Supporting early-design decisions with LCA: comparison of several architectures of electrochromic display for anticounterfeiting application

LCM 2021

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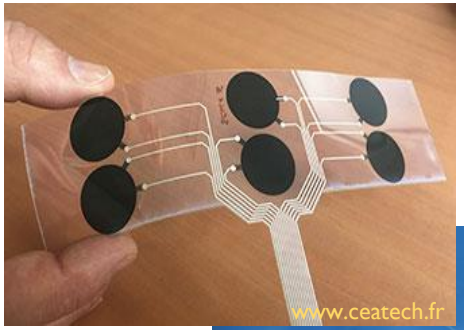
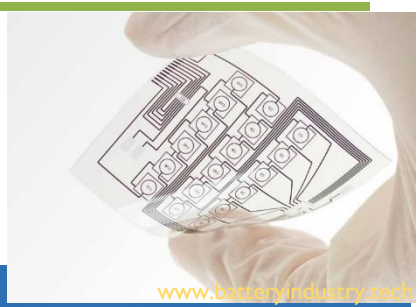
Outline

- Introduction:
  - printed electronics
  - sustainable innovation
  - Life Cycle Assessment (LCA)
- Study objective
- Materials and methods
  - technology
  - modelling assumptions
- Results
- Discussion and conclusions
- Perspectives and future work

Introduction: printed electronics

- Advantageous cost and design, e.g., easy printing on flexible substrates
- New and existing applications (e.g., IoT)
- Electrochromic display (ECD) – energy efficient display for anti-counterfeiting application



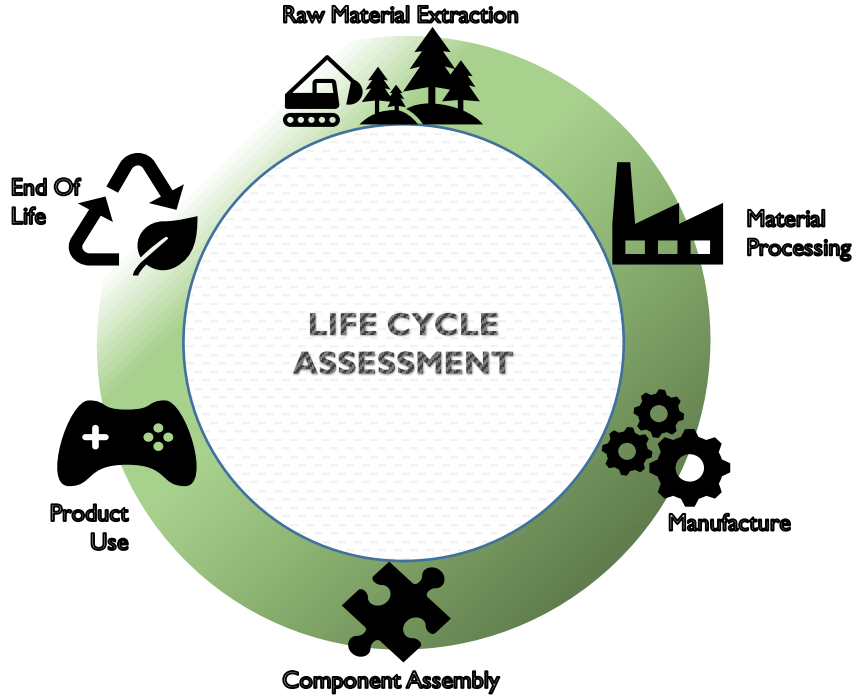


Introduction: sustainable innovation

- Design of new devices with consideration to their impact on the environment
- Development/design of ECD entails broad range of possible architectures: order and presence of layers, material quantities, etc.
- Quantitative tools can be used to prioritize research efforts of devices with lower environmental impacts

Introduction: Life Cycle Assessment (LCA)

- Life cycle assessment (LCA):
  - systematic accounting of impacts across product life cycle
  - ISO 14040 and ISO 14044
- Direct applications
  - Product development and improvement
  - Strategic planning
  - Public policy making
  - Marketing
  - **Research**



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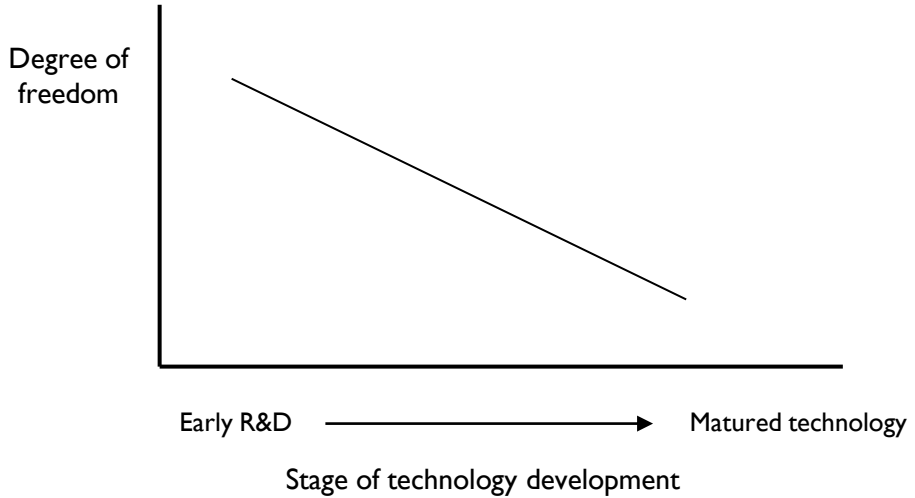
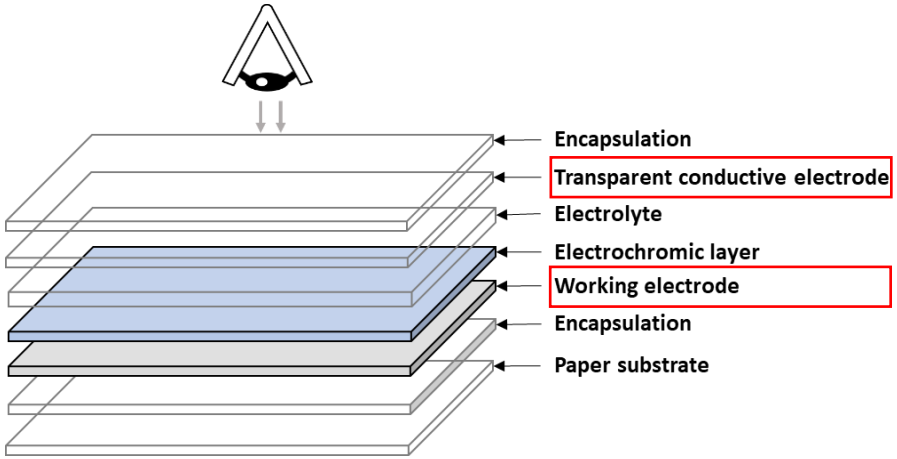


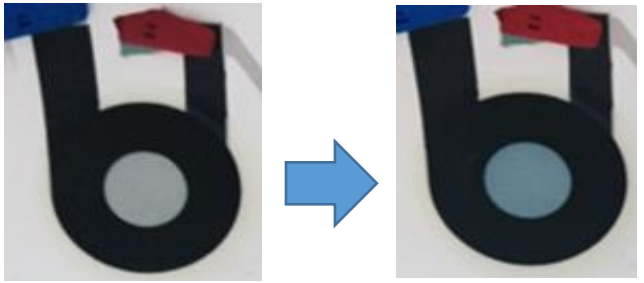
Study objectives

- Compare several architectures for electrochromic display (ECD) to inform the most promising research directions

Methodology: technology description

- Electrochromic display (ECD):





Methodology: technology description

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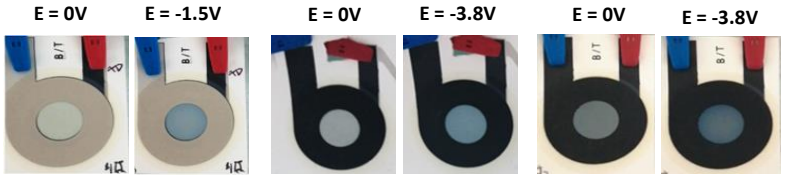
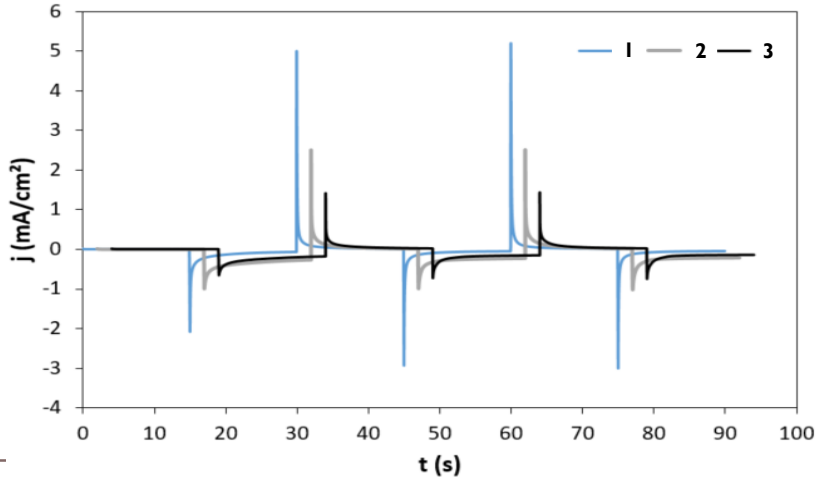


Arch - 1		
E	0V	-1.5V
L*	74.5	64.3
a*	-3.3	-5.8
b*	7.8	-6.0
ΔE*	**17.3**	

Arch - 2		
E	0V	-3.8V
L*	76.5	64.8
a*	-3.5	-5.5
b*	7.1	-5.8
ΔE*	**17.5**	

Arch - 3		
E	0V	-3.8V
L*	68.5	60.1
a*	-3.5	-5.5
b*	2.0	-7.6
ΔE*	**10.6**	



$$\Delta E^* = \sqrt{\left(L^*_{red} - L^*_{ox}\right)^2 + \left(a^*_{red} - a^*_{ox}\right)^2 + \left(b^*_{red} - b^*_{ox}\right)^2}$$

Chromaticity parameters:
L*red, a*red, b*red - reduced state
L*ox, a*ox, b*ox - oxidized/neutral state

Methodology: technology description

- Choice of electrode materials for six possible architectures of ECD:
  - Silver + Carbon
  - all-Carbon
  - indium-tin-oxide (ITO)

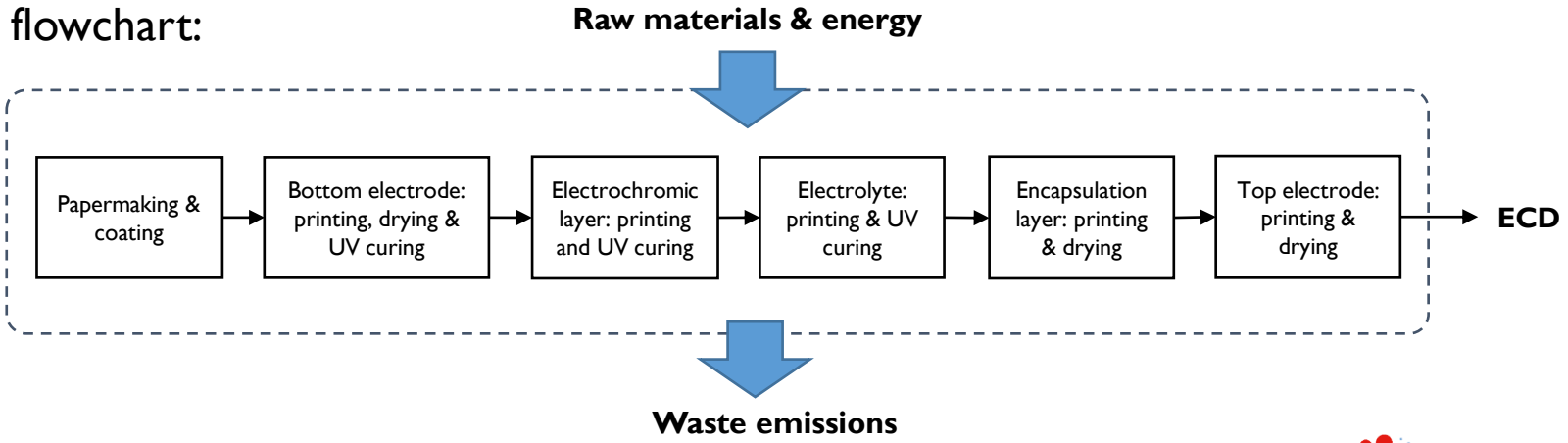
	Bottom electrode	Top electrode
Arch 1 (default)	Silver + Carbon	Carbon
Arch 2	Silver + Carbon	Silver + Carbon
Arch 3	all-Carbon	all-Carbon
Arch 4	ITO	Carbon
Arch 5	ITO	Silver + Carbon
Arch 6	ITO	ITO

Tested in lab

Hypothetical

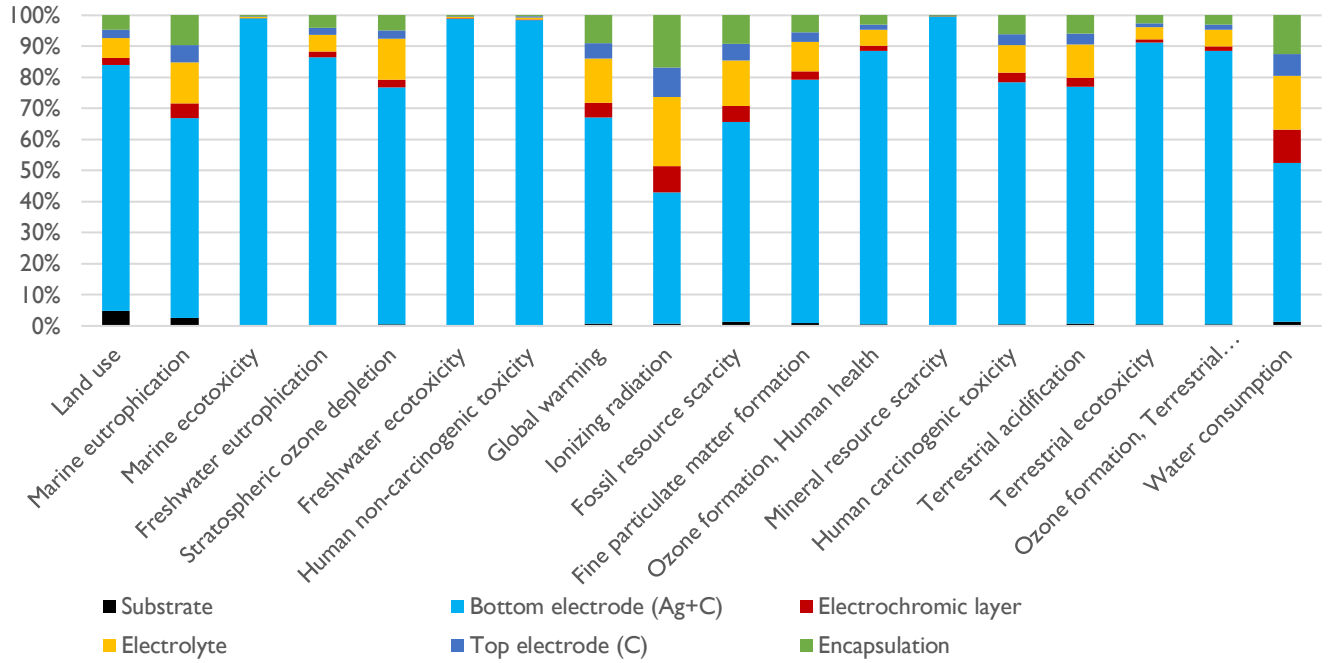
Methodology: modelling assumptions

- System boundaries: cradle-to-gate
- Classification & characterization: ReCiPe midpoint (H), OpenLCA & Ecoinvent (cut-off)
- Reference flow: 1 ECD
- Process flowchart:



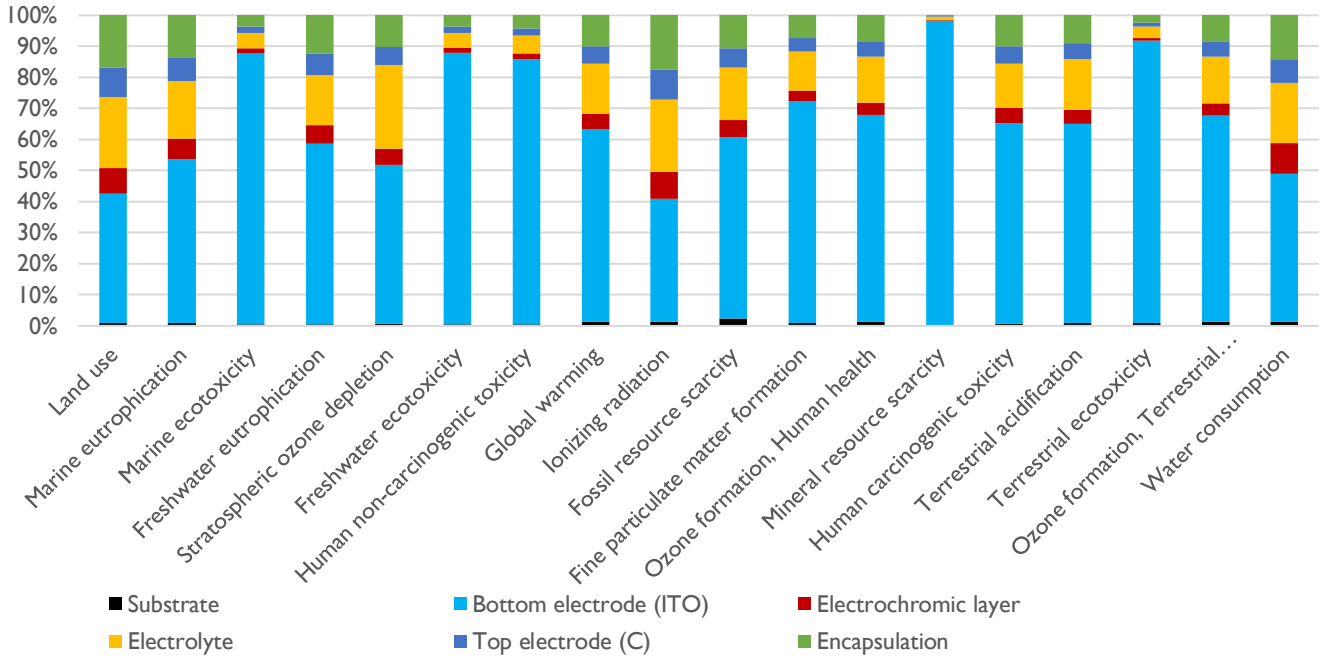
Results

- Architecture 1:



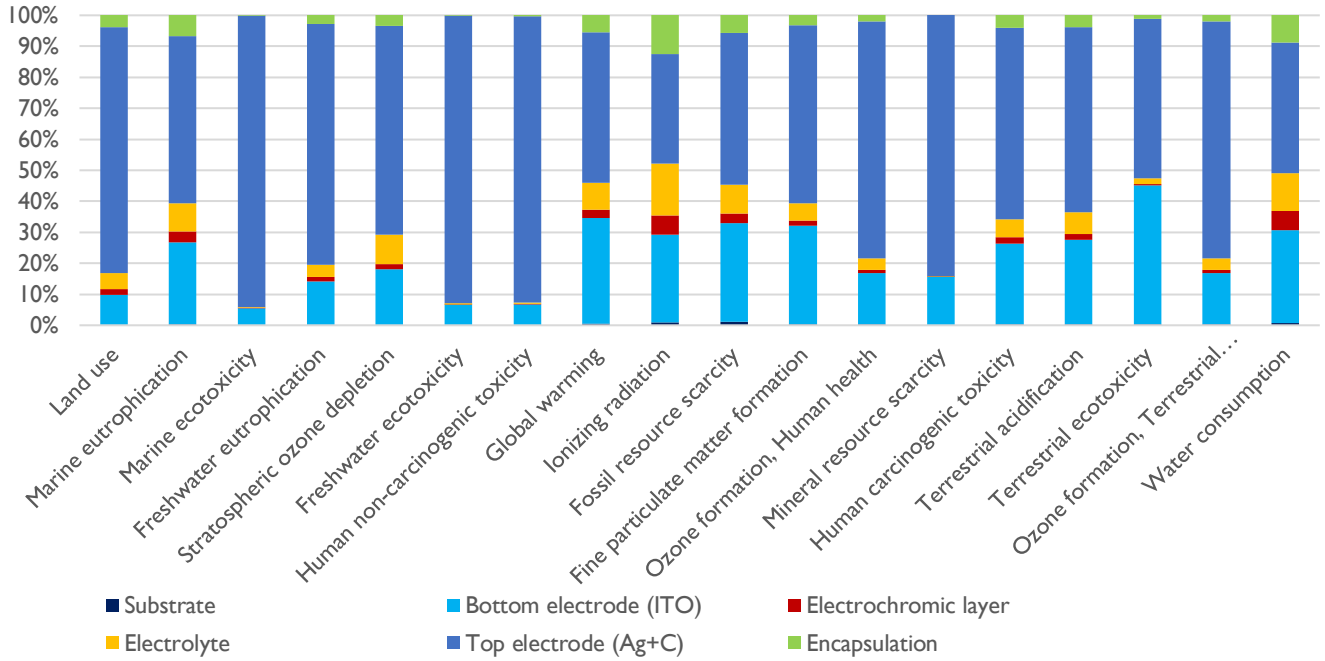
Results

- Architecture 4:



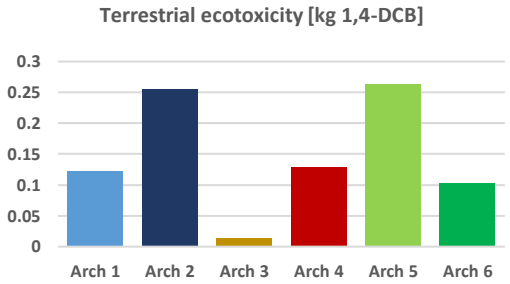
Results

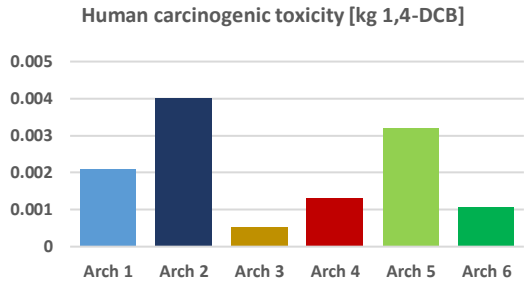
- Architecture 5:

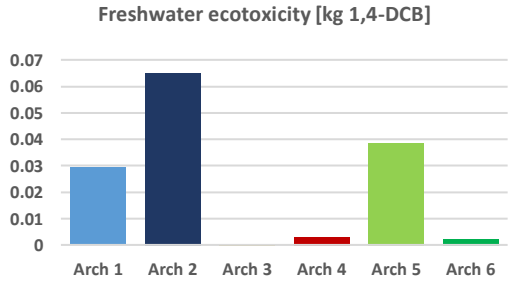


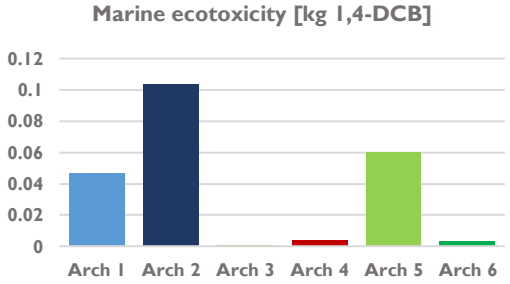
Results

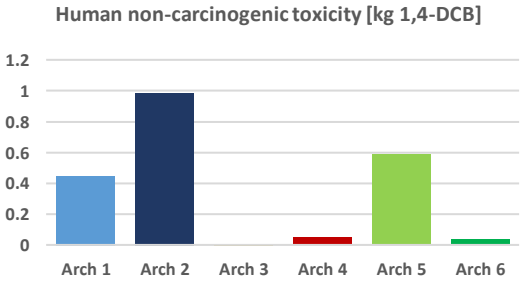
	Bottom electrode	Top electrode
Arch 1	Silver + Carbon	Carbon
Arch 2	Silver + Carbon	Silver + Carbon
Arch 3	Carbon	Carbon
Arch 4	ITO	Carbon
Arch 5	ITO	Silver + Carbon
Arch 6	ITO	ITO











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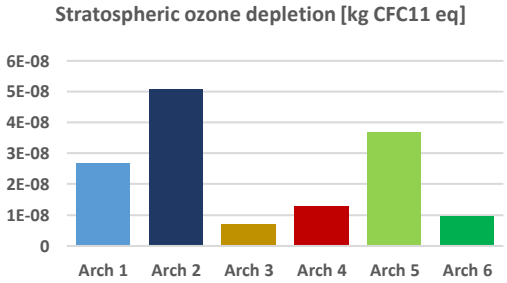

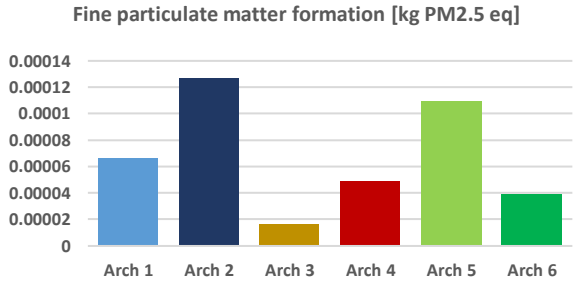

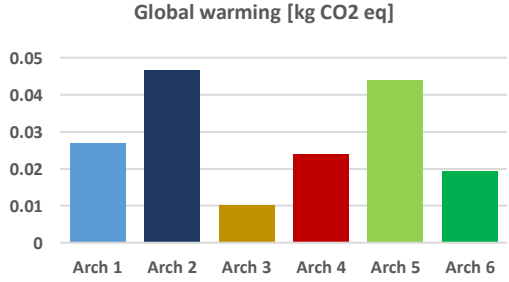

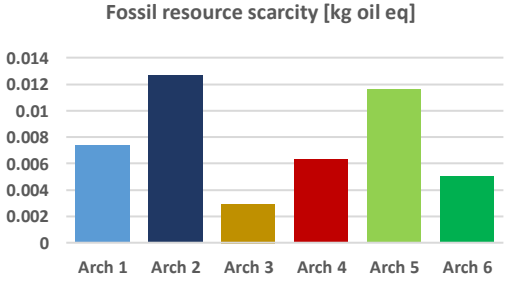

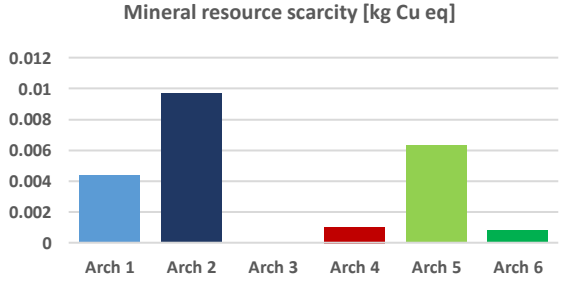

Discussion and conclusions

- Observations:
  - Arch 3 (all-Carbon) electrode preferrable, particularly toxicity-related categories
  - Arch 6 (ITO/ITO) preferred to Arch 4 (ITO/Carbon) although Silver+Carbon/Carbon preferred to ITO/Carbon
  - ITO generally preferred than Silver+Carbon
- Limitations
  - exclusions of end-of-life
  - assumptions of efficiency of ITO deposition can influence the results
  - comparability not normalized on entirely functional basis (optical spectrum - ΔL)

Perspectives and future work

- Future ECD integrations should focus on excluding silver and further improvement in carbon-based electrodes with ITO as a possible alternative
- Cost and criticality analysis to broaden sustainability of current design choices
- Consideration to other electrode materials

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Thank You.

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