ENVIRONMENTAL FOOTPRINT OF ELECTROCHEMICAL HYDROGEN PRODUCTION BASED ON CSP/PV HYBRID POWER PLANTS

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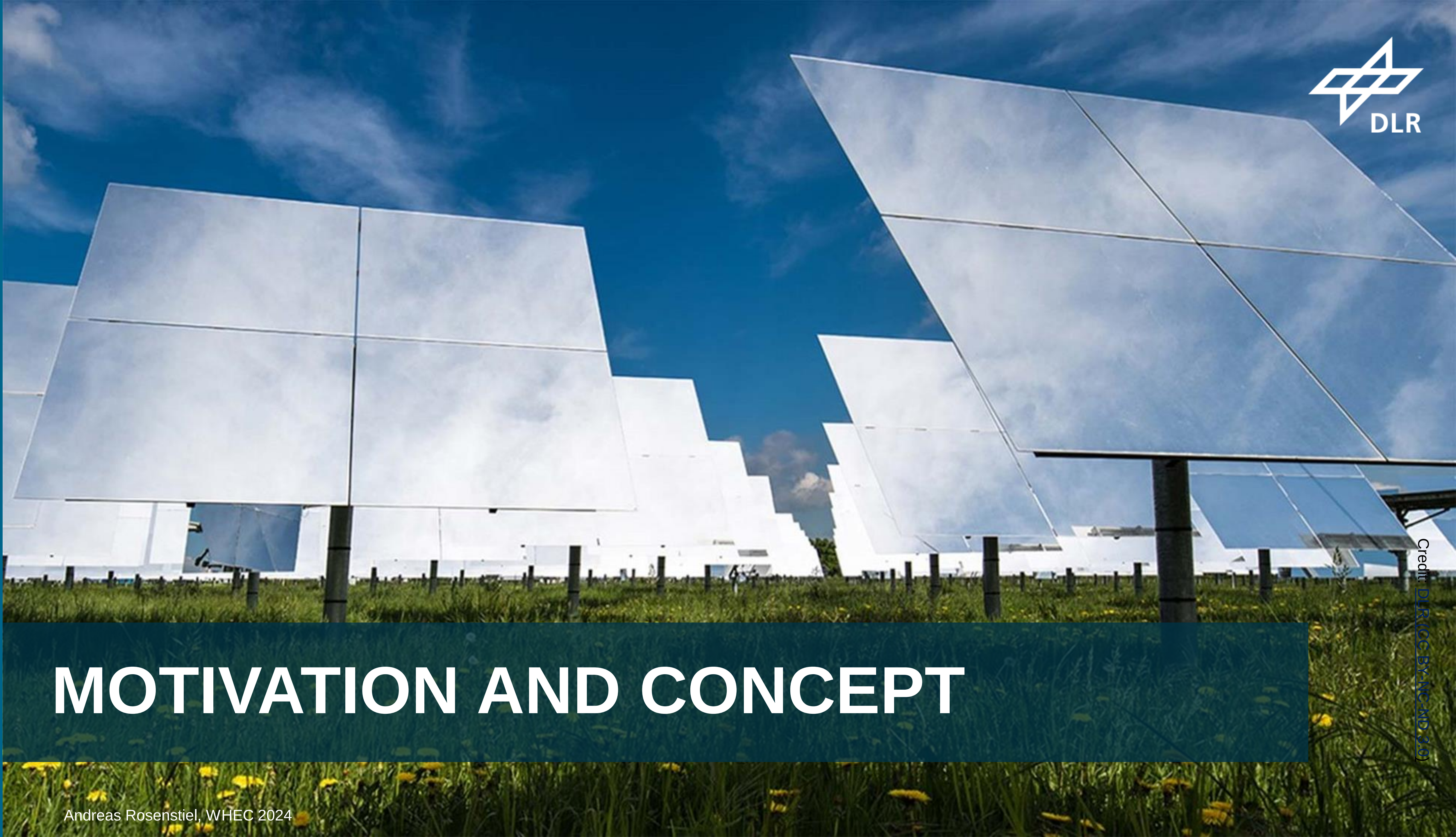


MOTIVATION AND CONCEPT

Motivation: Solar hydrogen potential

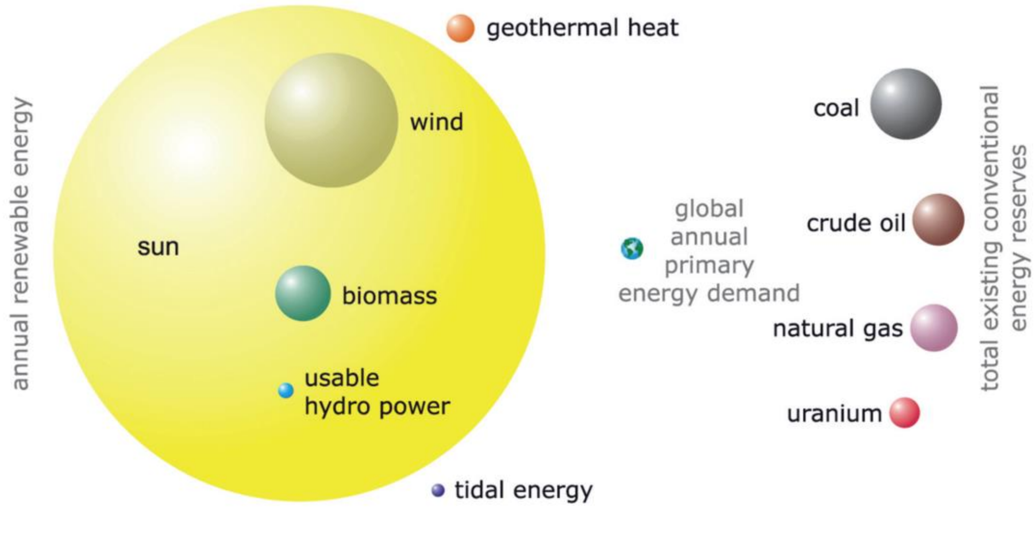
- Total solar irradiation potential ~ 6000 times world's primary energy demand (1).

➢ Sunbelt has great potential for the production and export of renewable energy carriers (green H_2 and H_2 derivatives).

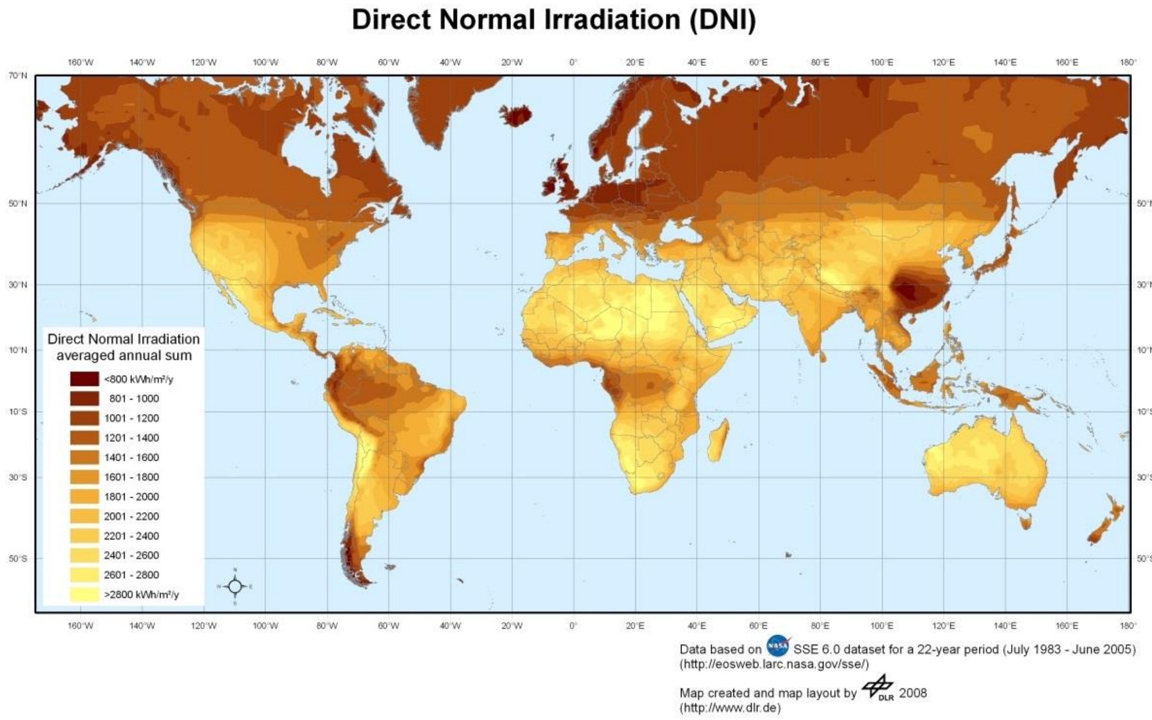
Focus of work:

- Development of cost-optimized systems for the production of solar fuels with the lowest possible environmental impact.

➢ Consider lifecycle emissions of the applied technologies especially global warming potential (GWP100).

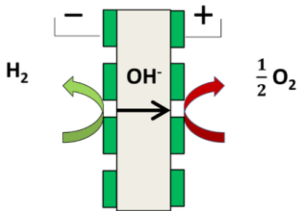


(1) Quaschning 2019



Concept CSP/PV hybrid power plant for electrochemical hydrogen and H_2 derivatives production

Electricity produced with solar energy



Electrochemical water splitting (AEL)

Photovoltaics (PV)

- Low levelized cost of electricity
- Availability depends on solar irradiation

Concentrated Solar Power (CSP)

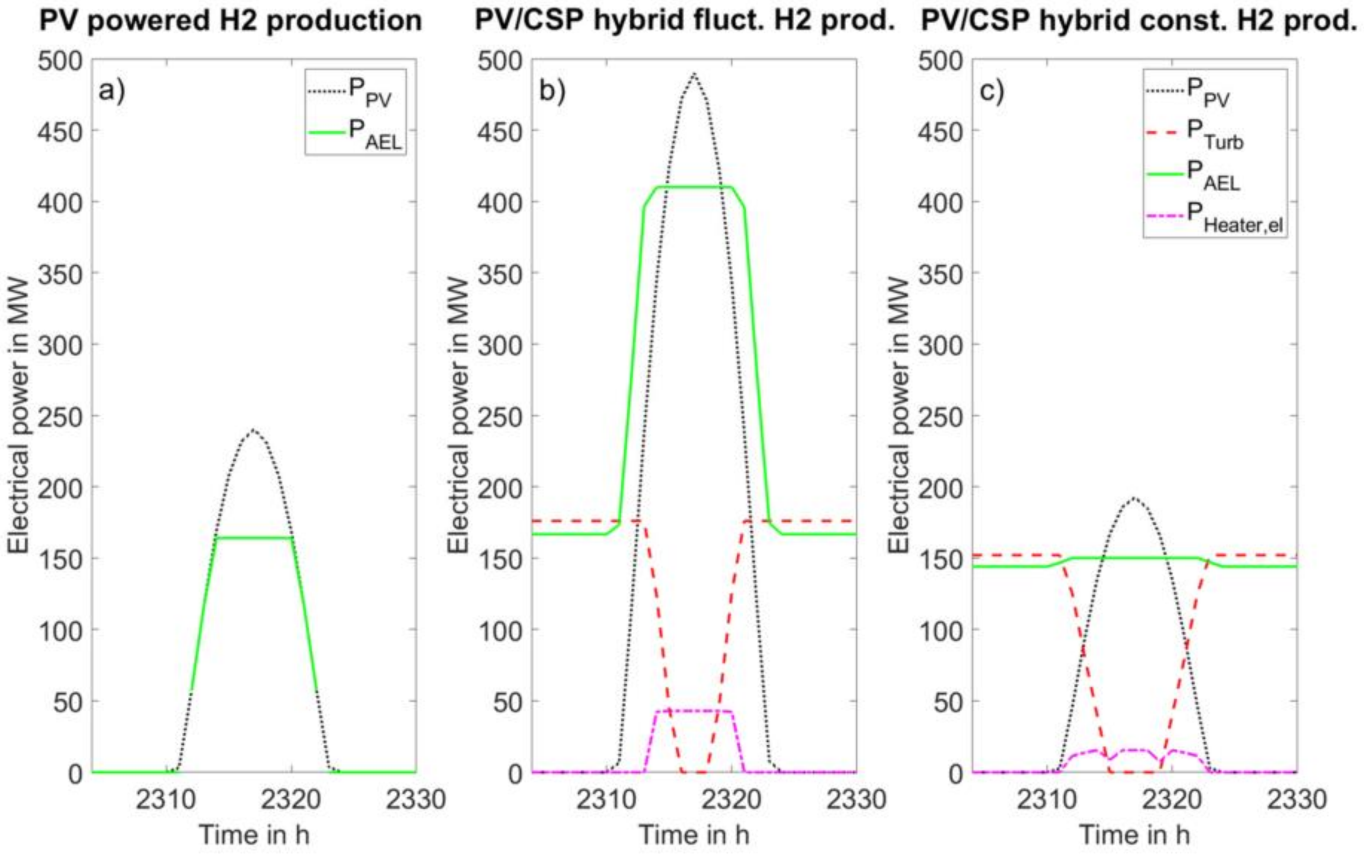
- Thermal storage (low cost)
- Flexible electricity production (steam cycle)

➢ Combination of PV and CSP can lead to high electrolyser full load hours with relatively low levelized cost of electricity.

➢ Synergies in hybrid system: E.g. additional electric heater and usage of PV electricity for internal demand of CSP plant

CSP/PV hybrid concept cost-optimal operational strategy

a) Overscaled PV-only system: fluctuating H_2 production
b) CSP/PV hybrid system: fluctuating H_2 production with overscaled electrolysis and PV
c) CSP/PV hybrid system: Continuous H_2 production



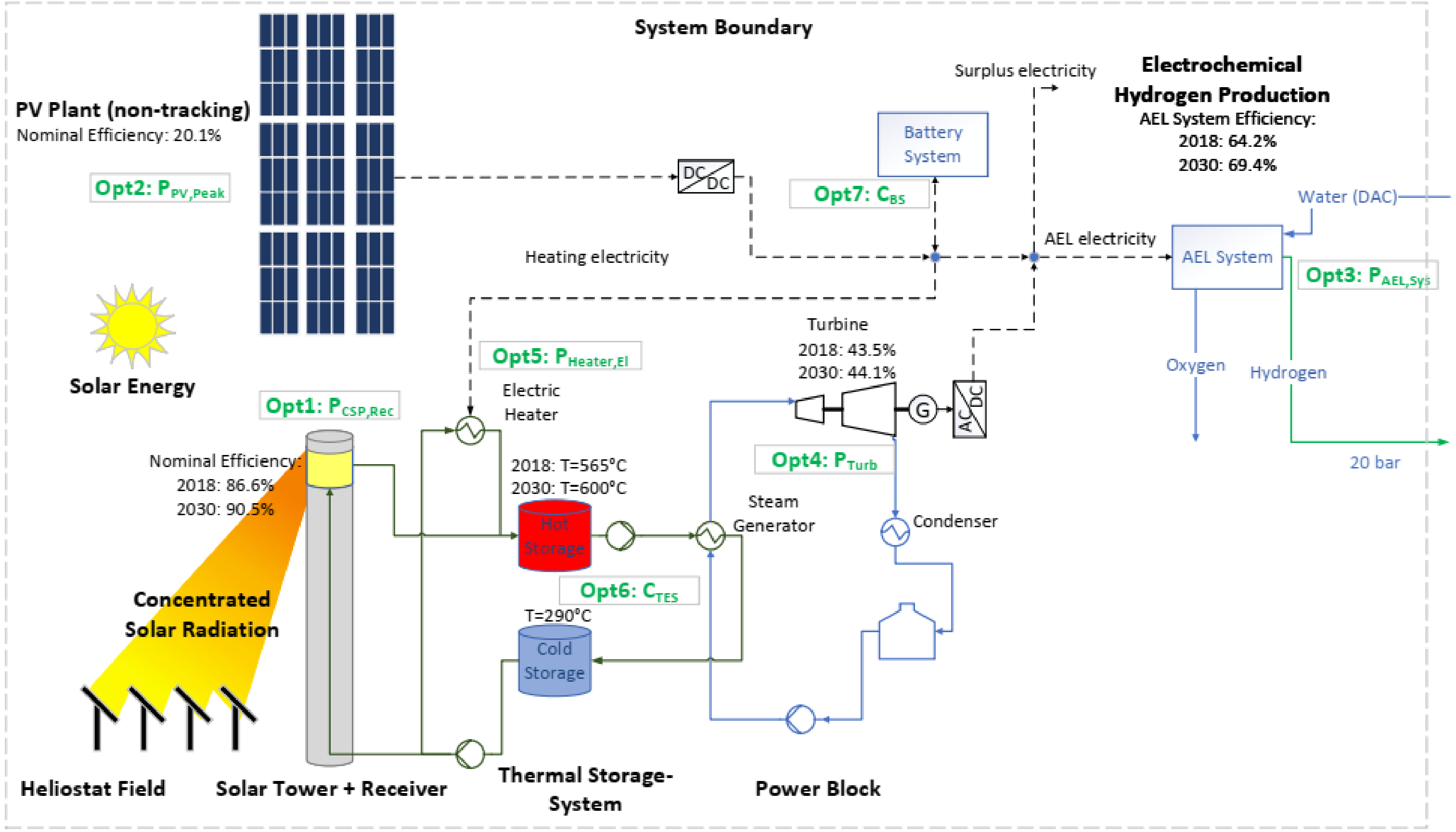
- Cost optimization to determine operational concept (plant design)
- Expectation: Environmental aspects favor continuous hydrogen production concepts

4) Rosenstiel et al (2021) https://doi.org/10.3390/en14123437

METHODOLOGY

CSP/PV hybrid energy system model and optimization variables

$$\min(\mathit{Levelized\ Cost\ of\ Hydrogen})\ or\ \min(\mathit{CO_2\ abatement\ costs}) = f\left(P_{CSP,Rec}, P_{PV,Peak}, P_{AEL}, P_{Turb}, \mathrm{P}_{Heater,el}, \mathrm{C}_{TES}, C_{Battery}\right)$$

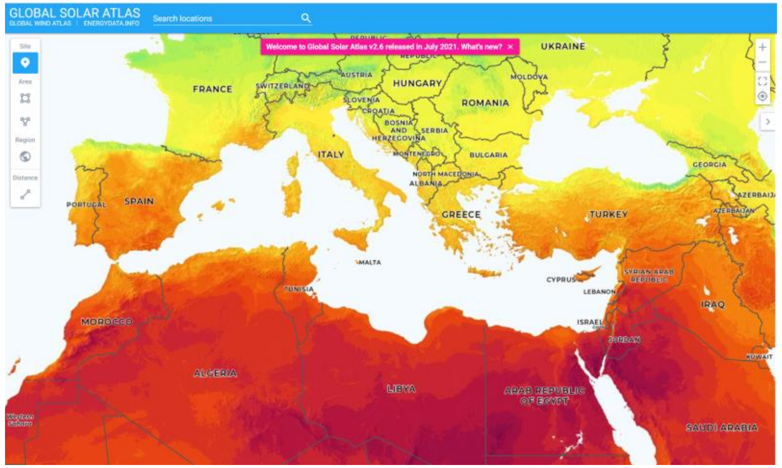


- Techno-economic energy system model with 7 optimization variables
- Stand-alone system, system boundary H_2 at 20 bar
- Previous study: Cost-optimal sizing of systems components by minimization of LCOH. (global optimization algorithm)
- New study: Design system by minimization of CO_2 abatement costs.

Techno-economic process evaluation: methodology

Weather data source: (Meteonorm 8.0) and Greenius (DLR tool)

- Freiburg, Germany: DNI: 971 kWh/(m^2a)
- Almeria, Spain, DNI: 1918 kWh/(m^2a)
- Ouarzazate, Morocco DNI: 2518 kWh/(m^2a)
- Tabuk, Saudi-Arabia DNI: 2882 kWh/(m^2a)
- Process simulation(1h) steps



- Study with constant electrolyser Total investment cost (TCI): 827 USD/kW
- Standard PV, CSP scenario (today)
- Outlook scenario:
  - PV: -55% (760, 340 USD/kW)
  - CSP approx. – 25 %, higher efficiency

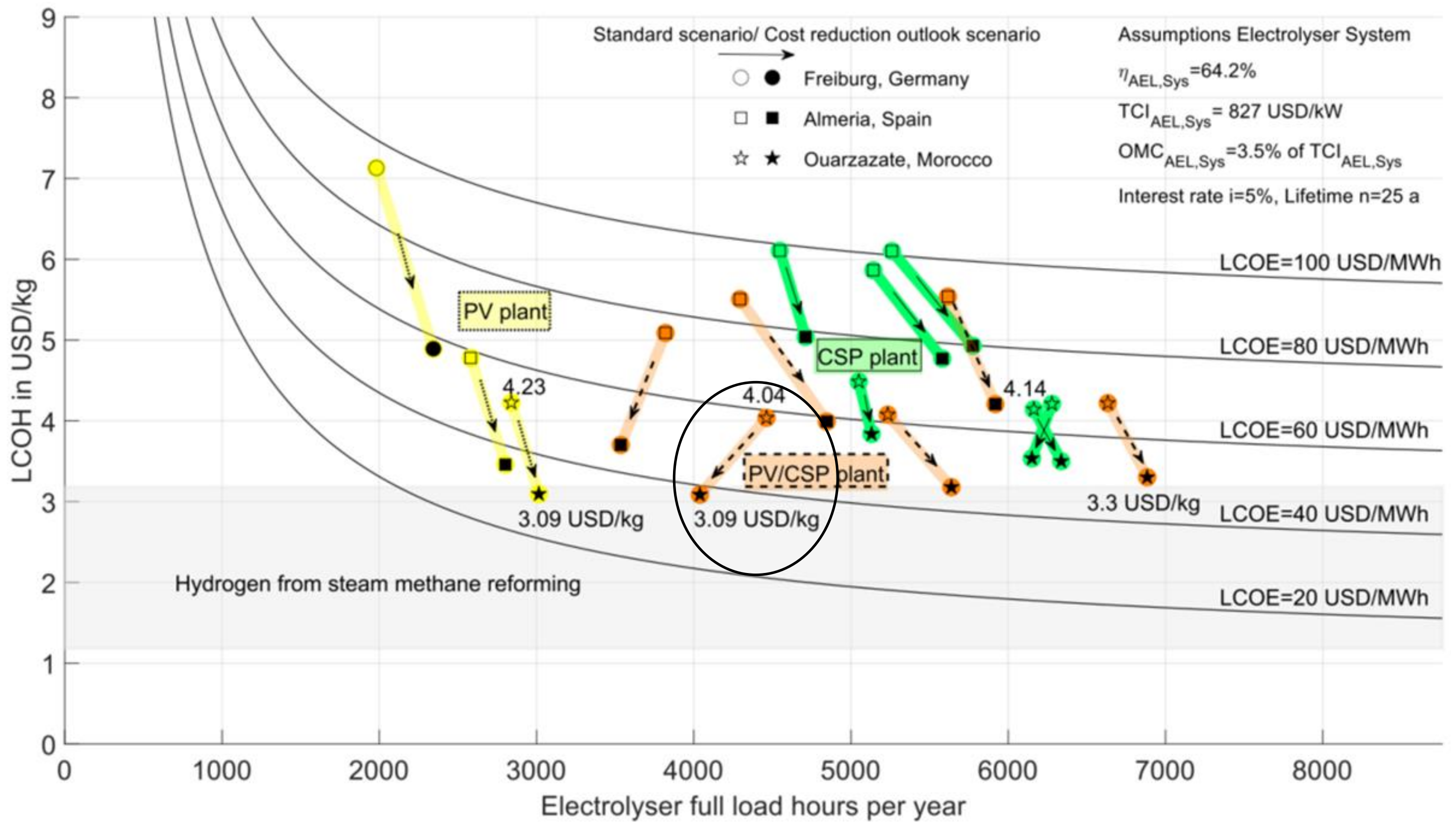
CSP cost assumptions: Total Sub component cost (7)

CSP equipment	**Location: Almeria, Spain Cost Index: 84**			**Location: Ouarzazate, Morocco Cost Index: 42**		
	Standard scenario	Outlook scenario	Cost reduction	Standard scenario	Outlook scenario	Cost reduction
Heliostat field (USD/m^2)	114.76	83.11	27.6%	87.88	65.27	25.7%
Tower (10^3USD/m	78.48	62.78	20.0%	48.24	38.59	20.0%
Receiver (USD/kW_{th})	146.57	102.60	30.0%	124.43	87.10	30.0%
Thermal storage (USD/kWh)	24.93	20.68	17.0%	21.09	17.75	15.8%
Power Block (USD/kW_{el})	785.12	708.45	9.8%	693.56	625.62	9.8%

Dersch et al (2020) https://doi.org/10.1063/5.0028883

CSP/PV hybrid power plant for hydrogen and hydrogen derivatives production

- Influence of electricity price and electrolyser full load hours on levelized cost of hydrogen (LCOH)
- Previous studies showed economical advantages of CSP/PV hybridization for hydrogen production (3,4).

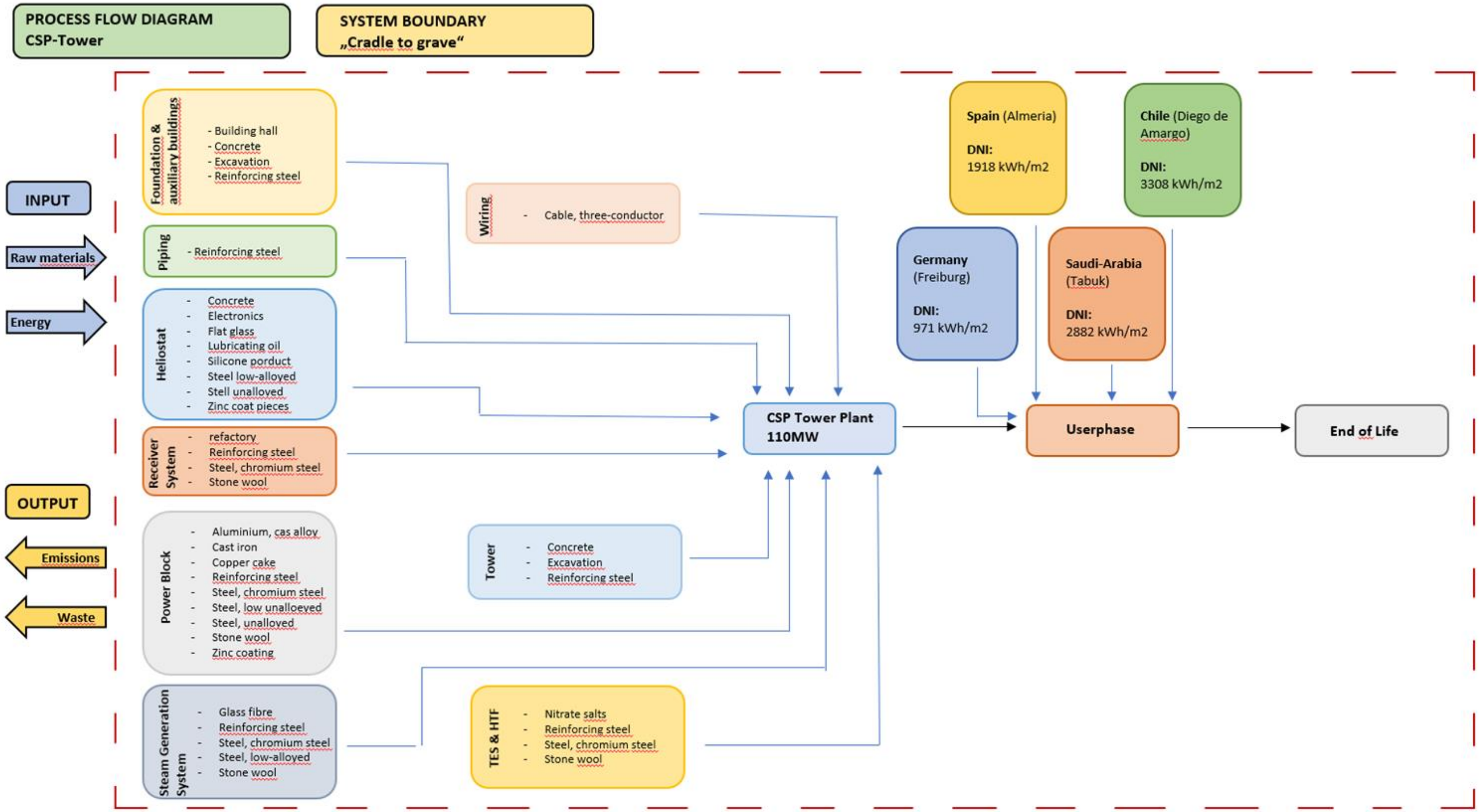


- Cost reduction outlook scenario analyzed effect of strongly decreasing PV costs and moderately decreasing CSP costs.
- Cost optimum of CSP/PV plants shifts with lower PV costs to lower electrolyser full load hours (fluctuating production).
- ➢ Include environmental aspects in system evaluation.

4) Rosenstiel et al (2021) https://doi.org/10.3390/en14123437

Environmental process evaluation methododoly: Life Cycle Assessment (LCA) of PV and CSP electricity provision

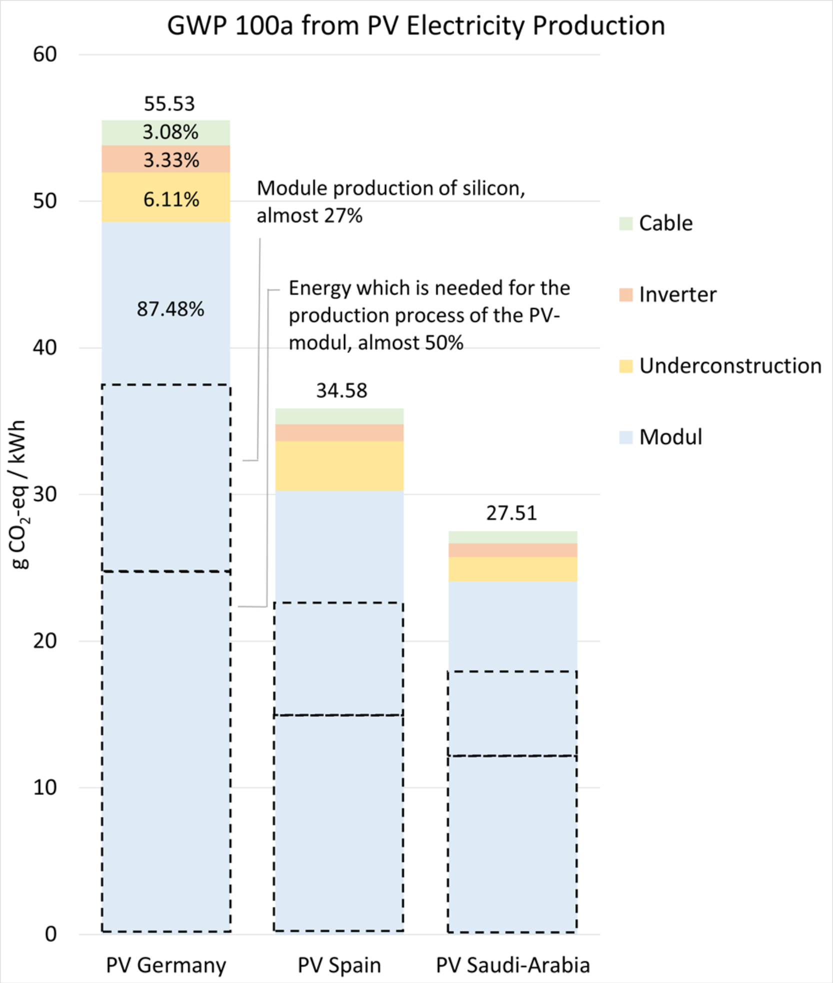
- LCA with the OpenLCA tool and Ecoinvent database
- CSP data based on G.Gasa (2021,2022)
- Focus impact category Global Warming Potential (GWP100)
- Functional unit: GWP/kWh_{el}

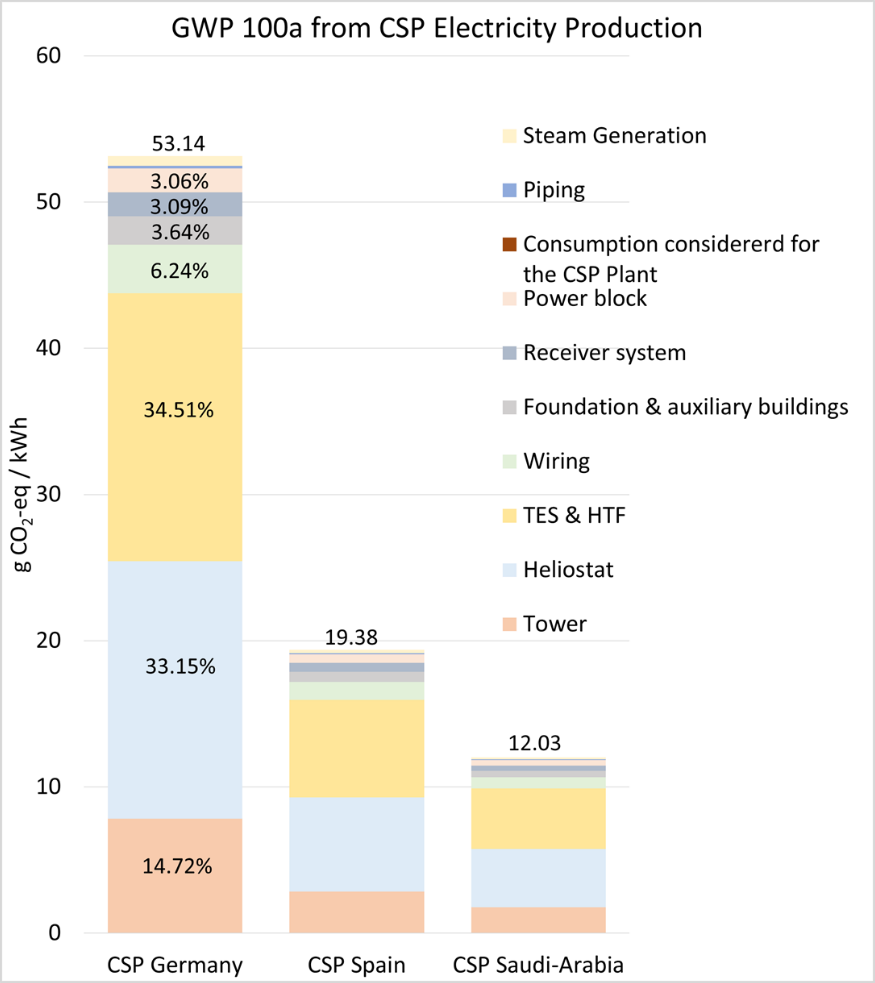


9) Gemma Gasa. 2021
10) Gemma Gasa, 2022

ENVIRONMENTAL PROCESS EVALUATION

Environmental process evaluation:
Global warming potential (GWP100) of PV and CSP electricity provision



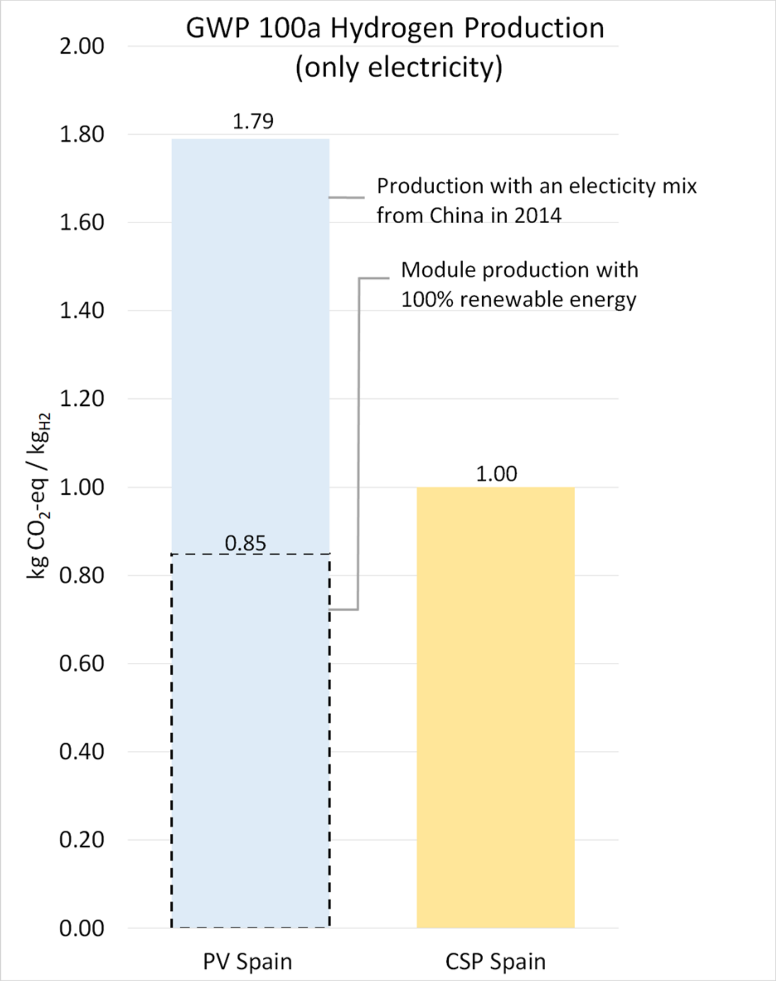


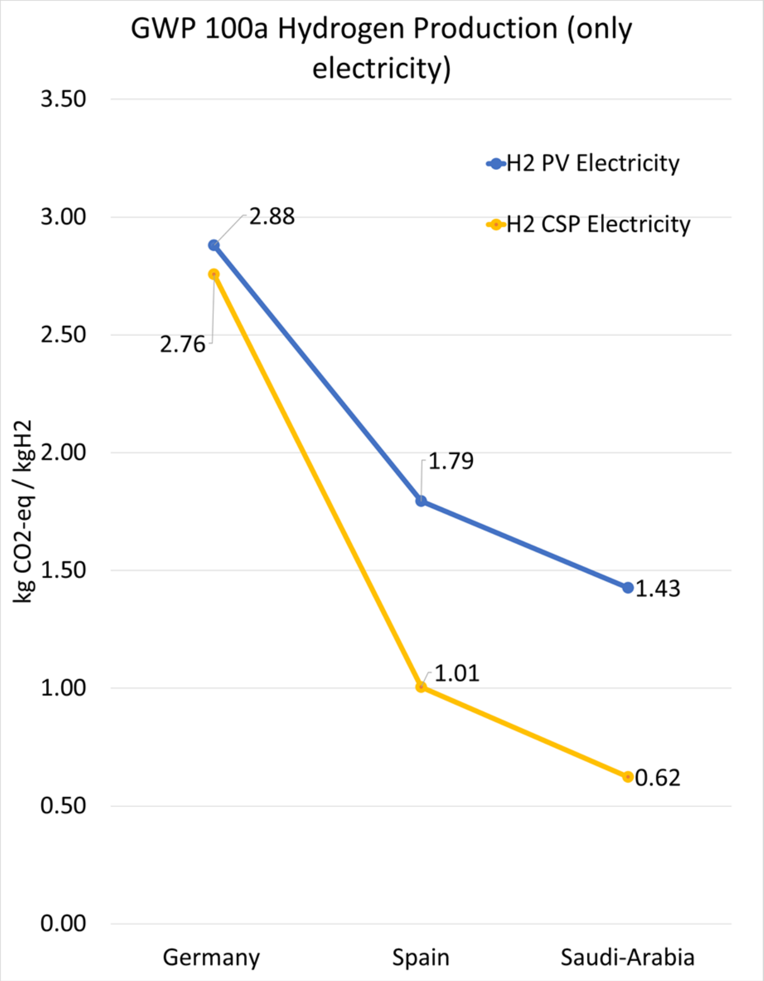
- Analysis for 3 locations
- Assumption lifetime 20 a
- ➢ CSP GWP potential up to 56% lower at good solar locations.

PV LCA evaluation based on Umweltbundesamt 2021 (11) and IEA 2020 (12)

CSP evaluation based on publication of Gasa et al 2021 (9) and Gasa et al 2022 (10)

Environmental process evaluation: Global warming potential (GWP100) of solar powered electrochemical hydrogen production



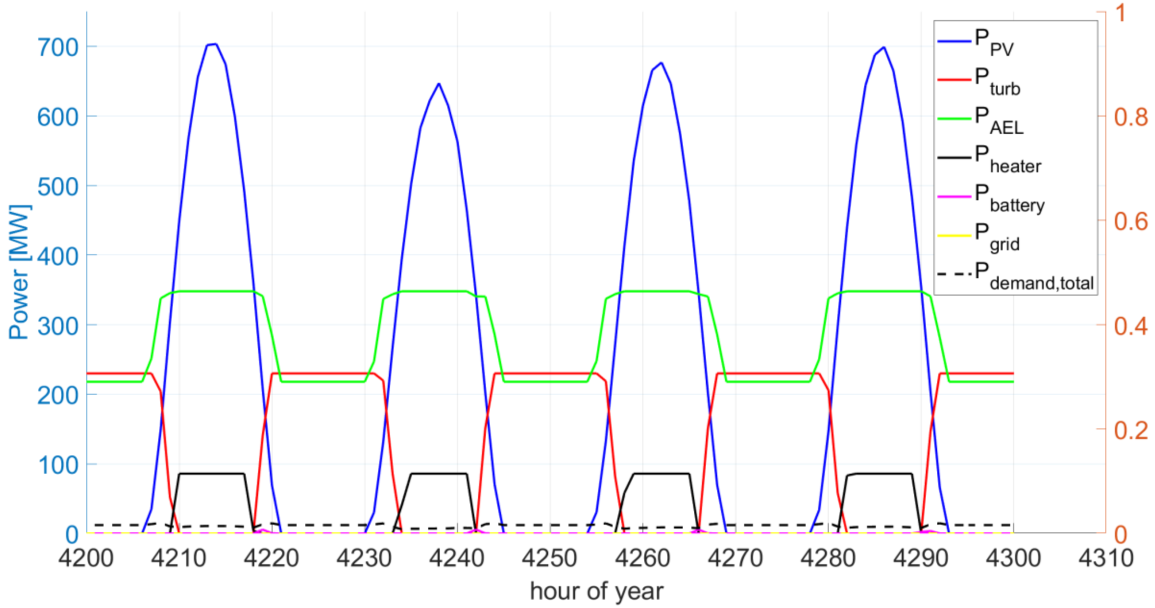


CO_2 abatement costs ($CO_{2,AC}$) minimization hydrogen production (only electricity)

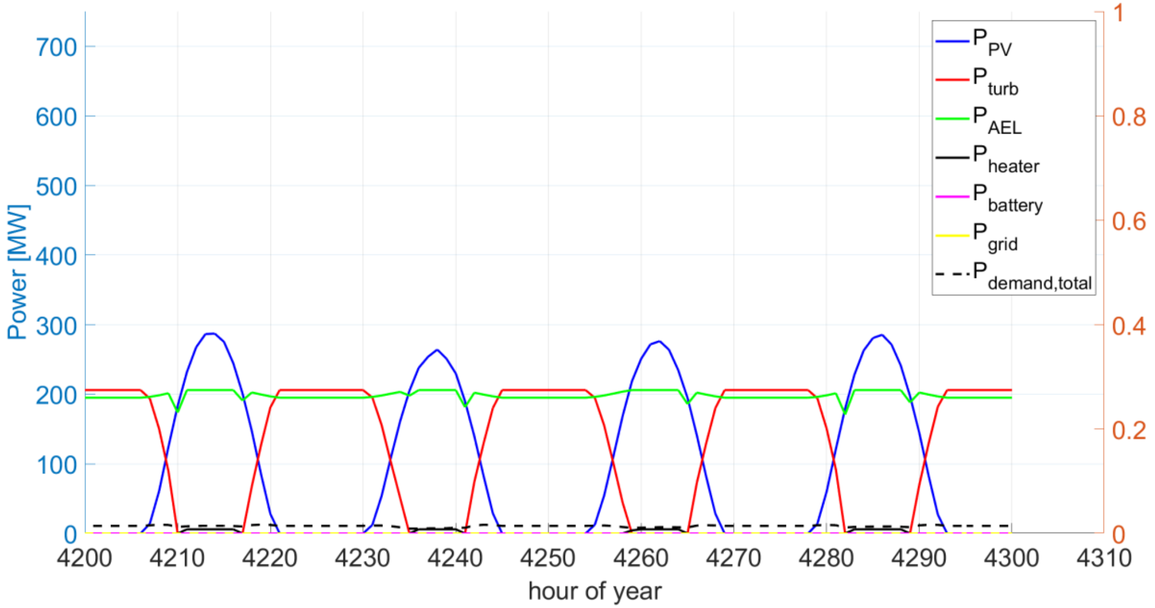
$$(CO_{2,AC}\ of\ H_2) = \frac{LCOH_{2,solar} - LCOH_{2,ref^*}}{GWP\ H_{2,ref^*} - GWP\ H_{2,solar}}$$

$$\min(CO_{2,AC}) = f(P_{CSP,Rec}, P_{PV,Peak}, P_{AEL}, P_{Turb}, P_{Heater,el}, C_{TES}, C_{Battery})$$

Economic system optimization, Almeria (Spain) 2020



Minimization $CO_{2,AC}$, Almeria 2020

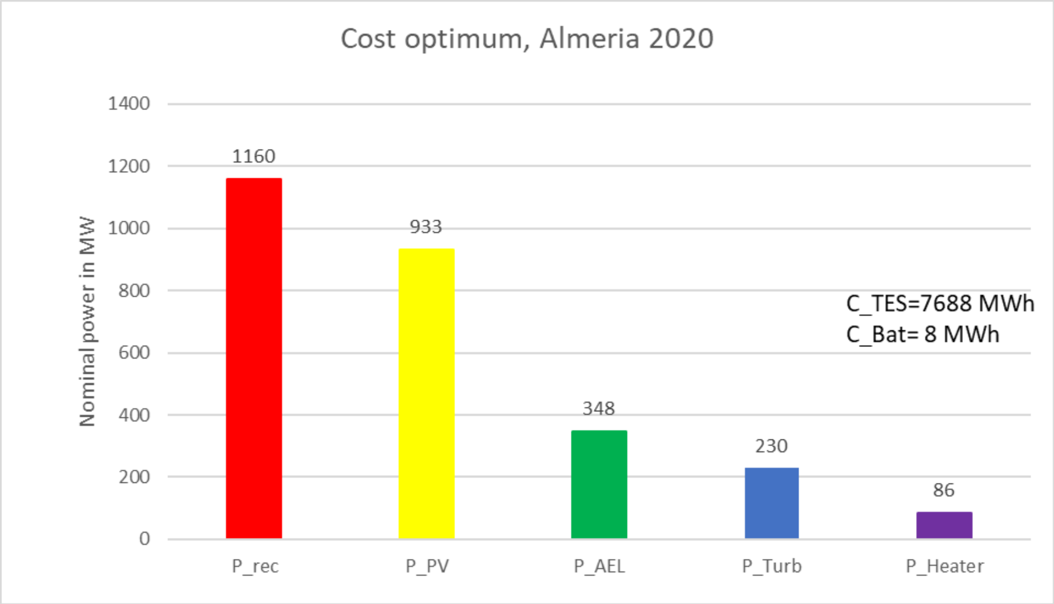


- $CO_{2,AC}$ minimization leads to more continuous hydrogen production concepts.

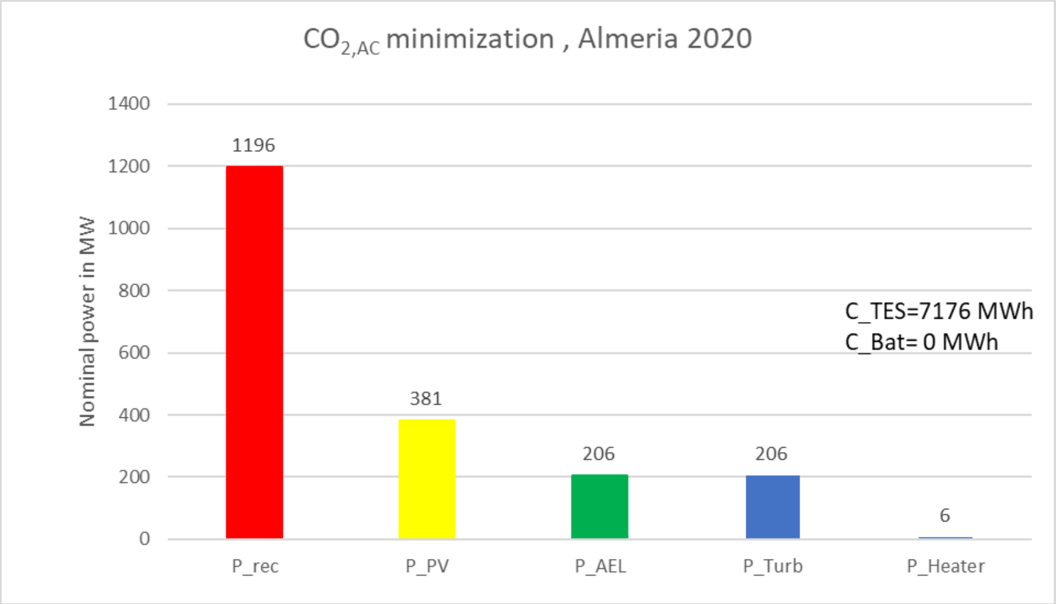
*Reference process: Hydrogen from steam methane reforming (SMR) : 2011 kg (CO_{2eq}/ t MeOH) (11)
Price for Hydrogen produced by SMR: 1.5 USD/kg

CO_2 abatement costs ($CO_{2,AC}$) minimization hydrogen production (only electricity)

Economic system optimization, Almeria 2020

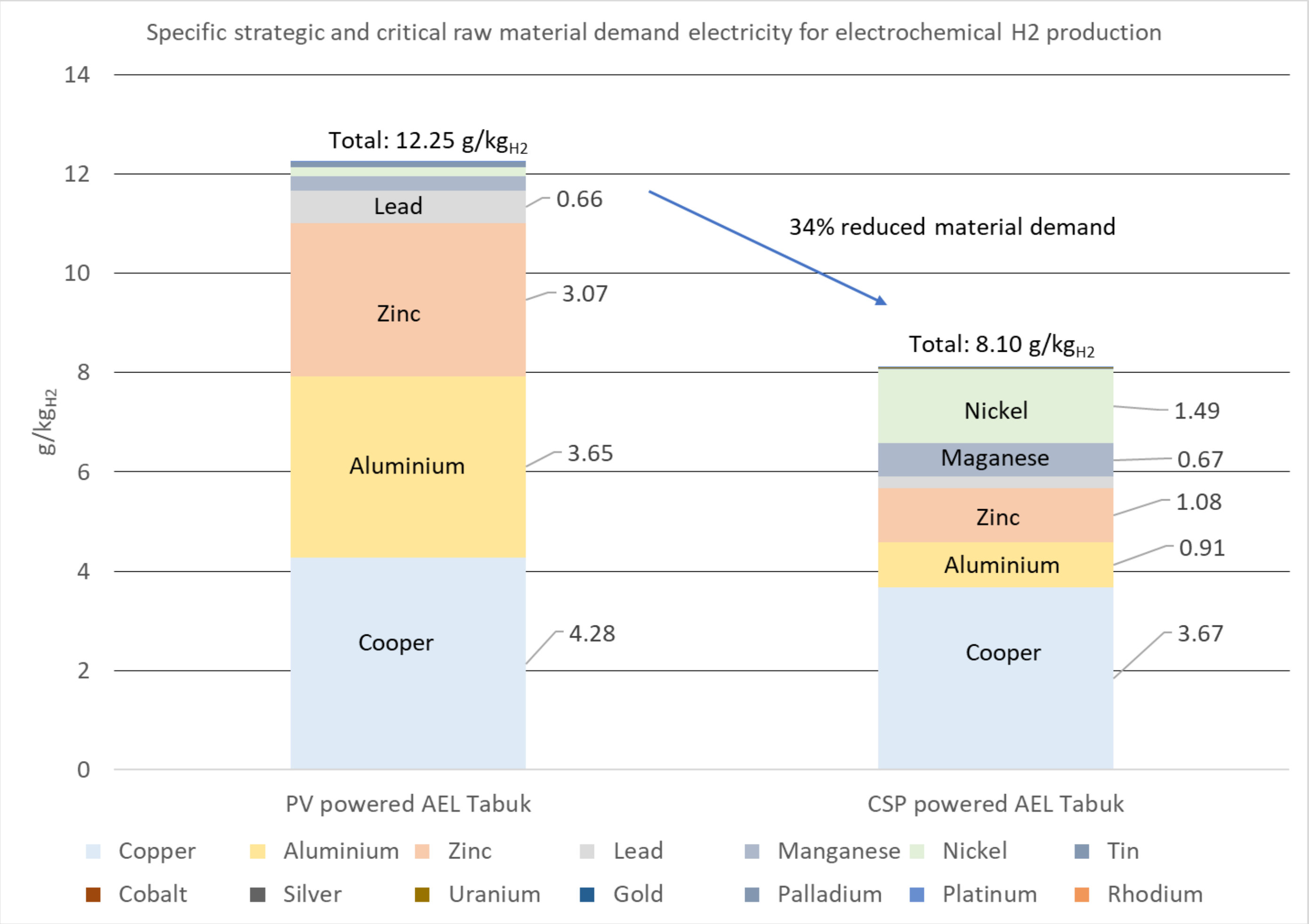


Minimization $CO_{2,AC}$, Almeria 2020



- Different plant design with consideration of lifecycle emissions of electricity generation.
- Cleaner energy usage in production processes will shift the results of CO_2 abatement cost minimization (prospective LCA).

Critical raw material demand for solar electrochemical hydrogen production (only electricity)



- Analysis for plant site with high solar irradiation potential (Tabuk, Saudi-Arabia)
- Production of PV electricity requires more critical and strategic raw materials.

SUMMARY AND OUTLOOK

Summary and Outlook

- Hydrogen production based on CSP/PV hybrid power plants with thermal energy storage are an economically promising approach for the production of green hydrogen.
- Environmental aspects of electricity provision should not be neglected.
- Focus on global warming potential (GWP100) over lifecycle and critical raw material demand.
- Lower PV system costs favor economically plant concepts with fluctuating hydrogen production (lower FLH)
- Environmental aspects favor continuous process concepts with a high share of CSP electricity. (>8000 electrolyzer FLH possible).

Next steps:

- Include more process equipment (e.g. electrolyser system) in environmental system evaluation based on a LCA analysis
- CSP LCA based on primary data
- Include prospective LCA
- Study for a great variety of locations, sensitivity analysis

➢ Identification of key performance factors

Impressum

Thank you for your attention!
Muchas gracias!

Topic: Environmental Footprint of Electrochemical Hydrogen Production Based on CSP/PV Hybrid Power Plants

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