**
  - **Repairable and modular**
  - **Long-term upgradeable, with delayed obsolescence**
  - **With ethical sourcing**
  - **Favoring low carbon footprint and low waste suppliers**
  - **Favoring low carbon footprint and low waste technologies**
    - ICs, batteries, PCBs, connectors, components, solar cells, supercapacitors…

HOW CAN OPEN SOURCE HARDWARE HELP?

What is open source hardware?

- **Open Source Hardware (definition by oshwa.org)**
  - **hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design, or hardware based on that design.**
    - In the form of mechanical drawings, schematics, bills of material, PCB layout data, HDL source code, and/or integrated circuit layout data
  - **The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it.**

Open source hardware for sustainability

- **Fighting against obsolescence**
  - **Long-term maintainance**
    - Open Source Software Linux is from 1991 !
  - **Superiority of community-based tools**
    - Examples of compilers: GCC, LLCM/Clang, etc.
  - **Stable APIs and interfaces**

- **Open documentation for repair and reuse**

Types of open source hardware?

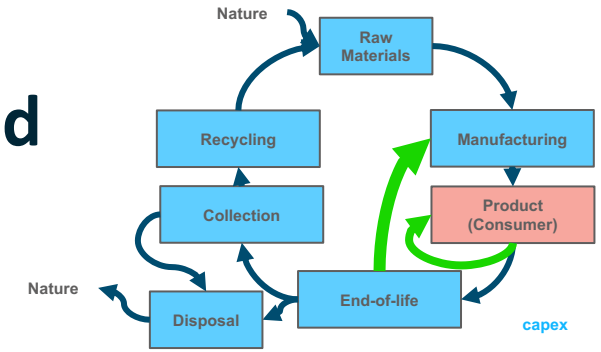
- **Open source hardware applies at three levels**
  - **Printed circuit boards design – RPi, Arduino …**
  - **Reconfigurable hardware design (FPGA)**
  - **Integrated circuits design (ASIC)**
- **Open source hardware applies in three forms**
  - **Open source design tools**
  - **Open source IPs (for Intellectual Property Block)**
    - To be integrated in own system
  - **Open source systems**
    - To be duplicated, repaired, transformed, enhanced, combined with

Open source hardware and sustainability

Open source hardware will help design sustainable systems

- By reducing dependence to suppliers products obsolescence, and availability limitations
- By giving new players an access to advanced electronics systems design
- By avoiding to redevelop many times similar technologies
- By inspiring from OSS community-based development

If impacts of decisions are understood



GDR SOC2 Involvement in OSH and SE

- **Sustainable SoCs: GDR SOC2 theme of the year 2020**

- **Open source IPs are booming, GDR SOC2 is involved**
  - **GDR SOC2 is very active on RISC-V**
  - **AI open-source developments reaches hardware, bringing more open-source software habits into hardware**

  - **GDR SOC2 groups particularly involved in open hardware**
    - Systèmes connectés pour les transitions
    - Calcul Embarqué Haute Performance
    - Méthodes et outils

THE ESOS PROJECT

The ESOS project

- **Electronics: Sustainable, Open and Sovereign**
- **France2030 *Compétences et Métiers d'Avenir***
  - **Consortium teaching electronics in Bac+3/5/8, strong links with research**
  - **30+ industrial partners**
  - **6.38M€ of aid obtained, over 5 year**
  - **https://esos.insa-rennes.fr**

ESOS

ESOS Objectives

- Objective 1: attract more students to the electronics field
- Objective 2: train teachers in sustainable electronics
- Objective 3: Train students in sustainable electronics
- Objective 4: train professionals in sustainable electronics

Some ESOS courses to be developed

- Life cycle analysis
  - Systems eco-design
  - Attributional and consequential GHG accounting
- Open source HW
  - For PCB design, for SoC design
  - Contributing to large-scale open source projects
- Electronics for the transitions
  - Power electronics: novel substrates and technologies
- Sustainability and open source versus:
  - Cost, pure performance, safety, cybersecurity, …
- Business and legal aspects

Wraping-up

- **Sustainable Electronics**
  - **A lot to do!**
  - **Open source hardware will help!**

- **ESOS recruits!**
  - **13 teachers – researchers**
  - **Stay tuned! https://esos.insa-rennes.fr**

- **For more on GDR SOC2**
  - **https://www.gdr-soc.cnrs.fr**

Questions?

QUESTIONS?

A few open source hardware projects

- **Front-end design-level OSH**
  - **SoC simulators: gem5, sniper, McPAT, GPUWattch**
  - **RTL simulators: Verilator, Ghdl**
  - **High-Level Synthesis: Gaut, LegUp, XLS, ScaleHLS**
- **Back-end design-level OSH**
  - **ASIC**
    - **Open-road** and **Alliance VLSI/CAD System**
  - **FPGA**
    - **IceStudio** and open source FPGAs, **openFPGA**
- **Fabrication-level OSH**
  - **Google Skywater PDK 130nm process**

Actions towards Electronics Sustainability

- European Green Deal on climate change – 2019
- National laws: many in France
  - Duty of vigilance 2017
  - AGEC: lutte contre le gaspillage et à l'économie circulaire 2020
  - REEN: réduire l'empreinte environnementale du numérique 2021
- Labels and incentives
- Projects: focus on open source hardware and ESOS

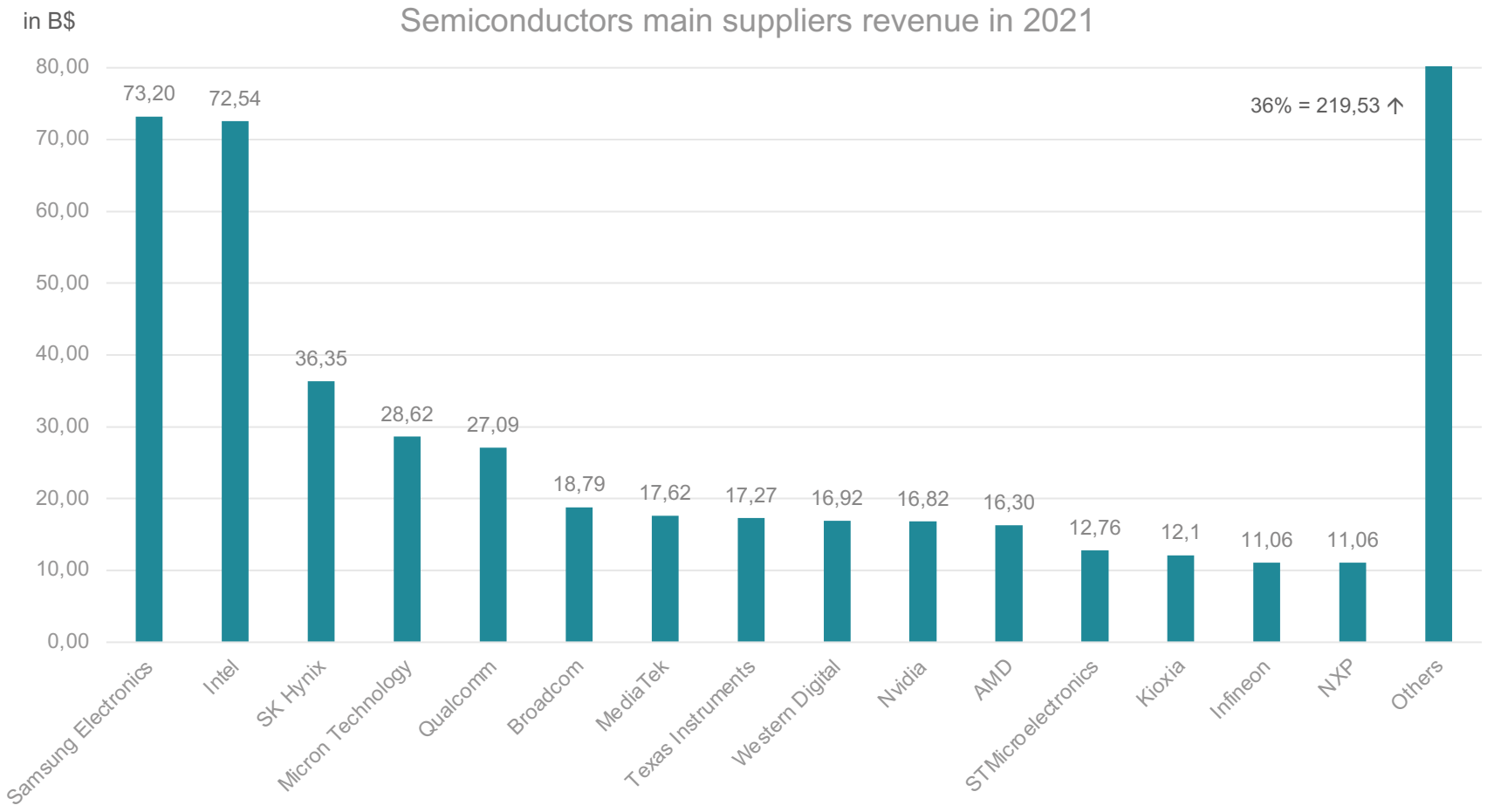
Some data on semiconductor scope 3

- **Intel evaluates Scope 3 downstream**
  - **22,9 Mt CO_2eq in 2021 for product energy usage**
    - Use of yearly-produced electronics over lifetime
  - **Average product lifetime is estimated 4 years and 4 months**
- **Intel evaluates Scope 3 upstream**
  - **4,9 Mt CO_2eq in 2021 for supply chain**
  - **Does it include full mining impact or only part of the supply chain?**

Data and Actions in France

- ***Commission de l'aménagement du territoire et du développement durable du Sénat***
  - ***rapport de la mission d'information sur l'empreinte environnementale du numérique, 2019***
  - **if nothing is done, by 2040 digital technology would be the source of 24 million tons of CO_2 equivalent, or about 7% of France's emissions, compared with 2% today.**

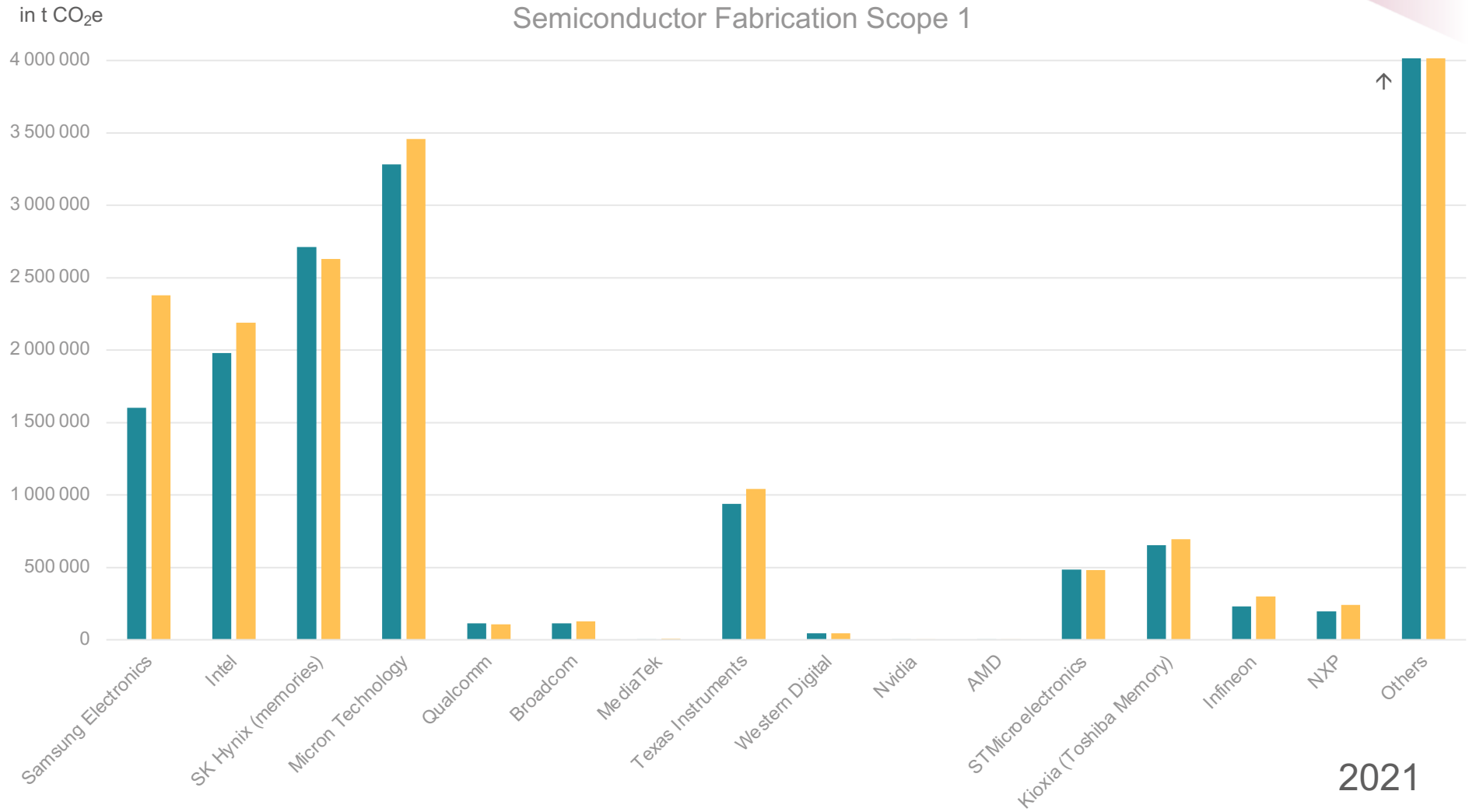
Semiconductor industry GHG accounting



2021

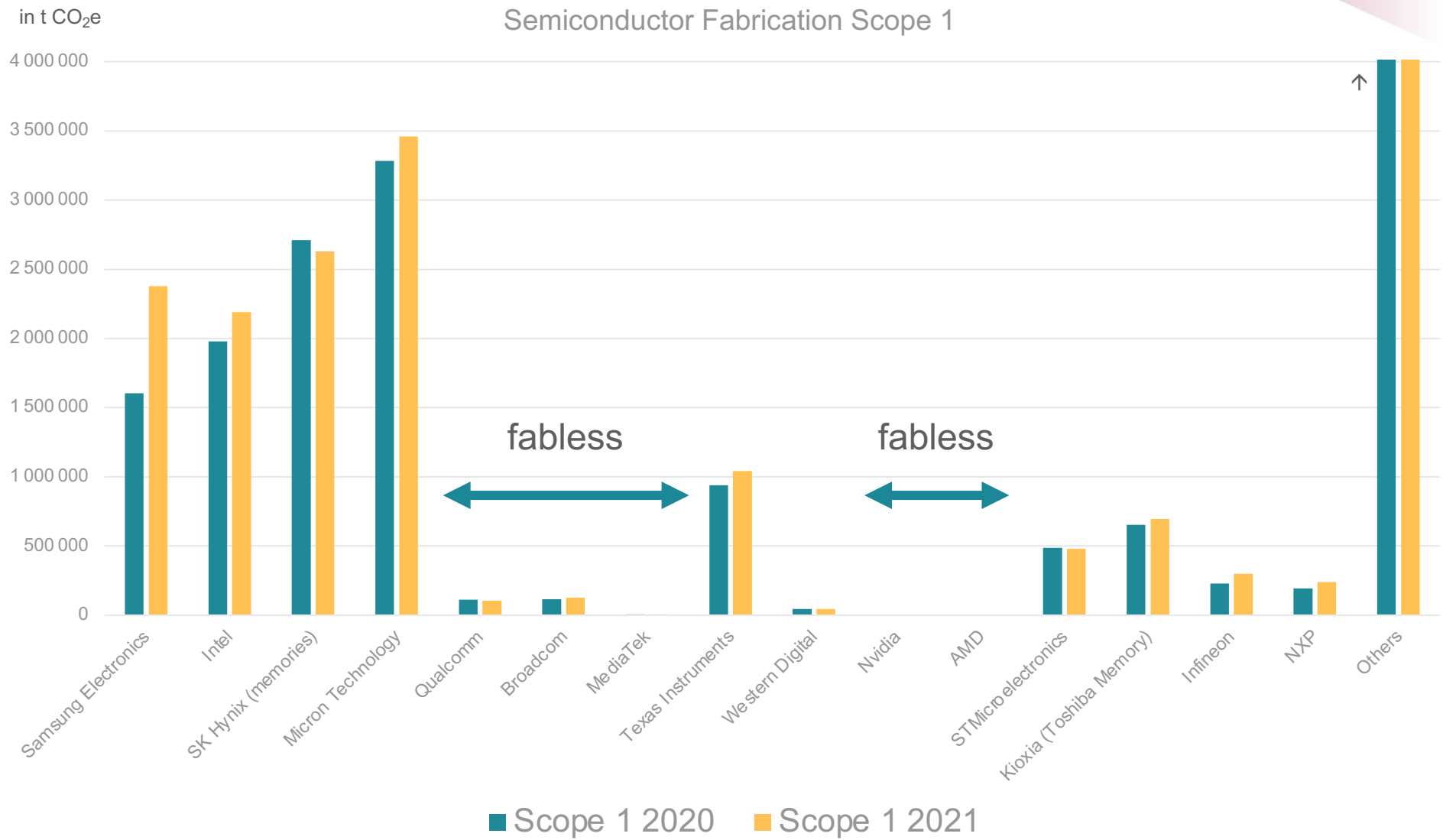
Sources: companies CSR
Others are extrapolated from total market size

Scope 1: direct impact

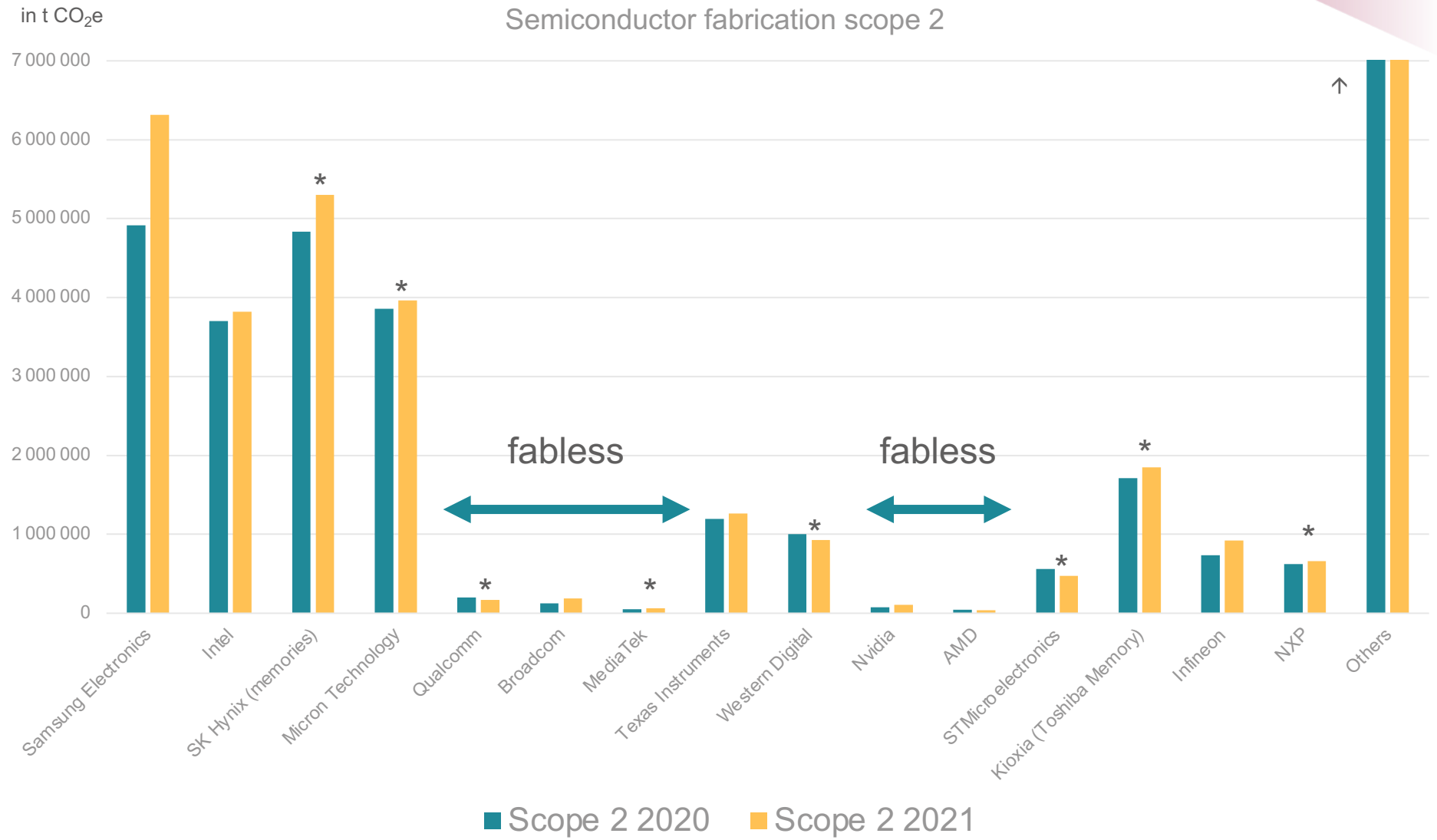


Sources: companies CSR
Samsung electronics GHG emissions are counted only for 31.3% (percentage of semiconductor in company revenues)
Others are extrapolated from market share

Scope 1: direct impact



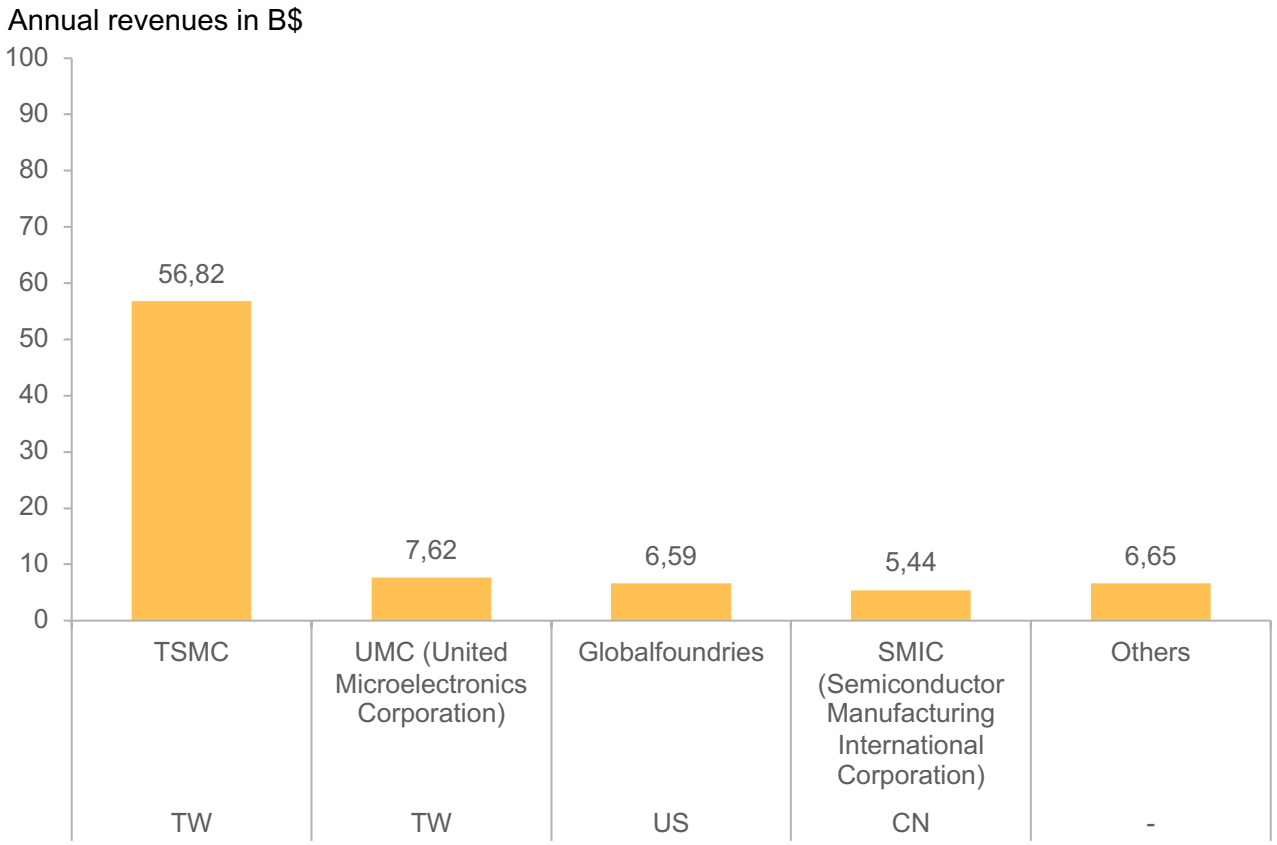
Scope 2: impact from energy



Sources: companies CSR

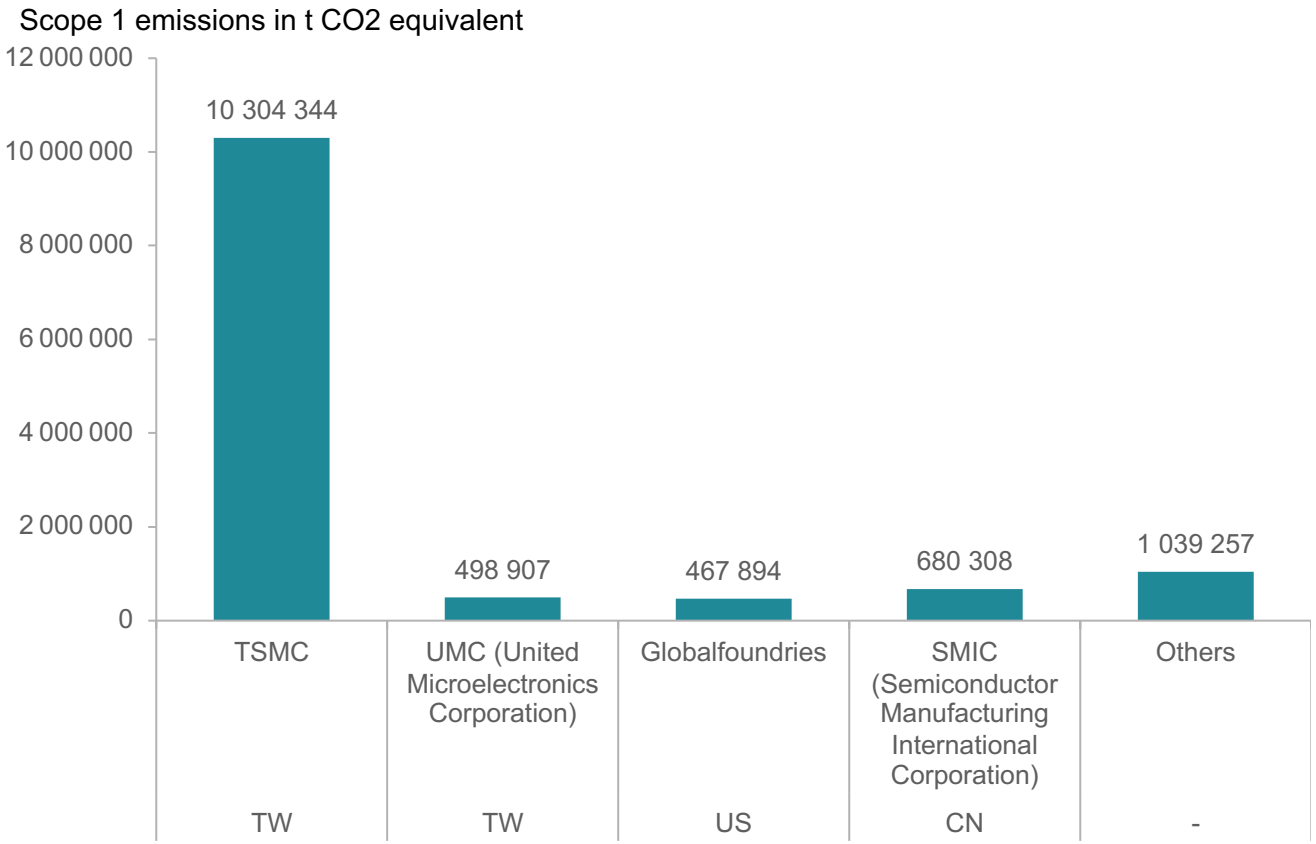
Location-based scope 2 if available, otherwise market-based or non-specified (marked with *)

Foundries carbon impact



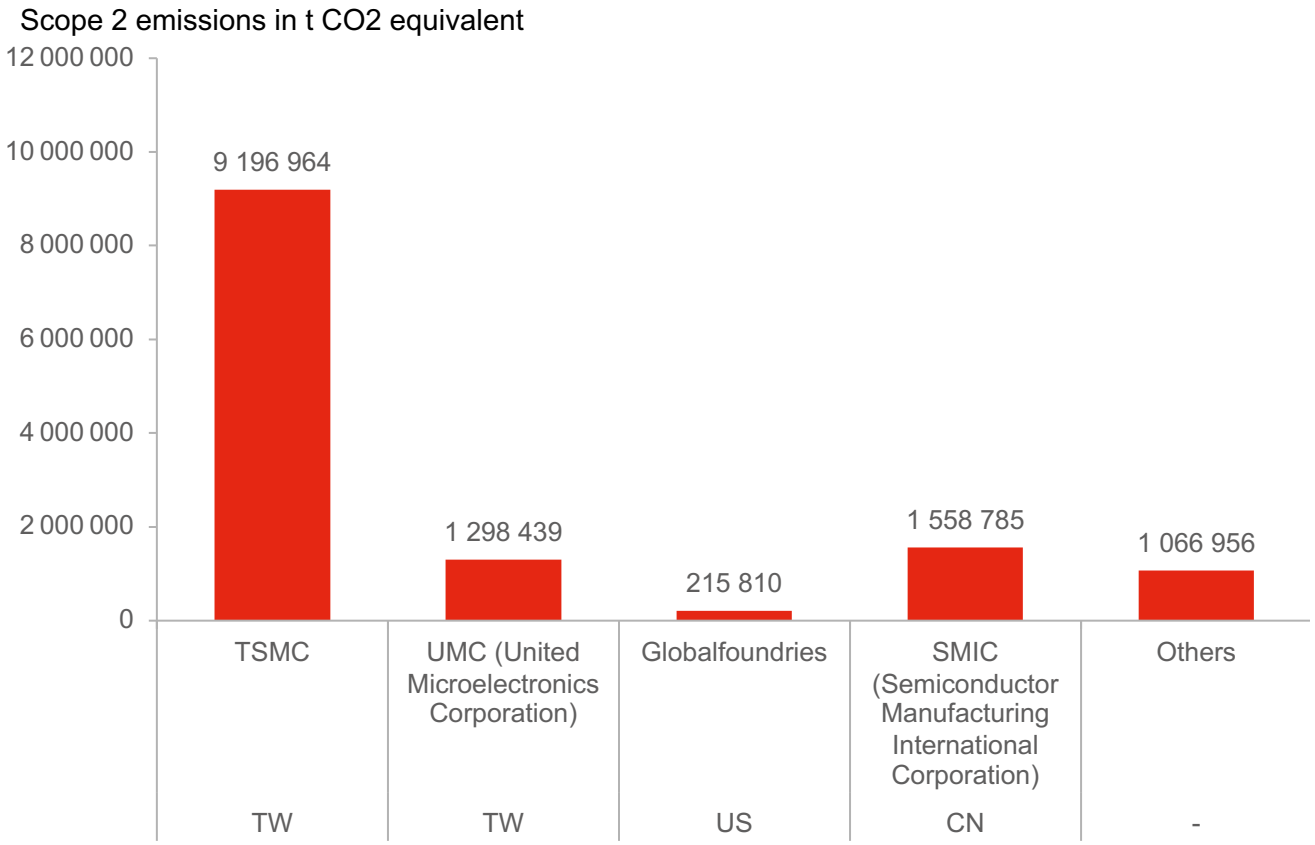
2021

Foundries scope 1



2021

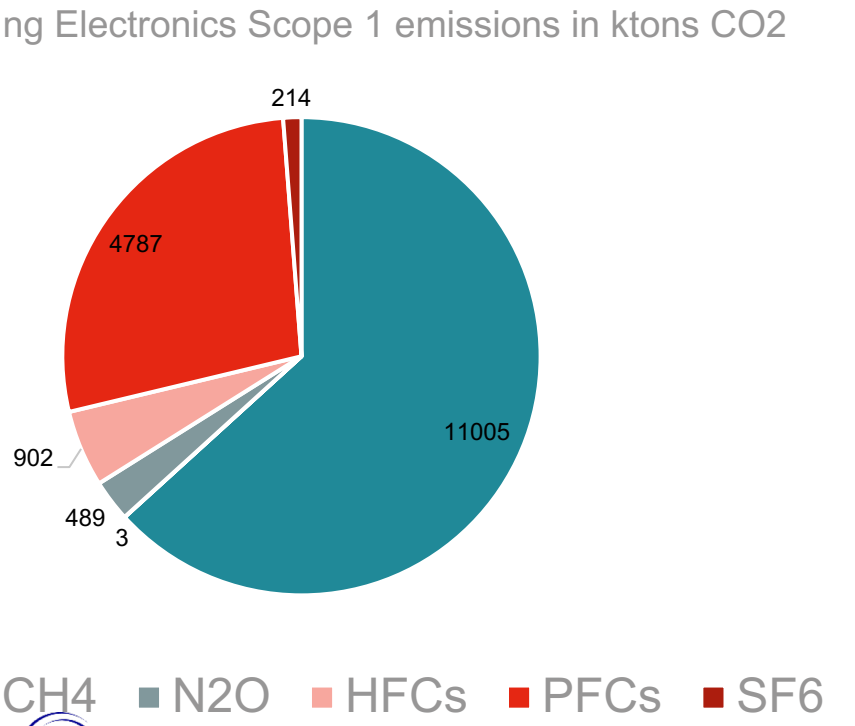
Foundries scope 2



2021

Some details on scope 1 emissions

- **Semiconductor industry heavily use F-Gases**
  - **HFC (hydrofluorocarbons): cooling**
  - **PFC (perfluorocarbons): etching and cleaning**
  - **SF6: 1kG = 22.8t CO_2eq**

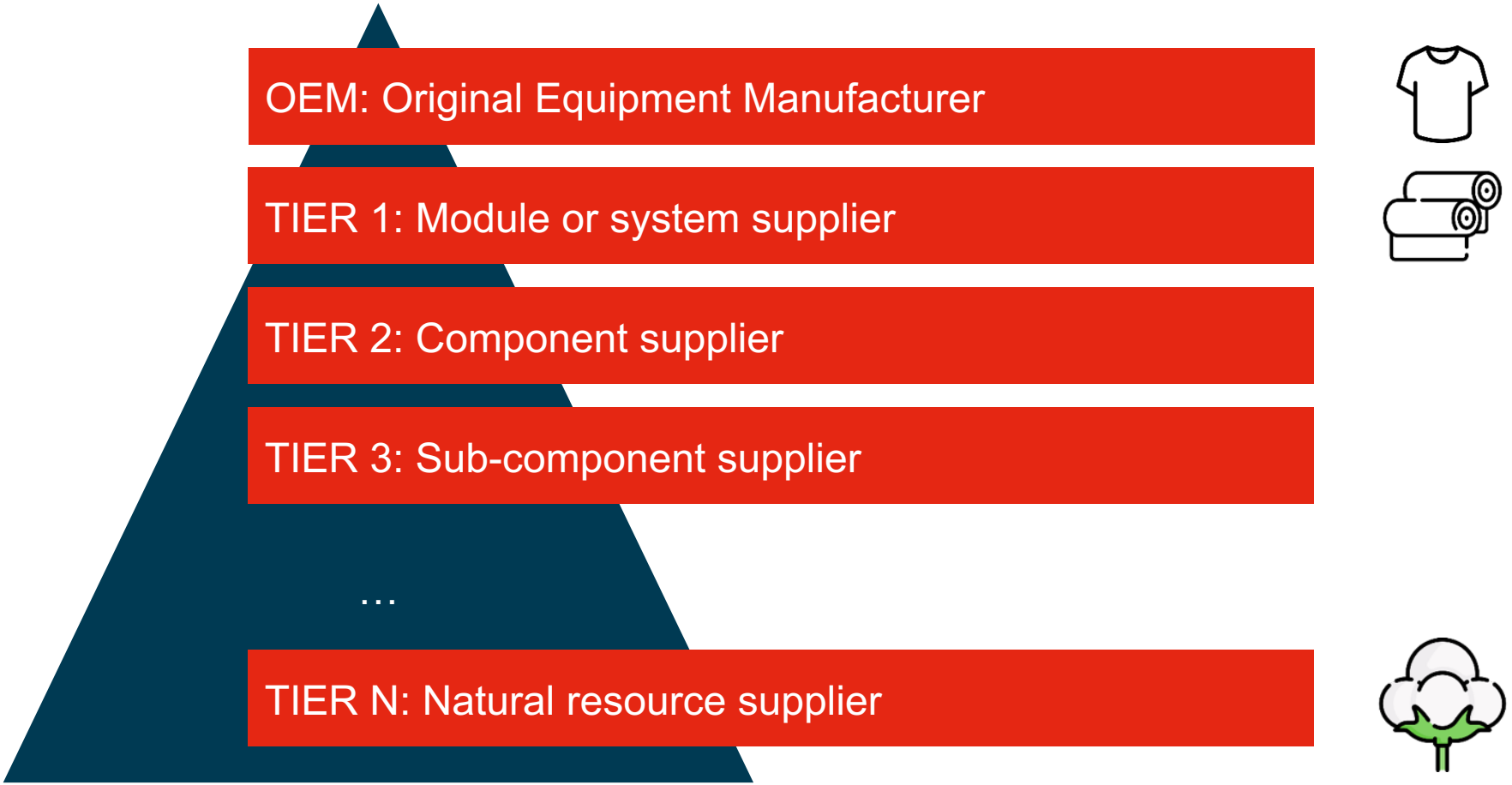


Semiconductor GHG accounting Limitations

- **Mixing location-based and market-based scope 2**
  - **Underestimating scope 2**
  - **When both numbers are available, market-based is lower by 7 to 75% (for Intel)**
- **Extrapolating to others**
  - **36% of revenues for semiconductor vendord**
  - **8% of revenues for foundries**
- **Missing scope 3**
  - **Upstream: mining**
  - **Downstream: usage and end-of-life**
- **Budget granularity is company per company**
  - **Retrieved from company estimations**

Supply chain (in general)

- **Industry employs a supply chain pyramid with Tiers**



Flaticons: Mehwish, Freepik

Types of ICs

- **Digital ICs**
  - **Processor SoC**
    - Large microprocessor or small microcontroller
    - Specialized processors (telecommunications, cameras, …)
  - **Memory (data storage): ROM, RAM**
- **Analog ICs – Systems-on-a-Chip**
  - **Amplifier, sensor**
  - **Power integrated circuit**
- **Mixed signals ICs – Systems-on-a-Chip**
  - **Radio Frequency SoC**
- **MEMS (Micro Electro Mechanical System) SoC**

Claims on sustainable electronics

- Researchers and teacher are key players to reach sustainable electronics
- To progress towards sustainability, we shall
  - Employ verified, scientific information
  - Go beyond extreme positions
  - Pinpoint the problems and the potential solutions
  - Incorporate engineering and social sciences
  - Pursue the goal with sincerity
  - Share information and question the method
- Open source hardware has a major role to play

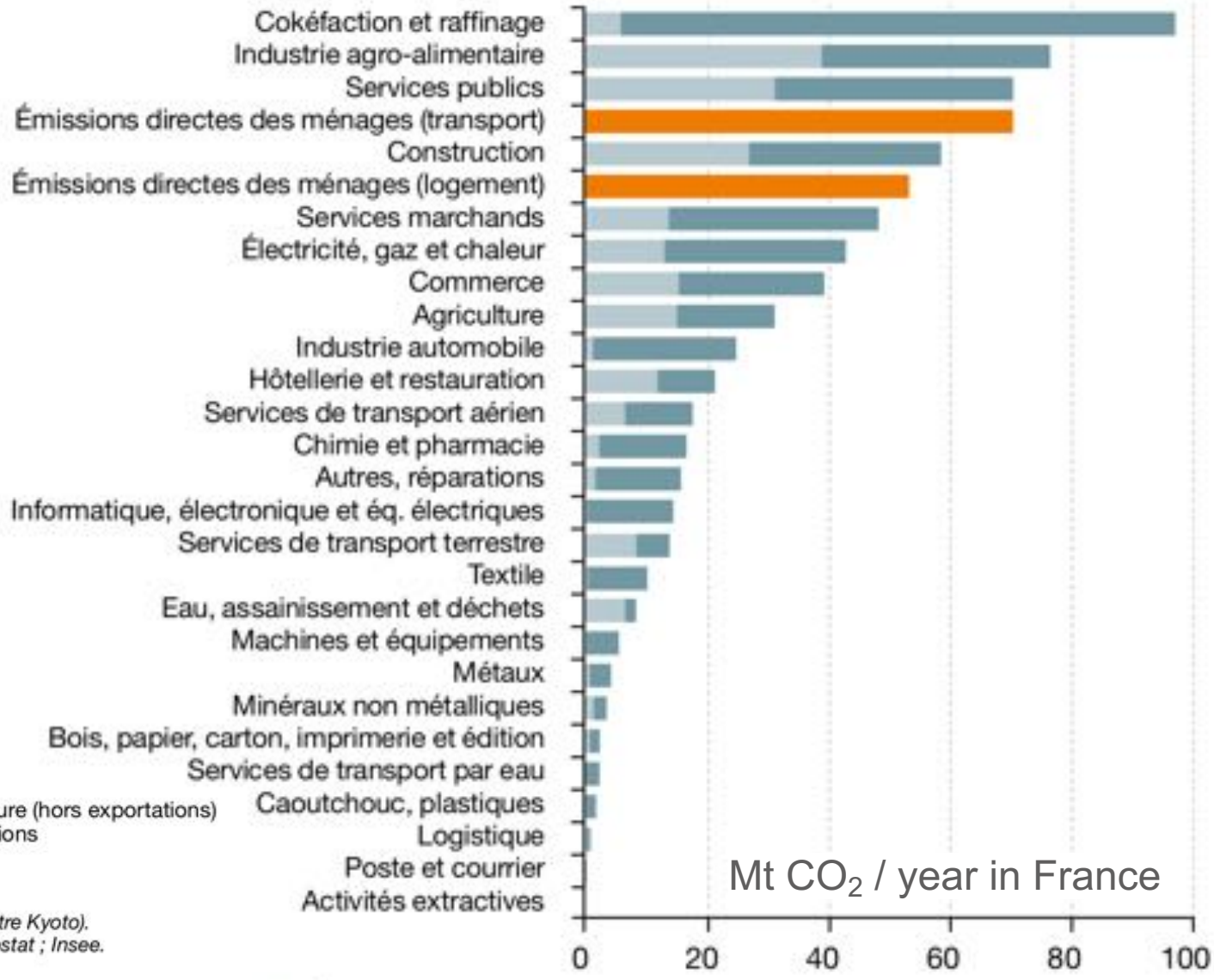
Electronics and Innovation

- **Electronics support most innovations in**
  - **Communication, Mobility, Health, Energy, Industry, Farming – Smart*, e-***
- **In particular, digital technologies help:**
  - **Improved social connectivity**
  - **Improved communication speeds**
  - **Enhanced learning opportunities**
  - **Improved versatile working**
  - **Automation of tasks**
  - **Information storage**
  - **Information editing**

The case of global warming

- **All human activities produce CO2**

Total: 749 Mt CO_2 in 2018

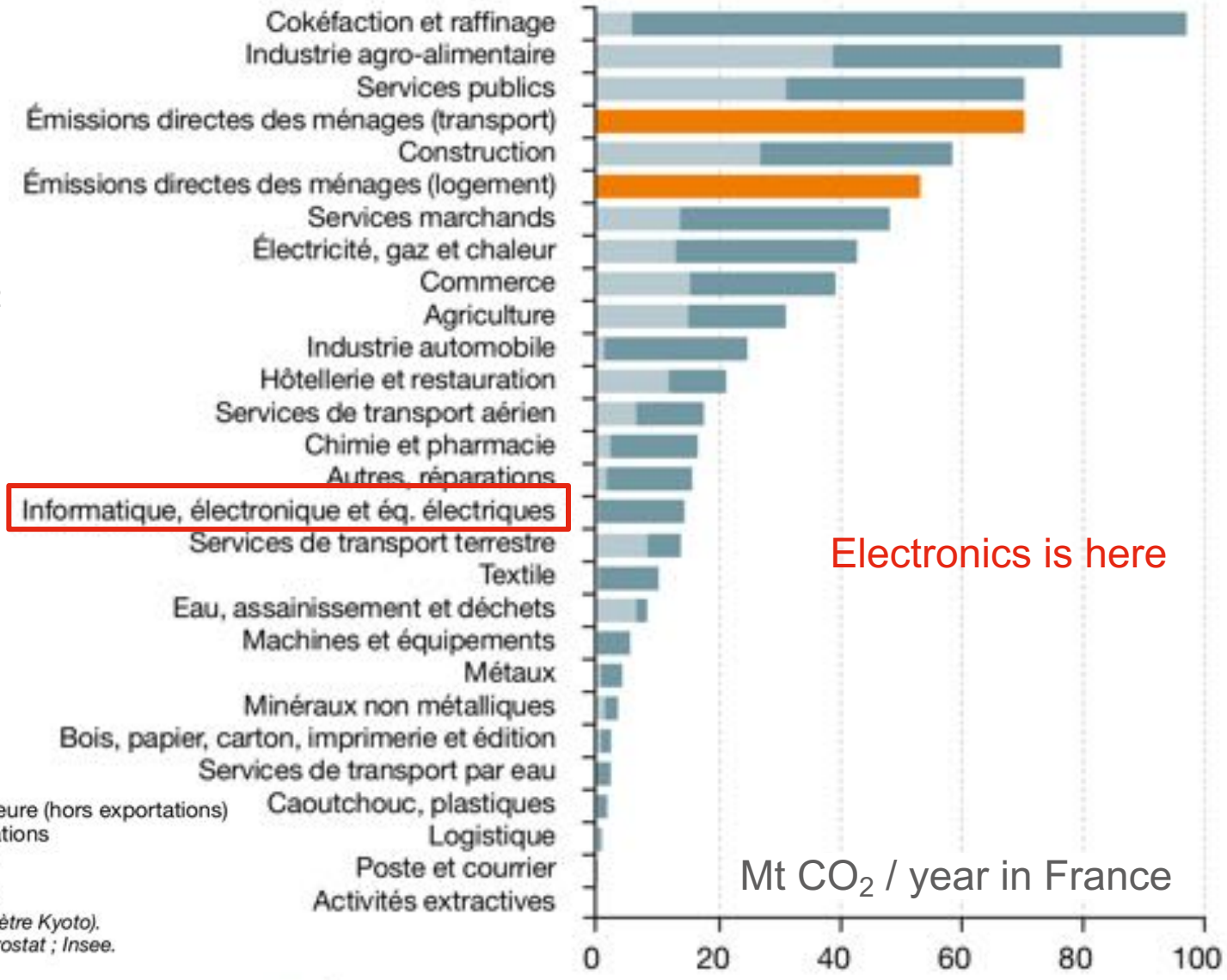


Note : GES pris en compte : CO_2, CH_4 et N_2O.
Champ : France métropolitaine + Drom (périmètre Kyoto).
***Sources :** Citepa ; AIE ; FAO ; Douanes ; Eurostat ; Insee.*
Traitements : SDES, 2019

The case of global warming

- **All human activities produce CO2**

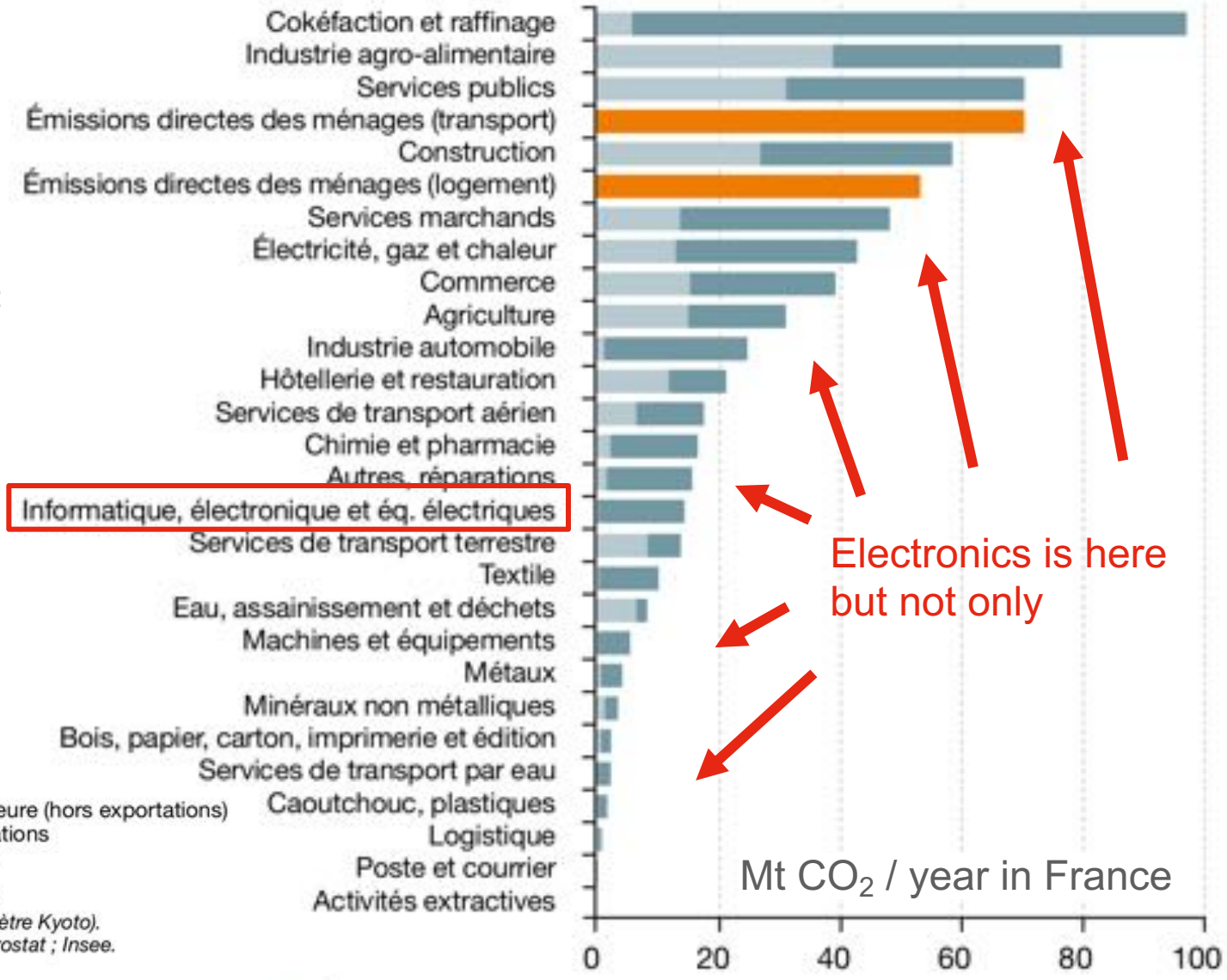
Total: 749 Mt CO_2 in 2018



The case of global warming

- **All human activities produce CO2**

Total: 749 Mt CO_2 in 2018



Note : GES pris en compte : CO_2, CH_4 et N_2O.
Champ : France métropolitaine + Drom (périmètre Kyoto).
***Sources :** Citepa ; AIE ; FAO ; Douanes ; Eurostat ; Insee.*
Traitements : SDES, 2019