Insight about magnetron sputtering using Life Cycle Assessment (LCA)

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PEPs CHEMICAL ENGINEERING

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Presentation structure

- Introduction
- LCA methodology
- Magnetron Sputtering and LCA
- Considerations on metal consumption
- Considerations on energy consumption
- Possible improvements
- Conclusions and perspectives

Introduction

- Thin films are becoming more prevalent than ever

… and there is a need for environmental accountability!

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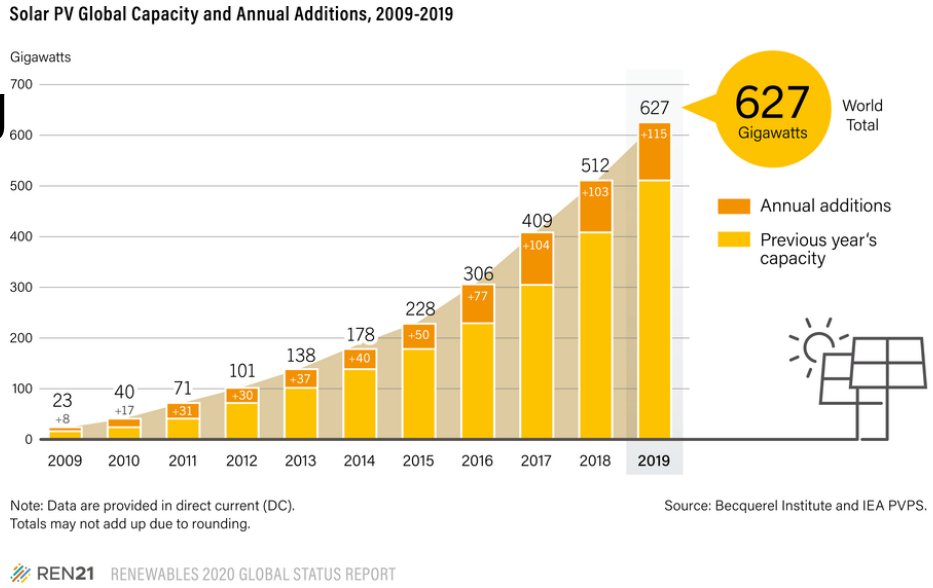


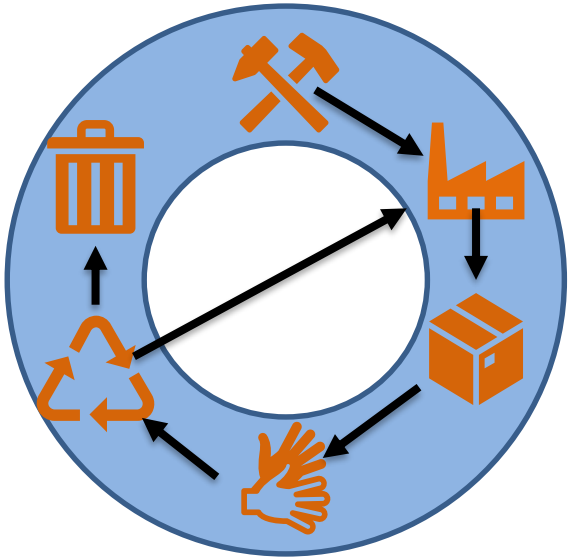
- ➔ Applying assessment techniques to deposition processes

- Life cycle assessment (LCA) on magnetron sputtering

[1] Reve news : *https://www.evwind.es/2020/07/05/in-2019-the-solar-pv-market-increased-an-estimated-12-to-around-115-gw/75561*

Life Cycle Assessment

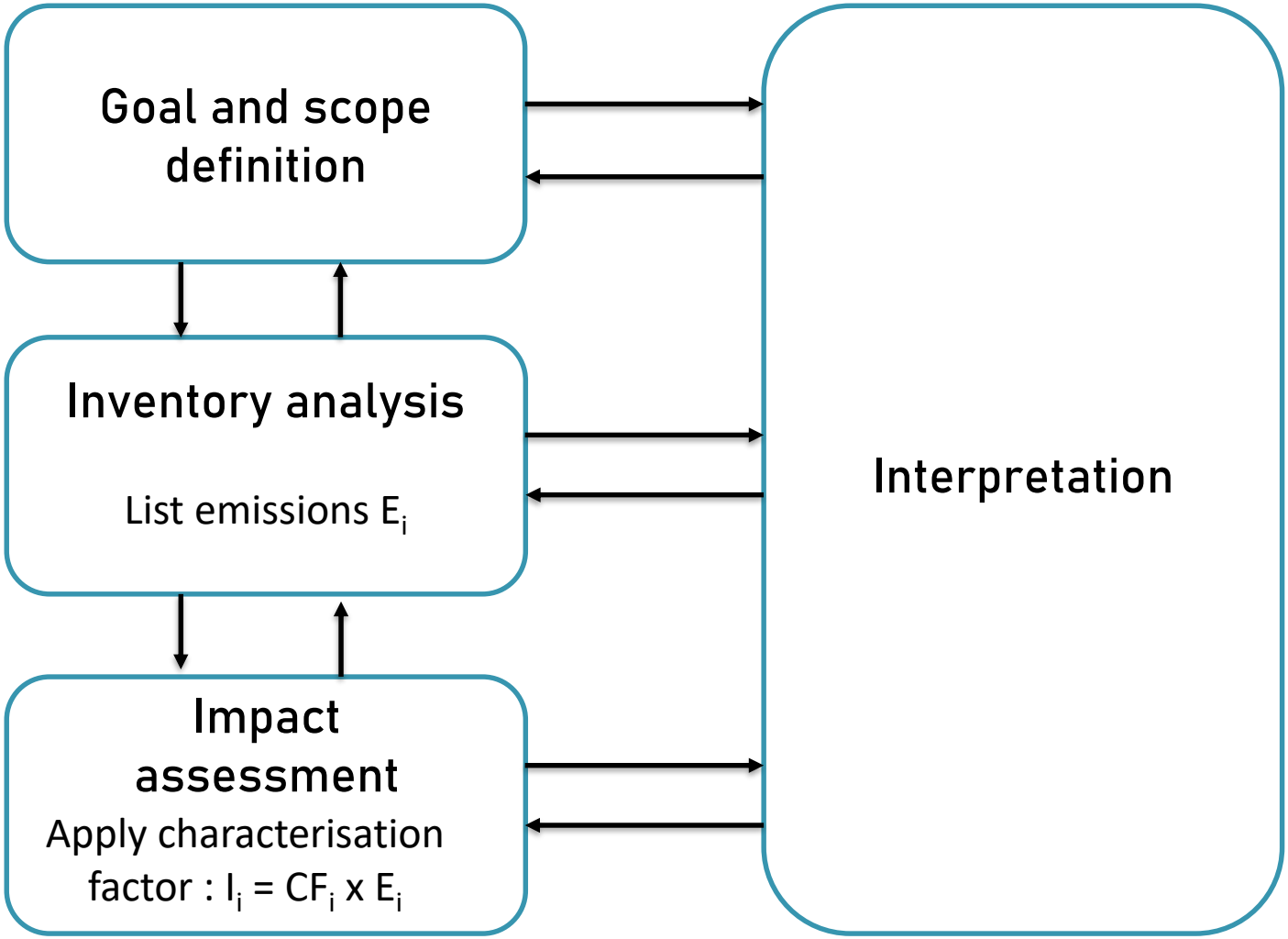
- Takes into account emissions over the whole life cycle
- From extraction to end-of-life



International Organization for Standardization

- Use standardised by ISO (ISO 14040 & ISO 14044)
- 4 phases of study

Life Cycle Assessment

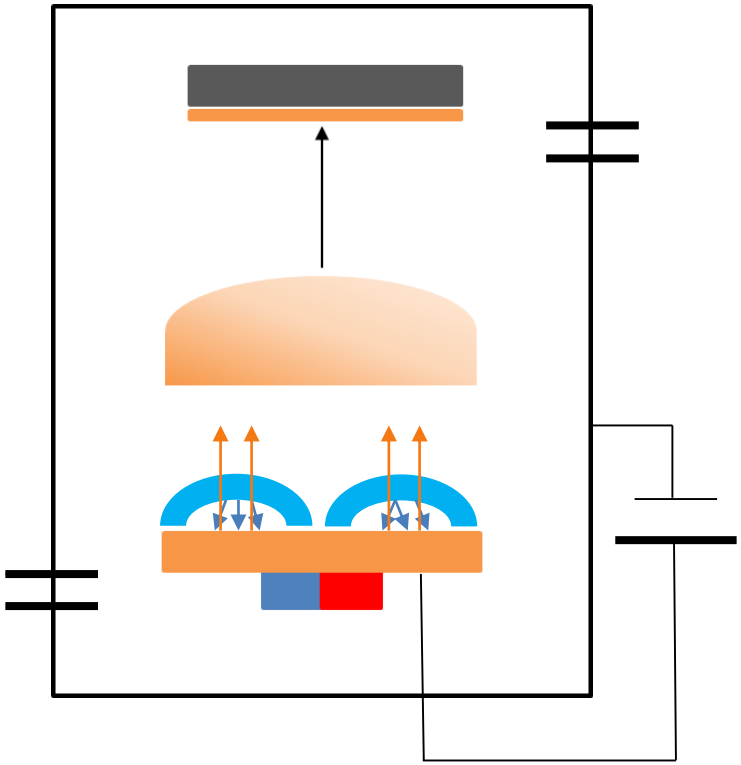


Magnetron sputtering and LCA

Magnetron sputtering

➔Deposition technique
➔Voltage applied to target in vacuum chamber
➔Plasma bombardment on target
➔Film growth on substrate

Ar
Reactive gases



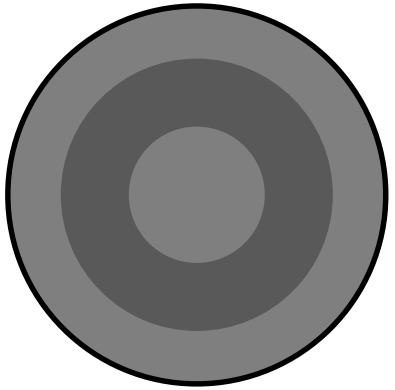
During process, almost no emissions, but …

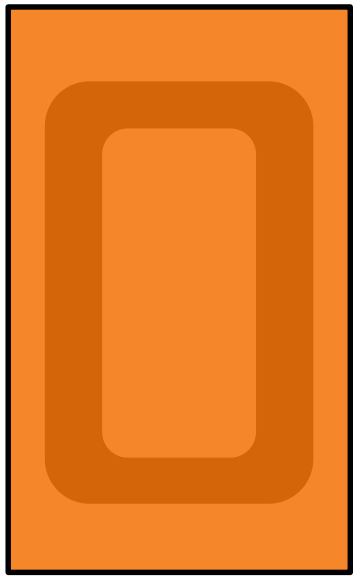
Magnetron sputtering and LCA

- Target production can have a huge impact
  - Metal extraction and refining can be energy intensive and have a lot of emissions
  - Target manufacture can be an impactful process
- Very high energy consumption per g deposited !
  - Impact depends a lot on electricity production mix
- Inert and reactive gases production usually have a negligible impact

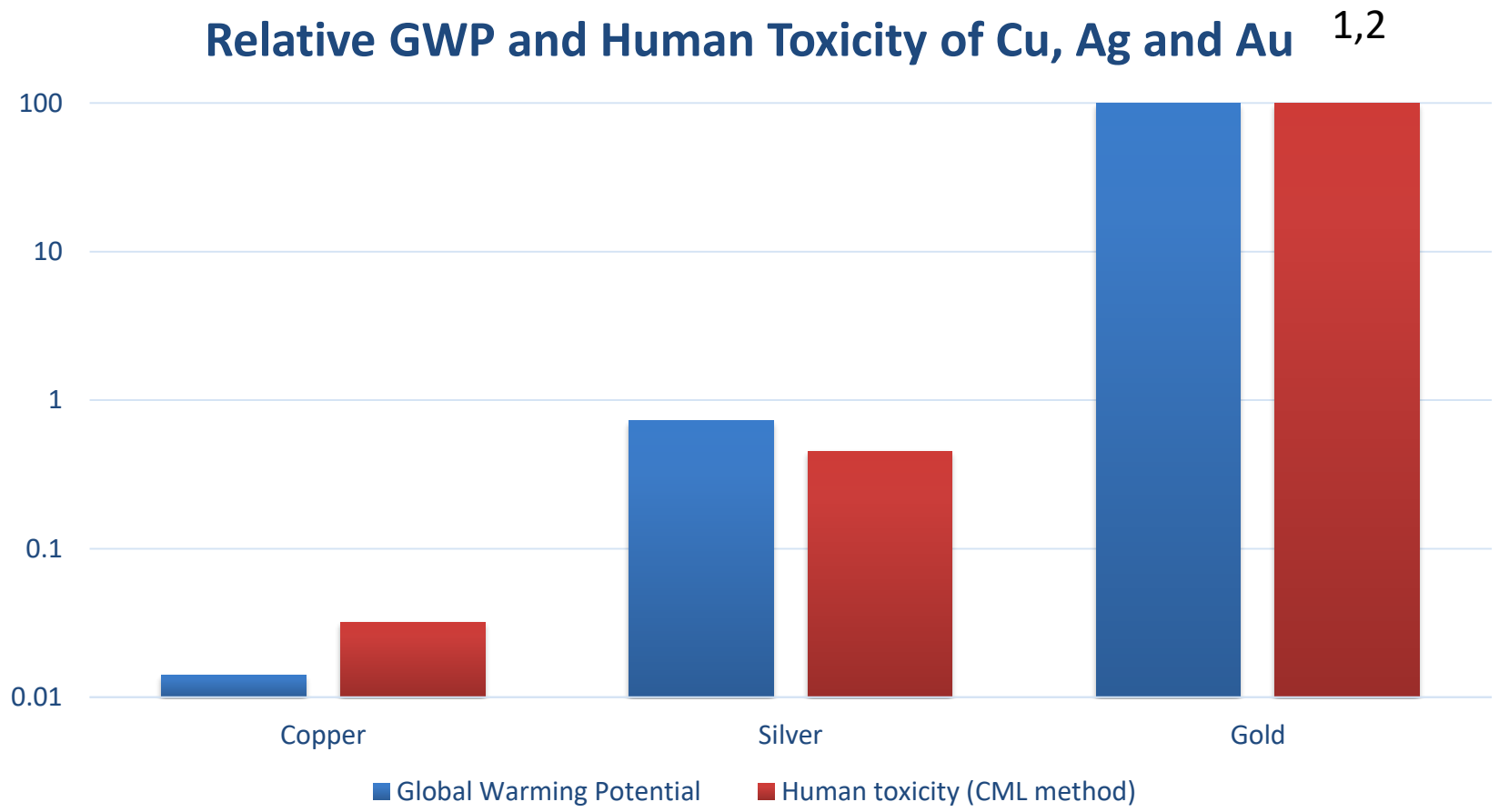
Considerations on metal production

- Rarer metals ➔ Higher impact!
- Toxicity linked to metal production
- Inefficient in MS : only part of the target is used (race tracks)
- Waste on vacuum chamber walls





Example : rare metals production



Element abundance in Earth's crust[3] :

Cu : 60 ppm Ag : 0.075 ppm Au : 0.004 ppm

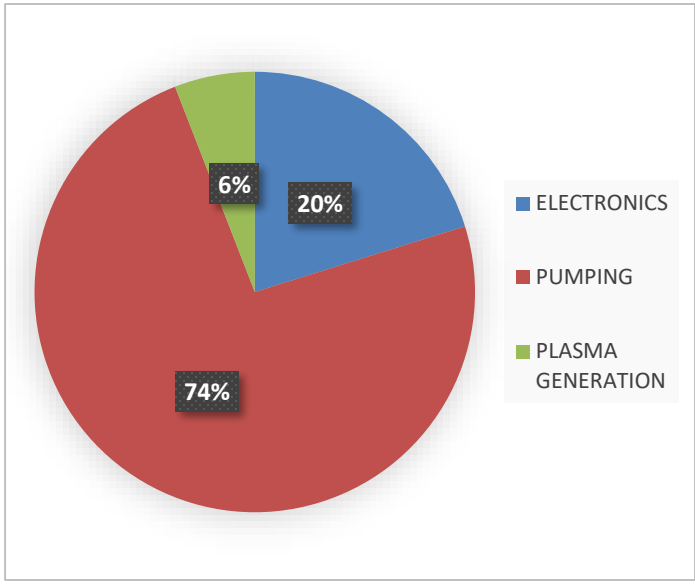
1 : *Ecoinvent database* Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: <http://link.springer.com/10.1007/s11367-016-1087-8>2 : Environmental

2: Environmental impact assessment of european non-ferro mining industries through life-cycle assessment, Shahjadi Hisan Farjana et al., 2018, IOP Conf. Ser. : Earth Environ. Sci. **154 ,** 012019

3: ABUNDANCE OF ELEMENTS IN THE EARTH'S CRUST AND IN THE SEA, *CRC Handbook of Chemistry and Physics,* 97th edition (2016–2017)

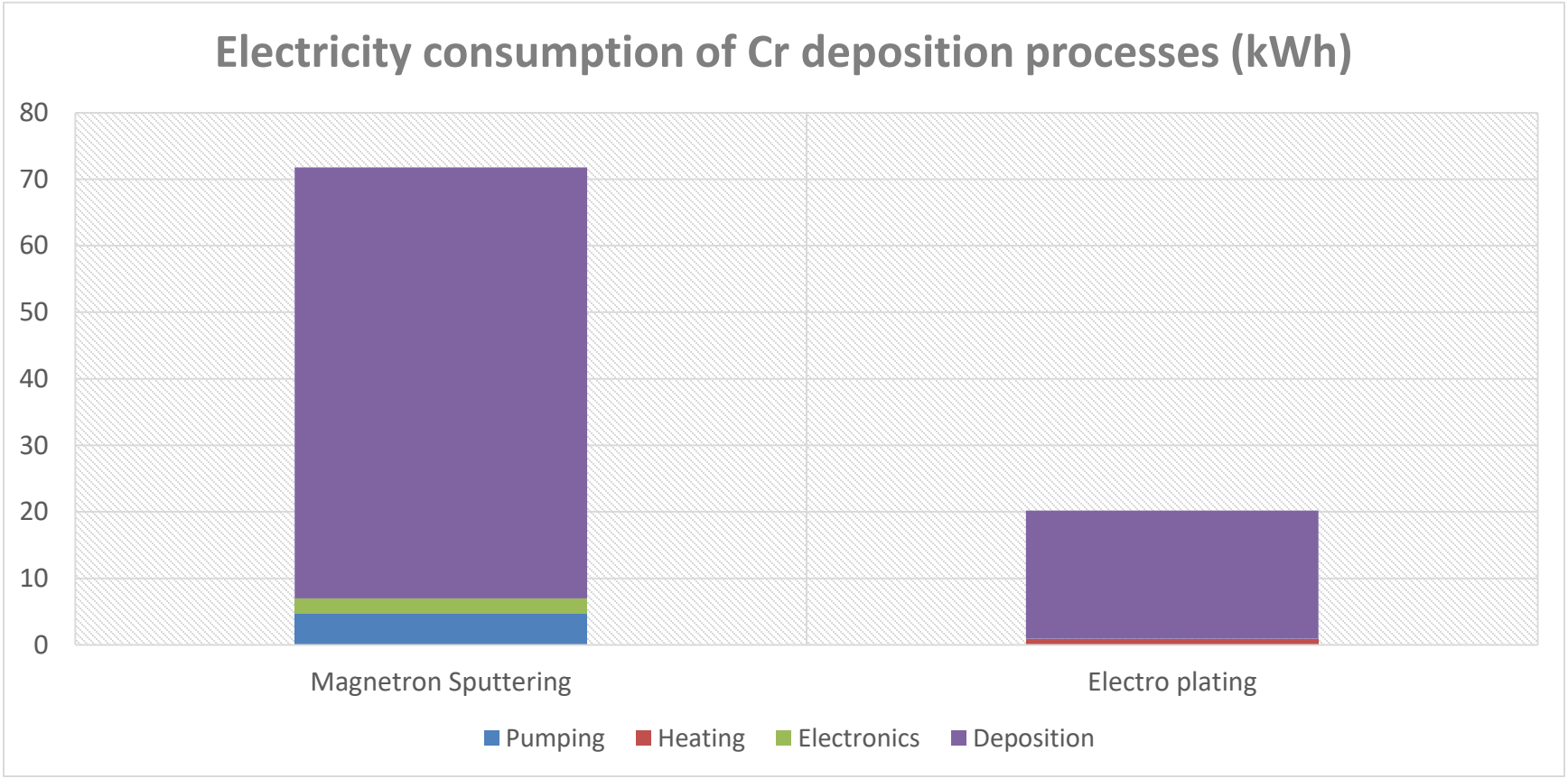
Considerations on energy consumption

- Pumping is not a negligible part of energy consumption
- High energy needed to maintain plasma and sputtering
- Depending on the country's electricity mix, impacts can vary



Example of energy repartition in a lab/experimental apparel (Process Not Optimised)

Energy consumption example: Cr film

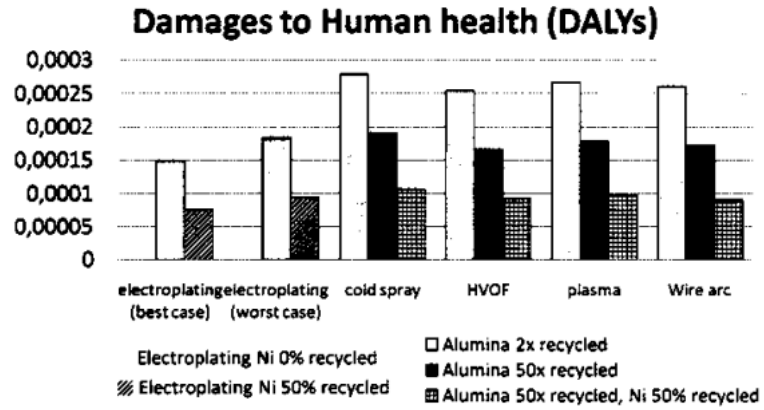


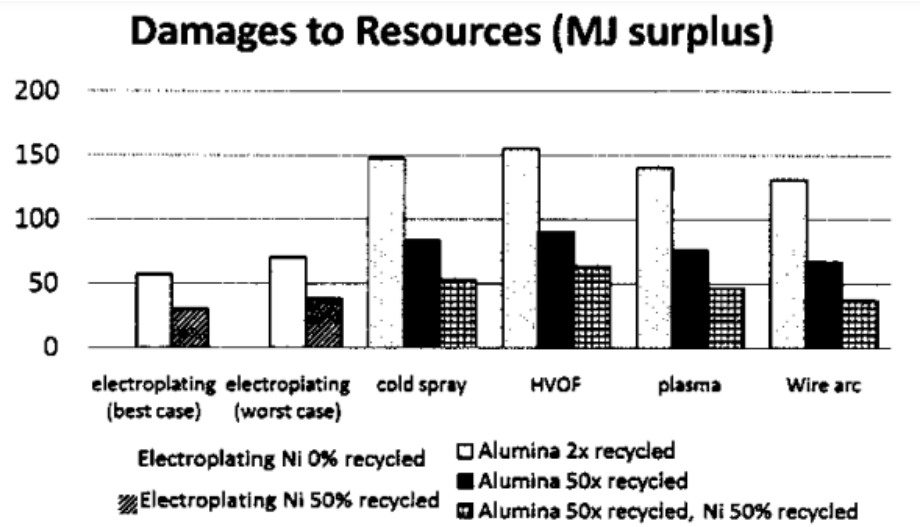
Functional unit : 20µm Cr film on 1 m²

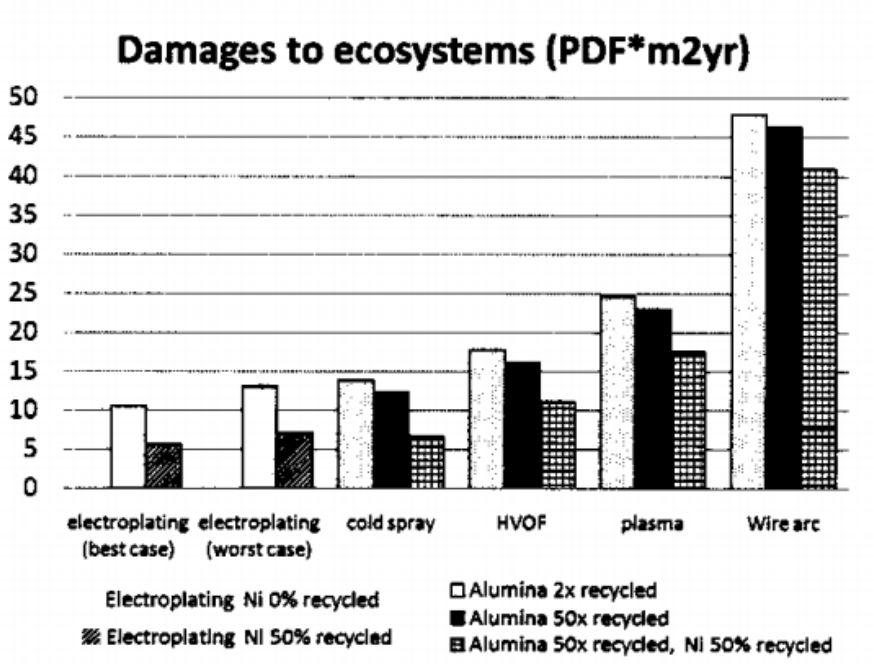
Possible improvements

- Reduce metal/energy consumption and impact
  - Careful chamber design : adapted pumping system, magnetic field to increase flow from target to substrate, …
  - Use of recycled materials or more abundant elements for the targets to limit impact
  - Improvements to deposition rate (target heating,…)
- Enhance film properties to improve efficiency in the use phase (HiPIMS, structured materials, …)

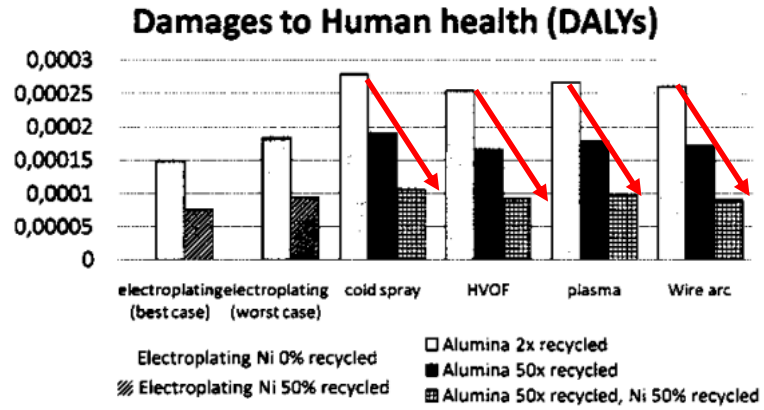
Impact mitigation with recycled metal feed

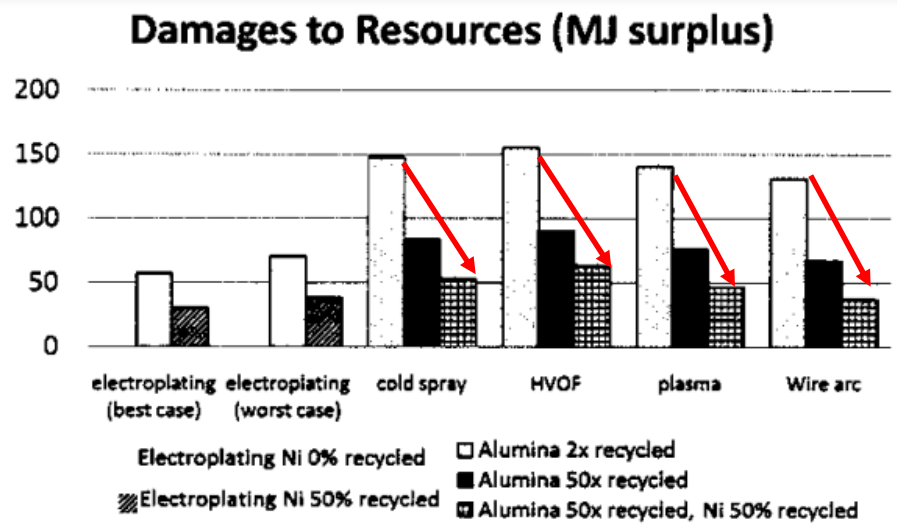


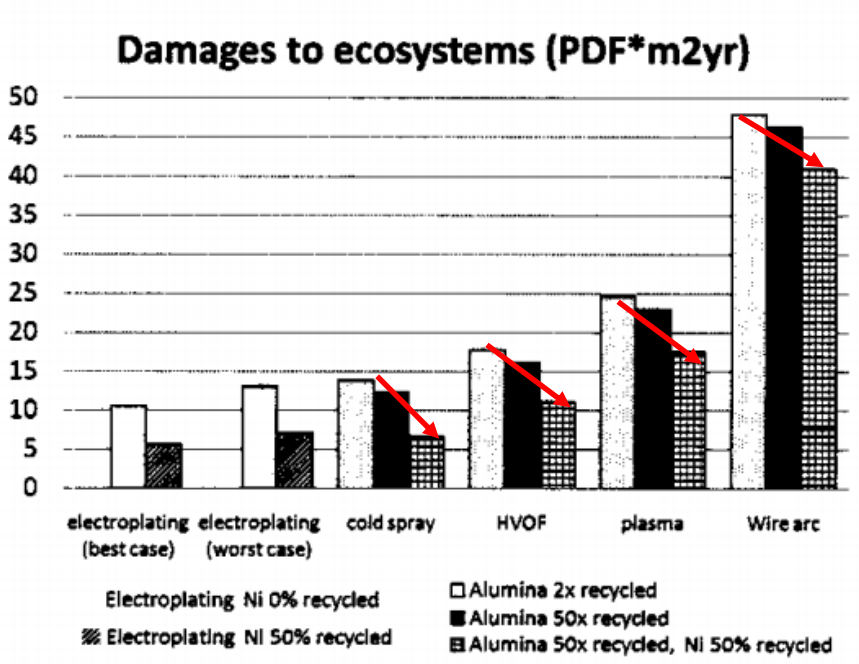




Impact mitigation with recycled metal feed







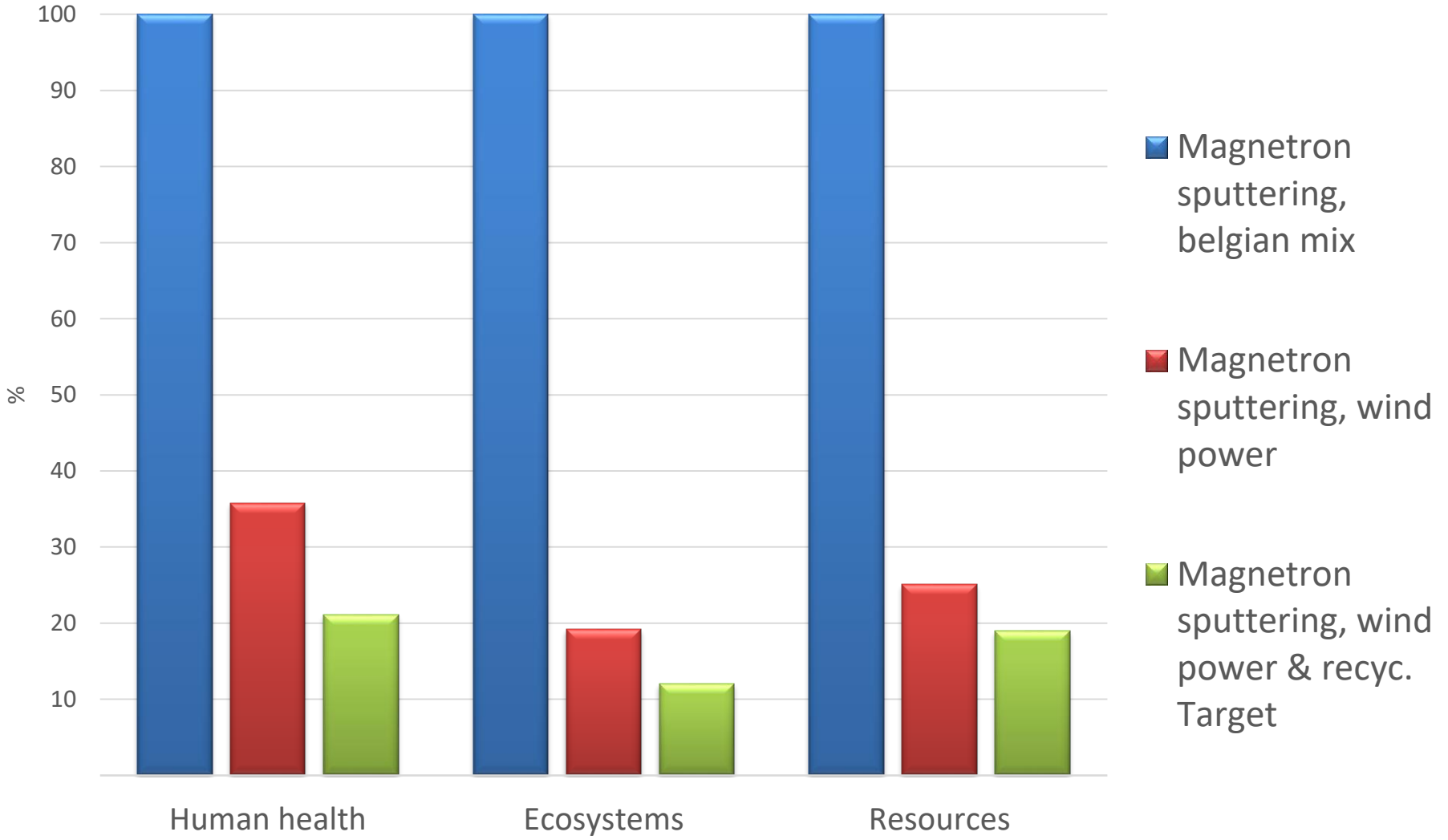
Example applied to chromium deposition (Assumptions)

- Going from belgian mix (~50% nuclear, ~25% natural gas, ~15% renewables, ~10% others) to energy coming fully from wind power, as an extreme example

- Use of recycled metallic chromium (recycling is assumed to be ~0.55 times as impactful as production from ore)

- Inventory from assumptions, data from Ecoinvent 3, impacts from ReCiPe 2016 method (Endpoints, humanitarian)

Potential mitigation: chromium deposition



Endpoints impact repartition of chromium deposition via magnetron sputtering

Conclusions

- LCA : powerful tool for environmental decision making
- For MS practicionners :
  - Prefer abundant, low-impact elements
  - Thinner films = lower impact
  - Optimise pumping, and chamber design
- Need for a metal recovery loop implementation
- Software for MS modelling could help make environmental decision by incorporation LCA directly

Perspectives

- Combine LCA with other assessment techniques (Techno-Economic analysis and social assessment p.e.)
- Study the use phase to make a more nuanced study
- Assess metal production in a more accurate way, and include recycling
- Apply the assessment techniques to the materials and techniques studied by PULSATEC partners

Thank you for your attention !

Any questions?