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Hydrogen Supply Chain Modelling at Fraunhofer ISE - From Global to Local -

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RD20 Conference 2025 – Technical Session
Tsukuba
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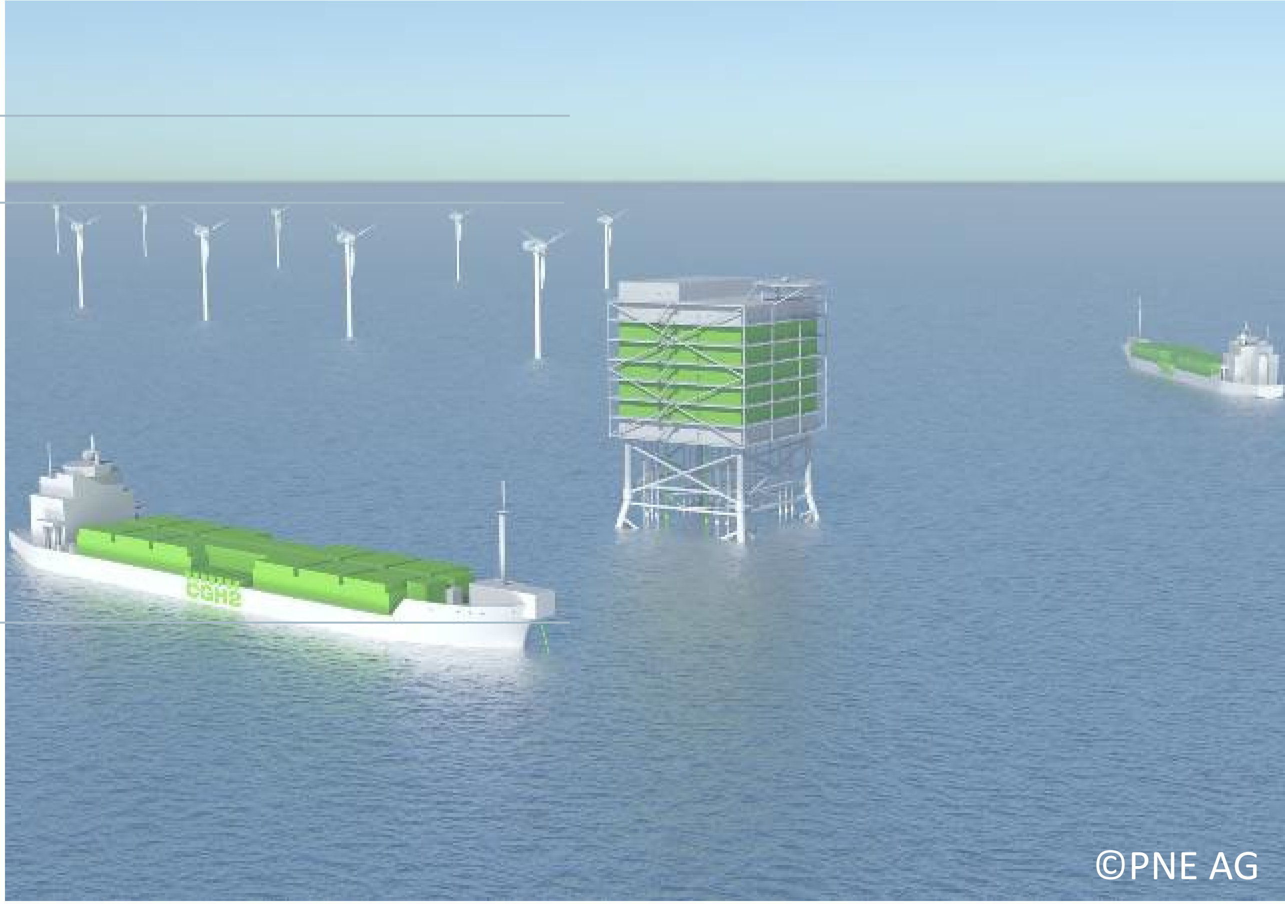
Agenda

- Hydrogen Technologies at Fraunhofer ISE
- Methodology Overview
- Exemplary Modelling Results
  - Global Supply Chains (TrHyHub project)
  - Hydrogen Valley Southern Upper Rhine
  - Electrolysis and Battery in Atacama Dessert
- Wrap Up



The Fraunhofer Institute for Solar Energy Systems ISE

Performing research for the energy transition for over 40 years.

The Institute in Numbers

Institute Directors

Prof. Dr. Hans-Martin Henning
Prof. Dr. Andreas Bett

Staff around 1400

Budget 2024

Operation	€125.3 million
Investment	€ 32.4 million
Total	€157.8 million

Founded in 1981

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Division Hydrogen Technologies

Green Hydrogen and Synthesis products for climate neutral industry, mobility and energy economy

Membrane fuel cell and electrolysis

Scalable production processes from powder to stack, including in-situ and ex-situ characterization, analytics and modelling

System analysis and H_2 infrastructure

Site specific simulations and optimizations of regional and global H2- and PtX-supply chains, from an technologic, economic and ecologic perspective

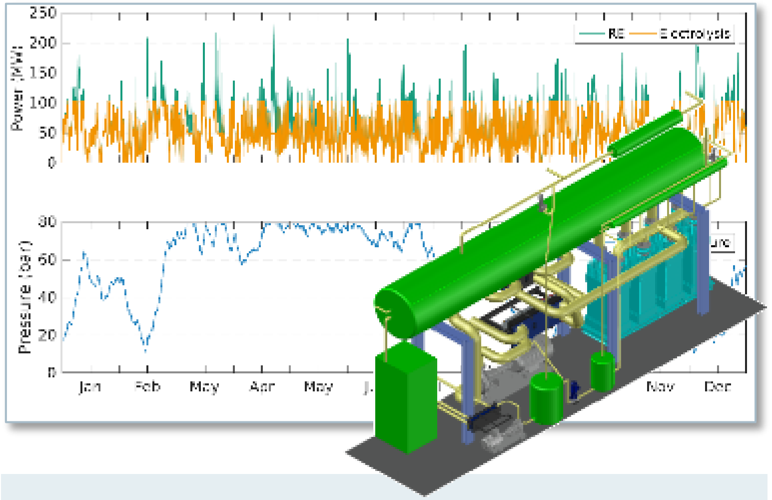
Sustainable Synthesis products

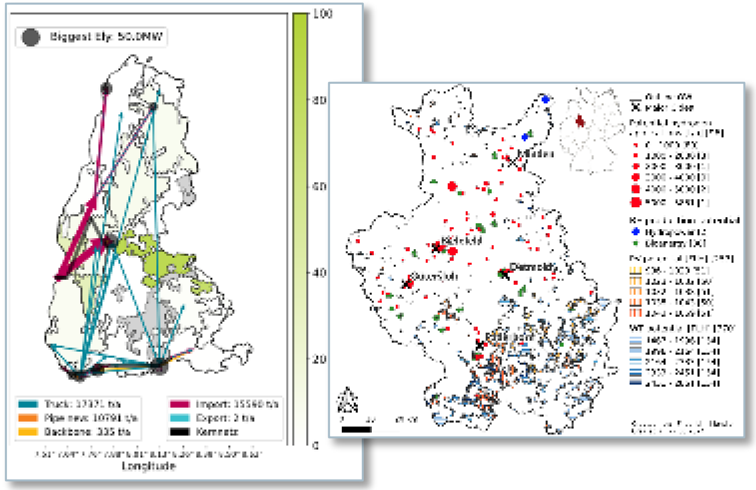
Production, transport and usage of hydrogen-based chemicals, energy carriers, and fuels enabling the defossilization of the industry and mobility sector

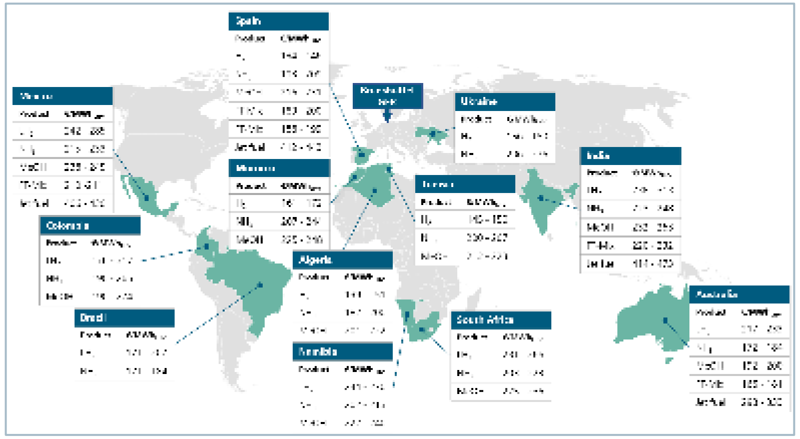
30 years H_2 experience | **170 employees** | **25 Mio € annual budget**

Group Hydrogen Infrastructure and Technical System Analysis

Research Topics







Electrolysis and H_2 Production

- Concept development of Hydrogen Generation Plants
- **Detailed plant simulation** and **LCOH calculation**
- Analysis of operational management
- **Regulatory aspects** (RED II, CBAM)

Interconnected H_2-systems / hydrogen valleys

- Identification of **best suited locations** for H_2 infrastructure
- Analysis of / Concepts for hydrogen valleys
- **Geo-techno-Economic Analysis** of H_2-Systems

PtX Supply Chains

- Techno-Economic Analysis and Optimization of **Supply-Chains for H_2 / PtX**
- Analysis of Supply Chain Infrastructure
- Site Suitability Analysis for renewable energy carriers
- Life Cycle Assessment (LCA)

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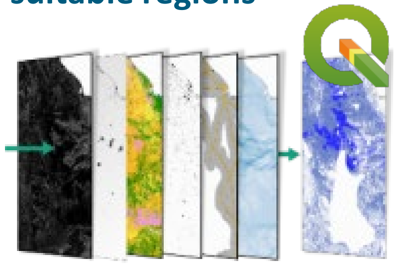
Techno-economic analysis of the PtX scenarios

Methodology Overview H2ProSim

Location Analysis and Data Preparation → System Simulation & Optimization → Results Analysis

GIS analysis to determine the most suitable regions



Techno-economic parameters

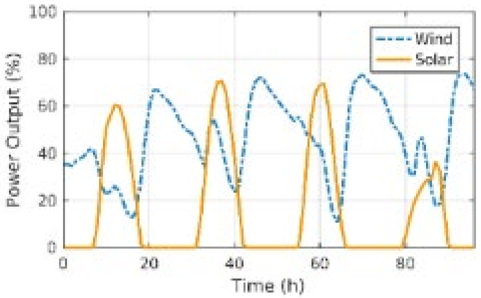
Location parameters

Export harbors

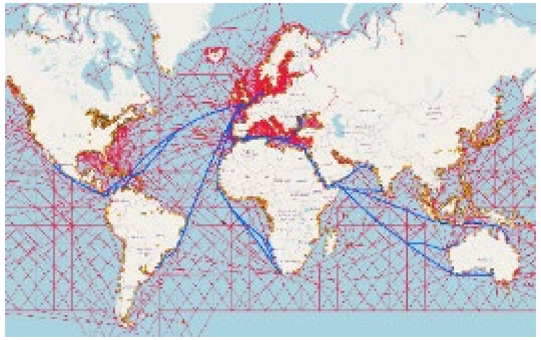
Scenario definition

Additional requirements

Generation of location specific **wind and solar** timeseries



Transport route analysis



Holistic **system optimization** with the help of a nonlinear solving algorithm to minimize costs.

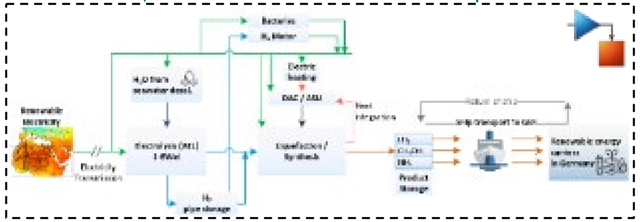
Dynamic, non-linear modelling of large-scale Power-to-X hubs.

Advanced operation management of electrolysis, storages, electricity management,…

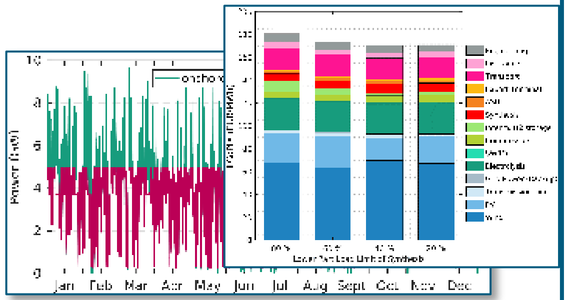
Optimization Algorithm
(mutation and crossover functions)

Handover of parameters

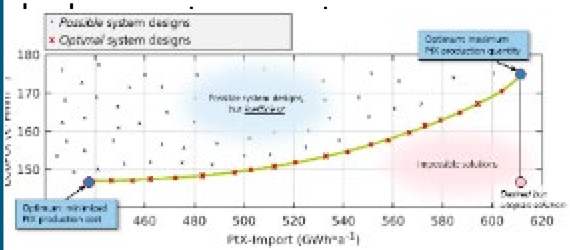
Results (EUR/kg)

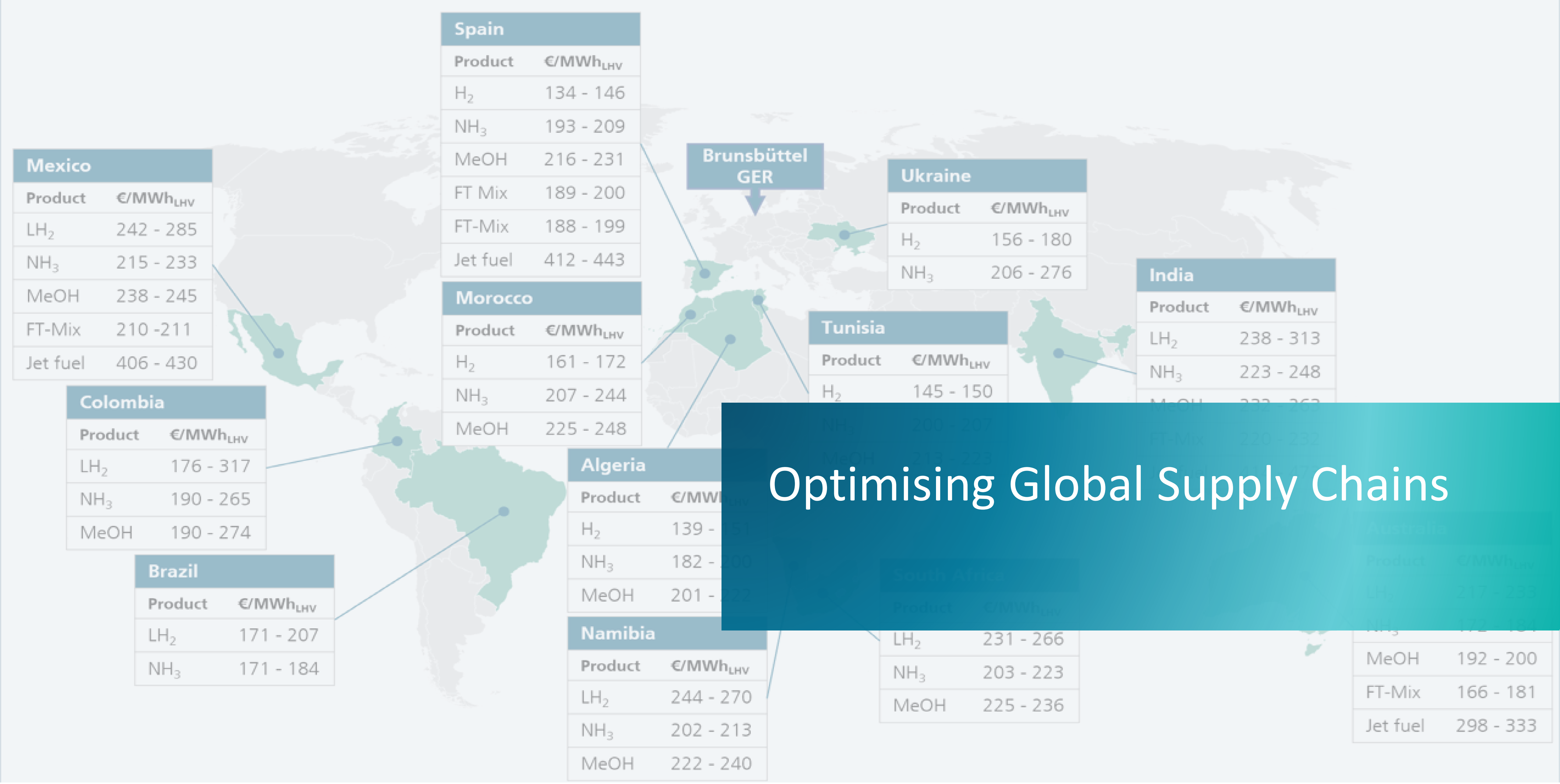


Key performance indicators: LOCH, quantities, efficiencies, cost structure, energy flows,…



Plant design in the cost optimum, e.g., optimized ratio of wind/ solar to electrolysis, intermediate



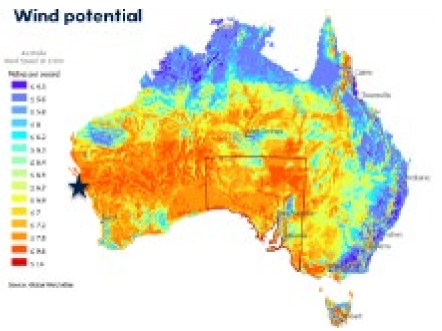


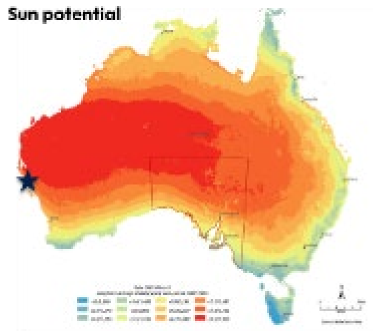
Optimising Global Supply Chains

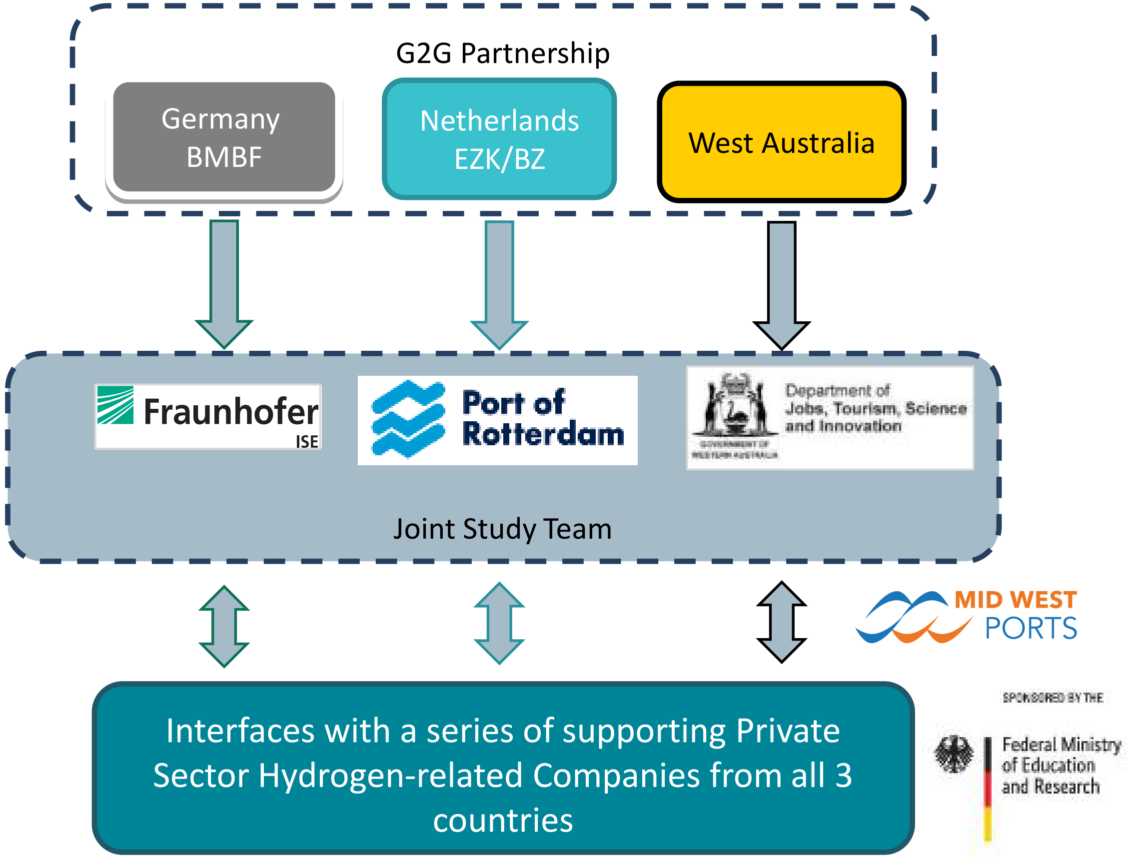
Optimising Global Supply Chains

TrHyHub Oakajee Project

- **Trilateral Hydrogen Innovation and Export Hub**
  - Partnership (AUS, NLD, GER) to accelerate hydrogen exports from Australia to NW Europe **via Port of Rotterdam (PoR)**
- **Objectives**
  - Develop the world's largest hydrogen and ammonia integrated port complex in Oakajee:
    Export of 3 Mtpa green NH_3 starting in 2030.
  - Techno-economic feasibility study for large-scale Wind and PV as well as Hydrogen and Derivatives Production in the Oakajee region
  - **Techno-economical PtX supply chain study from RE production to the supply of potential off-takers in Germany**
    - **Ammonia** as base case
    - **Liquid Hydrogen** and **Methanol** for comparison







Optimising Global S

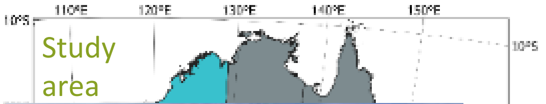
Results - Capacities and

The Trhyhub Project:
Green Ammonia production – Export infrastructure in Western Australia

Electrolysis: 17%
Installed cap.: 4.4 GW_{el}
CAPEX : EUR 4.4 bn.
Full load hours: 6277 h/yr (72% CF)

Compressor: 4%
Installed cap.: 0.31 GW_{el}
CAPEX: EUR 0.96 bn.

Haber-Bosch synthesis: 6%
Installed cap.: 3255 kt/yr
Output: 3000 kt/yr
CAPEX : EUR 0.96 bn.



NH_3 intermediate storage: 1%
Size: 120 000 m³
CAPEX : EUR 0.1 bn.

Renewable Energy
- Onshore Wind and PV

Power-to-X Hub
- Electrolysis
- Compressor
- Water supply via SWRO
- H_2 intermediate storage (80 bar)
- Haber-Bosch
- N_2 via ASU
- NH_3 intermediate storage

Transport
- Long-distance transport via ships

Green Ammonia
34732 JPY/MWh
180055 JPY/t

Supply cost: 201 EUR/MWh
1042 EUR/ton
Import of: 3000 kt/yr
15.54 TWh/yr

Wind and PV: 47%
Installed cap. Wind / PV: 5.3 / 7.7 GW_{el}
LCOE Wind / PV: 40 / 35 EUR/MWh_{el}
Surplus RE power: 17.2%

H_2 storage: 6%
Size: 915 000 m³
CAPEX : EUR 1.92 bn.

Air Separation Unit: 1%
Installed cap.: 2731 kt/yr
CAPEX : EUR 0.35 bn.

Ship transport: LPG Carrier 9%
Ship size: 84 000 m³
Number: 9
CAPEX : EUR 0.81 bn.

1 EUR ~= 172 JPY

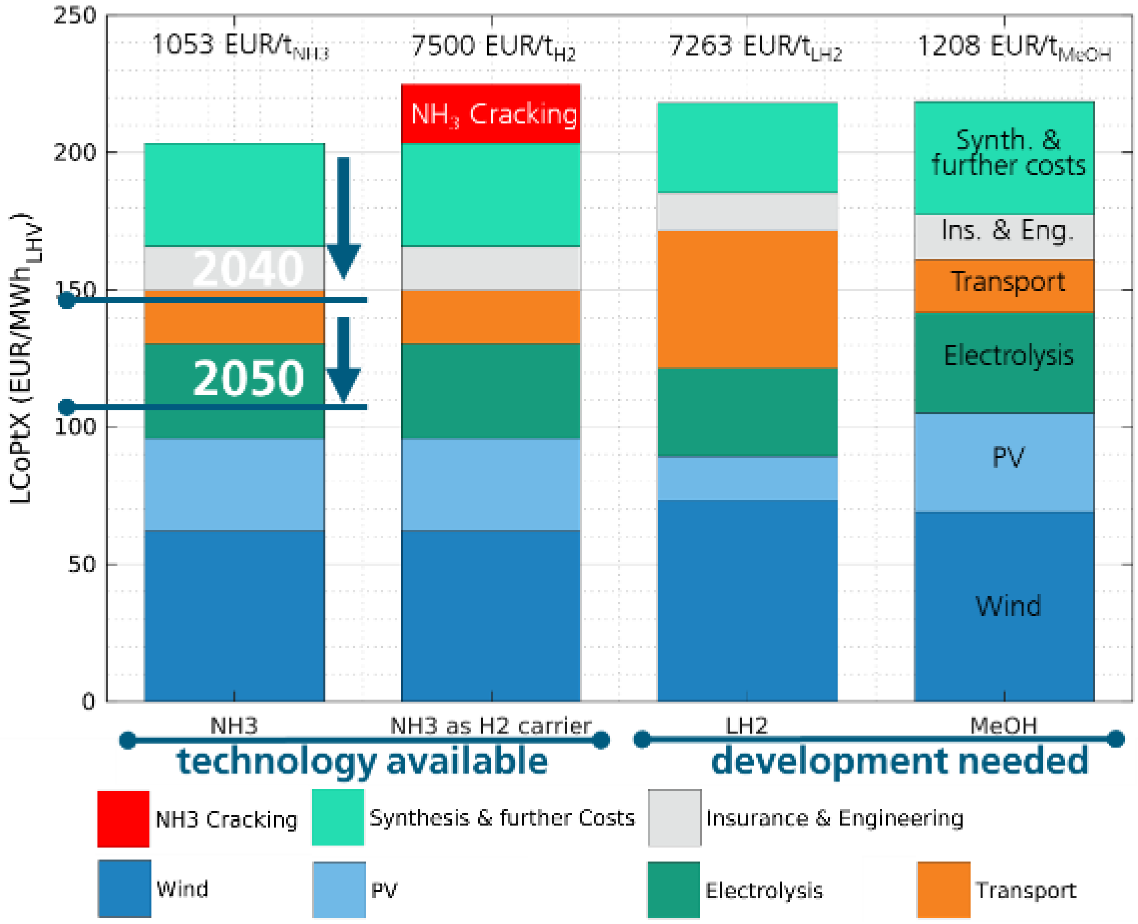
xx% Contribution to total supply cost

Optimising Global Supply Chains

Comparison of Energy Carriers

- **Ammonia** import cost reduction potential:
  - 2040 import costs of ~147 EUR/MWh
  - 2050 import costs of ~109 EUR/MWh
- NH3 Cracking adds costs of ~22 EUR/MWh

- **Methanol** production and transport state of the art
  - CO_2 generation with DAC is a bottleneck
- **Liquid hydrogen** not possible in 2030, but option for the future
  - Large-scale LH_2 carriers probably not available in 2030
  - Liquefaction capacity of ~1700 tpd would be several times the current aggregated global liquefaction capacity (<400 tpd)



Bundesministerium für Bildung und Forschung

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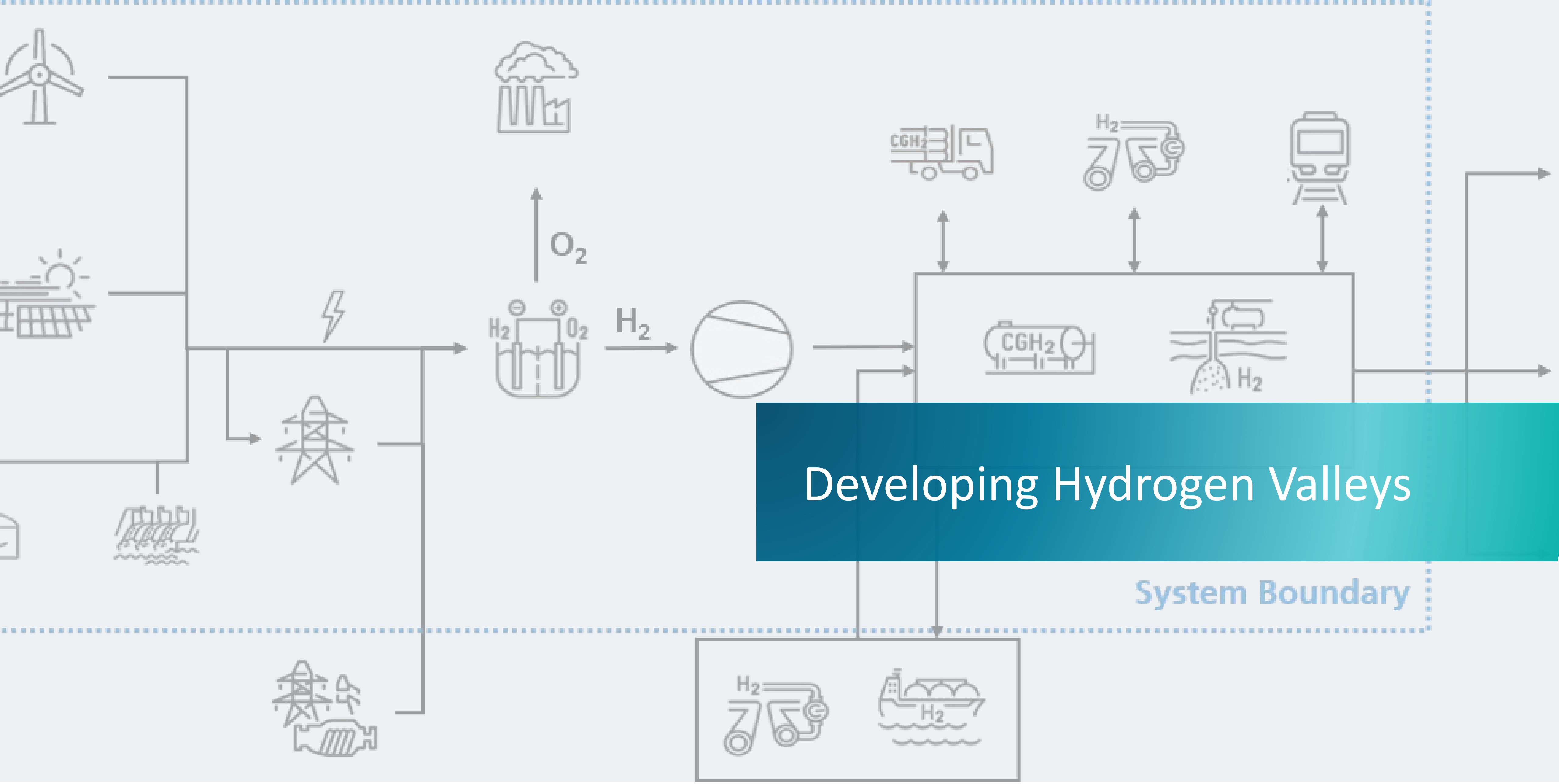

Developing Hydrogen Valleys

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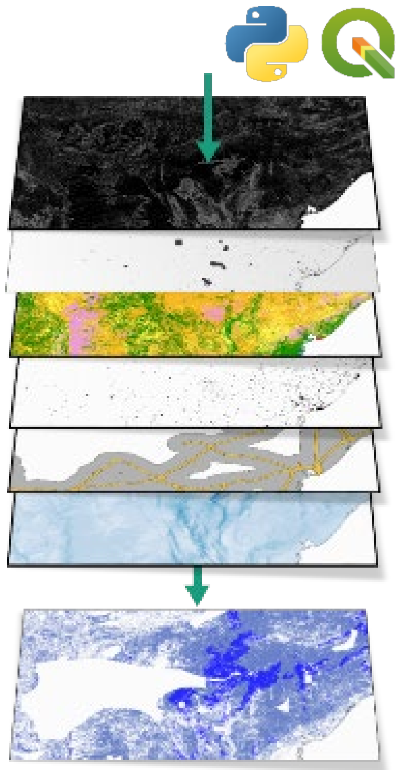
Developing Hydrogen Valleys

Methodology Overview HYSCOPE

Further details in *Advances in Applied Energy*

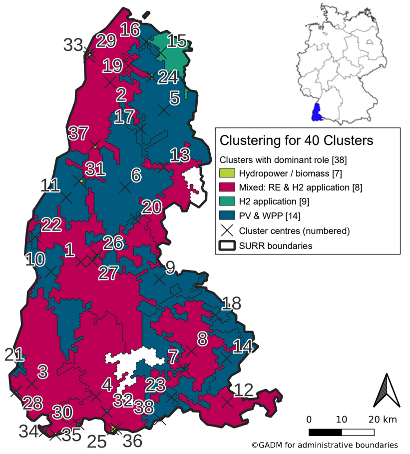
https://doi.org/10.1016/j.adapen.2025.100207

Input data

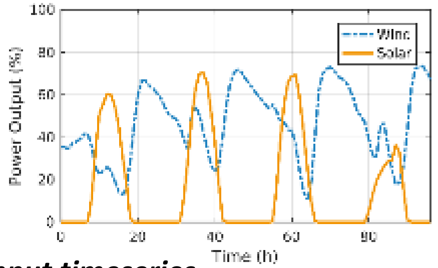


Combination of geodata

Preprocessing

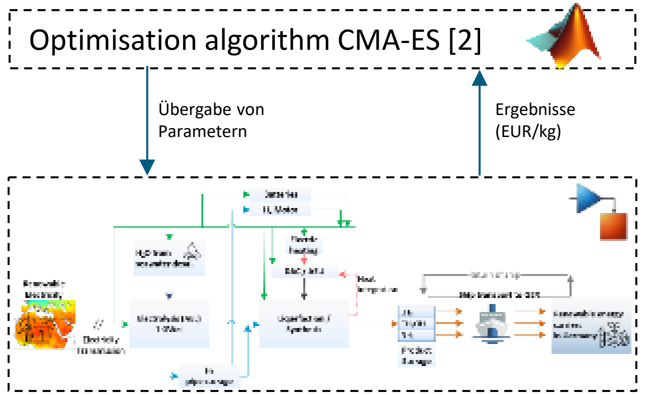


Spatial clustering [1]

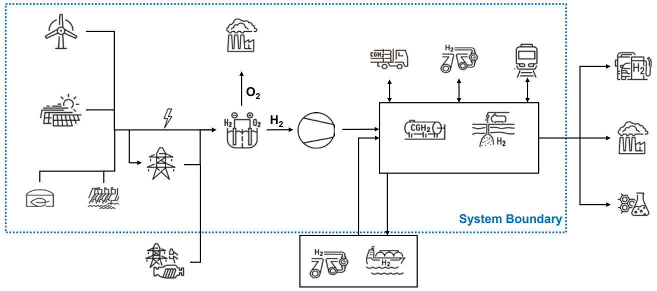


Input timeseries

System optimisation

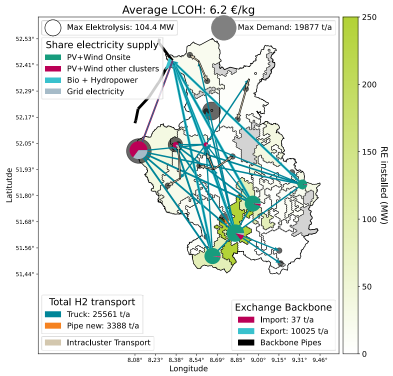


Nonlinear simulation-based optimisation

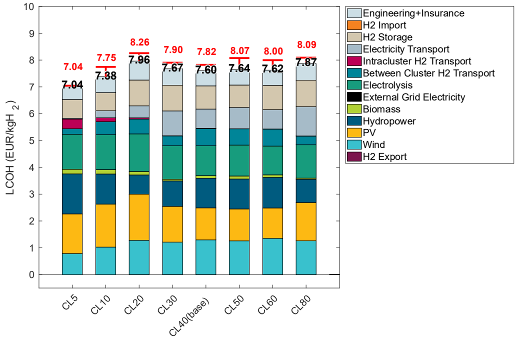


Technology chain

Results



Spatially resolved supply chain



Scenario analysis

[1] **Mendler F, Koch B, Meißner B, Voglstätter C, Smolinka T.** Evaluation of spatial clustering methods for regionalisation of hydrogen ecosystems. *Energy Strategy Reviews* 57: 101627, 2025.

[2] **Hansen N.** *The CMA Evolution Strategy: A Tutorial*, 2016. http://arxiv.org/pdf/1604.00772.

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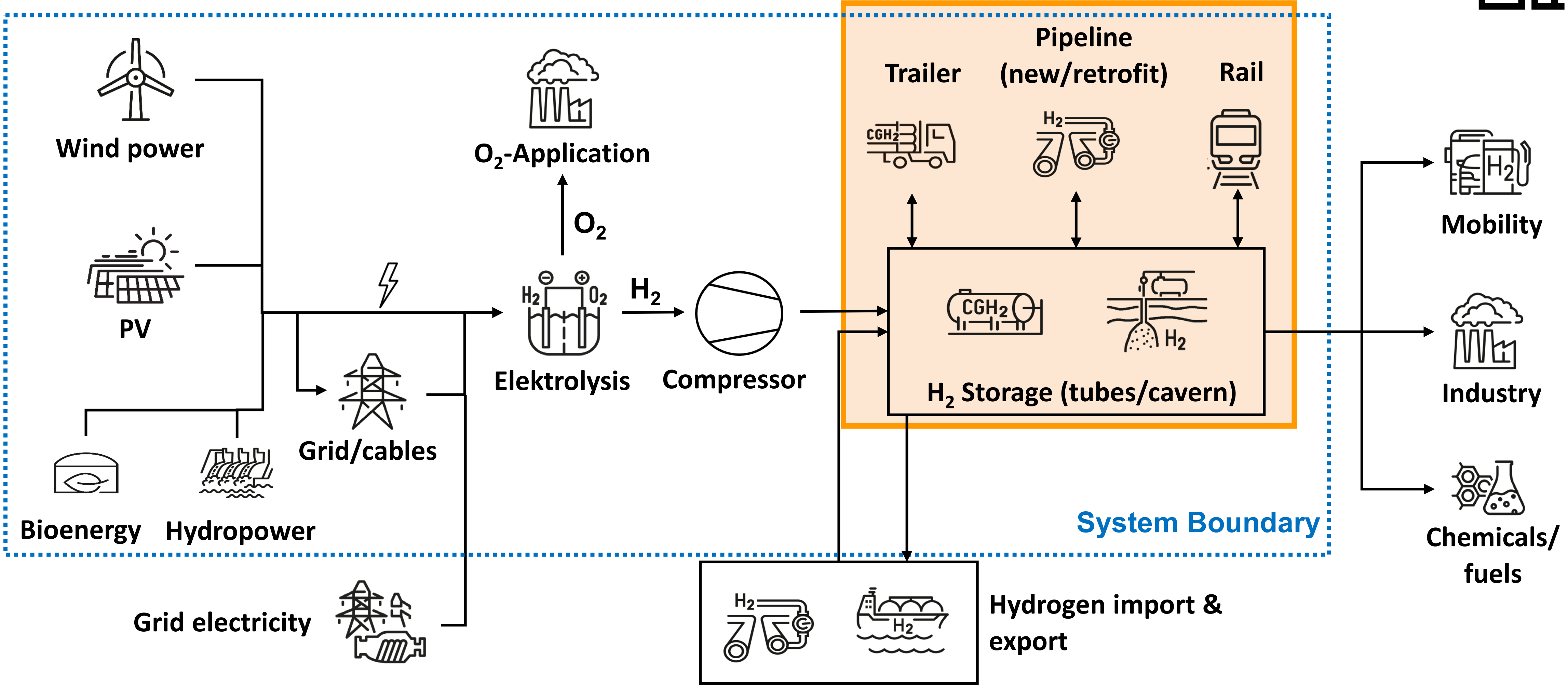
Developing Hydrogen Valleys

Technology Chain HYSCOPE

How to operate hydrogen storage and transport in hydrogen valleys?

Further details in *Advances in Applied Energy*
https://doi.org/10.1016/j.adapen.2025.100207



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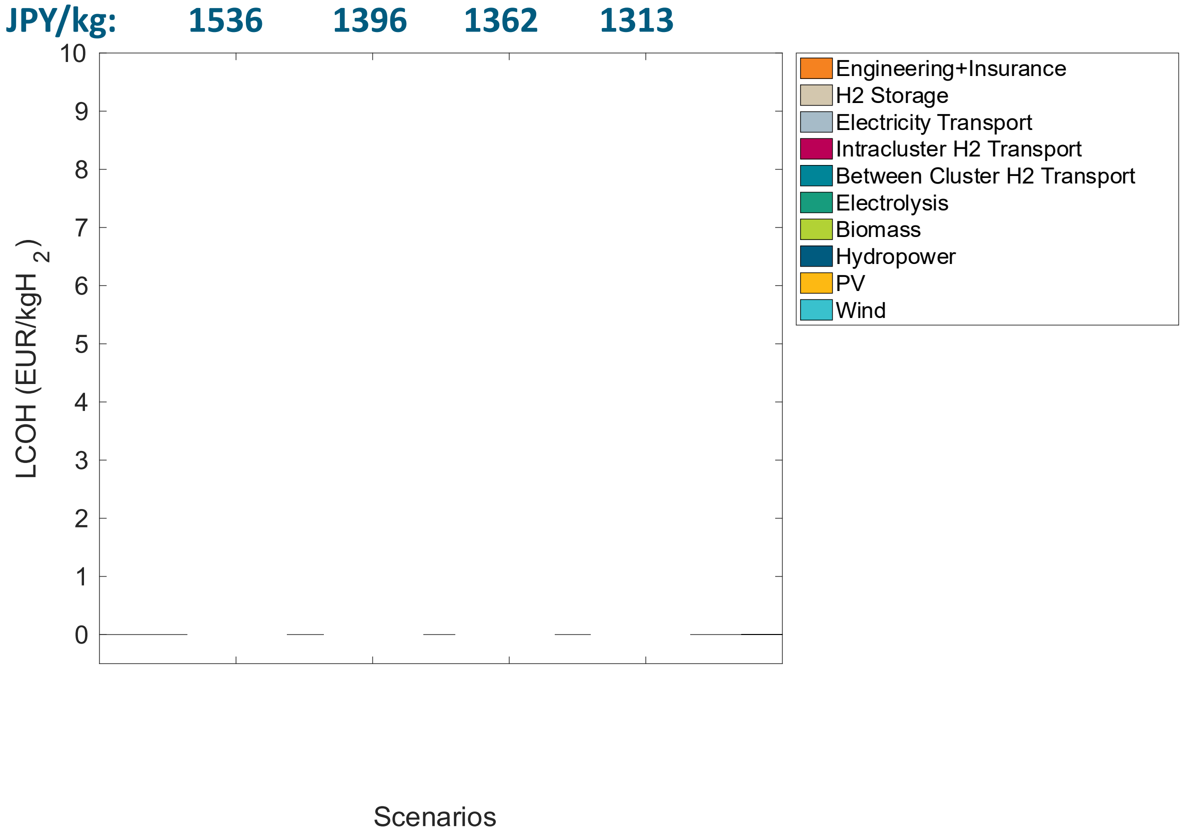
Developing Hydrogen Valleys

Scenario Analysis: Operation of H2 Storage and Transport

Further details in *Advances in Applied Energy*
https://doi.org/10.1016/j.adapen.2025.100207

- Analysis of potential hydrogen valley in south Germany
- Exchange of hydrogen is mainly controlled through **hydrogen storage levels**
- Comparison of operation strategies:
  - *Bilateral Hydrogen Contracts* (BHC): only exchange between predefined position to fulfil demands
  - *Flex Market*: flexible supply of demands from available hydrogen storage in proximity
  - *Max Yield*: H2 overproduction at sites with full storage is distributed to available storage in proximity (Additionally to BHC + Flex)

Intelligent operation can maximize yield and reduce over dimensioning (→ system-wide operator?)



Hydrogen supply cost in the Southern Upper Rhine depending on exchange algorithm

1 EUR ~= 172 JPY

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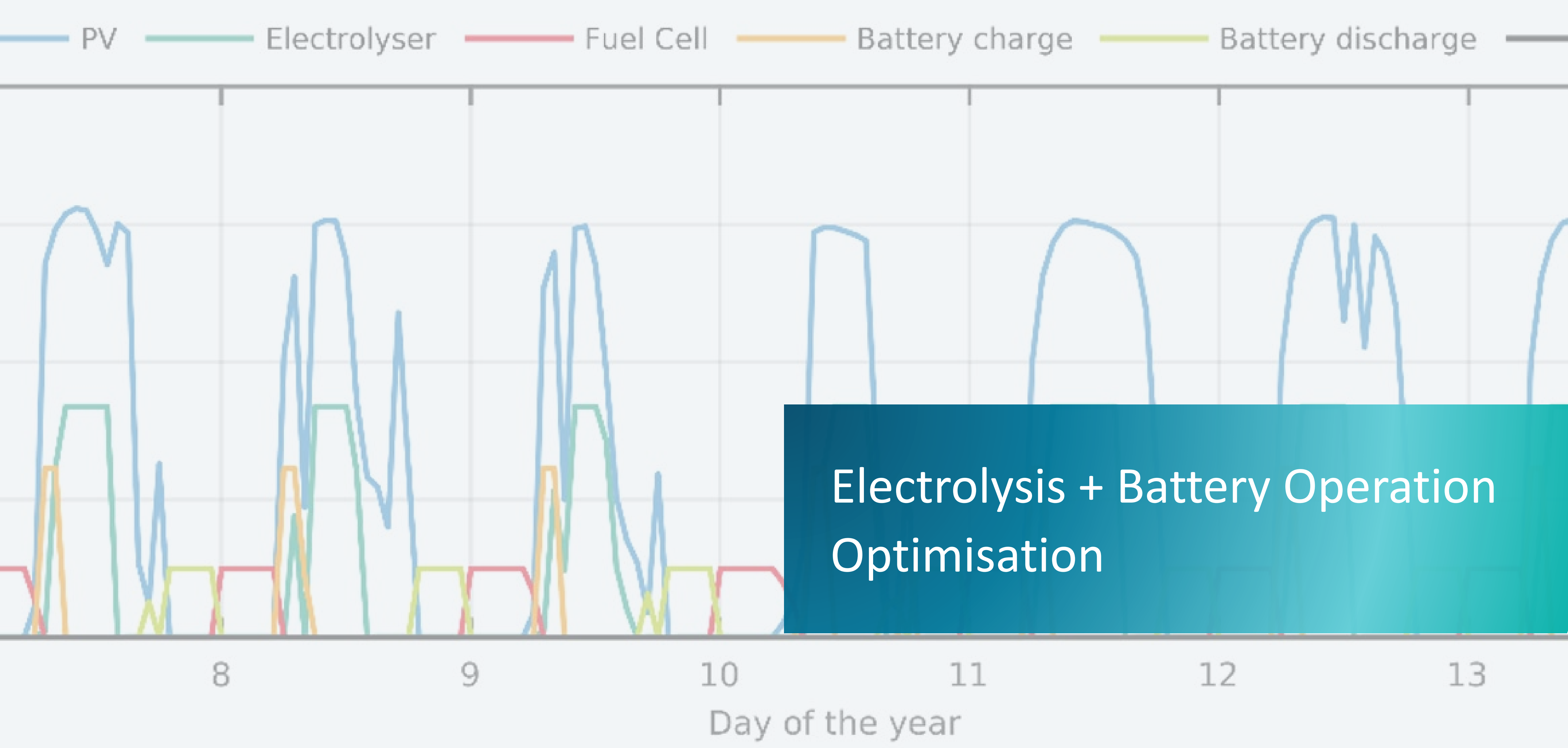
Electrolysis + Battery Operation Optimisation



Electrolysis + Battery Operation Optimisation

Scenario: Constant Electricity Supply in Atacama Desert, Chile

- Goal: constant 50MW electricity supply for industry
  - PV-based, battery and hydrogen for storage
- Exceptional PV potential (cold, dry, elevated) → 2550 full load hours
- Grid electricity as backup possible
  - Different autarky levels analysed (80%, 90%, 99%)
- Optimisation: Higher autarky requires substantial overcapacity PV + EL, but less battery
- Results: Higher autarky reduces system efficiency and increases cost

	Autarky level:	**80%**	**99%**
Optimised	PV installed	235 MW_p	394 MW_p
	EL installed	58 MW_p	166 MW_p
	Battery installed	274 MWh	246 MWh
	FC installed	20 MW_p	56 MW_p

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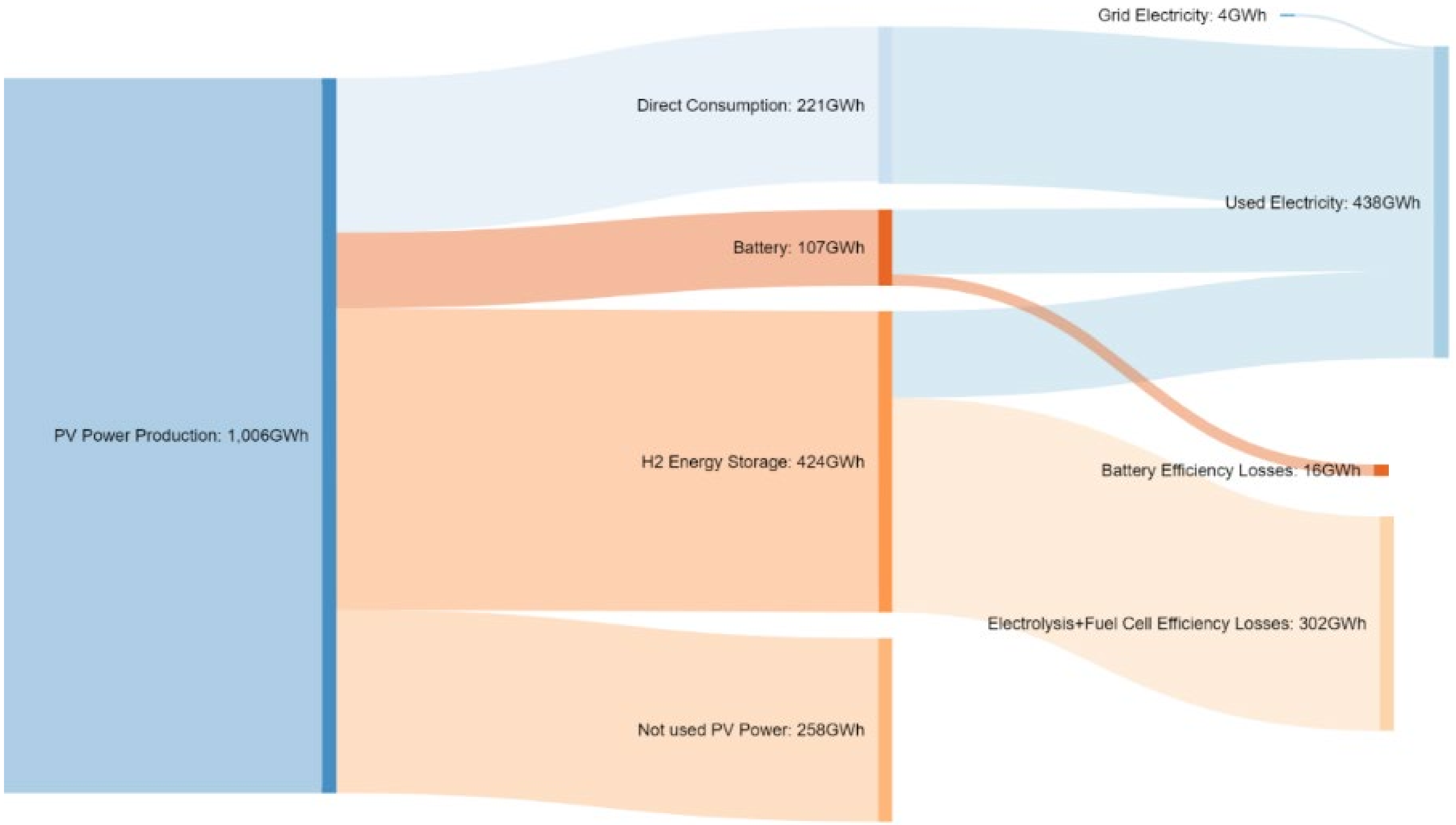
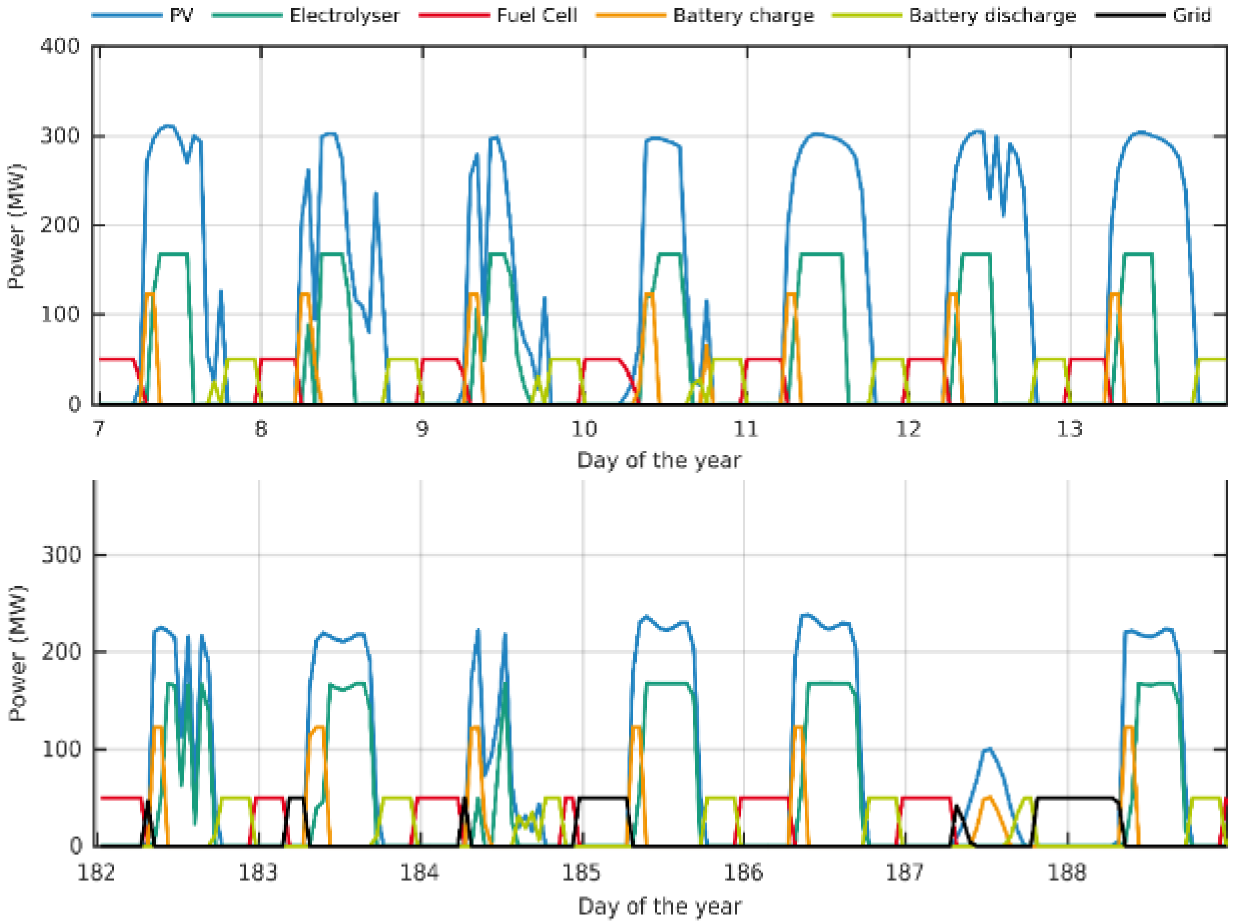
Electrolysis + Battery Operation Optimisation

Energy Flows , 99% Autarky



Electrolysis + Battery Operation Optimisation

System Operation, 99% Autarky



Summer week:

- High PV overproduction
- Day: first battery charge, then electrolysis
- Night: first battery discharge, then fuel cell
- No grid consumption

Winter week:

- Less PV overproduction
- Grid consumption at the end of the night, if day before little PV

Wrap-Up

Modelling Hydrogen Supply Chains Across all Spatial Scales

- **Green H_2 will become the energy currency of defossilised advanced energy systems.**
- Sector coupling & renewable energy supply of hard to electrify applications, international transport & **long-term storage** of energy
- Fraunhofer ISE is supporting the transition of the energy systems worldwide towards this goal trough **technical system analysis**
- Combination of long-term **modelling expertise with hands-on technical experience** from the lab and demonstration projects
- Analysis of **supply chains along spatial scales**: international trade, hydrogen valleys, single plant operation
- Support in identifying **optimal transport vectors, operation strategies and potential LCOH** including all steps up to final consumption
- Create **synergies between stakeholders and technologies** (e.g. battery + hydrogen storage)

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Thank you for your attention!
ご清聴ありがとうございました！

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