The controversial role of technological innovation
Who am I?

Computer scientist
Research topic: environmental impact of ICT (Information and Communications Technology)

LIMSI (CNRS) / LISN (CNRS, Université Paris Saclay)

+ EcoInfo

ENSIIE
How does technological innovation, focusing on ICT, influence climate change?

⇒ carbon footprint of ICT, expressed in Global Warming Potential (GWP) or Greenhouse Gases (GHG) emissions
ICT is non physical, right?
It avoids the use of paper, ink, planes...
User devices...

source: ADEME
Data centers and servers
Network infrastructure...
ICT, a non-polluting industry?

environmental footprint largely under-estimated by its users:

- "invisibility" of infrastructures
- cloud services
- miniaturization of devices
So let’s minimize our consumption of energy?
Lifecyle of ICT

- Raw material extraction
- Manufacturing
- Transport
- Use
- Value and material recovery
- End of life

Anne-Laure Ligozat

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Lifecyle of ICT

- **Raw material extraction**
- **Manufacturing**
- **Transport**
- **Use**
- **Value and material recovery**
- **End of life**

The controversial role of technological innovation
Production phase

Smartphone:
> 90% of its carbon footprint during production

(in France, excluding network usage)

GWP of each lifecycle phase for a smartphone with a global electricity mix [Ercan et al., 2016]
Production phase

Elements of a Smartphone

**Screen**
- Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.
- The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina ($\text{Al}_2\text{O}_3$) and silica ($\text{SiO}_2$). This glass also contains potassium ions, which help to strengthen it.
- A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

**Electronics**
- Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.
- Nickel is used in the microphone and as a glass for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.
- Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.
- Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

**Battery**
- The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese in place of cobalt. The battery’s casing is made of aluminium.

**Casing**
- Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.
Production phase

Material evolution

Elements widely used in energy pathways

Materials critical to the energy industry, Achzet et al., 2011
Production phase

1. **Design**, often in the United States.

2. **Extraction** and **processing** of raw material in Southeast Asia, Australia, Central Africa and South America.

3. **Manufacturing** of the main components in Asia, the United States and Europe.

4. **Assembly** in Southeast Asia.

**Distribution** to the rest of the world, often by plane.

*source: ADEME and France Nature Environnement*
End of life phase

E-waste growth

source: E-waste monitor 2020
End of life phase
Recycling

Figure 16.1: End-of-life recycling input rates (EOL-RIR) in the EU-28[170,171].

End-of-life recycling input rate (EOL-RIR) [%]

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<th>B</th>
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<td>&gt; 50%</td>
<td>&gt; 25-50%</td>
<td>&gt; 10-25%</td>
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<tr>
<th>Element</th>
<th>Al</th>
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<th>S</th>
<th>Cl</th>
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<td></td>
<td>12%</td>
<td>0%</td>
<td>17%</td>
<td>5%</td>
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| Element | K* | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
|---------|----|----|----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|    |
|         | 0% | 0% | 0% | 19%| 44%| 21%| 12%| 31%| 35%| 34%| 17%| 31%| 0% | 0% | 0% | 0% | 0% |    |

| Element | Rb | Sr | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
|---------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|    |
|         |    |    | 31%| 0% | 30%| 9% | 9% | 9% | 9% | 55%|     |    |    |    |    |    |    |

| Element | Cs | Ba | La | Lu* | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
|---------|----|----|----|------|----|----|---|----|----|----|----|----|----|----|----|----|----|----|    |
|         | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% |    |

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<th>Sg</th>
<th>Bh</th>
<th>Hs</th>
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<th>Ds</th>
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<th>Fl</th>
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1 Group of Lanthanide: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
2 Group of Actinide: Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr

* Aggregates: Baryte 7%, Barite 50%, Coating Clay 0%, Diorite 0%, Feldspar 10%, Gypsum 1%, Kaolin 0%, Limestone 53%, Magnesite 2%, Natural Cork 0%, Natural Graphite 3%, Natural Rubber 1%, Natural Topaz 90%, Perlite 42%, Soapstone 15%, Silica Sand 0%, Talc 5%

source: [European Commission, Joint Research Centre, 2018]
E-waste health and environmental impact

source: E-waste monitor 2020
Environmental impact of ICT lifecycle

- Global Warming Potential
- Abiotic resource depletion
- Blue water shortage
- Human toxicity
- ...
ICT \approx 4\% \text{ of global GHG}\\
with an 8\% annual growth!
GHG emissions
Digital share and trajectories compatible with a 2 degrees scenario

Figure 3: Evolution 2013-2035 of the share of digital technology in GHG emissions. The share of digital technology in GHG emissions. (Source: Lean ICT Materials Forecast Model. Produced by The Shift Project from data published by (Andrae & Eller, 2015))

Figure 4: Emission trajectories compatible with a temperature increase limited to 2°C. (Source: The Shift Project, 2016)

Source: The Shift Project, 2018
But doesn’t ICT help reduce GHG emissions?
### Types of ICT effects

<table>
<thead>
<tr>
<th>type</th>
<th>perimeter</th>
<th>negative effects</th>
<th>positive effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 direct effects</strong></td>
<td>technology</td>
<td>life cycle of ICT</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>2 enabling effects</strong></td>
<td>application</td>
<td>induction</td>
<td>substitution</td>
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<td></td>
<td></td>
<td>obsolescence</td>
<td>optimization</td>
</tr>
<tr>
<td><strong>3 systemic effects</strong></td>
<td>economy &amp; society</td>
<td>rebound effects</td>
<td>sustainable production and consumption</td>
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Based on [Hilty, 2008, Hilty and Aebischer, 2014]
1st order effects

Autonomous vehicles

cameras, sensors, embedded systems, network infrastructures (5G)...

production

use

on-board and remote data processing

from Jacques Combaz and [Taiebat et al., 2019]
2nd order effects

Autonomous vehicles

- eco-driving
- accidents

- car sharing
- traffic congestion
- optimization of use of road infrastructure

+ increased speed on highways
+ auto-parking
+ empty trips

optimization of fuel consumption

production
use

environmental impacts

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3rd order effects

Autonomous vehicles

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The rebound effect
Or why ICT emissions (and others) keep growing nonetheless...

technological progress

norms

taxes

optimization sobriety

incentives

resources, pollution...
The rebound effect
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The rebound effect
Or why ICT emissions (and others) keep growing nonetheless...

- technological progress
- norms
- taxes
- optimization sobriety
- direct or indirect effect
- incentives
- psychological effects
- unsaturated resource
- resources, pollution...
The rebound effect
Or why ICT emissions (and others) keep growing nonetheless...

\[ \varepsilon = \frac{\text{rebound effect}}{\text{technical progress}} < 1 \]

- technological progress
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- optimization sobriety
- direct or indirect effect

resources, pollution...

- psychological effects
- unsaturated resource
The rebound effect
Or why ICT emissions (and others) keep growing nonetheless...

\[ \varepsilon = \frac{\text{resources, pollution}}{\text{technological progress}} < 1 \]
Jevons’s paradox
Another example: Blablacar

Main motivations:
- savings 69%
- socialization 87%

(source: Ademe, 2015)
OK... So what about paper vs screen reading?
Je suis écolo, aucun arbre n’a été abattu pour faire mon livre!

Moi aussi, le mien ne contient aucun matériau polluant!

Emma.
Example: book vs e-reader

≈ 1 to 3 kgCO₂e

≈ 40 to 170 kgCO₂e

⇒ 3 to 35 books each year to make the e-reader more environmental friendly than books (with a 5 year lifetime for the e-reader)

sources: Base carbone Ademe and [Wells et al., 2012]
So back to an Amish lifestyle right?
Key notion with ICT

= Sobriety
Why is digital sobriety difficult to promote?

- requires systemic changes
- linked to political visions of the future, and in particular the notion of progress
Do we have a choice?
Limits to growth

Technological
Limits to gains in efficiency e.g. Moore’s law or Koomey’s law

Figure 1: Peak output energy efficiency of computing, historical and projected

[Koomey and Naffziger, 2016]
Do we have a choice?

Limits to growth

Environmental

- resource (material and energy) depletion
- climate change...

source: [Blengini et al., 2020]
How to implement sobriety?
The Shift Project’s recommendations for companies, organizations and governments

1. Adopt digital sobriety as a principle of action
2. Inform and spread awareness
3. Mobilize the lever of public purchasing
4. Allow companies and organizations to manage the environmental dimension of their digital transition
5. Carry out a carbon balance of digital projects to facilitate their prioritization
6. Improve consideration of the systemic dimensions of digital technology
7. Work at the European scale and with international organizations
How to implement sobriety?
As an individual

- acquisition
  - second-hand acquisition
  - use responsible criteria: repairability, recycling potential, energy use, local...
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- use less
  - material: buy less often, make equipments last longer, use responsible software...
  - energy: turn off equipments, use energy-saving modes...
  - data storage and transfer
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  - data storage and transfer

- end of life
  - donate equipment still in good condition, have it recycled by approved organizations
References I


