# BRIGHTCON 2024

Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

eXACT®

# Prospective Life Cycle Assessment of Future Propulsion Systems for Aviation: A Fuel-cell Based Auxiliary Unit for a Commercial Aircraft


STEFANY VILLACIS | VEATRIKI PAPANTONI | URTE BRAND-DANIELS | THOMAS VOGT

DLR Institute of Networked Energy Systems – Energy Systems Analysis, Carl-von-Ossietzky Str. 15, 26129 Oldenburg, Germany


## Background

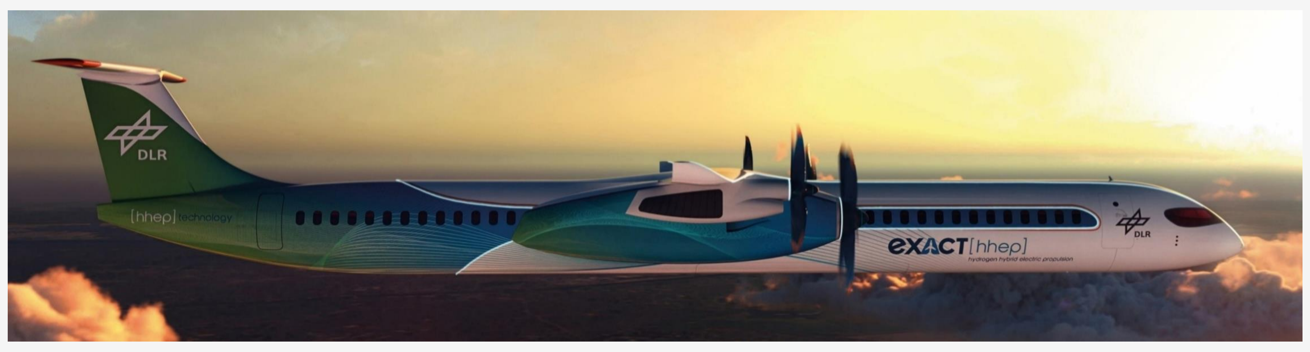

*Figure 1: Overview of one of the aircraft concepts studied in EXACT (DLR-SL)*

- In 2020, the aviation sector represented about 3,5 % of all human-induced $CO_2$ emissions worldwide, and it is expected to increase in the future [1].
- It becomes relevant to assess the environmental impacts of emerging lower-emission propulsion technologies.
- Within the DLR research project EXACT different aircraft concepts are investigated to achieve more sustainable commercial flights by 2040 (see Figure 1).

## This Study

- Conducts a prospective LCA to evaluate the potential environmental impacts in 2040 from the production of the propulsion technology (PEM fuel cell system powered by hydrogen) used in an aircraft concept. The PEM fuel system works as the auxiliary power unit (APU) to power all on-board systems, e-taxi and assisted idle operation systems.
- Considers the parameter uncertainty (due to inaccurate or lack of input data) of the foreground system by performing a “Global sensitivity analysis”.

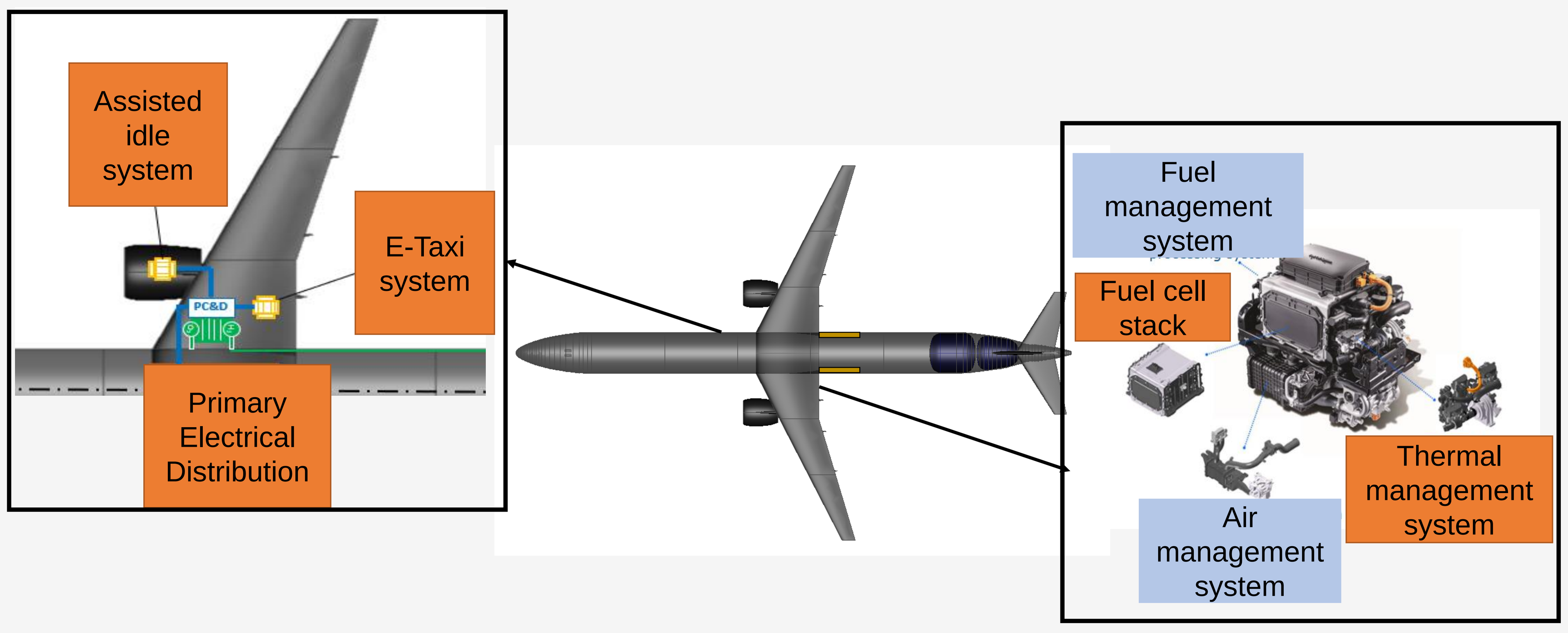


*Figure 2: Overview of the components of the PEM fuel system as APU for a hydrogen hybrid aircraft (DLR-SL)*

## Methodological approach

- Model of the life cycle inventory (LCI) of the fuel cell system based on primary and secondary data from ecoinvent 3.9.1. Prospective aspects and parameter uncertainty are included by following a systematic approach (see Figure 3).
- Identification the systems components that contribute the most to several impact categories according to E.F v 3 no LT.
- Conducting a global sensitivity analysis using the “Activity Browser” [2] to determine the main contributors of the total uncertainty for each impact category (500 iterations were performed due to current computing capacity).

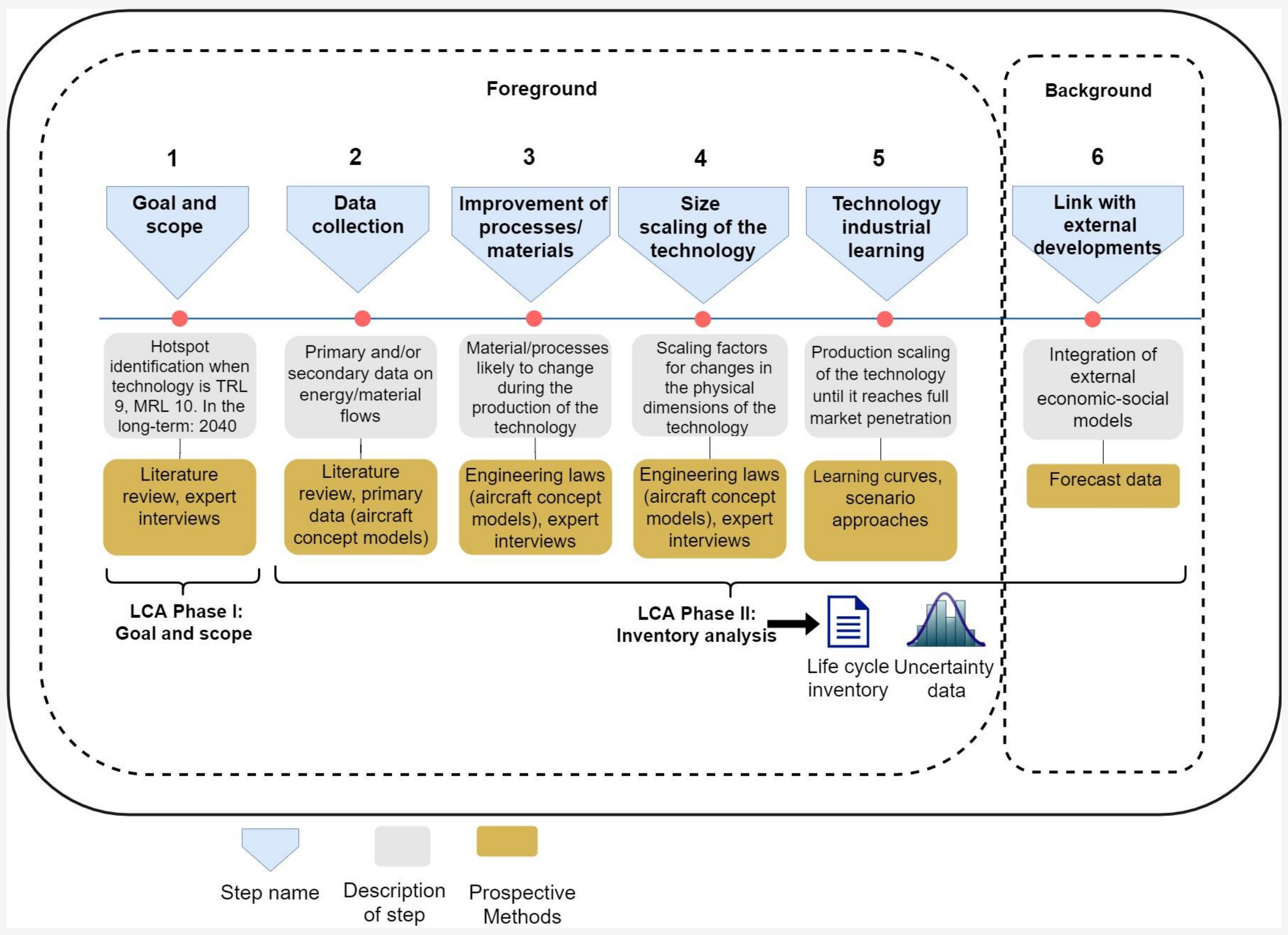


*Figure 3: Overview of framework to model the prospective LCI including uncertainty (own figure based on [3])*

## Results

**Contribution analysis of the production of the PEM fuel cell system (multiple impact categories):**

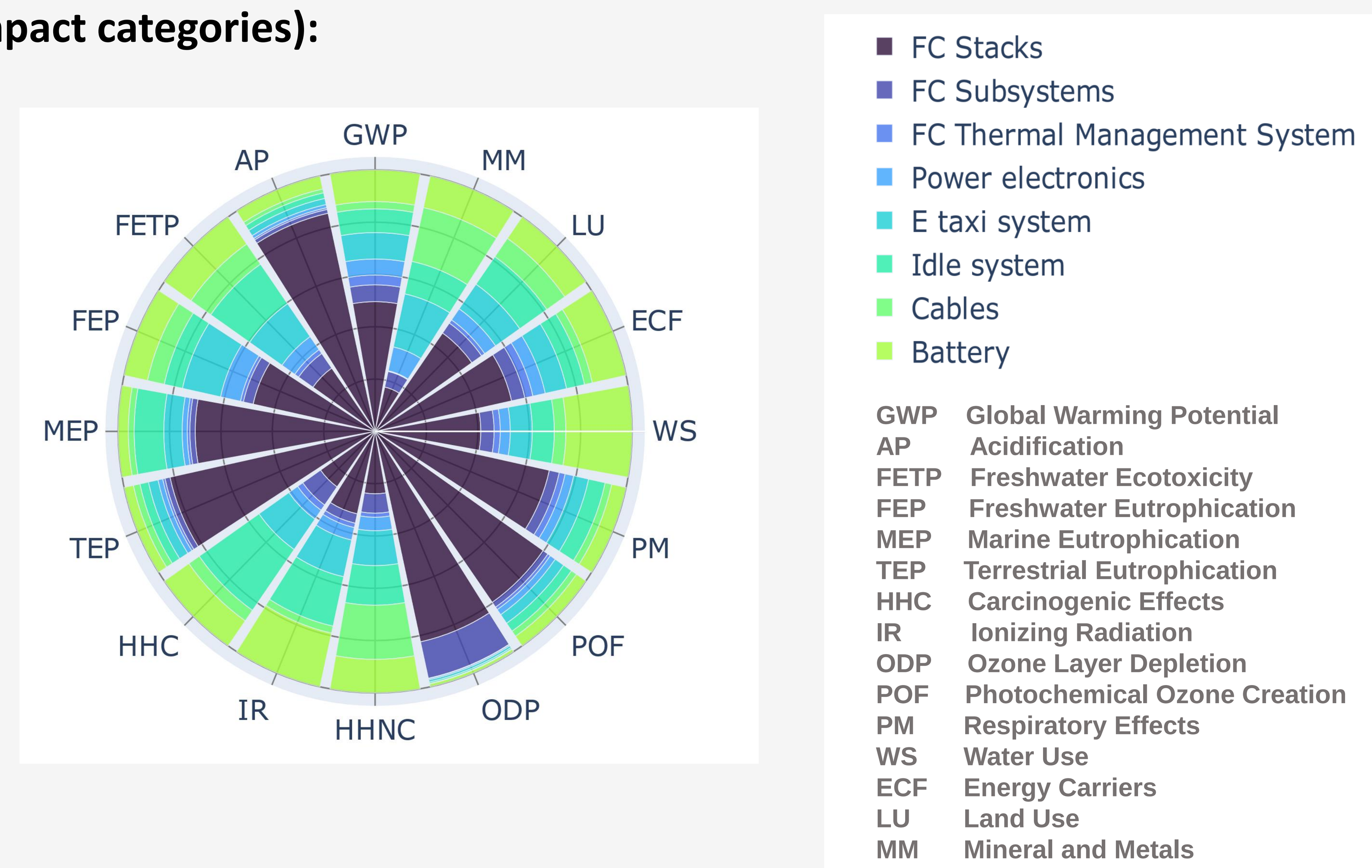


*Figure 4: Contribution analysis results on the PEM fuel-cell system for the aircraft concept (own figure)*

**Uncertainty analysis of the production of the PEM fuel cell system (global warming potential as example):**

1. ***Uncertainty propagation to the LCA results (Monte Carlo simulations):***

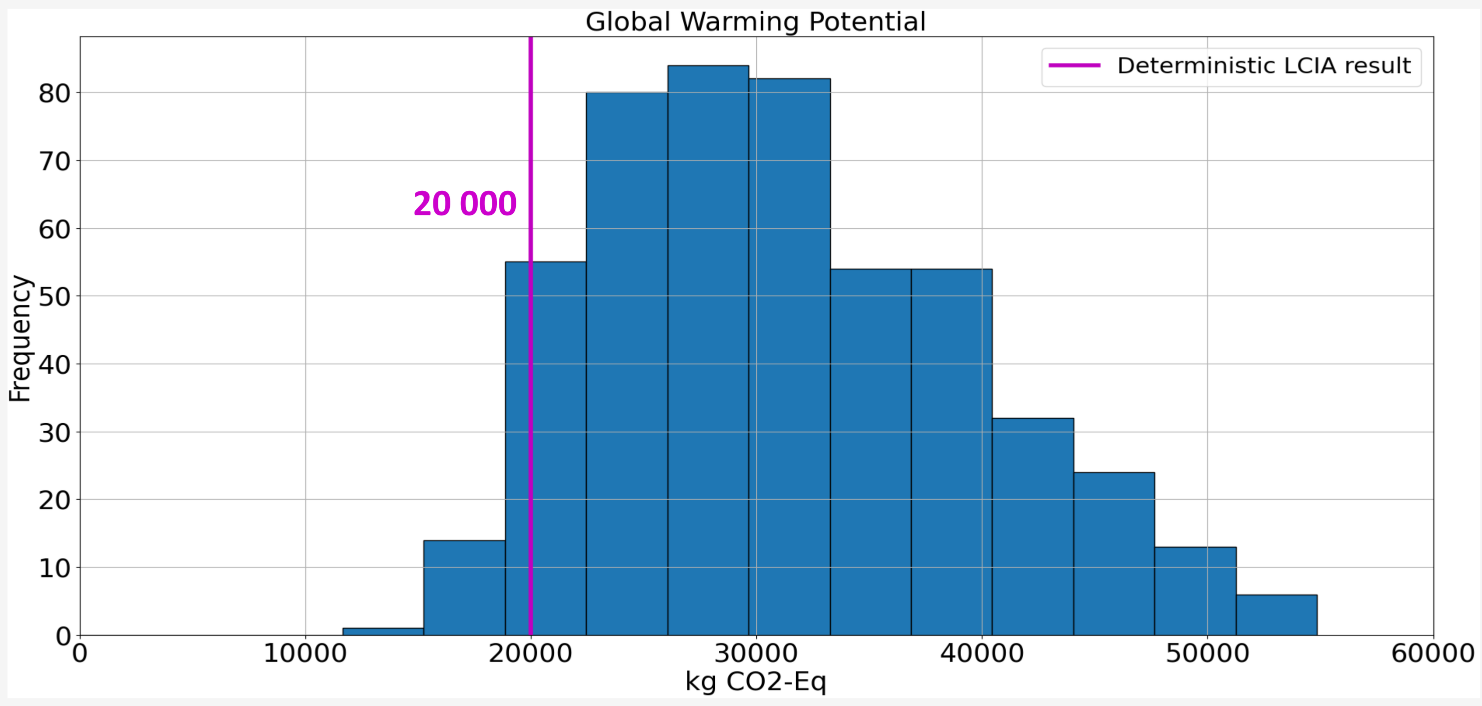


*Figure 5: Probability distribution function of the Global Warming Potential for the production of a PEM fuel cell system for the aircraft concept (own figure)*

2. ***Global Sensitivity Analysis : Ranking of most influential inputs with respect to the output uncertainty:***

| Rank | Exchange name |
|---|---|
| 1 | Aluminium production (electric motors, battery, etc) |
| 2 | Catalyst production for manufacturing the fuel cell stacks |
| 3 | Steel production (electric motors, battery, fuel cell stack) |
| 4 | Industrial heat used for smelting of copper (anode of the battery) |

## Conclusions and Limitations

- The higher contribution in most of the impact categories comes from the platinum in the catalyst of the fuel cell stacks. Therefore, recycling and end-of-life strategies should be further studied.
- The uncertainty inputs ranking analysis shows where to direct the data collection effort in order to obtain more robust results.
- The implementation of more detailed prospective aspects in the background system such as future scenarios on energy-intensive industries (e.g. steel) is important to be able to evaluate this type of new technology more holistically.
- This study is limited to the production phase of the technology. The environmental impacts during operation of the aircraft are modelled using other metrics (e.g. average temperature response) and more effort and expertise is needed to combined them with the LCA methodology.
- This study does not consider the parameter uncertainty in the characterization nor in the biosphere flows.

## Acknowledgements


The authors would like to thank Matthias Schröder (DLR Institute of Engineering Thermodynamics) and Georgi Atanasov (DLR Institute of System Architectures in Aeronautics) for their expertise and data provided for the case study.


## References


[1] Lee, D. S.; Fahey, D. W.; Skowron, A.; Allen, M. R.; Burkhardt, U.; Chen, Q. et al. (2021): The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. In: Atmospheric Environment 244, S. 117834. DOI: 10.1016/j.atmosenv.2020.117834.

[2] Cucurachi, Stefano; Blanco, Carlos Felipe; Steubing, Bernhard; Heijungs, Reinout (2022): Implementation of uncertainty analysis and moment-independent global sensitivity analysis for full-scale life cycle assessment models. In: J Ind Ecol 26 (2), S. 374–391. DOI: 10.1111/jiec.13194.

[3] van der Hulst, Mitchell K.; Huijbregts, Mark A. J.; Loon, Niels; Theelen, Mirjam; Kootstra, Lucinda; Bergesen, Joseph D.; Hauck, Mara (2020): A systematic approach to assess the environmental impact of emerging technologies: A case study for the GHG footprint of CIGS solar photovoltaic laminate. In: Journal of Industrial Ecology 24 (6), S. 1234–1249. DOI: 10.1111/jiec.13027


**23-27 september, 2024, Hamburg, Germany**