

System Optimization and Techno-Economic Analysis of Renewable Hydrogen Production Plants

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Photovoltaics

Energy Efficient Buildings

Solar Thermal Power Plants and Industrial Processes

Power Electronics, Grids & Intelligent Systems, Electrical En. Storage

Hydrogen Technologies

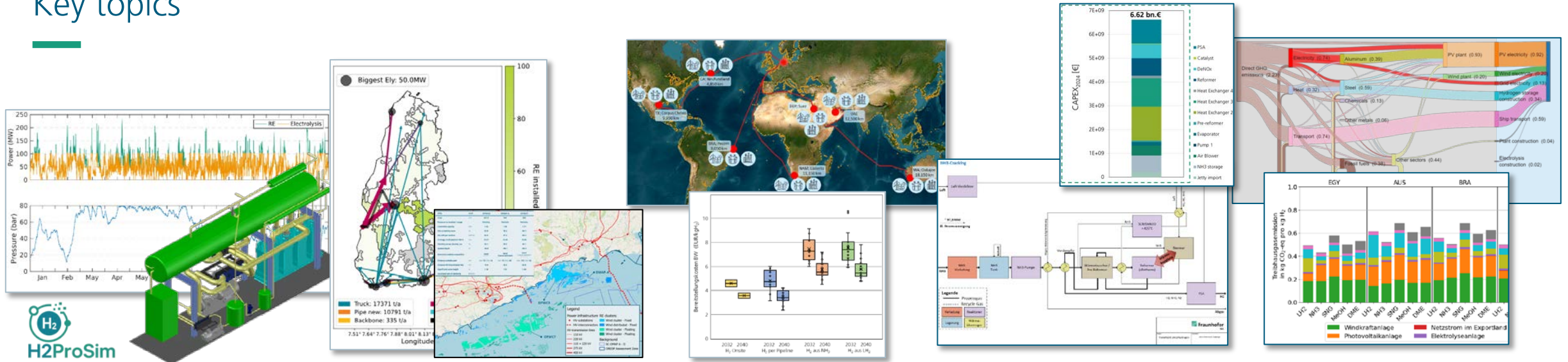
Fuel Cell Systems

Sustainable Synthesis Products

Electrolysis and Hydrogen Infrastructure

System Analysis

Key topics



Electrolysis and H₂ production

- System analysis with **detailed plant simulation** and LCOH calculation
- **Concept development** for hydrogen plants
- Plant condition monitoring

Site Analysis

- **GIS-based site analyses** for renewable energies and PtX plants
- Analysis and concept development for **hydrogen regions**
- Geo-techno-economic analysis of infrastructure expansion paths

Hydrogen Imports

- Techno-economic analysis of **PtX import chains** based on sustainable hydrogen
- Analysis of **maritime and pipeline transportation**
- Evaluation of export infrastructures

Process Simulation

- Design and evaluation of **process engineering plant concepts**
- E.g. large-scale synthesis or **reforming units, DAC**
- Tools: ASPEN
- Goal: Process optimization and cost estimation

Life Cycle Assessment

- **Prospective** life cycle assessments based on transition scenarios (PREMISE) and defossilization scenarios
- Holistic determination of **environmental impacts**, resource and energy requirements

Considered H₂ carriers / energy sources: **LH₂, NH₃, MeOH, DME, LOHC, SAF, SNG, CO₂**

Exemplary Case Study

Hydrogen production in Cuxhaven/ Germany

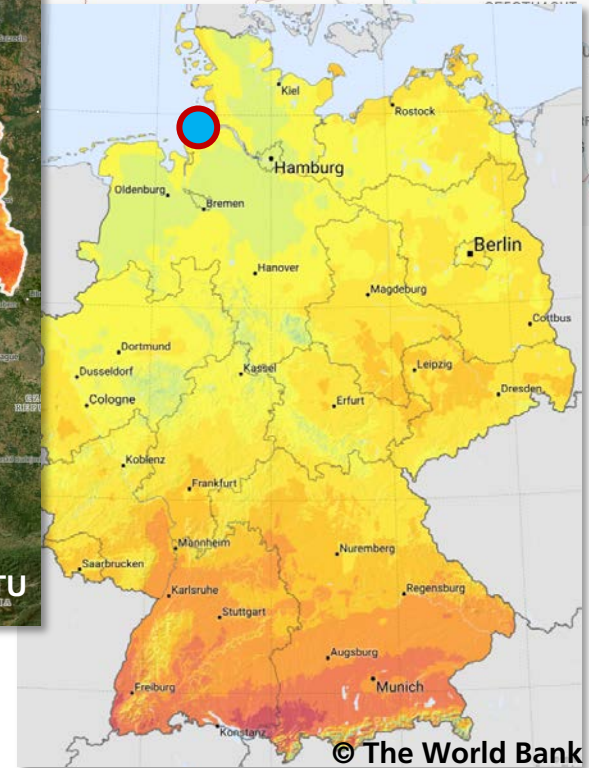
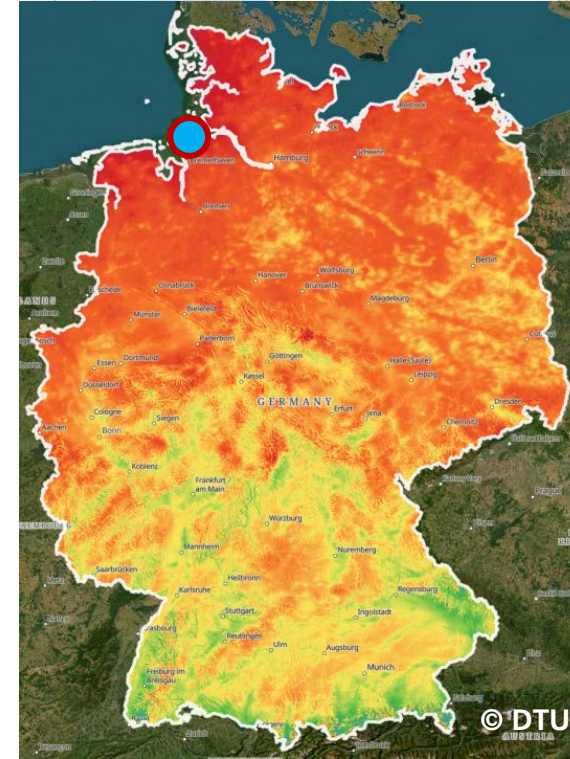
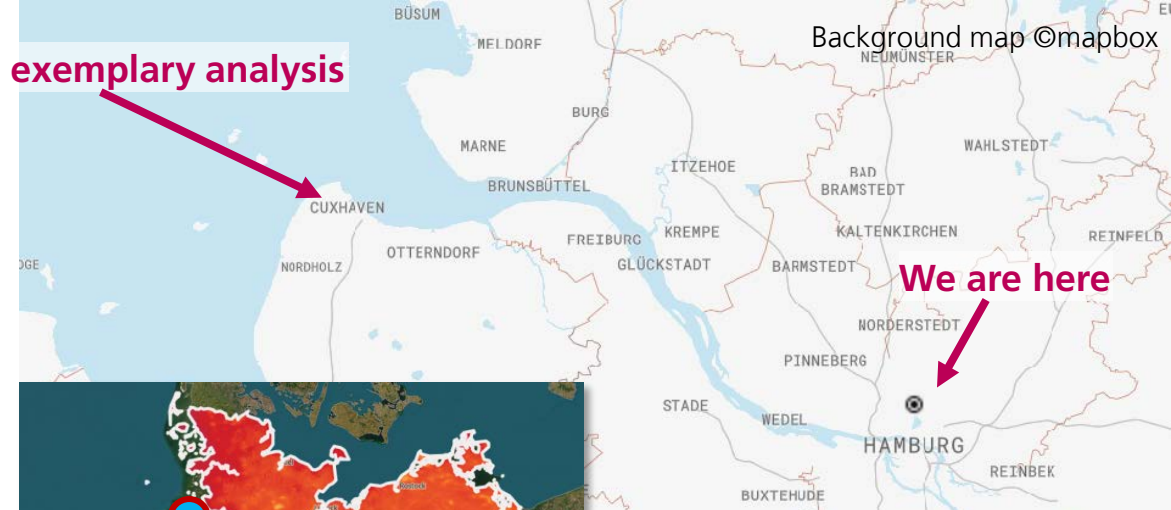
Exemplary Analysis of electrolytic hydrogen production from onshore wind and PV for Cuxhaven/Germany

- Typical northern Germany climate (windy, rainy, cloudy) ☺
- Capacity factor solar PV: 12 % (low)
- Capacity factor onshore wind: 41% (high)

Research question of the analysis

- What is the least-cost dimensioning of system components?
 - How much PV wind, electrolysis, etc.?
- What are hydrogen production costs (LCOH)?
- How much full load hours of the electrolysis can be archived?

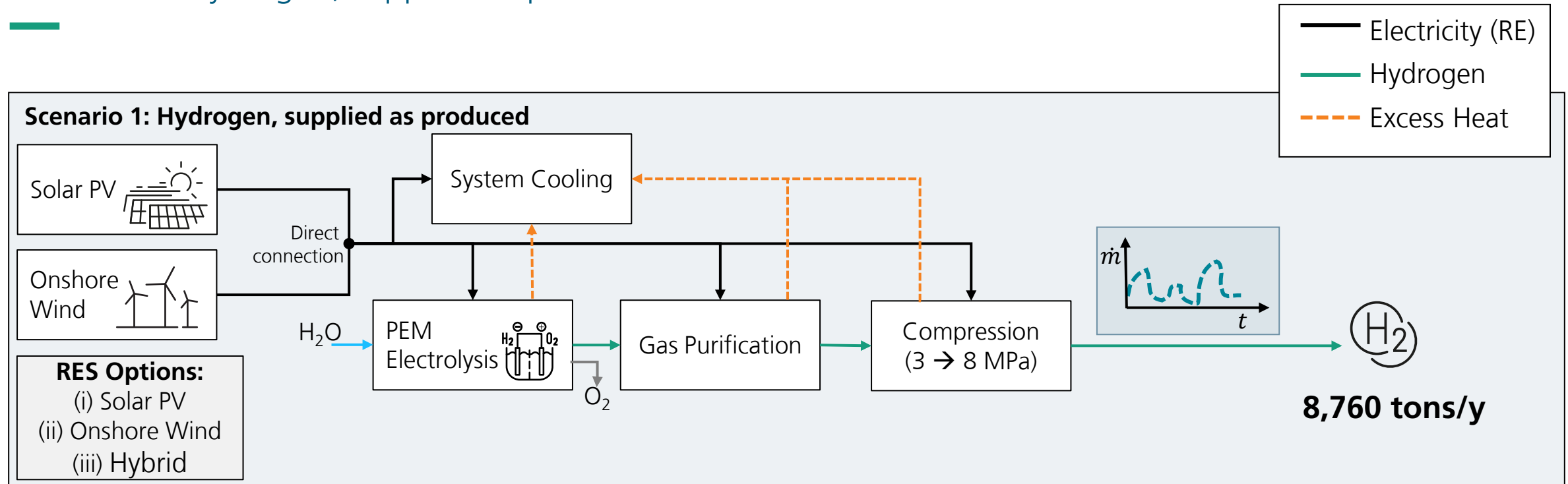
Detailed exemplary analysis



Mean wind speed at 100 m (top) and specific PV potential (right) for Germany

Overview of the Analyzed System Layout

Scenario 1: Hydrogen, supplied as produced

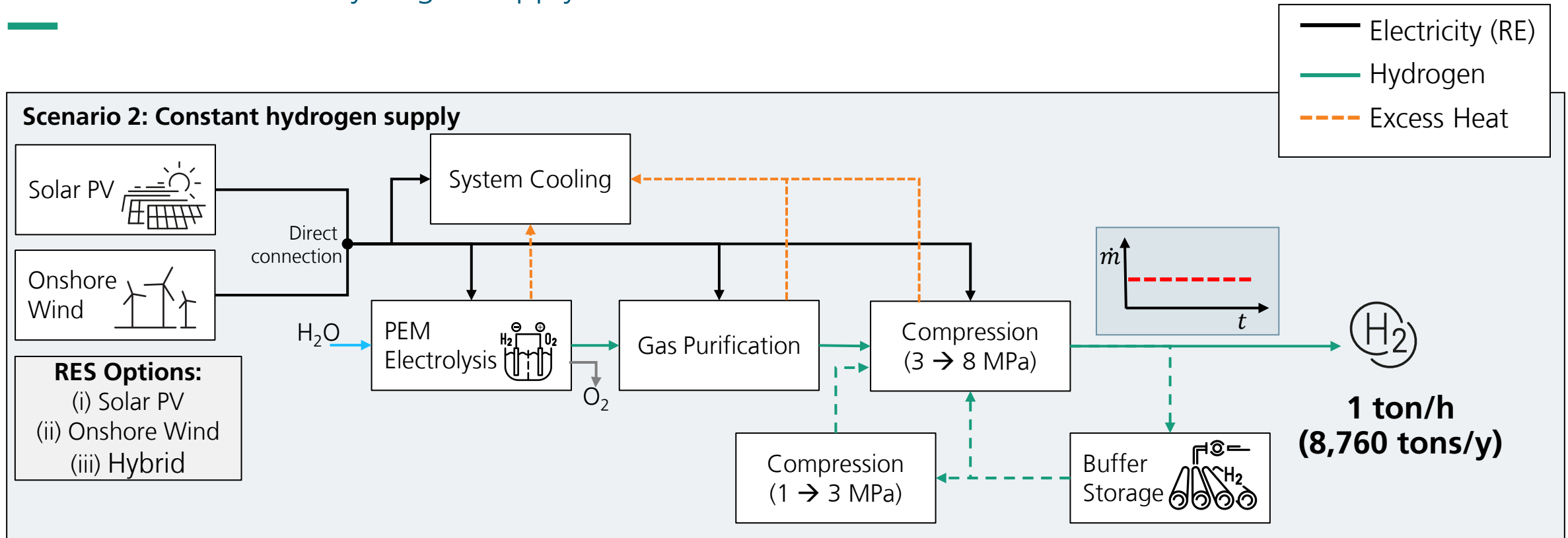


Hydrogen can be supplied as produced

➔ No demand constraint, i.e. pipeline connection without feed-in limitations

Overview of the Analyzed System Layout

Scenario 2: Constant hydrogen supply



A constant H_2 mass flow must be supplied! (i.e., for industrial supply)

➔ Additional H_2 storage required ➔ underground pipe storage

How should the **components** be dimensioned to meet the H_2 supply constraint and minimize production costs (LCOH)?

System Analysis with H₂ProSim

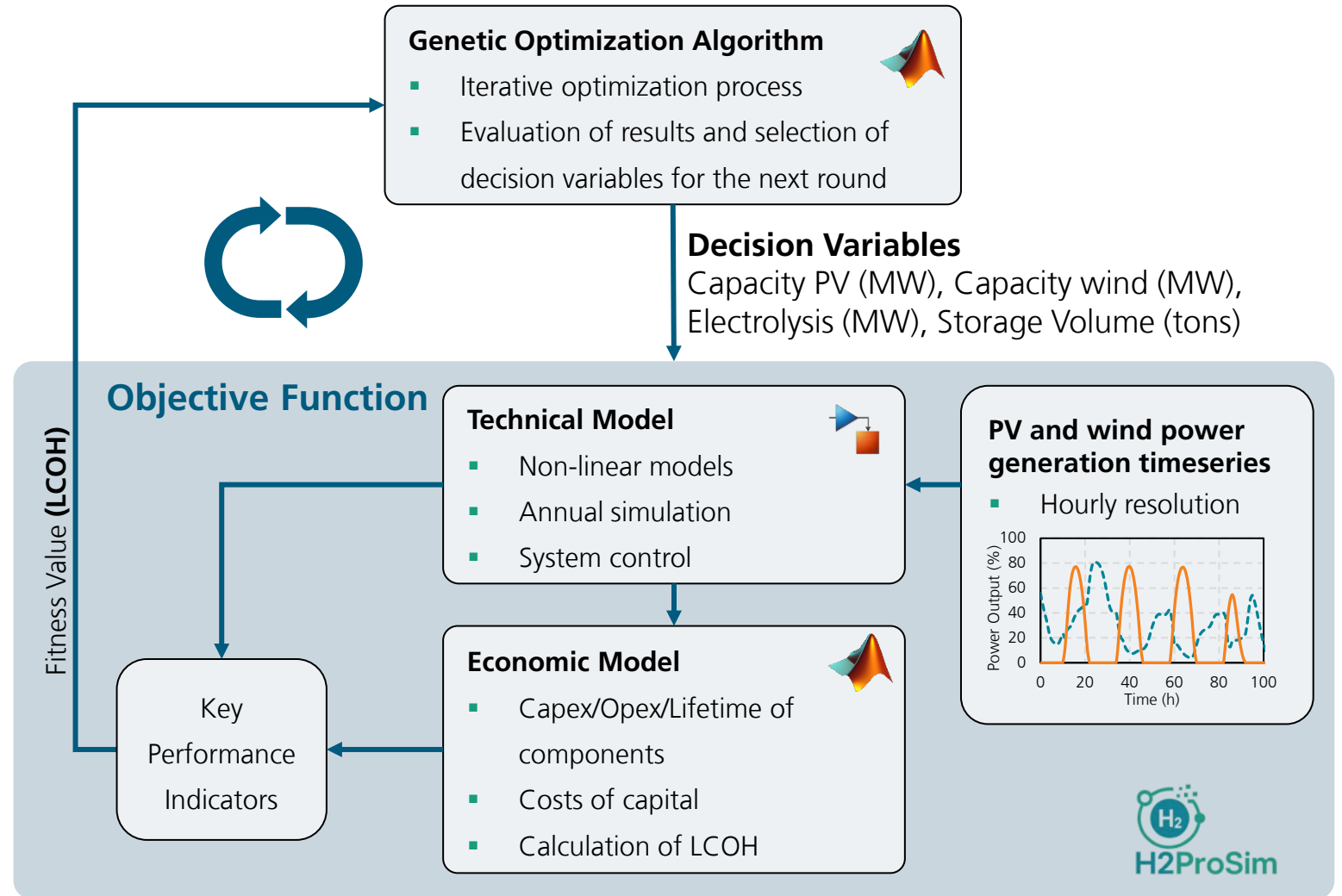
Optimization approach

H₂ProSim

- Self developed model library and toolbox to analyze H₂ systems
- Developed since >10 years at Fh ISE

Integrated Optimization Algorithm

- Iterative process
- Determination of **least-cost system configuration**; finding the best combination of PV, wind, electrolysis, storage,...



Central Parameters of the Analysis

Solar PV and onshore wind

- **Hourly power generation timeseries based on satellite data as input to the simulation model**

- **Solar PV**

- South-facing modules, optimal tilt angle determined based on latitude

- **Onshore wind**

- Smoothed power curve of an Enercon E112 as reference turbine
- Hub height: 120 m

- **Cost data** based on IRENA “Renewable Power Generation Costs” report.
 - Uniform data for Europe applied to the analysis

	Solar PV	Onshore wind	Unit
CAPEX	700	1,440	€/kW _{el}
OPEX	2	3	% _{CAPEX} /year
Lifetime	30	25	Years
Capacity factor	12	41	%
LCOE	57	43	€/MWh _{el}

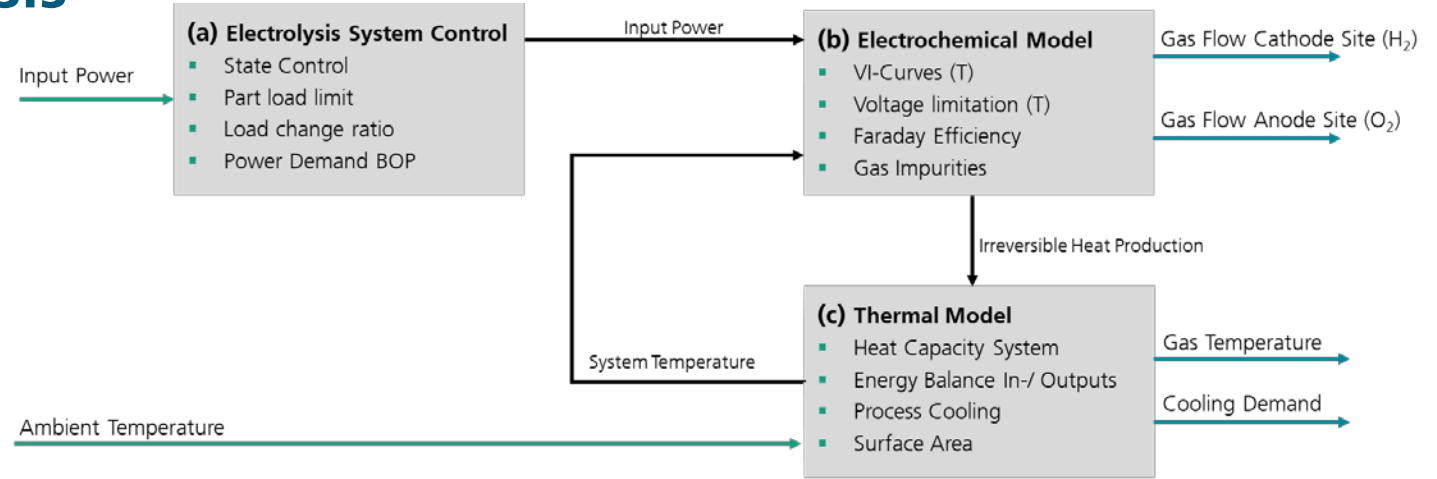


Technical and cost parameters reflecting today's installations

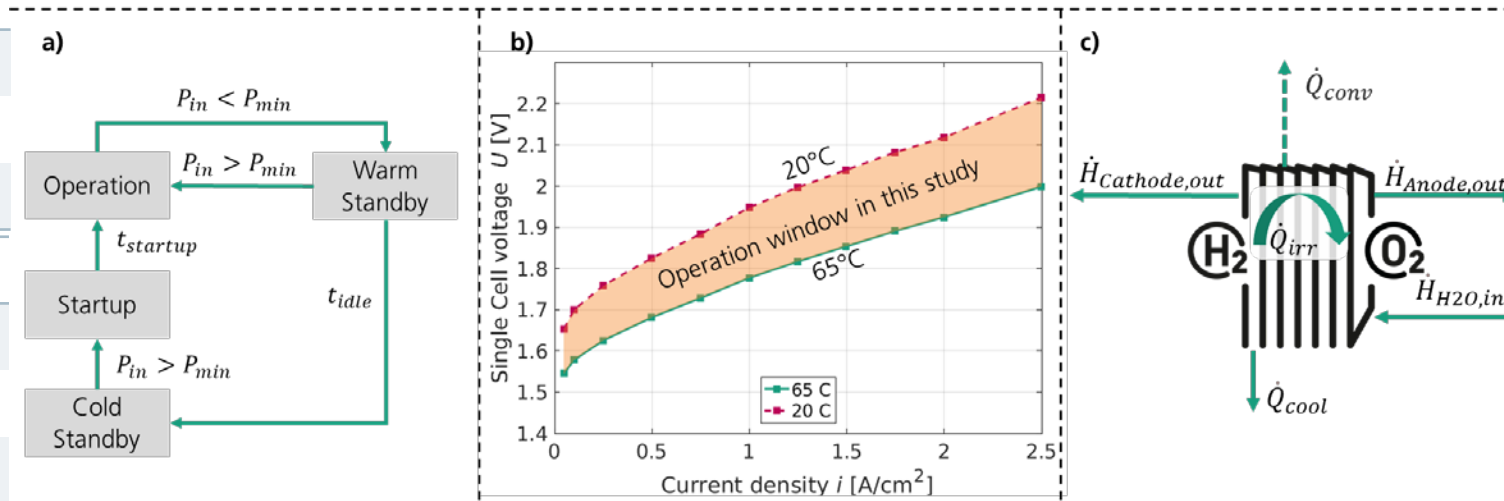
Central Parameters of the Analysis

Electrolysis

- Hydrogen production via **PEM electrolysis**
 - Dynamic operation in combination with RE
 - Large operation window



Parameter	Value	Unit
Specific Energy demand	~56	kWh _{AC} /kg
H ₂ outlet pressure	30	bar
Minimal part load	10	%
CAPEX	2,000	€/kW _{el}
OPEX	50	€/kW _{el} /y
Technical lifetime	25	y
Stack lifetime	60,000	hours



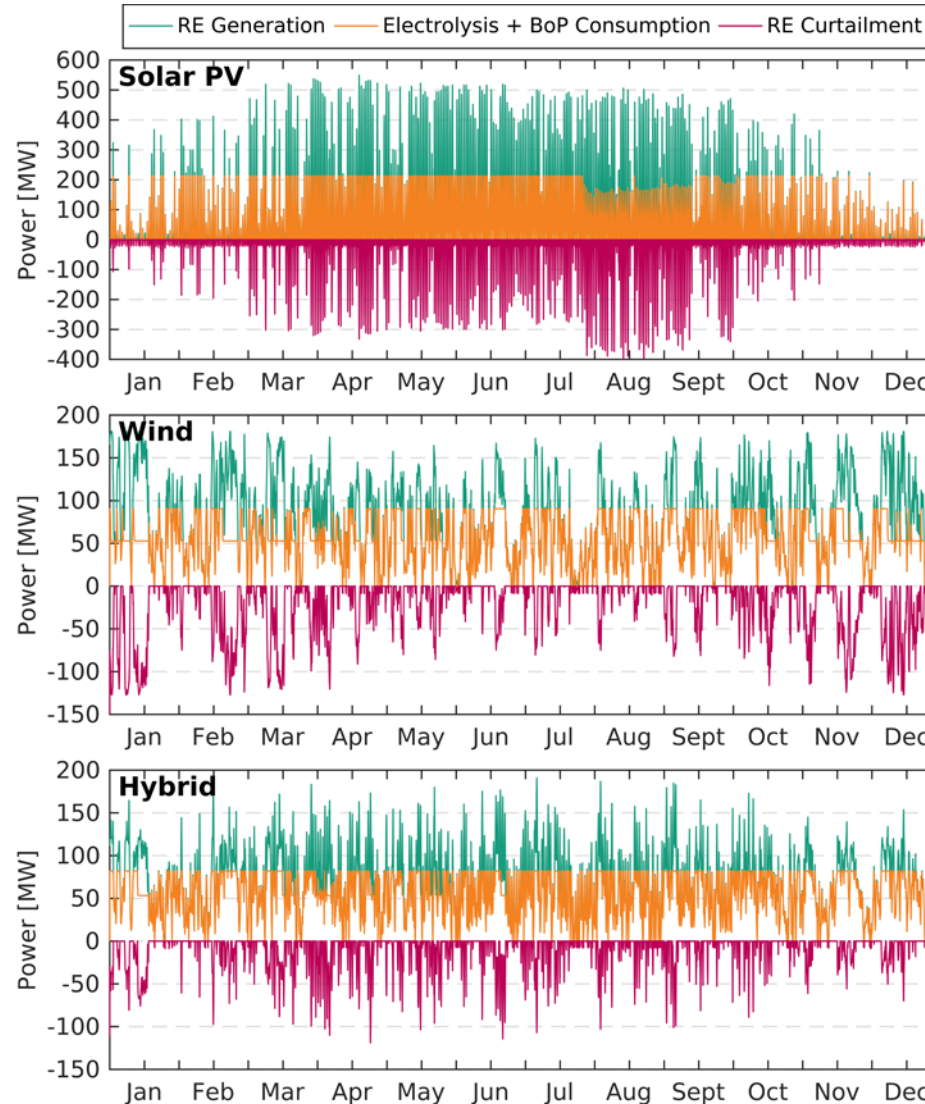
Technical and cost parameters reflecting today's installations

Results of the Exemplary Case Study

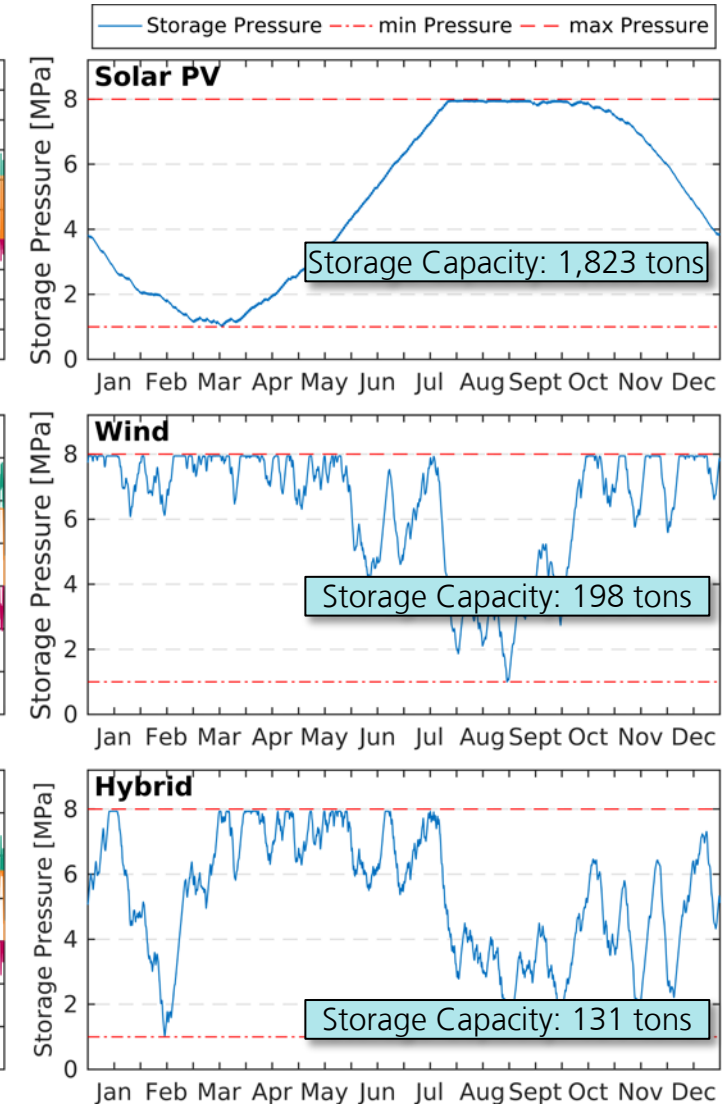
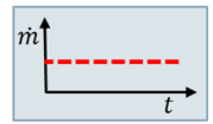
Operational insights – Scenario 2

- **PV:** production during summer month → large (!) seasonal storage
 - **Wind:** More constant production: lower RE and electrolysis capacity
 - **Hybrid:** combination of wind and PV; lowest storage demand
- Capacities in the **cost optimum:**

	PV (MW)	Wind (MW)	PEM (MW)
Standalone PV	641	n/a	213
Standalone Wind	n/a	184	91
Hybrid	104	125	82



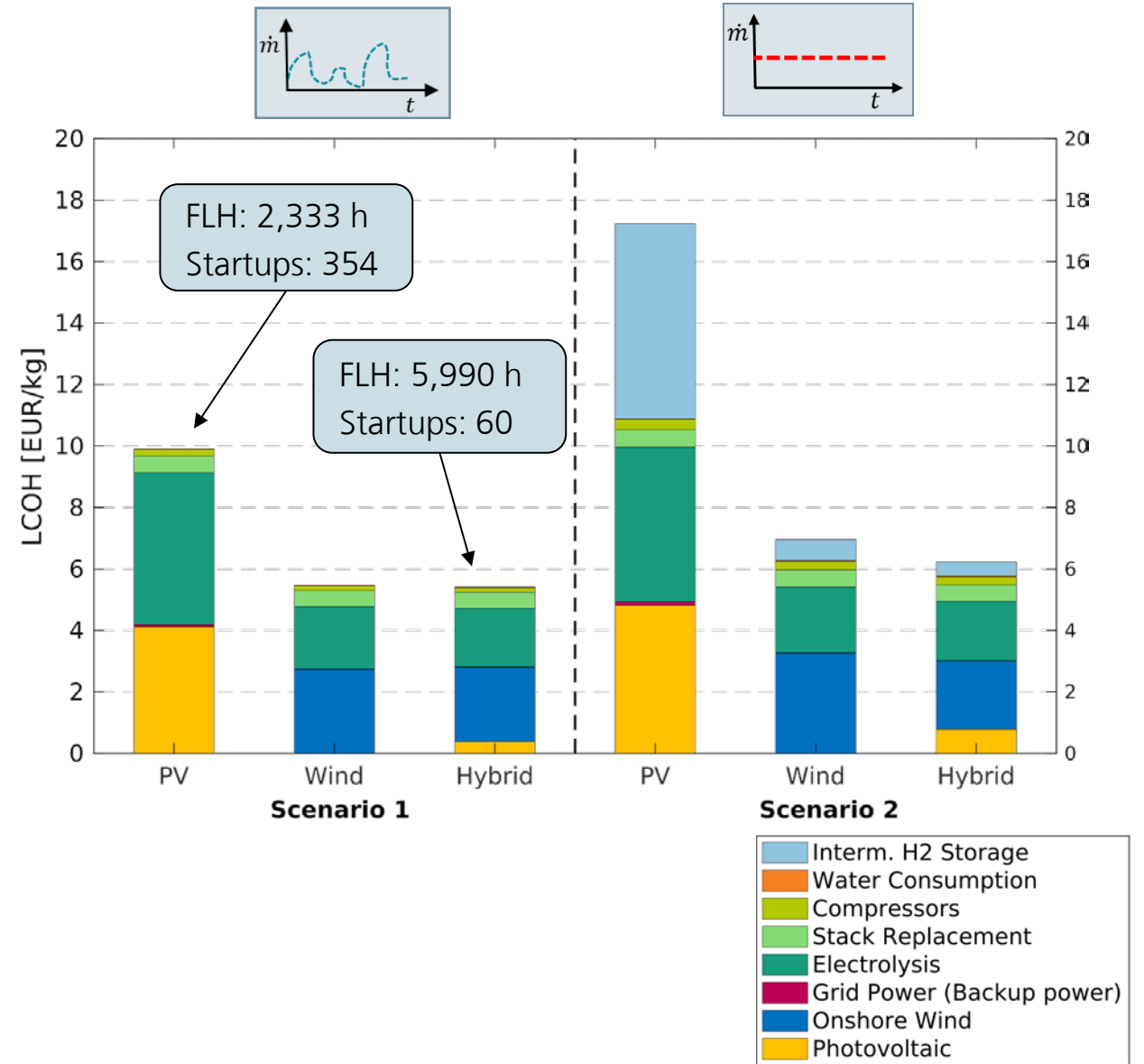
Results for Scenario 2: constant supply



Results of the Exemplary Case Study

Levelized costs of hydrogen production (LCOH)

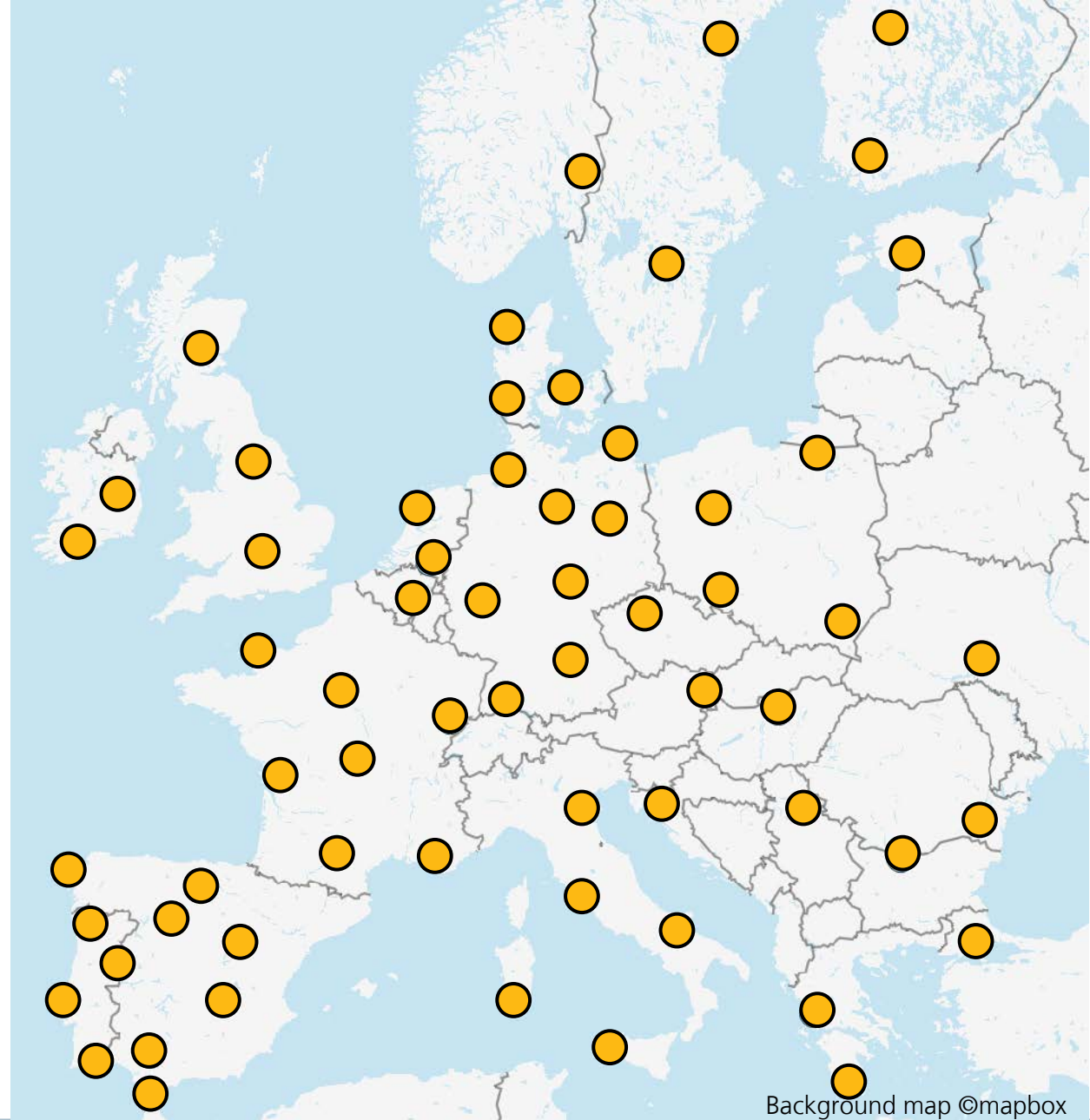
- **Standalone PV results in highest LCOH**
 - Low full load hours of the electrolysis
 - **Lowest LCOH for hybrid solution**
 - Up to ~6,000 full load hours of the electrolysis
 - **Standalone onshore** wind close to hybrid case
-
- RE and Electrolysis **main cost driver**
 - Stack replacement up to 10% of LCOH
 - **Water costs** almost neglectable
 - **Grid power** is only used for power supply for compressor, cooling during periods without RE generation



Expanding the Case Study

The same analysis has been performed for additional 64 sites across Europe!

- Sites selected based on existing wind and PV power plants
- Representing a large range of onshore wind and PV capacity factors
 - **Solar PV: 9-20 %**
 - **Onshore wind: 14-50 %**



Background map ©mapbox

Result: Correlation of Capacity Factor and LCOH

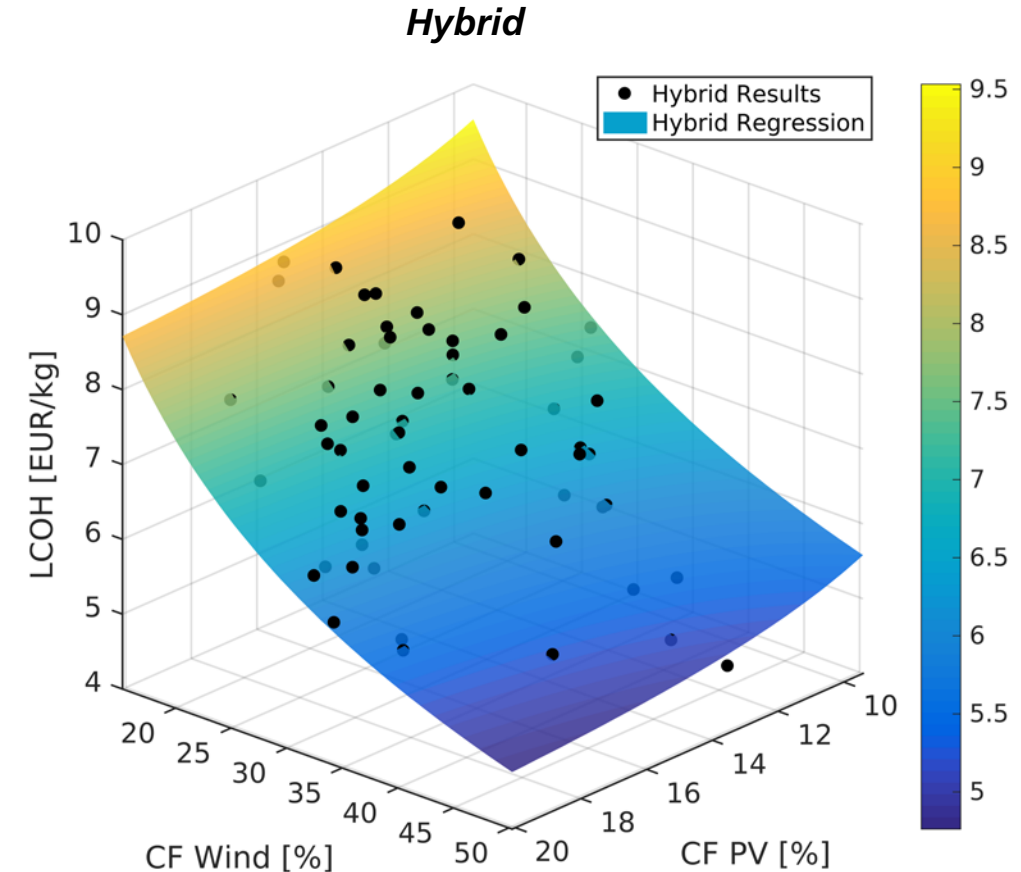
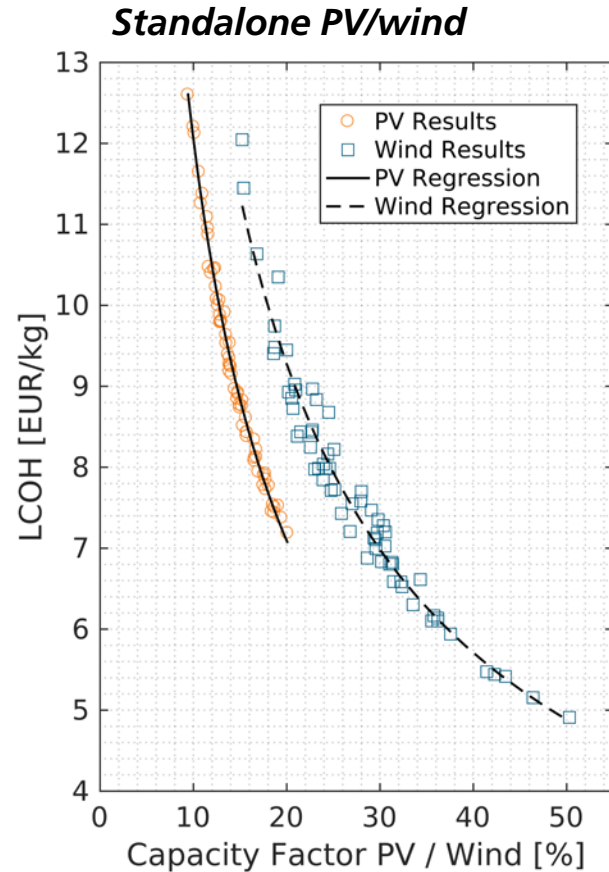
Scenario 1: Hydrogen, supplied as produced

Results for Scenario 1:
H2 supply as produced



High RE capacity factor is key for low LCOH

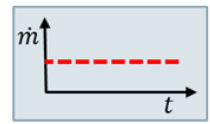
- **Low LCOE of PV** at locations with high CF, **but low FLH of electrolysis** increase LCOH
- **Hybrid systems** in almost all cases **the best solution**; increase of full load hours of the electrolysis



Result: Correlation of Capacity Factor and LCOH

Scenario 2: Constant hydrogen supply

Results for Scenario 2:
constant supply

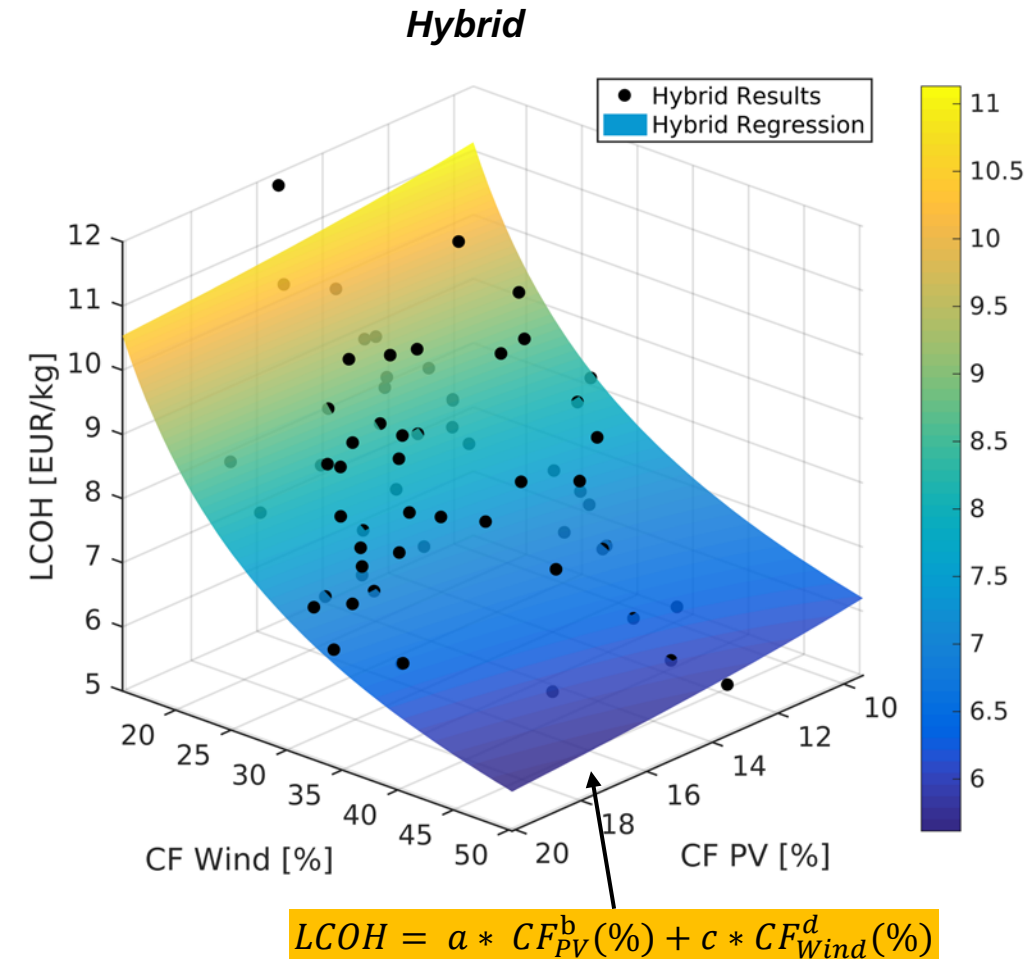
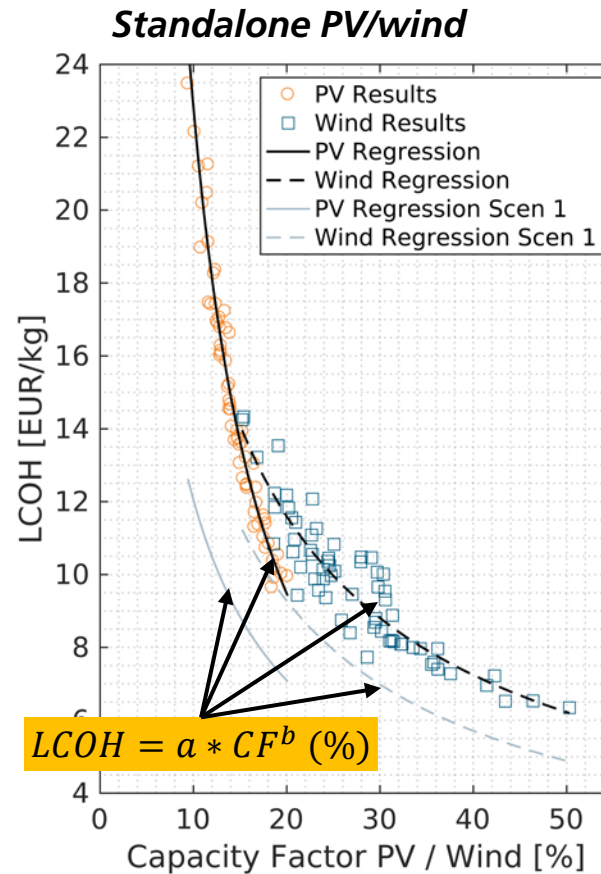


- Constant supply constraint increase LCOH by ~1 to 2.5 €/kg
 - Worst case: standalone PV in Scandinavia $\Delta\text{LCOH} > 10$ €/kg
- For both scenarios, **easy-to-apply correlations** have been developed to determine LCOH based on capacity factor of RE

Exemplary Equation constants

Onshore Wind (Scenario 1)

$a = 75.52$ $b = -0.7$



Conclusion

- **Detailed model-based simulation** of hydrogen production plants is central to analyze systems in advance
- A powerful **non-linear system optimization** algorithm can determine the best dimensioning of the components. For each application and location specific conditions need to be considered
- The developed **easy-to-apply correlations** can be used for estimate of LCOH in relation to RE conditions under today's conditions. Effect of future developments can be easily modeled.
- The **H₂ProSim** model environment can answer a wide range of techno-economic questions. The flexibility of the model allows to analyze **your specific use-case**. E.g.: battery integration, cavern hydrogen storage, by-product utilization, cash flow analysis, transport integration, ...



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