“ENVIRONMENTAL ASSESSMENT OF RENEWABLE HYDROGEN PRODUCTION IN EUROPE USING ALKALINE AND PROTON EXCHANGE MEMBRANE ELECTROLYSIS”

12th International Conference "Fuel Science – From Production to Propulsion"

Komal Mallesh Chougule

Institute of Networked Energy Systems, Oldenburg

Aachen - 11.06.2024

DLR

Agenda

Introduction

Background & Motivation

Case Study

Conclusions & Outlook

INTRODUCTION

Hydrogen: A key part of future Energy Systems

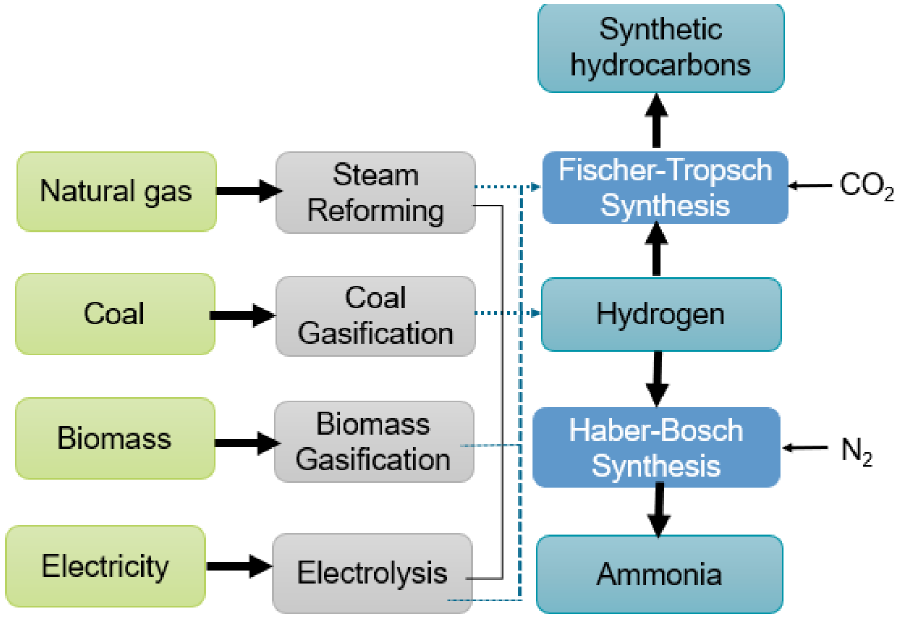
Fossil Fuel Production

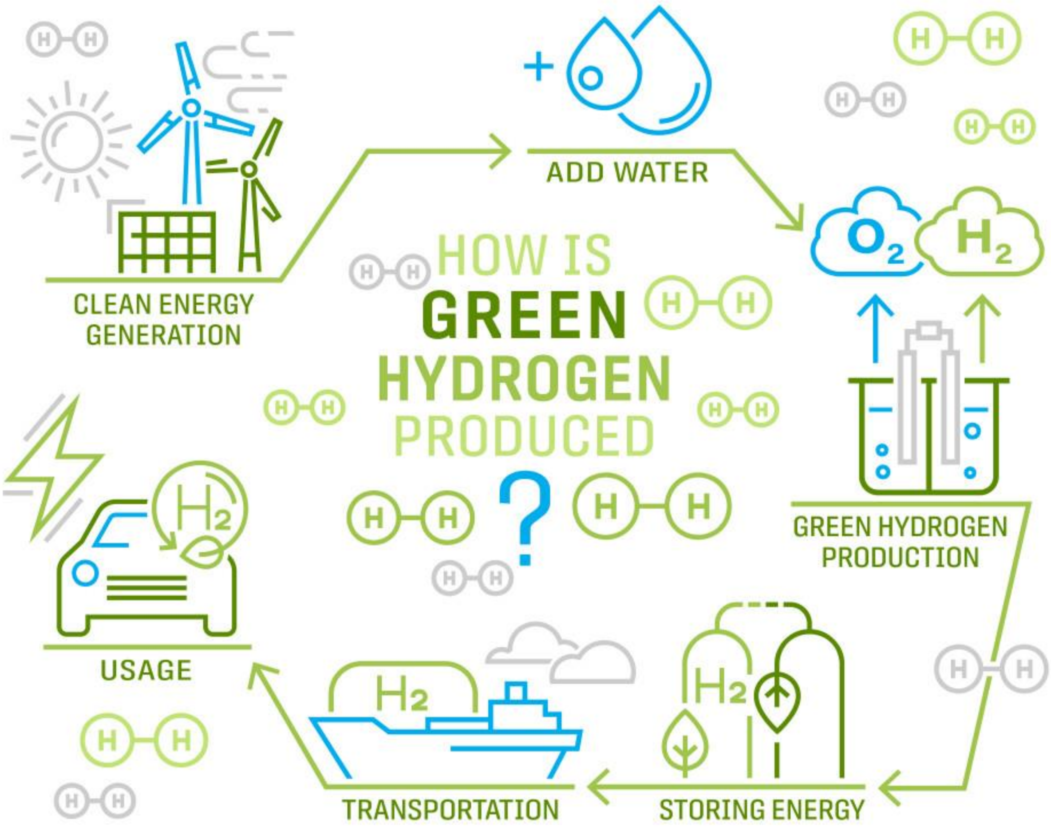
Renewable Energy

Hydrogen Applications

Green Hydrogen Produced?

Potential Pathways for producing hydrogen and hydrogen based Products





The Future of Hydrogen (iea.blob.core.windows.net)

Green hydrogen production landscape poster Vector Image (vectorstock.com)

Background and Motivation

The topic of LCA for marine fuels is getting more and more relevance

Assessment of Hydrogen fuel for sustainable transport sector

- Transport is one of the sectors considered as „hard-to-abate“ with respect to its climate impact.
- For eg. World yearly CO_2 emissions in 2021: 37,123 million tonnes; therefore, shipping releases 2.5 – 3% of world CO_2 emissions.[1]
- New solutions need to be found to reach the goals of the Paris Agreement of 2016.

This work:

- Environmental impact assessment of hydrogen production by electrolysis.
- Analysis includes **fuel production phase with compression and liquefaction.**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Meeting Summaries and schedule
IMO Assembly

Marine Environment Protection Committee (MEPC 80), 3-7 July 2023

1.Tackling climate change - cutting GHG emissions from ships

IMO has developed global regulations on energy efficiency for ships (read more here) and continues to take concrete actions to ensure that international shipping bears its fair share of responsibility in addressing climate change.

After several months of negotiations, the MEPC 80 session adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, with enhanced targets to tackle harmful emissions. Read full details here.

Life cycle GHG assessment guidelines adopted

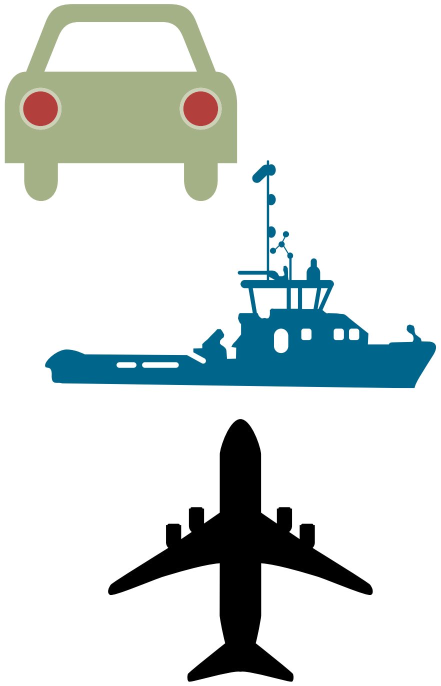
The MEPC adopted Guidelines on life cycle GHG intensity of marine fuels (LCA guidelines). The LCA guidelines allow for a Well-to-Wake calculation, including Well-to-Tank and Tank-to-Wake emission factors, of total GHG emissions related to the production and use of marine fuels.

[1]Source: IMO Fourth GHG Study

DLR: Projects

Matrose

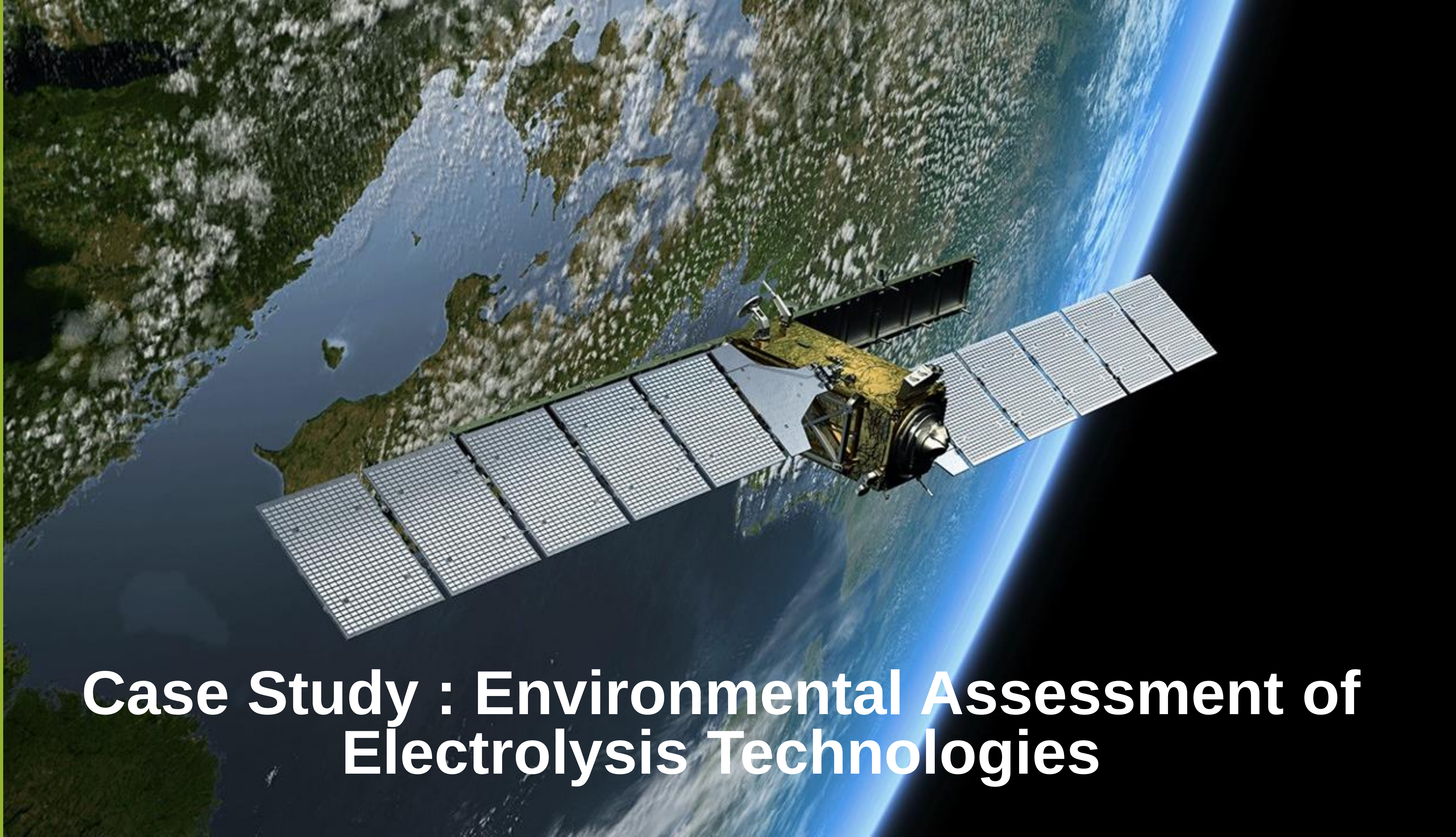
Assessment of maritime fuels (H_2 , NH_3, Syn CH_4) using LCA(Life cycle assessment) and LCC(Life cycle cost) to quantify the environmental and economic effects at their production and use phase



Neofuels

Assessment of different production routes of synthetic fuels with regard to sustainable indicators using existing lifecycle-based methods

- Focused alternative fuels
- Hydrogen (H_2) , Ammonia (NH_3) , Methanol (CH_3OH) , Fischer-Tropsch fuels (mix of hydrocarbons, often alkanes with formula (C_nH_{2n+2})

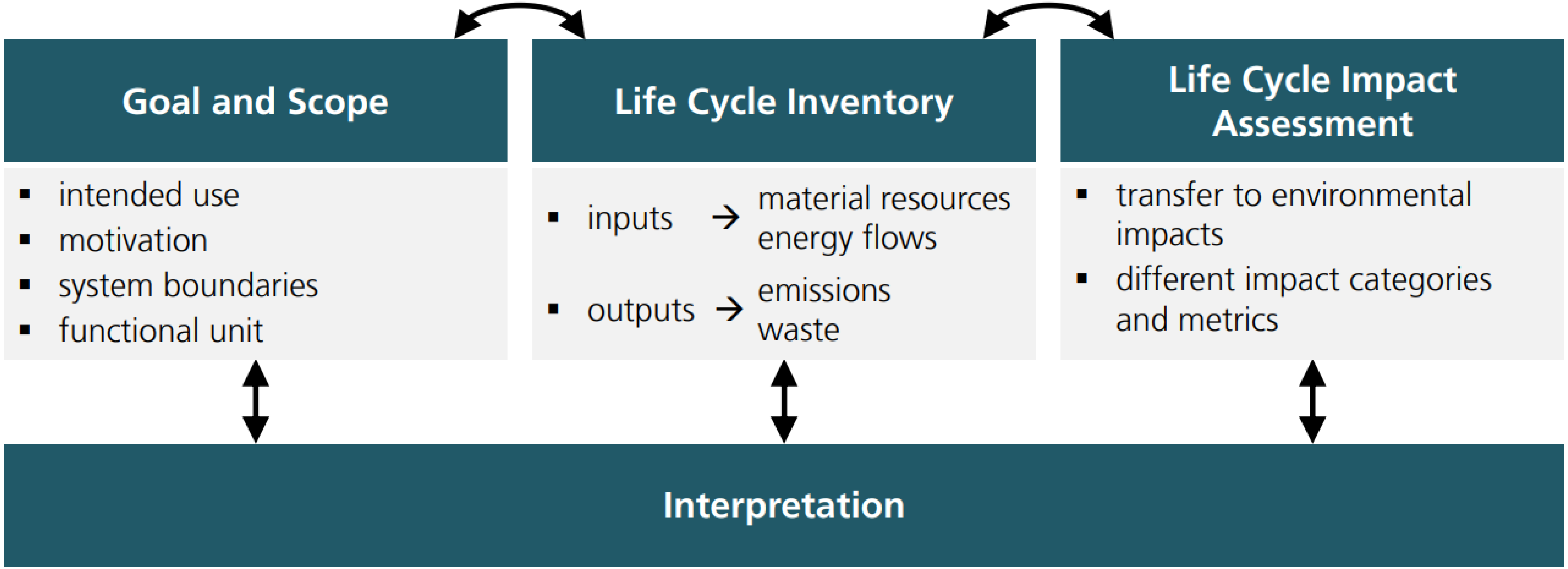


Case Study : Environmental Assessment of Electrolysis Technologies

Methodology: Life Cycle Assessment (LCA) – DIN EN ISO 14040 & 14044

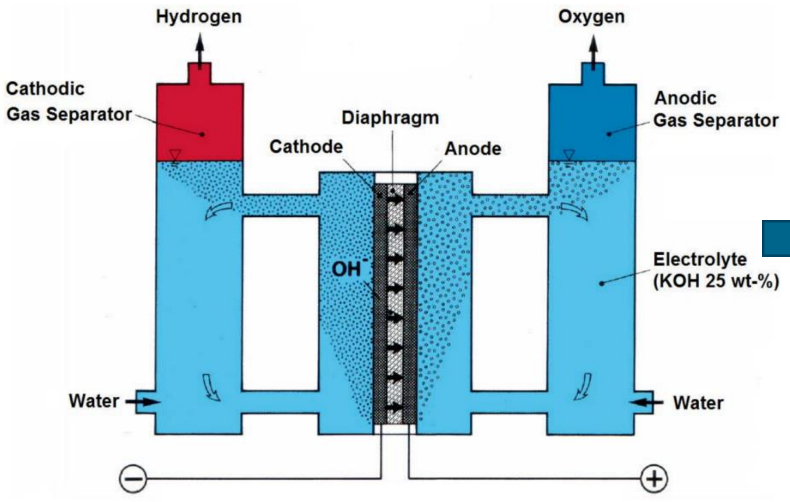
Life Cycle assessment

“LCA is a tool for examining the total environmental impact of a product through every step of its life”

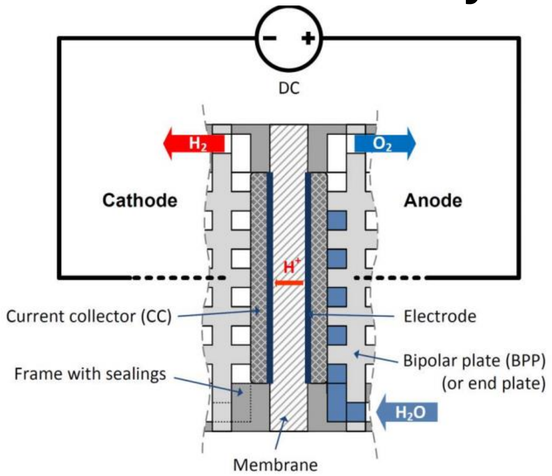


from DIN EN ISO 14040/14044

Hydrogen Production: Alkaline(AEL) & Proton Exchange Membrane Electrolysis (PEMEL)



Alkaline Electrolysis (AEL)



Proton exchange membrane Electrolysis (PEMEL)

Specification	AEL	PEM
Electrolyte	25-30% KOH aqueous solution	Solid Polymer
Operating Temperature(°C)	60 - 80	50 – 80
Pressure (bar)	2–35	15–40
Efficiency (%)	50 -78	50 - 83
Technology readiness Level (TRL)	9	8
Electrodes and catalysts	an: Ni, Fe cat: Ni/Ni-Co + Pt	an: Ti + Ti/RuO2 , IrO2 cat: Ti + Pt
Development status	Mature	Commercialized

[An overview of water electrolysis technologies for green hydrogen production - ScienceDirect]

[Modeling alkaline water electrolysis for power-to-x applications: A scheduling approach ScienceDirect]

Case Study: Methodology Overview

Goal and scope definition of the Lifecylce Assessment (LCA)

Goal of our study	Compare the environmental Impacts of Alkaline (AEL) and Proton Exchange membrane (PEMEL) electrolysis using different datasets by Life cycle assessment
Temporal Boundaries	2020 - 2050
Location	Germany, Denmark and Spain
Software and Database	Activity Browser & Ecoinvent Database 3.9.1
Impact assessment method	Environmental Footprint 3.1
Functional Unit	1 kg of LH_2 (LHV)
Environmental Impacts	Global warming potential, Acidification , Eutrophication, Land use, Ecotoxicity, Human Toxicity

System Boundary : Well-to-gate

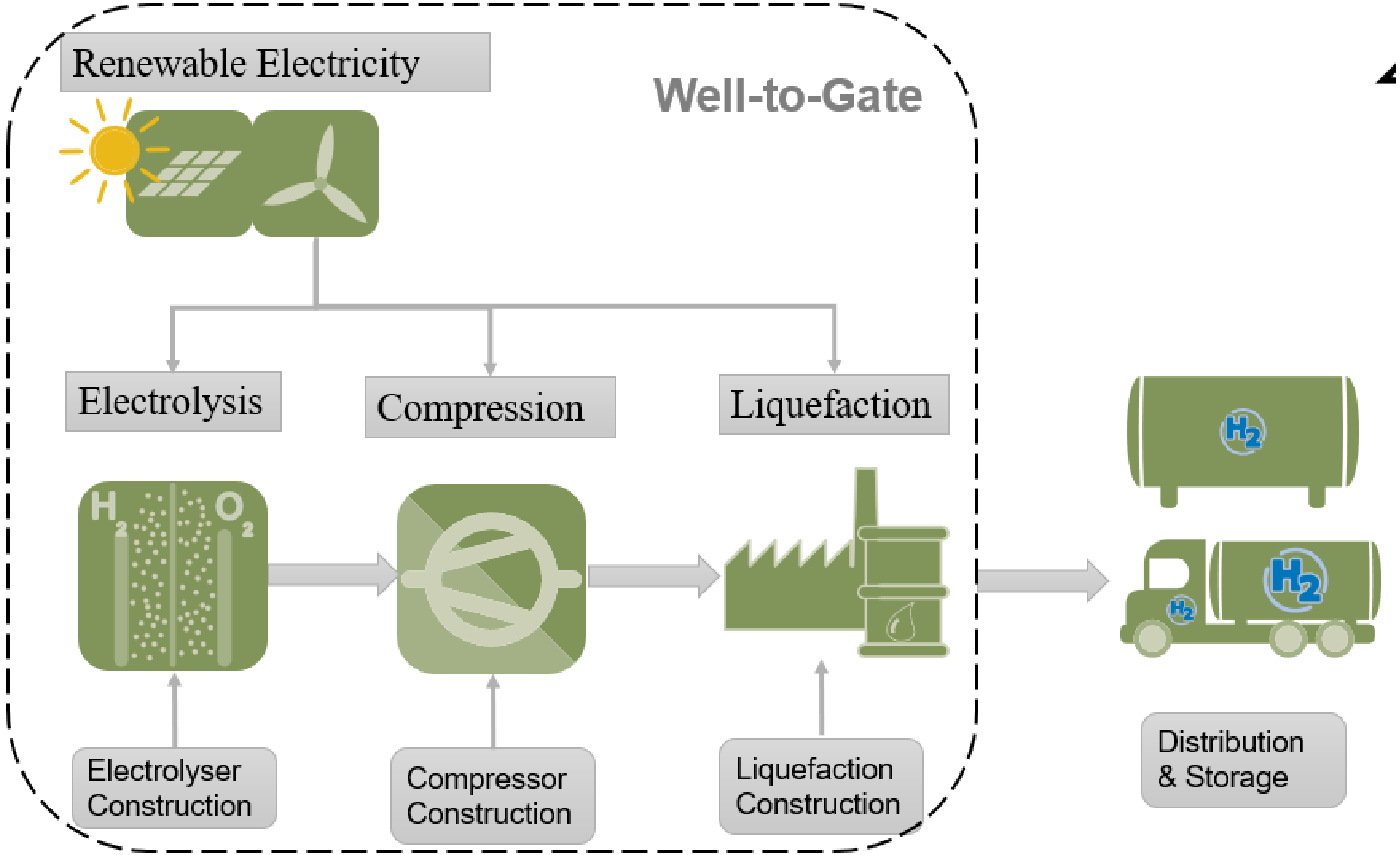


Figure 1: Schematic overview of hydrogen supply chain used in this study (Well to Gate). Source: Own plot

Life Cycle Inventories: Assumed Hydrogen Supply Chain

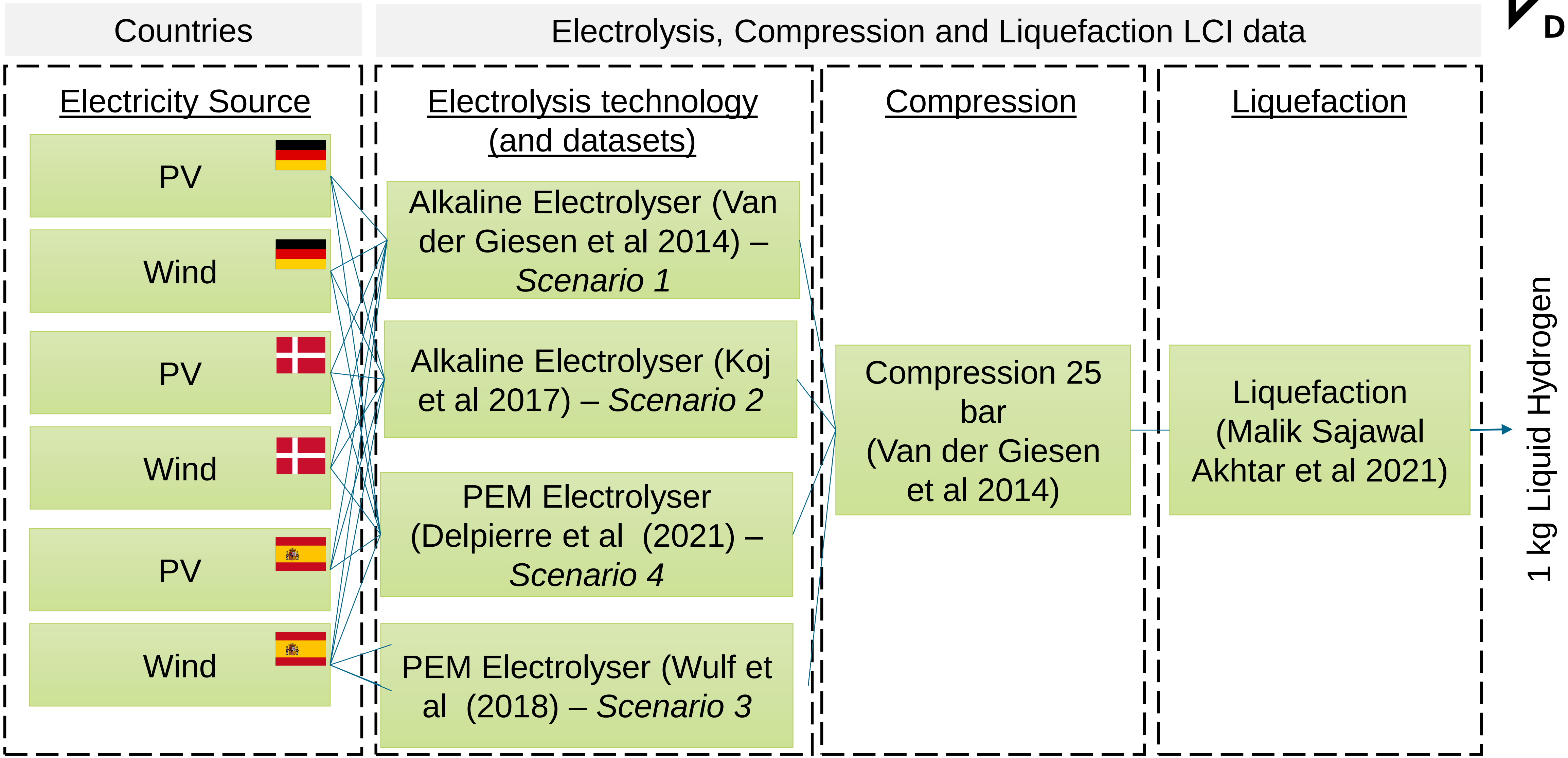


Figure 3: Hydrogen supply chain for selected countries and LCI datasets. Own plot

Assumptions considered from Literature Sources

	Scenario 1 : AEL (Van der Giesen)	Scenario 2: AEL (Koj)	Scenario 3: PEM(Delp)	Scenario 4 : PEM (Wulf)
Efficiency (%)	**58**	**66**	**60**	**66**
Functional unit	1 MJ of fuel	1 kg of hydrogen	1 kg of hydrogen	1 kg of hydrogen
Lifetime (years) stack	10	10	30	8
Data age	2014	2017	2021	2018
System boundary	Cradle to Gate	Cradle to Gate	Cradle to Gate	Cradle to Gate
Software	Cmlca version 5.2	Gabi	Openlca	Umberto
Impact assessment method	-	ILCD	ILCD	CML
Secondary database	Ecoinvent 2.2	Ecoinvent 3.1	Ecoinvent 3.4	Ecoinvent 3.1
Compression & Liquefaction	Included	Not included	Not included	Not included

Results:

Hydrogen Production (Electrolysis) + Compression (25bar) + Liquefaction

Results: Life Cycle Assessment – contribution analysis

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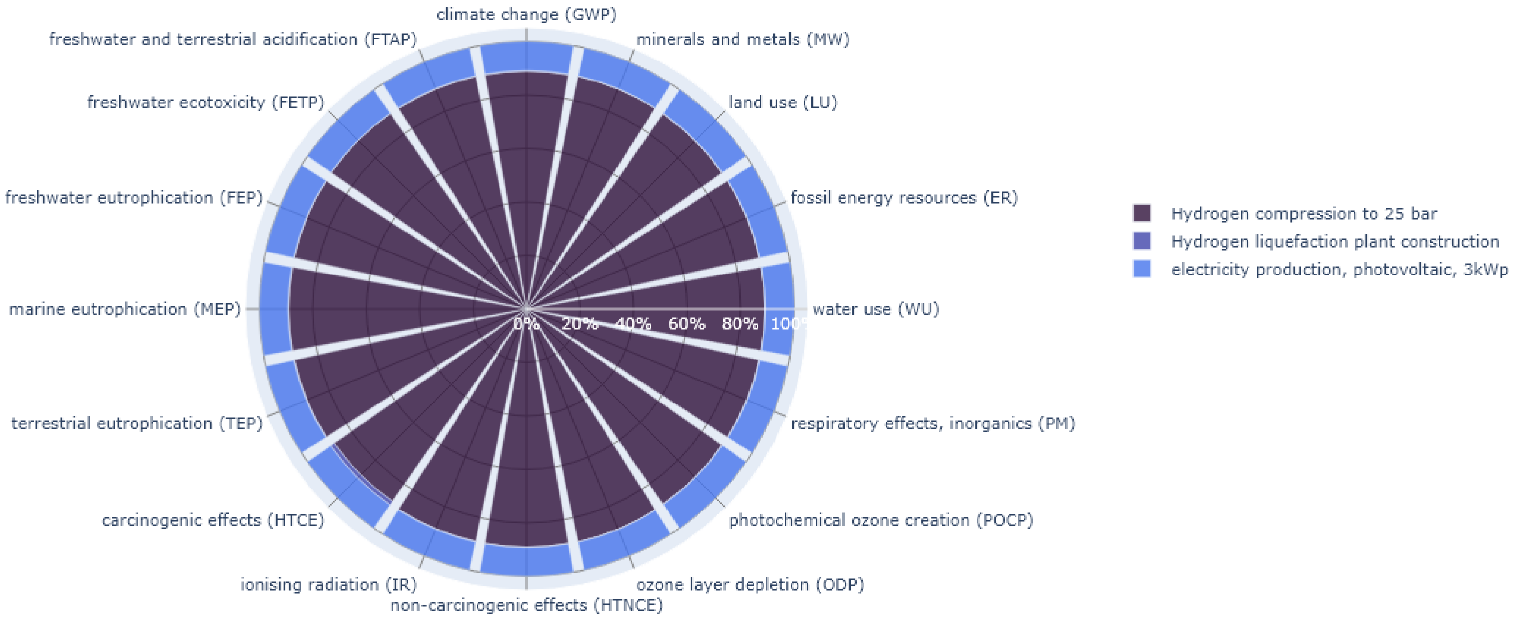
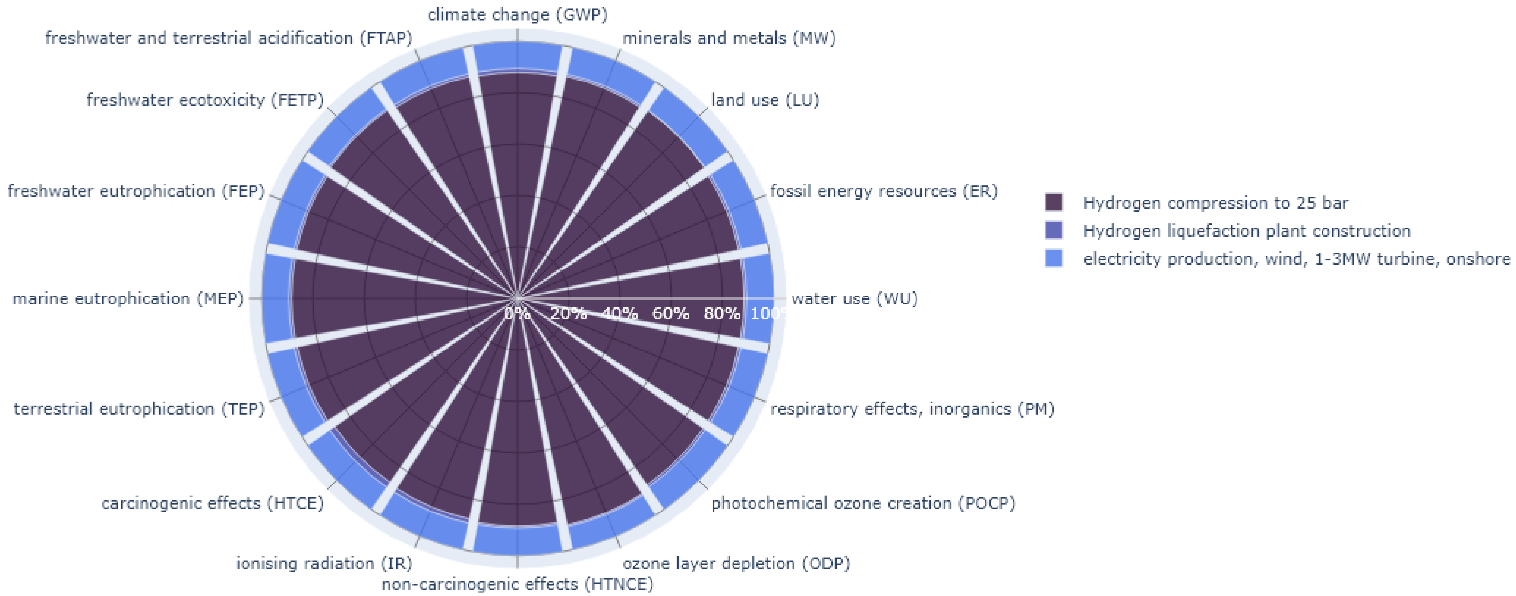
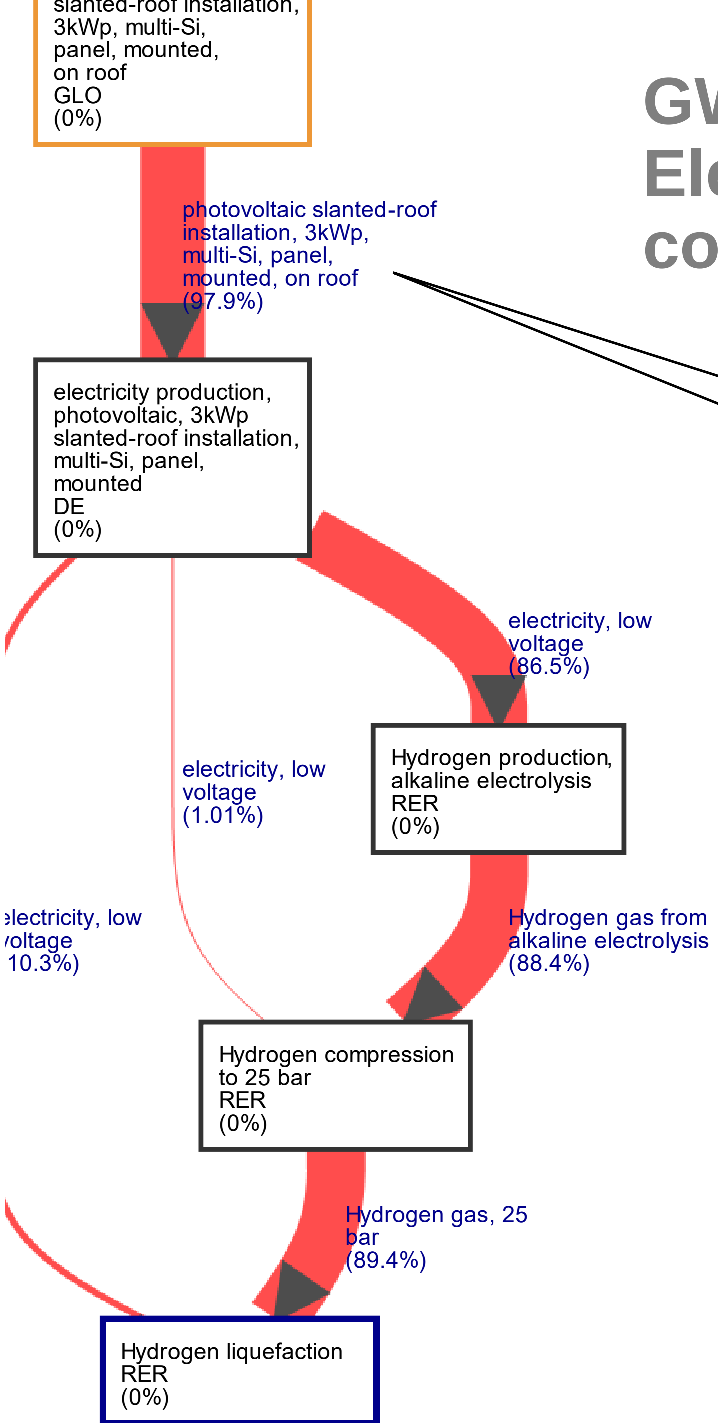
Impact category	Abbrev	Unit
Global Warming Potential	**GWP**	**kg CO2 eq**
Resources - Minerals and Metals	**MM**	**kg Sb eq**
Land Use	**LU**	**soil quality index**
Resources - Energy Carriers	ECF	MJ
Water Scarcity	WS	m^3 water
Particulate matter/ Respiratory inorganics	PM	Disease incidences
Photochemical 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**





GWP Sankey Diagram: Alkaline Electrolysis (AEL) with compression and liquefaction



97 % impacts from electricity source

Results of LCA – Climate change

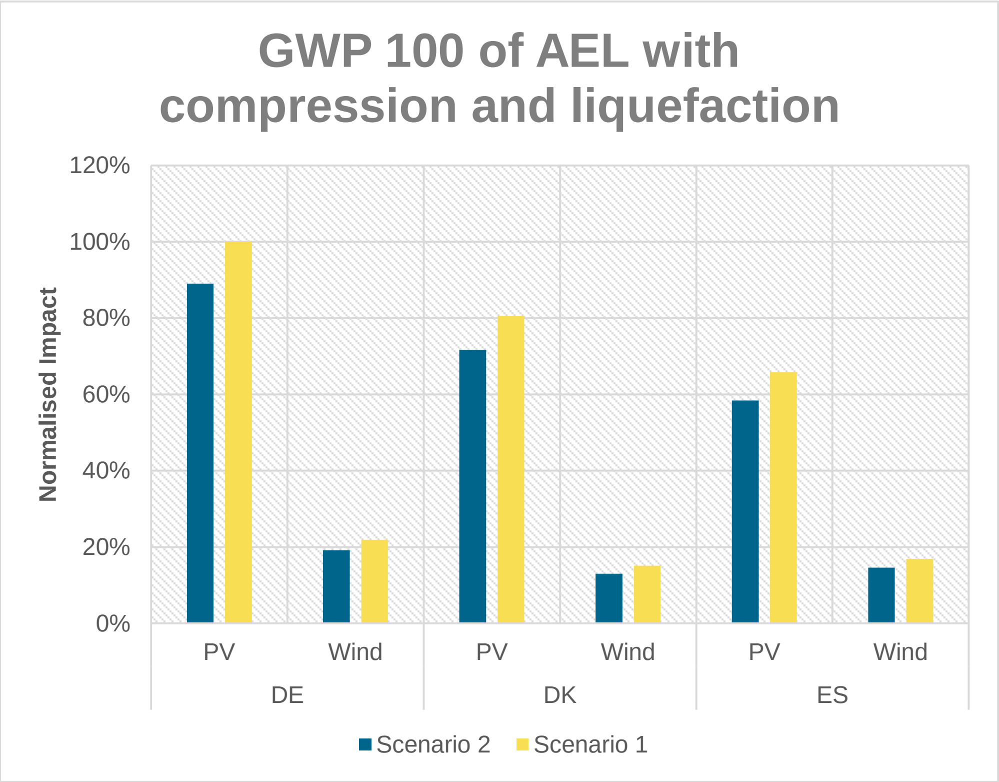


Figure 2 : Impacts of production the production (AEL), compression and liquefaction of hydrogen for different electricity sources, locations and using two different LCI sources for electrolysis.

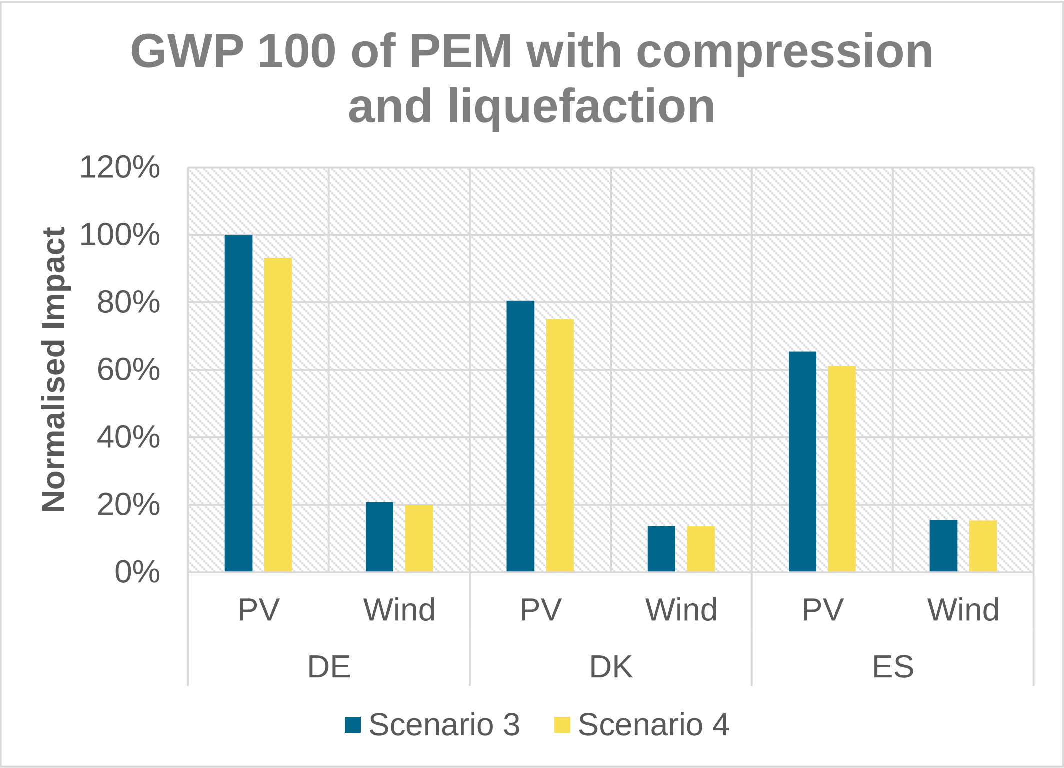
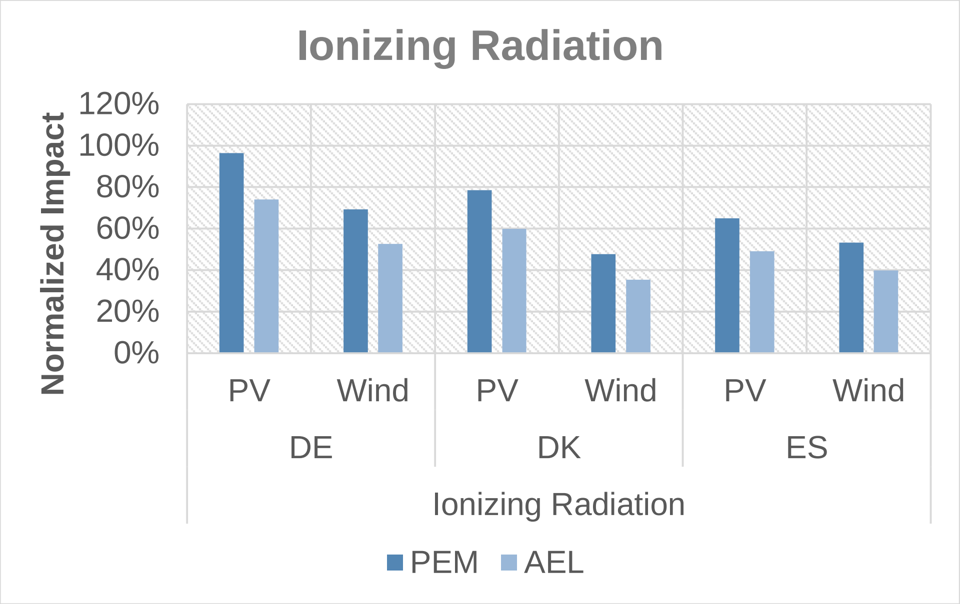
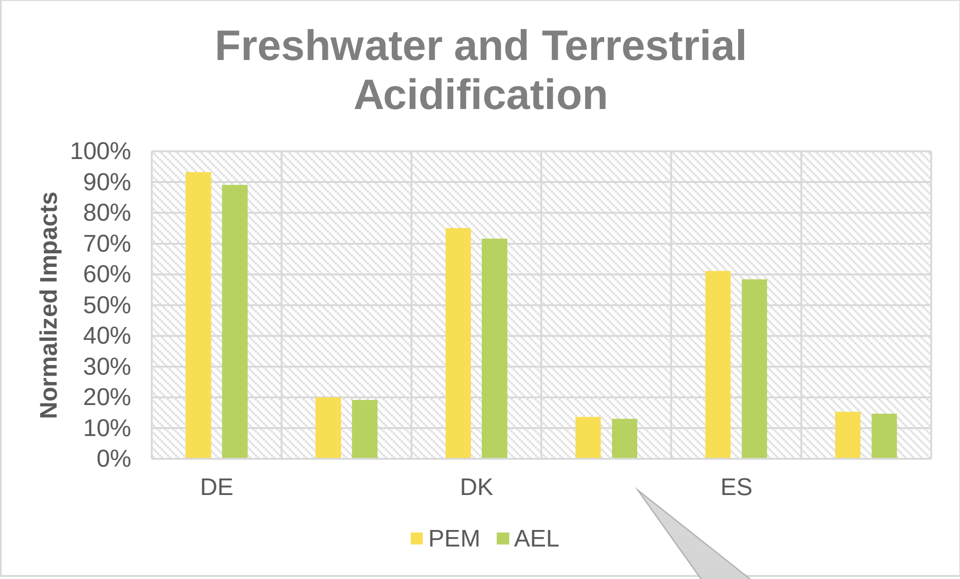


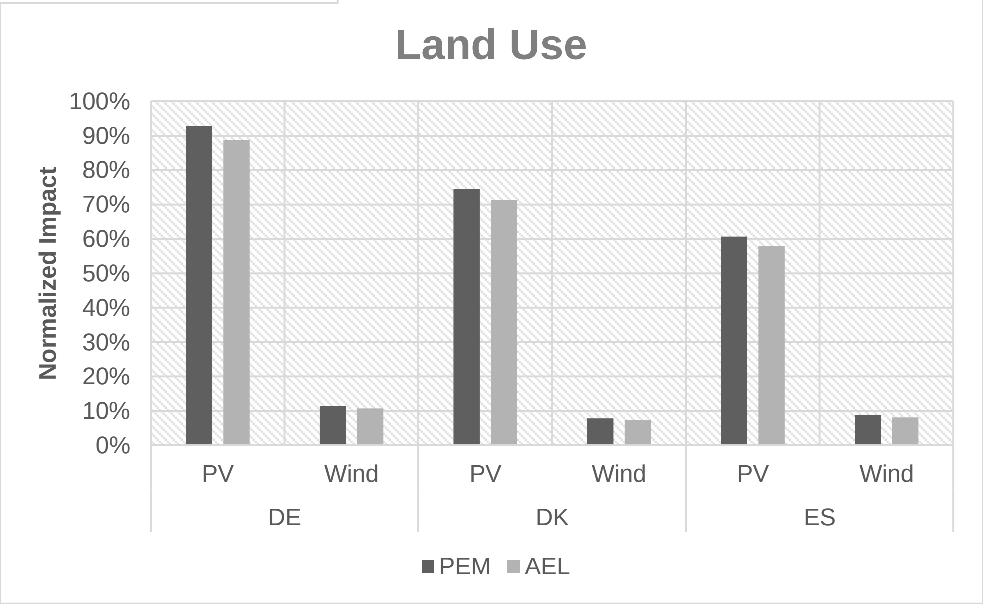
Figure 3 : Impacts of production the production (PEM), compression and liquefaction of hydrogen for different electricity sources, locations and using two different LCI sources for electrolysis.

Results of LCA – Other impact categories





Slightly higher impact for PEM Electrolysis



Komal Mallesh Chougule, Institute of Network Energy Systems, DLR 11.06.2023

Conclusion

Environmental Assessment:

- The potential of environmental impact of Hydrogen fuel from renewables such as PV and wind to reduce climate impact of transportation sector has been assessed.
- In Hydrogen production, source of **Electricity** played a key role in **significant reduction** of GWP.

- Environmental impacts during production depend greatly on location, influenced by the site-specific renewable potential, as the chosen electricity production technology (wind vs. PV) has vastly different life cycles and environmental effects.

- Within the scenarios the impacts from Spain are lower than Germany and Denmark due to the higher solar resource in that selected location.

Outlook

- Consider the environmental impacts from transport and distribution of hydrogen.
- As, a part of project hydrogen is used for the production of ammonia production by Haber-Bosch process and methanol production.
- Together with environmental impacts the economic costs are should be taken into consideration.

References

Environmental Assessment

- Koj, J. C., Wulf, C., Schreiber, A., & Zapp, P. (2017). Site-dependent environmental impacts of industrial hydrogen production by alkaline water electrolysis. *Energies*, *10*(7), 860.
- van der Giesen, C., Kleijn, R., & Kramer, G. J. (2014). Energy and climate impacts of producing synthetic hydrocarbon fuels from CO2. *Environmental science & technology*, *48*(12), 7111-7121.
- Delpierre, M., Quist, J., Mertens, J., Prieur-Vernat, A., & Cucurachi, S. (2021). Assessing the environmental impacts of wind-based hydrogen production in the Netherlands using ex-ante LCA and scenarios analysis. *Journal of Cleaner Production*, *299*, 126866.
- Wulf, C., & Kaltschmitt, M. (2018). Hydrogen supply chains for mobility—environmental and economic assessment. Sustainability, 10(6), 1699.

Contact

Msc. **Komal Mallesh chougule** | Research Scientist

Komalchougule@dlr.de

German Aerospace Center (DLR)

Institute of Networked Energy Systems

Oldenburg, Germany

Electricity data from ecoinvent 3.9.1

Name Dataset	Country											
	BE	DE	DK	FI	FR	GB	LT	LV	NL	NO	PL	SE
electricity production, wind, >3MW turbine, onshore												
electricity production, wind, 1-3MW turbine, onshore												
electricity production, wind, <1MW turbine, onshore												
electricity production, wind, 1-3MW turbine, offshore												
electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted												
electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted												
electricity production, photovoltaic, 570kWp open ground installation, multi-Si												

Figure 4: Renewable Energy dataset availability in the database ecoinvent 3.9.1. Green means a dataset is available and red unavailable.

LCA Results: Comparison of Alkaline Electrolysis (AEL) Datasets, Locations and Electricity Sources

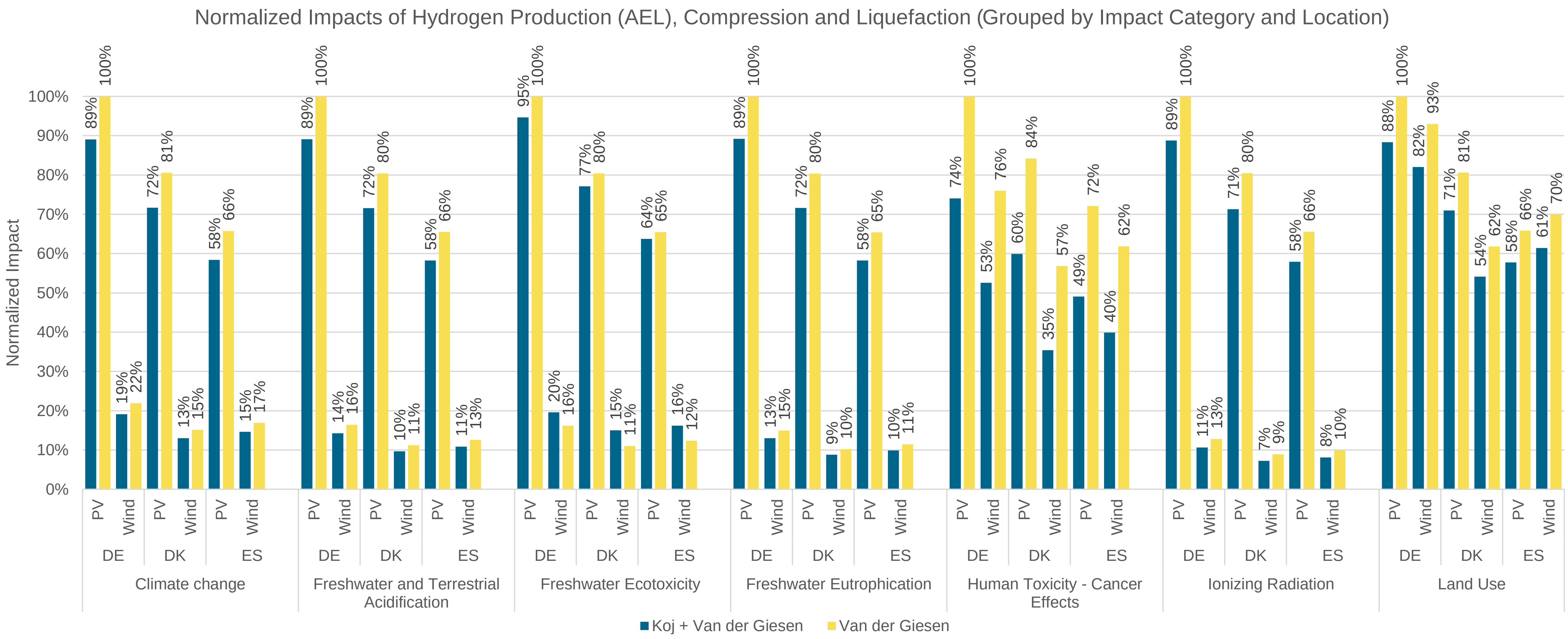


Figure 5: Comparison of the impacts of production the production (AEL), compression and liquefaction of hydrogen for different electricity sources, locations and using two different LCI sources for electrolysis. Source: own plot with LCI Data taken from (van der Giesen et al 2014) and (Koj et al 2017)

LCA Results: Comparison of Proton Exchange Membrane (PEMEL), Locations and Electricity Sources

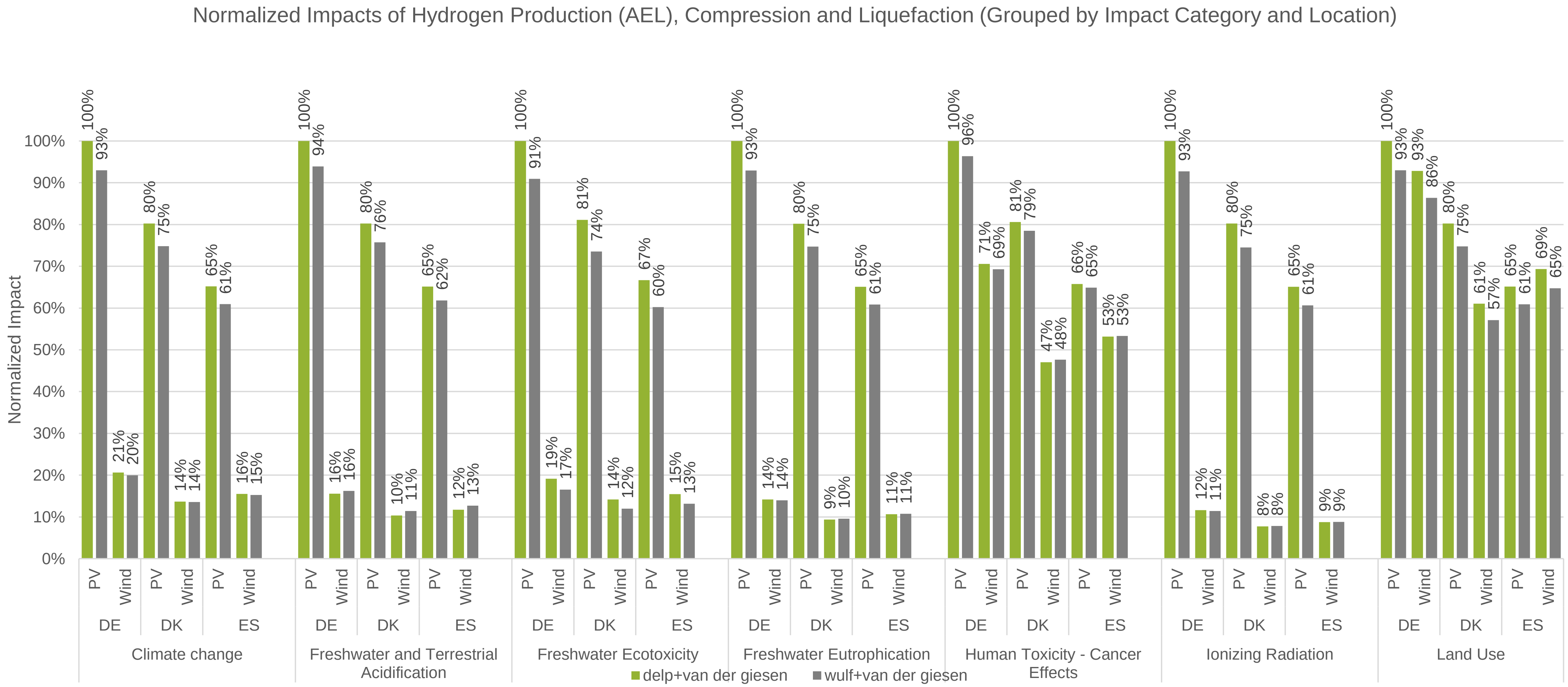


Figure 6: Comparison of the impacts of production the production (PEMEL), compression and liquefaction of hydrogen for different electricity sources, locations and using two different LCI sources for electrolysis. Source: own plot with LCI Data taken from (Delpierre et al 2021) and Wulf et al 2017)

LCA Results: Comparison AEL and PEMEL

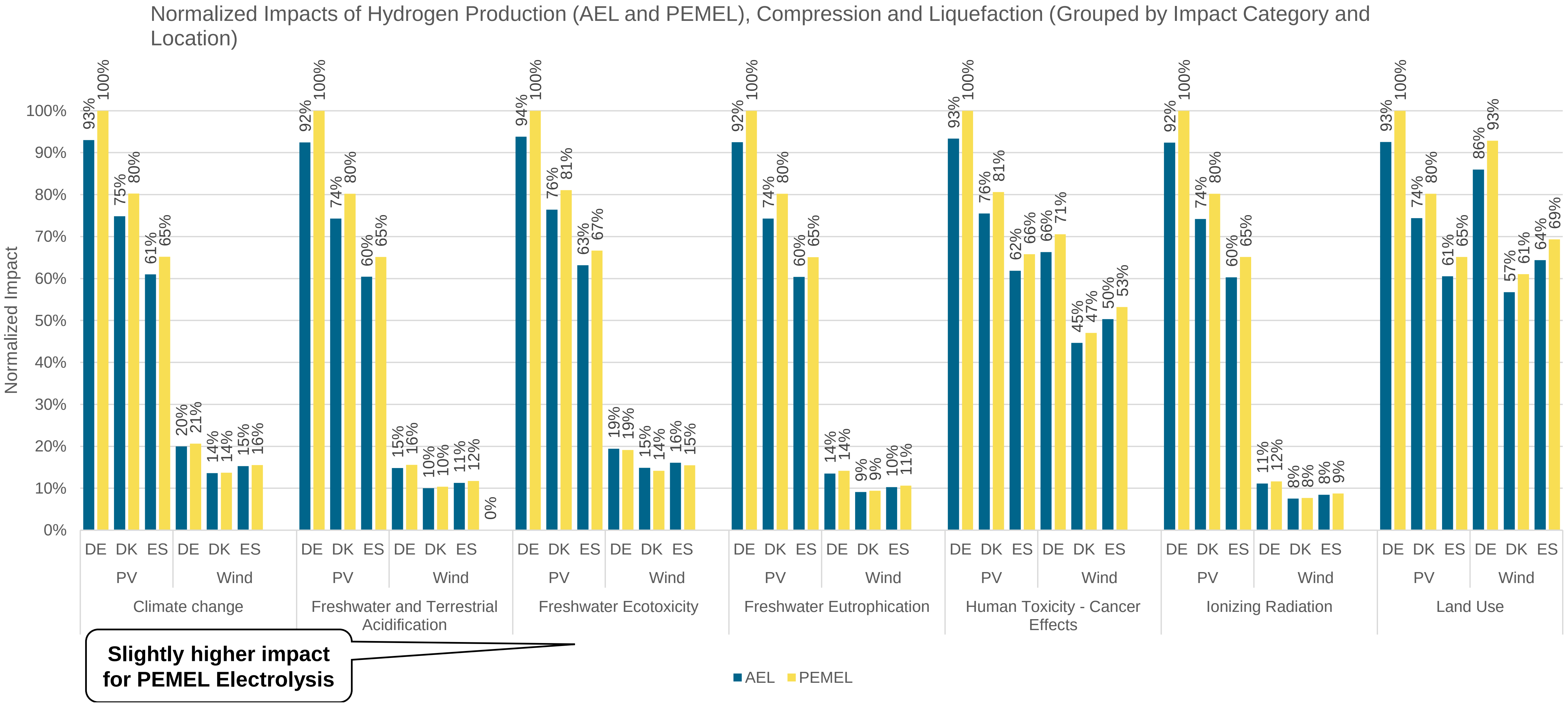


Figure 7: Comparison of the Impacts of production the production (AEL + PEMEL) compression and liquefaction of hydrogen for different electricity sources, locations. Source: own plot with LCI Data taken from (Koj et al 2017), (Delpierre et al 2021)