Seminar IRIT-LAAS 2024

Environmental impact of wireless networks

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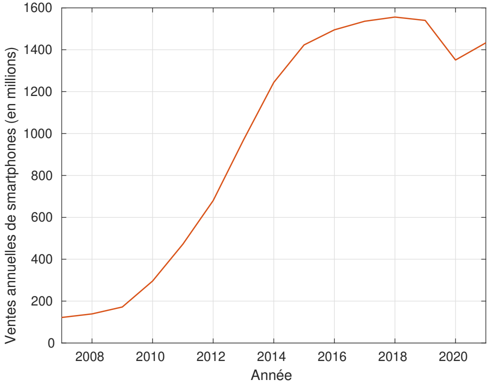
Section 1 : Some figures

Some data to start...

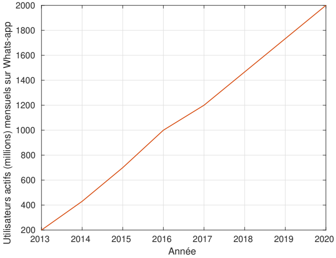
At worldwide: 67% of people get a mobile phone (+2% a year while +1.1% in population)

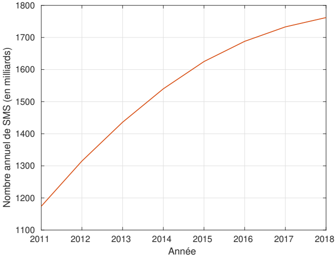


Sales of smartphones in millions a year

source : Statista2022 and WeAreSocial (Ericsson)

but traffic increase



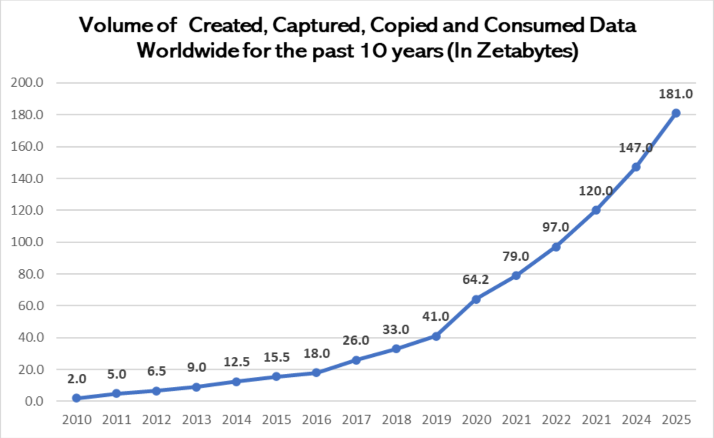


Left : Monthly active users in millions for Whatsapp
Right : Yearly SMS transmission in billion

Tools accumulation without replacement

source : Statista2022

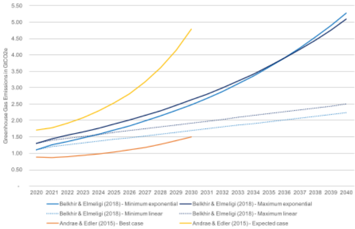
but data center increase

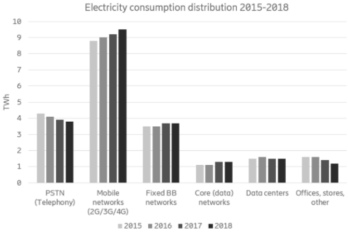


source : Statista2024

Energy consumption for ICT

- ICT corresponds roughly to 3,5 to 4% of total GHG emissions
- Trend on energy consumption: direct consumption increases, some devices slightly decrease (less TV or Desktop PC)



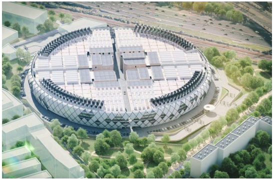


source : D. Lunden, "Electricity consumption and operational carbon emissions of European telecom network operators," Sustainability, Feb. 2022 ; A. Andrae and T. Elder, "On the global electricity usage of communication technology: trends to 2030," Challenges, June 2015

Section 2 : Materials

Dematerialization with ICT ?

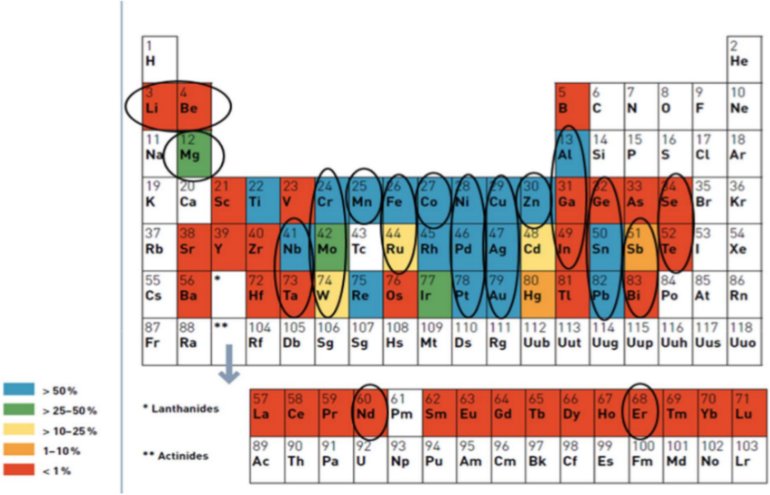
- ICT is not virtual
- since a lot of devices and so of materials !



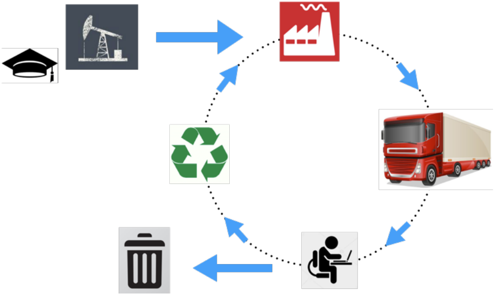
Figures on data center (2020)

- 400TWh ($\approx$ French nuclear plants or 2% of worldwide electricity production)
- Issue : cooling
  - solution by free cooling with **water**: less energy but biodiversity issue and use conflict
  - Power Usage Effectiveness (PUE) close to 1.1 now

Materials and mining



Life Cycle Assessment (LCA)



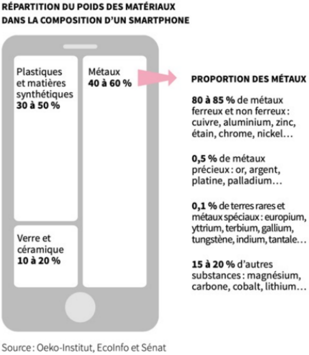
→ Mining → manufacturing → transportation-distribution

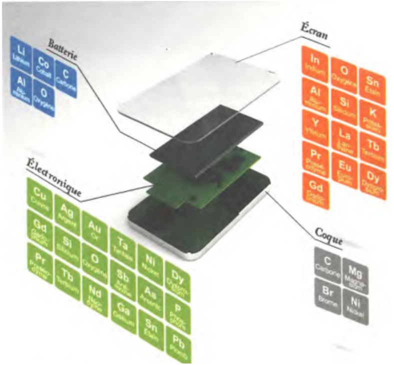
→ Use

→ End of life

Use not necessary the biggest part!
depends on the considered system

Example 1: a device (mobile phone)





source : G. Pitron (right)

- $70 kgCO_2e$ for a smartphone
- $10 kgCO_2e$ for a dumbphone

Example 2: a device (laptop)

MacBook 2019: 16 inches, storage 521 Go, frequency 2,6 GHz

- Use phase during 4 years
- Carbon footprint 394kgCO_2e
  - mining/manufacturing: 75%
  - transportation: 5%
  - use: 19%
  - end of life: 1%

Keep this laptop **4 times longer**
s.t use phase = manufacturing phase

Example 3: an application (email)

Hard to estimate *precisely* the carbon footprint for an email

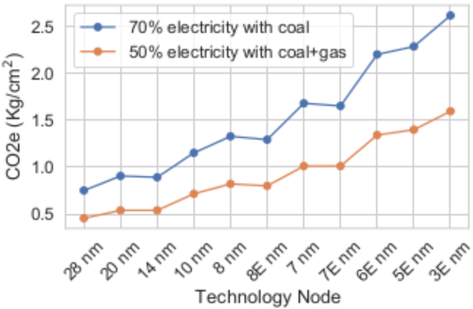
- 6mgCO_2e for 1MB email [Aslan2018]
- 2mgCO_2e for 1MB email on Renater [Ficher2021]
  but without storage and LCA

- with storage and LCA: 20gCO_2e for 1MB email [Ademe2011]

Manufacturing energy consumption

Be careful: new manufacturing process can be less efficient!

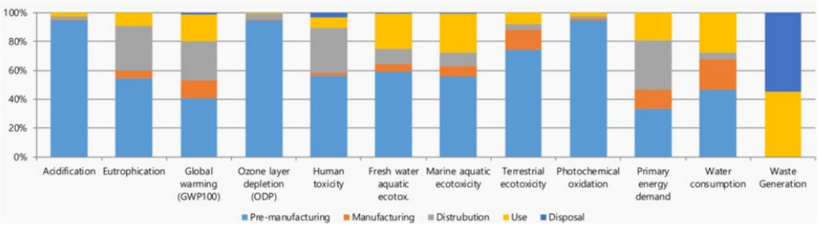
Example: **miniaturization** leads to speeder circuits for the same surface (and so the same thermal dissipation) but more complex industrial processing



source : S. Tamu and P. Nair, "The dirty secret of SSD: embodied carbon", preprint Arxiv, Jul. 2022

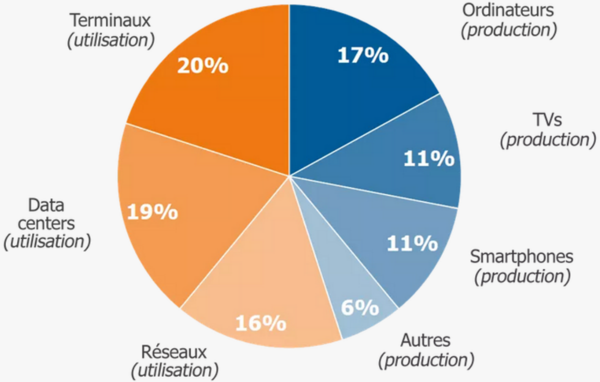
Global environmental cost

There is not only carbon footprint!



source : Life Cycle Assessment for Mobile Products, Samsung, 2018

ICT energy consumption chart



Distribution de la consommation énergétique du numérique par poste pour la production (45 %) et l'utilisation (55 %) en 2017

[Source : Lean ICT, *The Shift Project* 2018]

Section 3 : Application to wireless networks

Future wireless networks

A new generation each 10 years

- 2G: first digital generation: design for voice
- 3G: data (mobile Internet on the street: what an idea?)
- 4G: high data rate (touch screen saves the idea)
- 5G:
  - Very high data rate (eMMB) : cellular network
  - Low Latency and high reliability (URLLC) : automation
  - Massive connectivity (mMTC) : Internet of Things (IoT)
- 6G: under progress

Solutions "for" or "by" these networks

- Solution 1: *GreenIT*

$$\textbf{Energy efficiency} = \frac{\textbf{performance metric}}{\textbf{consumed energy}}$$

  - Relative goal (less GHG per unit)
  - Rebound effect (number of units increases)
  - This technical answer may be not enough to fix the problem
- Solution 2: *IT for Green*
  - Deported goal (less GHG but elsewhere)
  - Enablement effect with deportation of energy efficiency
  - This technical answer may be not enough to fix the problem
- Solution 3: Sufficiency
  - Consumed energy/power is pre-fixed
  - Avoid rebound effect, ensure enablement effect
  - but use limits to be defined. By whom?

Efficiency = Optimization ; Sufficiency = Way of Life

Rebound effect or Jevons' paradox

- when a technology efficiency improves
- use phase increases

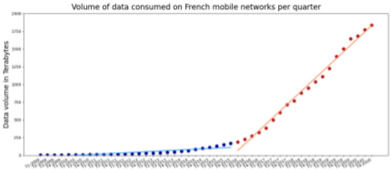
and finally global energy consumption increases as well

Rebound effect characterization [Combaz-Coupechoux2022]

Scope	Effect	5G Examples
First order	Embodied footprint	Production of 5G equipments and devices
	Operational footprint	Operation of networks, devices, data centers
	Disposal footprint	Equipments and devices end-of-life
Second order	Induction	5G motivates the sale of VR headsets
	Optimization	More efficient data transfer
	Substitution	Visio-conferencing replaces meetings
	Direct rebound	More mobile data are consumed
Third order	Indirect rebound	Footprint during time saved in data transfer
	Economy-wide rebound	Structural changes in production patterns and consumption habits
	Systemic transformation	5G modifies the way people are working and living

Examples from ICT

- Improvement of machine learning algorithms
  - Increase of apps using them
  - Increase of computed data
- Improvement of electronic devices and batteries
  - Increase of use for mobile phones
  - but phone autonomy keeps the same
- Improvement of mobile networks
  - Increase of data exchange



source : P. Ciblat, J. Combaz, M. Coupechoux, K. Marquet, and A.-C. Orgerie, "Environmental impacts of 5G (part 1)", 1024 newsletter, April 2024

Enablement effect

Thanks to ICT, other domains decrease (strongly) their energy consumption

Some figures: 1gCO_2e consumed in ICT avoids 10gCO_2e elsewhere [GSMA2019] ; fanciful figure [Roussilhe2021]

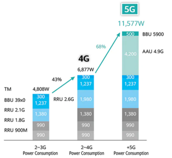
- self-driving cars but public transportation more efficient
- logistics (vehicle management in Livorno harbor with 250km container ship distance gain)
- smart farming (salmon farming in Norway required 5G even 6G)
- remote working

→ Problem with unsafe results except for limited areas

→ Topic with high imagination: praise of the promise

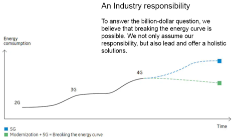
Some real figures

Basestation or network on use phase

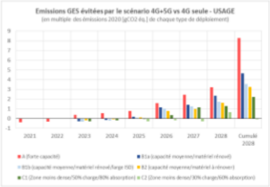


Typical maximum power consumption of a single 5G base station

Source: Huawei



Source: Ericsson

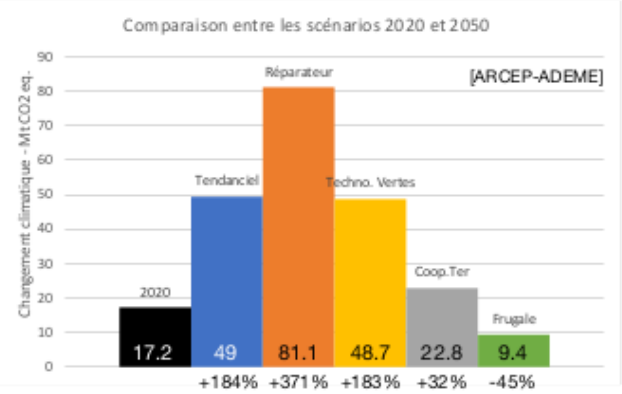


Network decommissioning with frequency re-use

source : Huawei, Ericsson, Arcep

Some perspectives

Scenarios ARCEP



State of the art on energy consumption

Until 5G, it was not a crucial topic

- Energy consumption
  - Issue for health
  - Issue for battery autonomy
- Mining resource: nothing to report

Example:

- Books did not provide global figures

  P. Nicopolitidis et al., "Wireless Networks", 2003
  N. Tripathi, J. Reed, "Cellular Networks", 2014

- Same thing in Wikipedia (except for 5G)
- Some figures on applications

  A. Shehabi, "Energy and Greenhouse gas implications of internet video streaming in the US", 2014
  M. Deltour et al. "Carbon footprint: streaming vs DVD", Telecom internship, 2020

Since 2020, exponential growth for this kind of analysis

Types of energy

- P_{tx}: transmission energy (so far, the only one considered)
- $P_{\mathrm{processing}}$: processing energy (decoding, sync, $\cdots$)
- $P_{\mathrm{circuitry}}$: circuitry energy (power amplifier, ADC/DAC)
- $P_{\mathrm{manufacturing}}$: manufacturing energy (related to LCA)

Efficiency for P_{tx}

$$E_{\mathrm{tx,file}} = \frac{LP_{\mathrm{tx}}}{n_{\mathrm{tx}}B\log_2\left(1+\gamma\frac{P_{\mathrm{tx}}}{n_{\mathrm{tx}}BN_0}\right)}$$

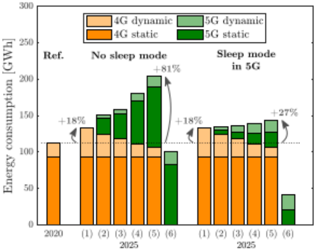
- Efficiency in transmit energy E_{tx}: yes
  - Bandwidth and carrier frequency (B)
  - Multiple antennas (MIMO) (n_{tx})
    - $\hookrightarrow$ Multiplexing, Beamforming, Relaying (*RIS*)
  - Interference management (γ)
    - $\hookrightarrow$ Intra-user (OFDM), Inter-user (xDMA/NOMA)
- Efficiency in consumed energy per device: ?
- Efficiency in consumed energy for manufacturing: ?

Other ideas for 6G <u>but</u> only in efficiency or decarbonization

- Distributed storage to limit core network access
- Harvested (solar/wind) energy

Example 1: macroscopic analysis

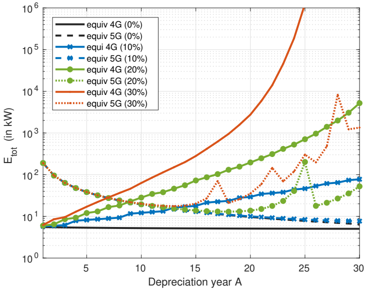
- 4G model: $P = P_0 + \alpha R$
- 5G model: $P_{5g} = \beta P (B_{5g}/B)^{0.95} (S_{5g}/S)^{0.1}$ with S flows
- Traffic (sleeping mode)



source : L. Golard et al., "Evaluation and projection of 4G and 5G RAN energy footprints : the case of Belgium for 2022-2025," Annals of Telecoms, 2024

Example 2: microscopic analysis

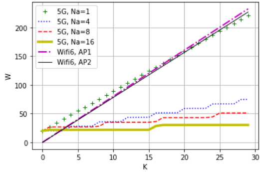
- 4G model: 4 antennas, already 10 depreciation years
- 5G model: 100 antennas
- Manufacturing taken into account (especially antennas cost)



source : P. Ciblat, "A propos du MIMO massif dans un contexte de sobriété numérique," Gretsi, 2022

Example 3: xG vs. Wifi

- Use phase ($E_{\text{tx}} + E_{\text{processing}} + E_{\text{circuitry}}$)
- Teleworking case (one user per Access Point in Wifi)



Extension to distributed Wifi as cellular network not easy

- No handover in Wifi
- Security level not the same
- Coverage guarantee not the same
- Provider not the same

source : M. Hentati, T. Chahed, P. Ciblat, M. Coupechoux, and S. Najeh : "5G vs Wifi6 downlink power consumption comparison for teleworking use case", IEEE International Conference on Communications and Networking, Nov. 2023

Future 1: 6G

Honestly, no learning about 5G controversy to design 6G. the show must go on.

Examples:

- Zeppelin with solar panels to replace basestations on ground. Energy cost in that paper: 0.
- Reflecting Intelligent Surfaces (RIS), so adaptive electro-magnetic mirror. Energy cost in that paper: 0.

sources : D. Renga and M. Meo, "Can High Altitude Platforms make 6G sustainable," IEEE Com Mag, Sep 2022 ; M. Di Renzo, "Smart Radio Environnment empowered by RIS: state of the art and the road ahead, Jnl of Sel. Areas in Coms, Nov. 2020

6G: for which applications?

Reminder:

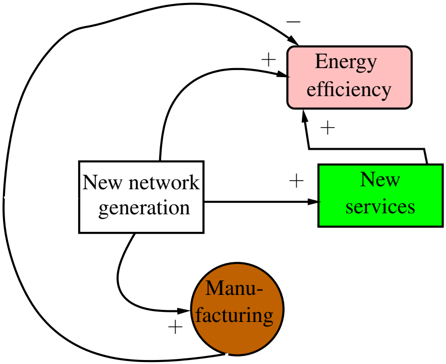
- Bibop launching (1993): P. Meyer, "imaginez-vous au restaurant ou dans la rue, environné d'écervelés qui se font appeler? En 2000, un million d'appareils à striduler n'importe quand, n'importe où et pour n'importe quoi"
- First works on 3G (1991): data transmission while fixed Internet only for researchers
- First works on 4G (2001): touch screen does not work well

Advocated applications:

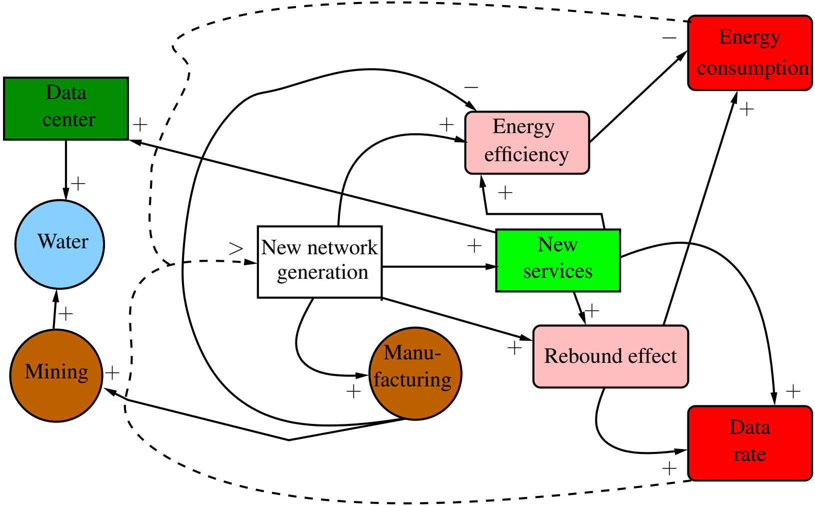
- 3G: videophone, video streaming (advertising, news, $\cdots$), online shopping, mms, video meeting, $\cdots$
- 4G: virtual meeting, informed shopping (via localization), $\cdots$
- 5G: Smart farming, Autonomous car, $\cdots$
- 6G: ?

Usually, ultra-light business map

Systemic chart for 6G

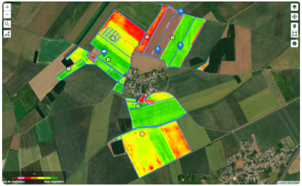


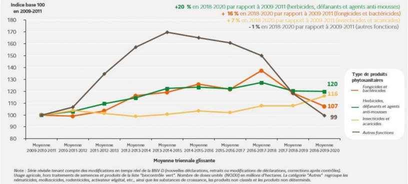
Systemic chart for 6G



Future 2: smart farming

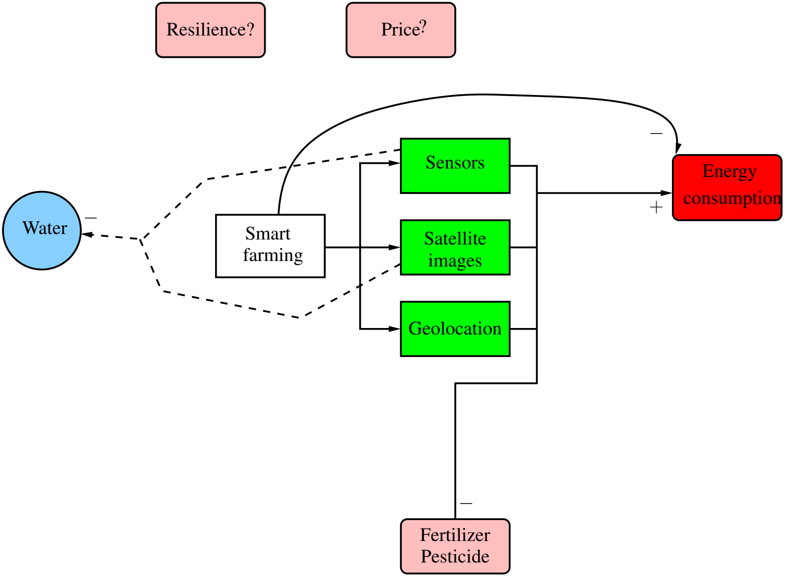
- Sensing, monitoring (communication & control)
  - ↪ geolocation, satellite image, local sensors, data network, computation for decision-making → large techno-structure
- Goals
  - ↪ First, increase of yields
  - ↪ Second, fertilizer/water decrease <u>but</u> failure of Ecophyto plan





source: https://blog.spotifarm.fr ; http://www.ofb.gouv.fr ; J. Oui, "Produire une faute -conforme-. Outils numériques et normes environnementales en agriculture", Sociologies Pratiques, 2024

Systemic chart for smart farming



Systemic chart for smart farming