„PROSPECTIVE LCA OF FUTURE PROPULSION SYSTEMS FOR AVIATION: A FUEL CELL-BASED AUXILIARY POWER UNIT”

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AGENDA

1. Introduction to Prospective LCA

2. Background and Motivation

3. Methodology
   - 3.1 Modelling of foreground system
   - 3.2 Modelling of background systems

4. Results

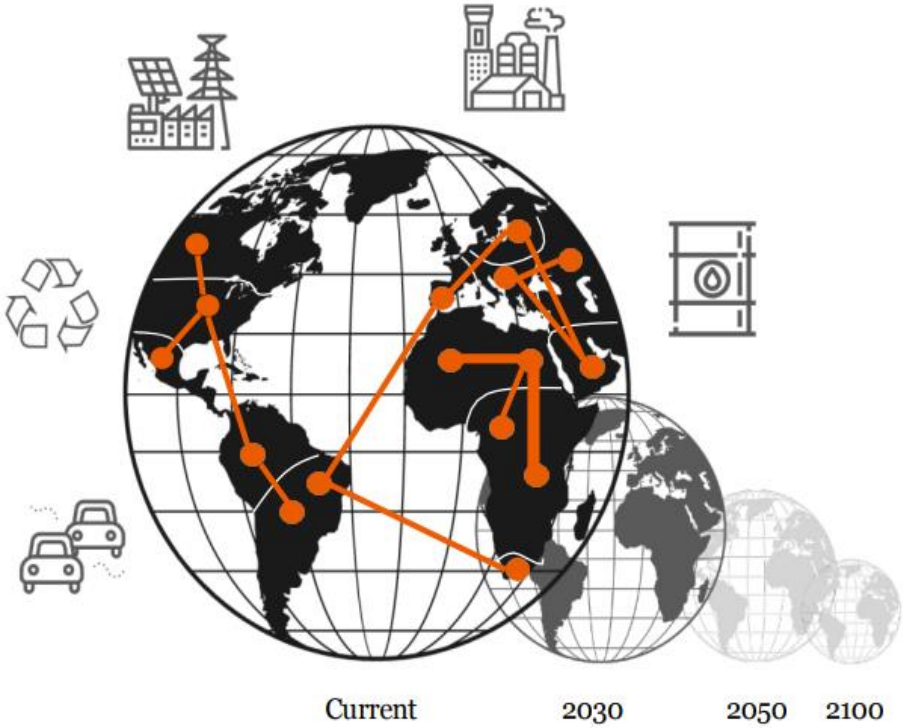
5. Conclusion

6. Outlook

1. Introduction to Prospective LCSA

- It is an assessment that covers the environmental, economic and social consequences and impacts of a technology in interaction with the surrounding system by means of an LCA, LCC, and SLCA
- It consciously incorporates changes over time in life cycle data, system/actor behavior and/or their relationships
  - How to avoid the mismatch between Foreground and Background ?
  - Background system data that represents the potential future transformation pathways

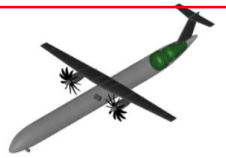
Transformation of energy pathways*



*Source:*Romain 2021*

2. Background and Motivation

Prospective comparative assessment of **future air transportation systems** with respect to **environmental impacts**

Aircraft Type		Energy Carrier
Turbofan 2015		• Fossil Kerosene • SynFuel
Turbofan		• Fossil Kerosene • SynFuel
Turboprop		• Fossil Kerosene • SynFuel
Turbofan Mild-Hybrid		• LH_2 + Fuel cell
Turboprop Mild-Hybrid		• LH_2 + Fuel cell
Plug-In Hybrid		• Fossil Kerosene + Battery • SynFuel + Battery

SynFuel: power-to-liquid (PtL)

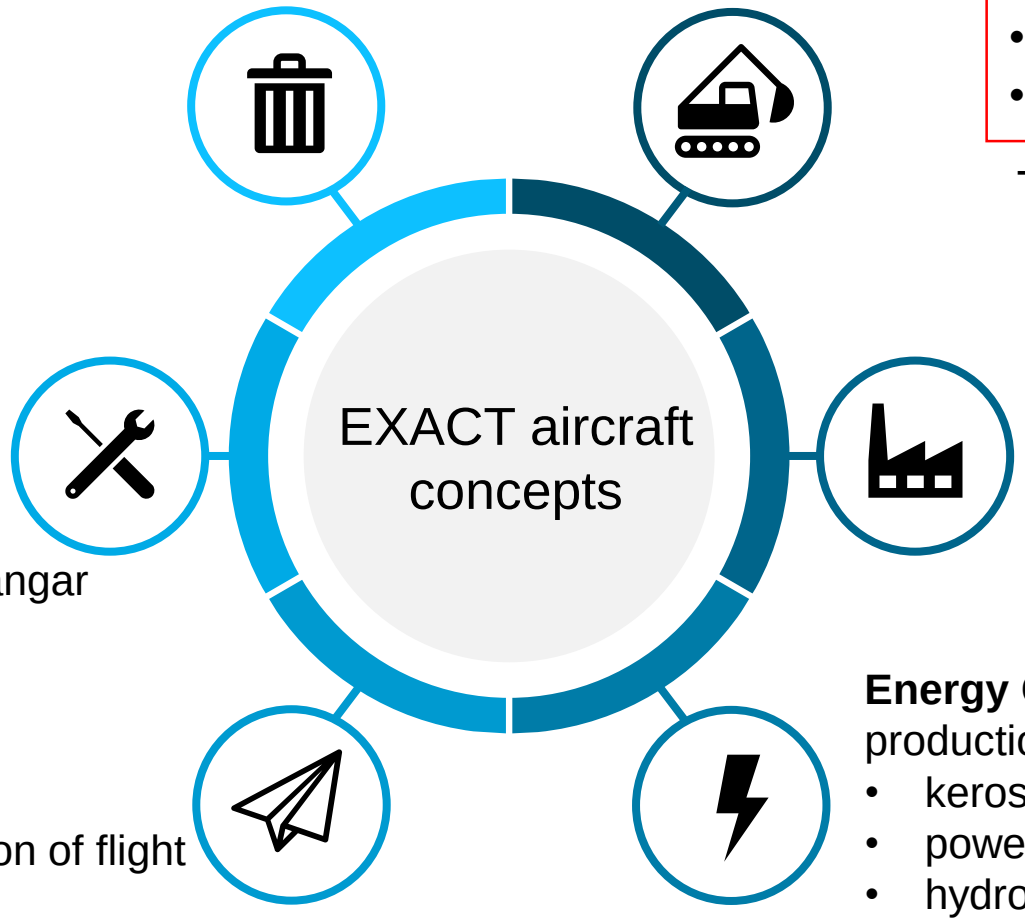
2. Background and Motivation

Life Cycle Assessment
Life Cycle Phases

End-of-Life
different recycling scenarios for batteries

Ground Operations
detailed consideration of all scheduled maintenance tasks
- replacement of components
- refill of lubricants
- electricity of equipment and hangar

Flight Operations
climate impact model for evaluation of flight phase



Manufacturing of propulsion system components:
- raw material extraction
- manufacturing and assembly

This presentation:

Functional unit: 1 unit of fuel-cell APU system for a hybrid-electric aircraft for entry into service in 2050

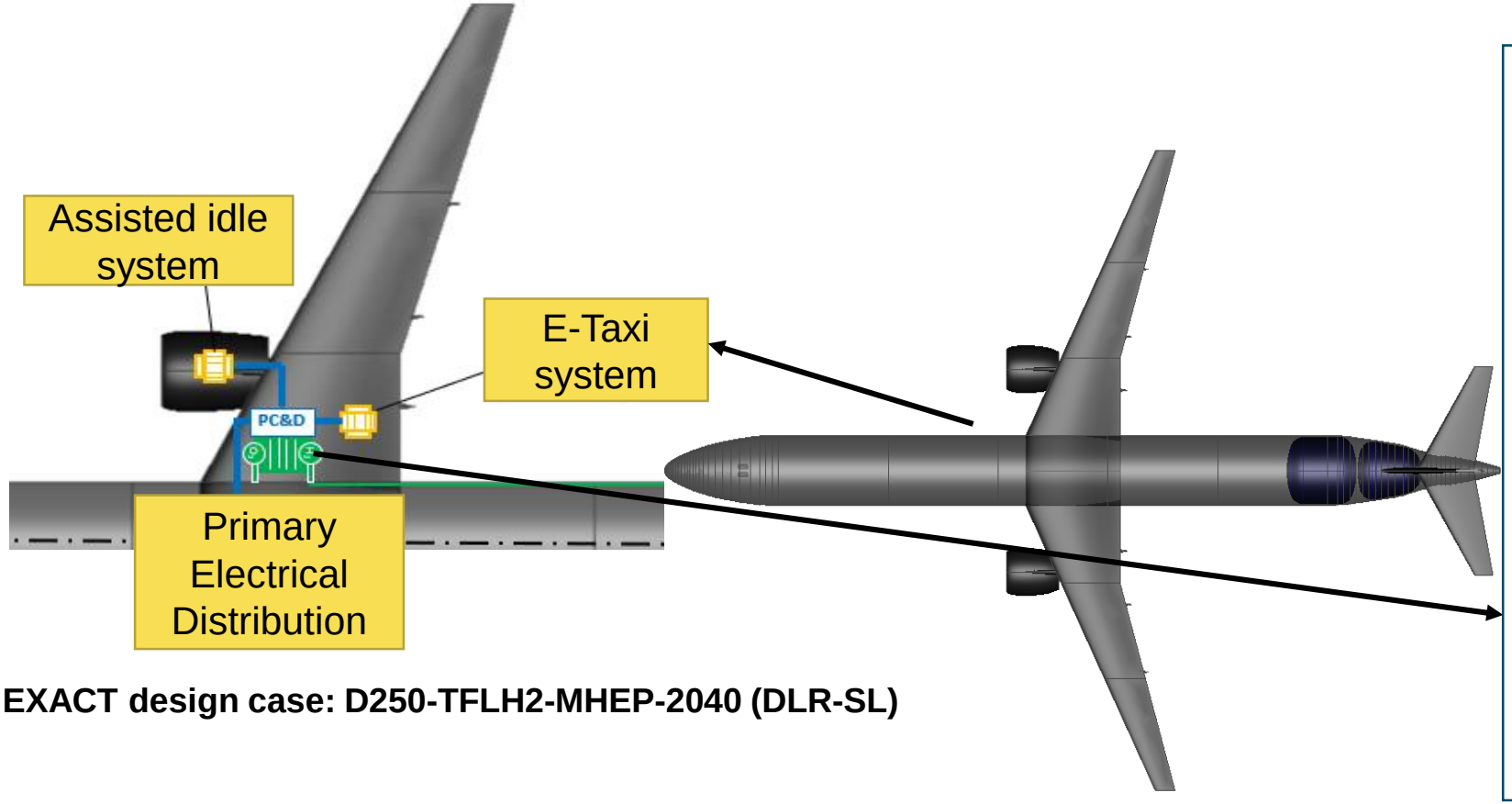
Impact assessment method: ILCD 2 (2018)

Energy Carrier
production of
- kerosene
- power-to-liquid (PtL)
- hydrogen
- green energy mix

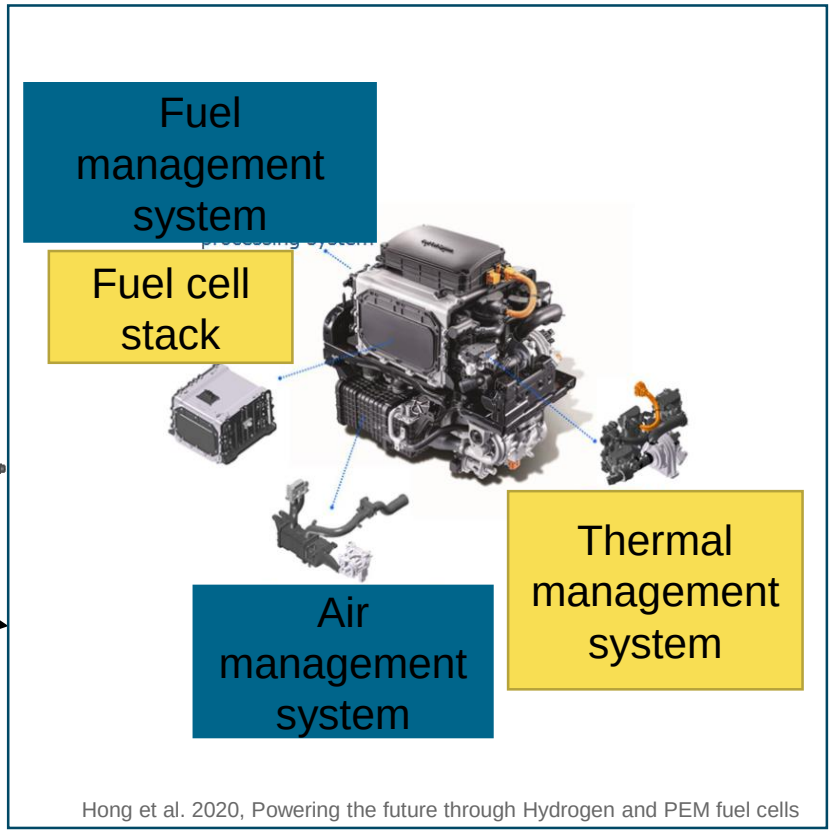
3. Methodology
Modelling of the Foreground System

Mild hybrid electric propulsion system (MHEP)

- Fuel cell based APU system for a turbofan short-range aircraft:



EXACT design case: D250-TFLH2-MHEP-2040 (DLR-SL)



Hong et al. 2020, Powering the future through Hydrogen and PEM fuel cells

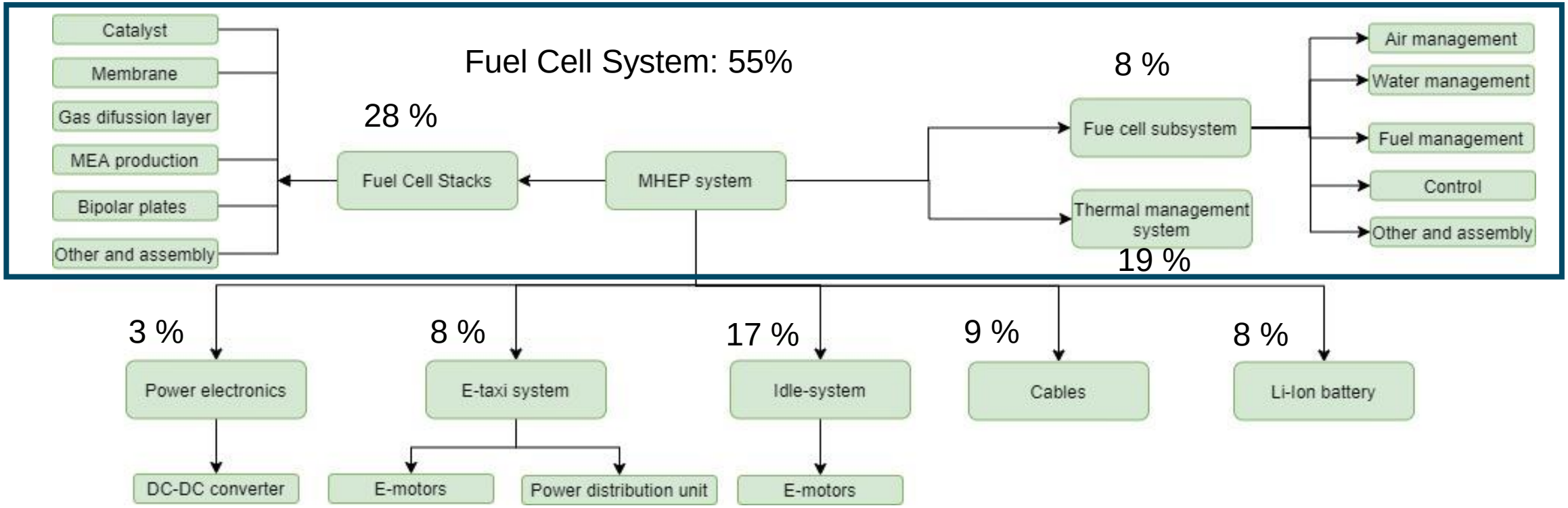
3. Methodology

Modelling of the Foreground System

MHEP System: focus on the fuel cell system

Primary data: sizing from aircraft designers
Secondary data: literature for automobile sector (Miotti et al.)

Components of the MHEP System: Mass breakdown ~ 1,200 kg



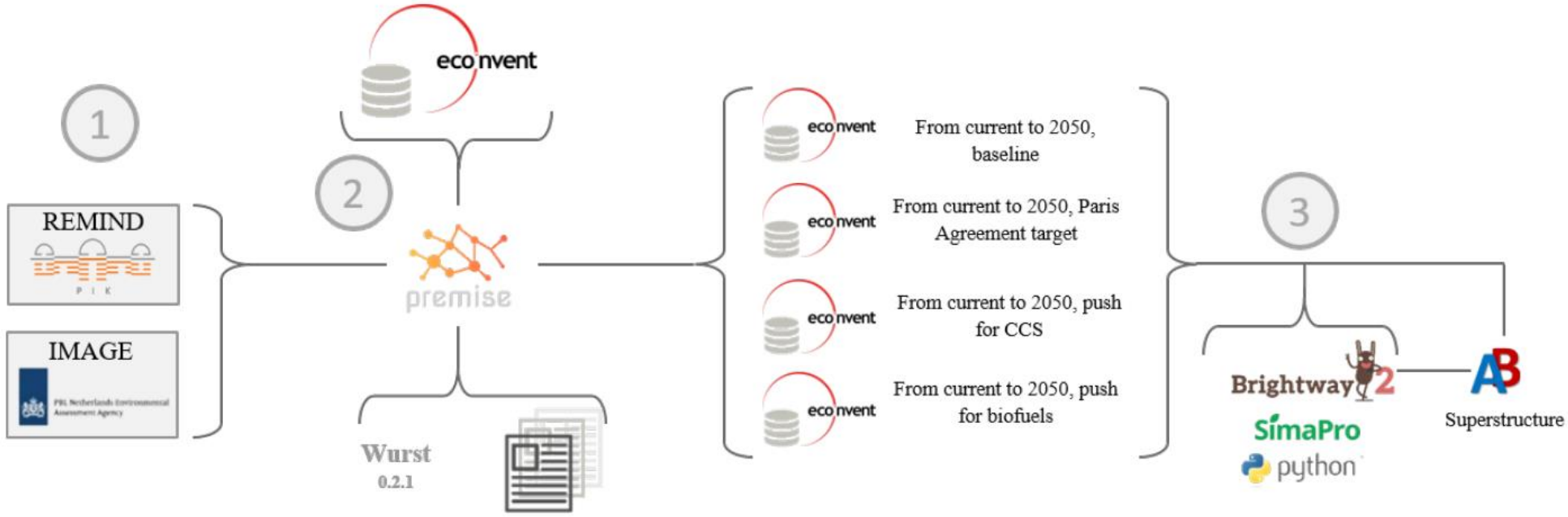
Components of the fuel cell system for a mild hybrid aircraft concept (own figure)

3. Methodology

Modelling of the Background System

What is Premise?

- Open source software → Align LCI's of ecoinvent with background scenarios



Source: Romain, 2021

3. Methodology

Background scenarios

- Integrated assessment models (IAM) → assess the interactions between human and natural systems

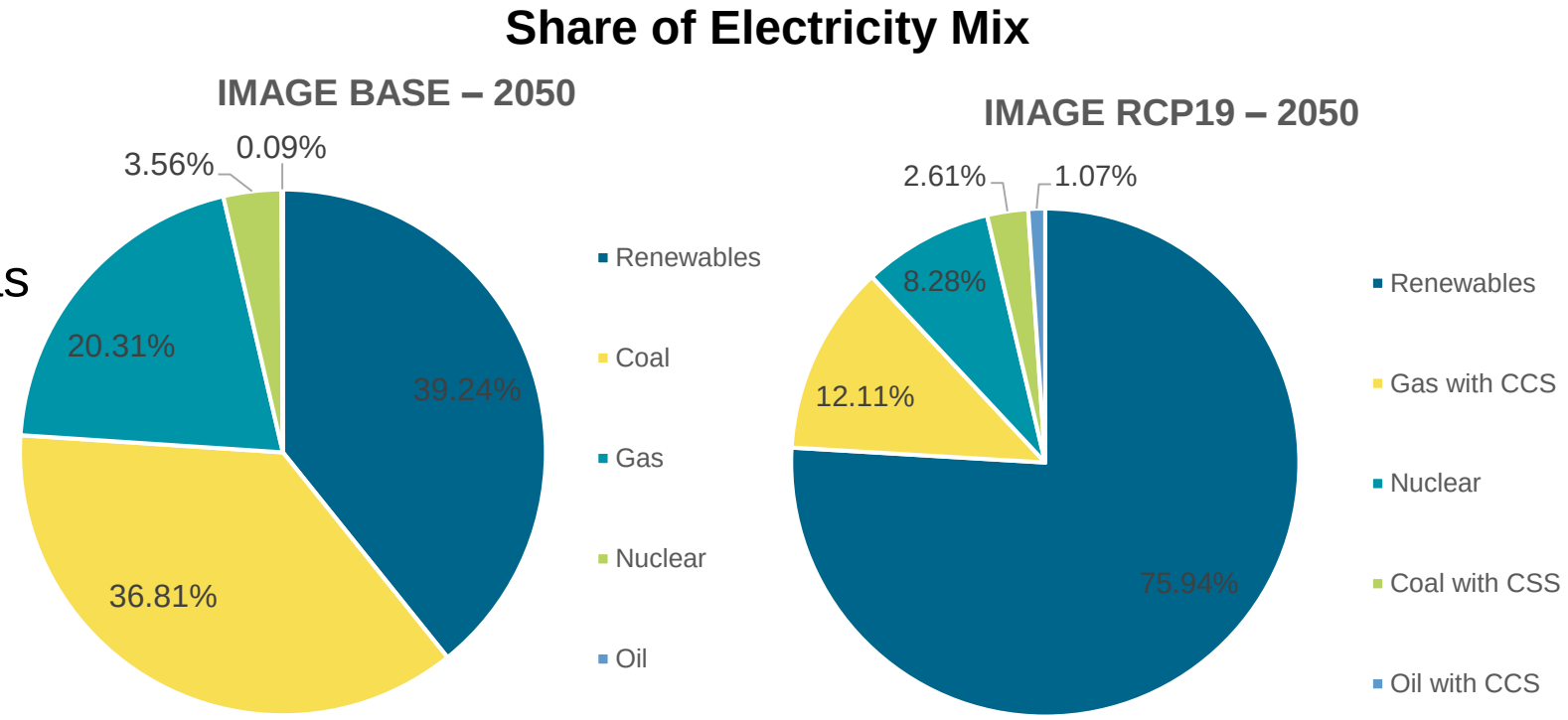
- IAM Scenarios → *Shared socio-economic pathway (SSP)* and a climate trajectory called *Representative concentrated pathway (RCP)*

- IMAGE SSP2 → Follow historical trends in terms of social and economic development

    - IMAGE SSP2 Base: BAU without any climate policy
    - IMAGE SSP2 RCP19: Aim to reach Paris agreement

3. Methodology
Scope of Background scenarios – Electricity and Steel

- Region → Western Europe (WEU)
- Base scenario narrative → Electricity mix remains same as BAU
- RCP19 scenario narrative → Optimistic installation of renewables
  - Deployment of CCS/CCU technologies

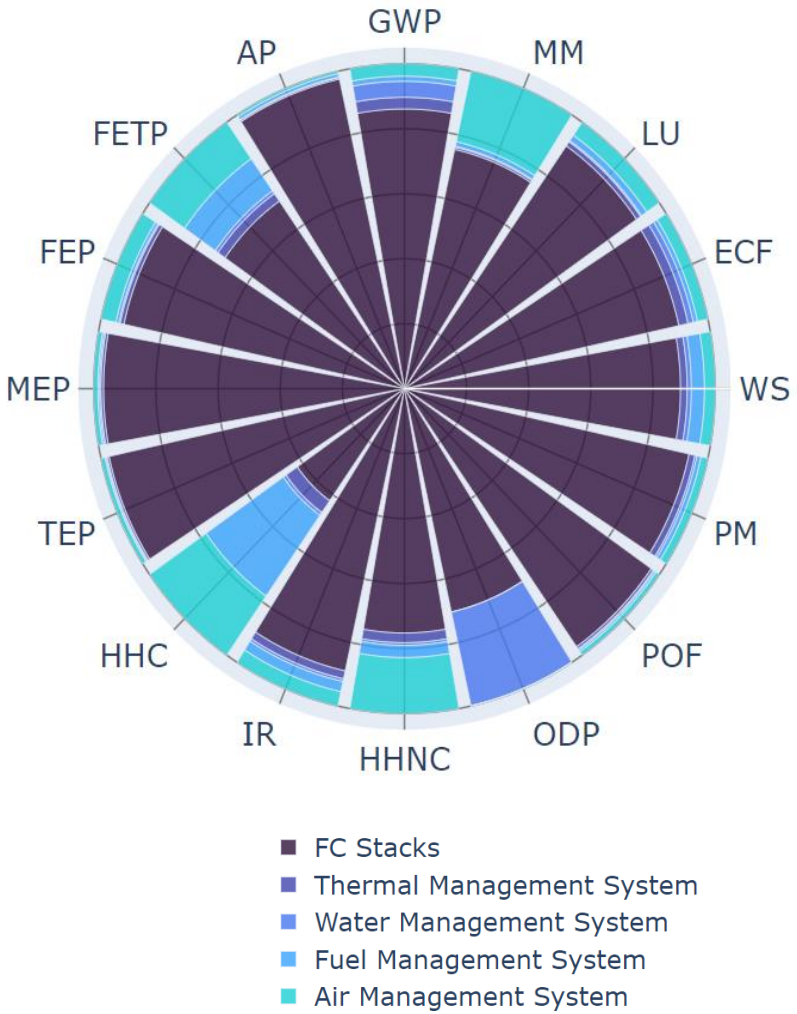


- Base scenario narrative → Steel Production dominated by blast furnaces (Coal)
- RCP19 scenario narrative → Steel Production dominated by Arc furnaces (Electricity)

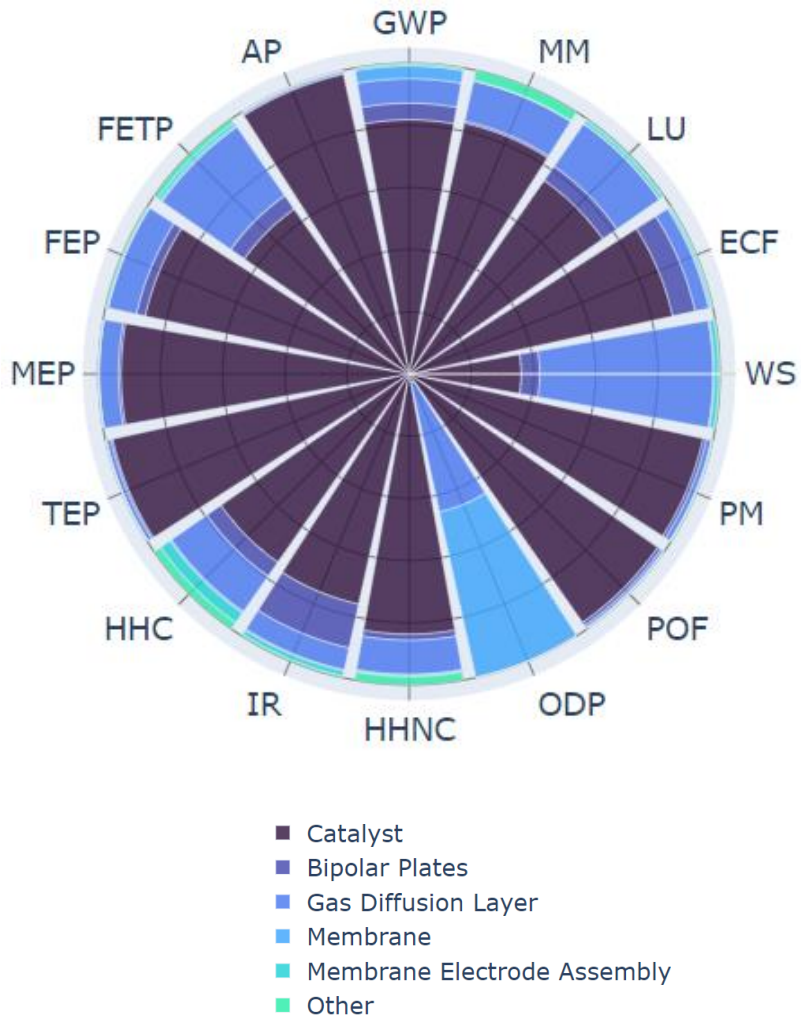
4. Results
Manufacturing phase – Fuel cell system
Life Cycle Assessment – contribution analysis

Impact category	Abbrev	Unit
Global Warming Potential	GWP	kg CO2 eq
Resources - Minerals and Metals	MM	kg Sb eq
Land Use	LU	soil quality index
Resources - Energy Carriers	ECF	MJ
Water Scarcity	WS	m^3 water
Particulate matter/ Respiratory inorganics	PM	Disease incidences
Photochemical Ozone Creation	POF	kg NMVOC eq
Ozone Depletion	ODP	kg CFC-11 eq
Ionizing Radiation	IR	kBq U235
Human Toxicity - Cancer Effects	HHC	CTUh
Terrestrial Eutrophication	TEP	mol N eq
Marine Eutrophication	MEP	kg N eq
Freshwater Eutrophication	FEP	kg P eq
Freshwater Ecotoxicity	FETP	CTUe
Freshwater and Terrestrial Acidification	AP	mol H+ eq

Fuel cell system

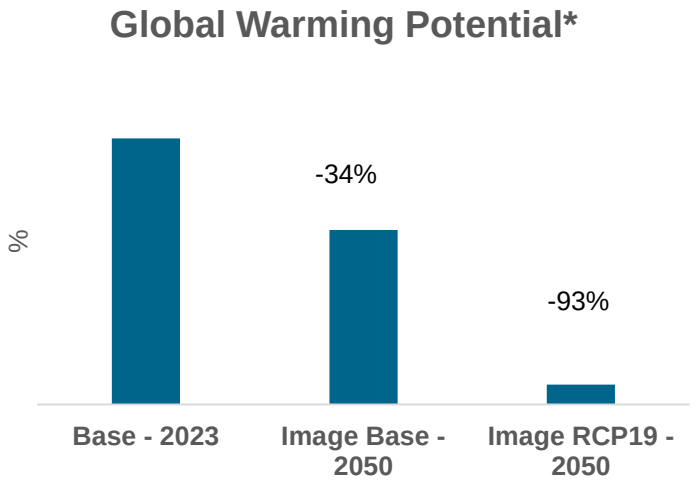


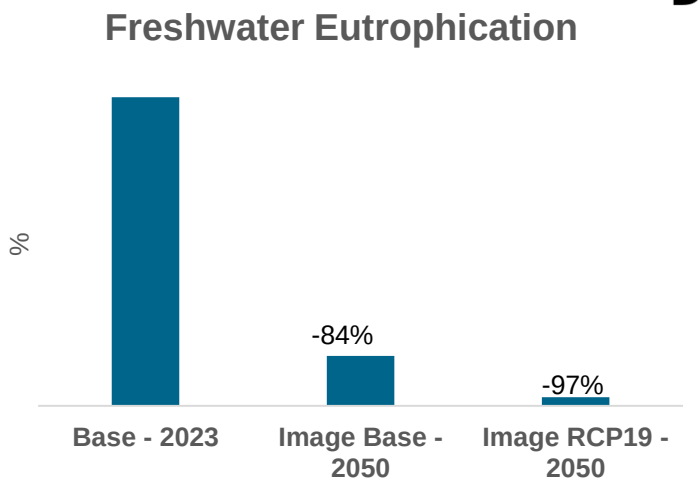
Fuel cell stack

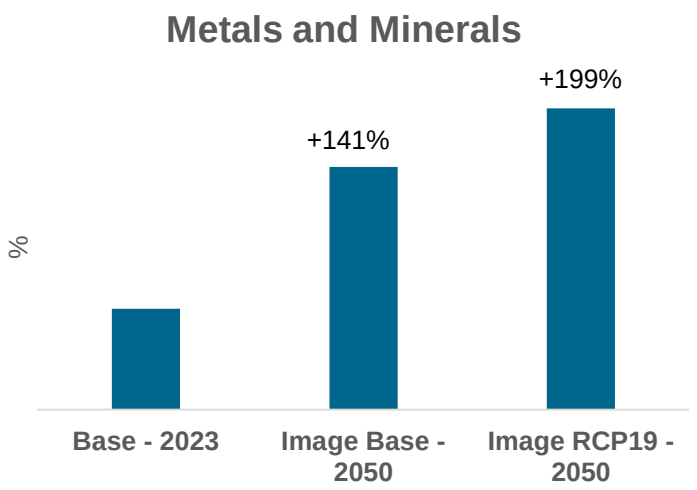


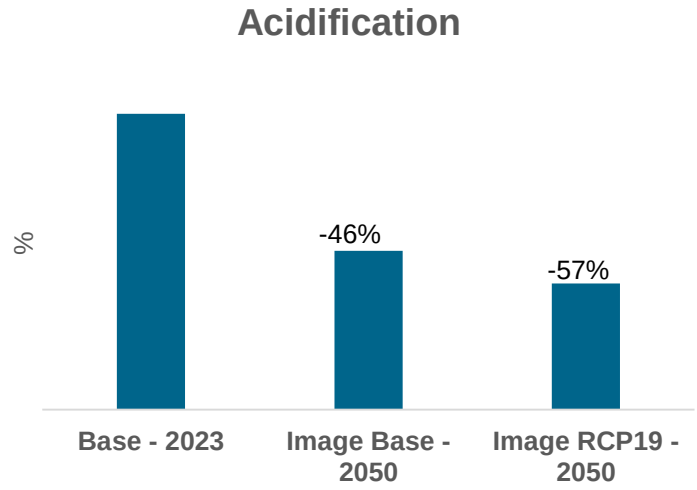
4. LCA Impact factors – Electricity Mix – 1 kWh

- GWP has reduced significantly → Rise of renewables and CCS/U technologies
- Freshwater eutrophication has decreased → reduction of spoil in coal mining
- Metals and minerals increased significantly → Copper and Silver usage in renewable energies
- Acidification reduced to half as production of coal and other fossils are shrunk



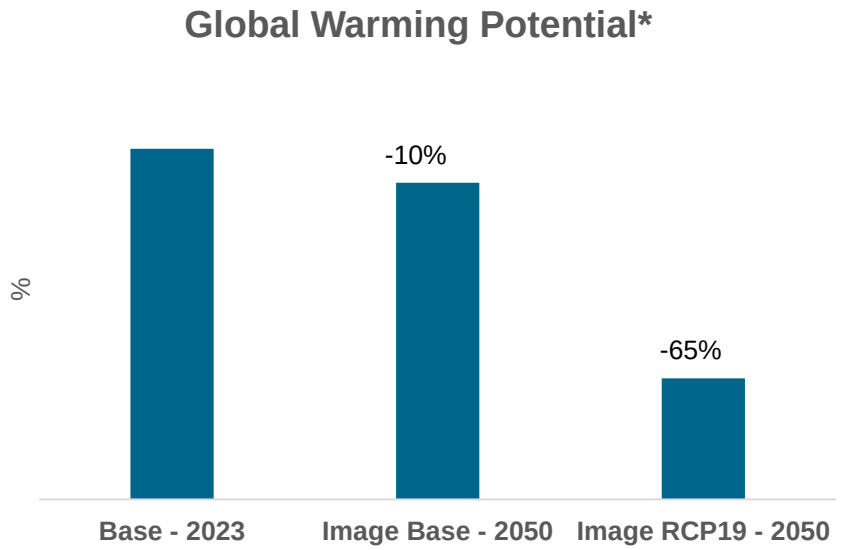


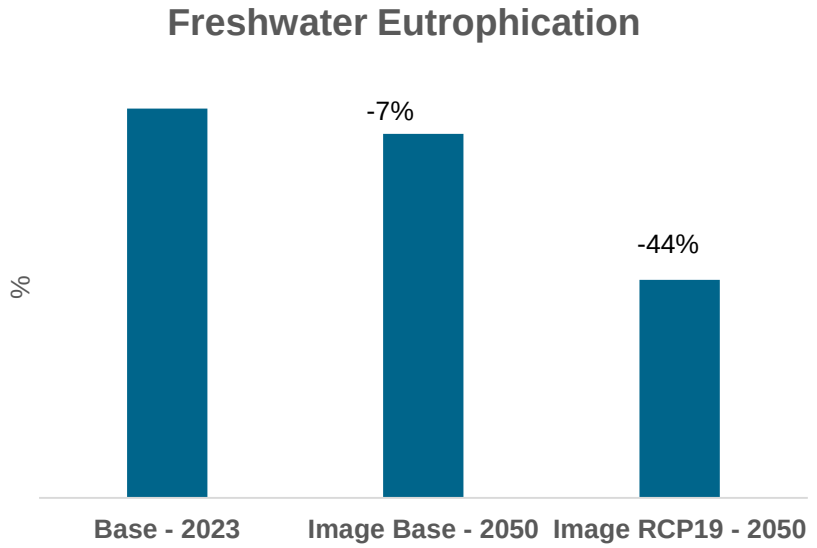


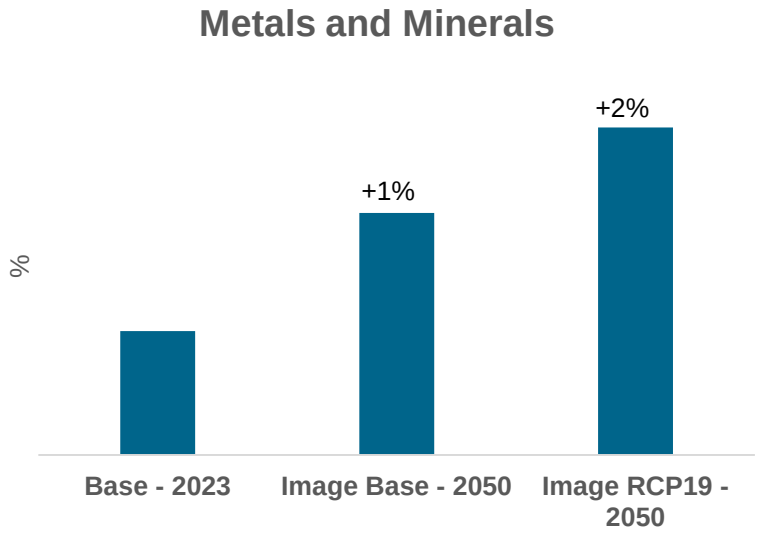


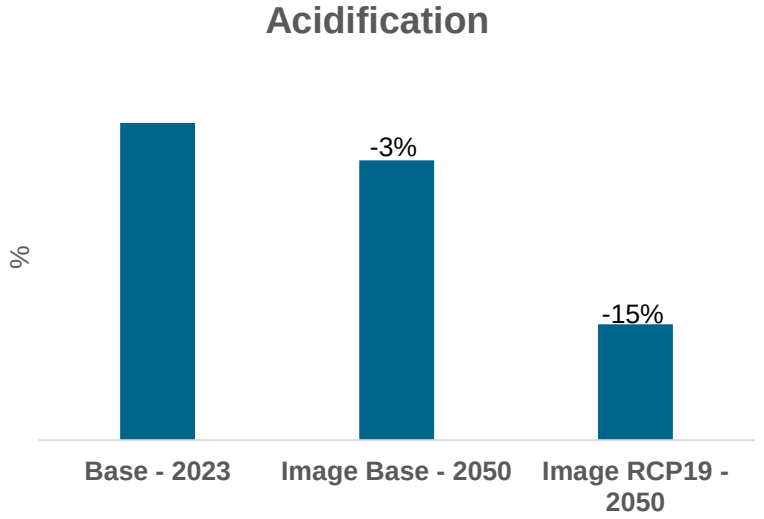
**X-axis represents the background scenarios*

4. LCA Impact factors – Fuel Cell









X-axis represents the background scenarios

5. Conclusion

Foreground system:

- It is important to consider **different impact categories** → The manufacturing of the fuel cell system also represent a high increase in materials and metal depletion
- The main contributor to most of the environmental impacts is the **catalyst** due to the amount of platinum
- **Recycling scenarios** for metals (e.g. platinum, lithium, cobalt, copper) should be also considered

Background system:

- In fuel cell manufacturing, electricity mix of Image RCP19 played a key role in **significant reduction** of GWP and Eutrophication
- Steel production in Image RCP19 scenario has **minimal effect** on impact factors owing to chromium steel

6. Outlook

- Development of a framework to link the foreground with user-defined background scenarios

- Background scenarios → Enhancement of scenario information
  - The IAM scenarios in Premise were not quite extensive in scope
  - IAM scenarios integrated only offers information at regional level
  - Link the DLR ESM scenarios → integrate country level data to Premise

- Testing on an use-case → TBD

Impressum

Topic:	*Prospective LCA of Future Propulsion Systems for Aviation: A Fuel Cell-Based Auxiliary Power Unit*
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