UiO University of Oslo

NORCE

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 48 (2023) 28712–28732

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Simulating offshore hydrogen production via PEM electrolysis using real power production data from a 2.3 MW floating offshore wind turbine

Check for updates

Torbjørn Egeland-Eriksen [a,b,c,*], *Jonas Flatgård Jensen* [a], *Øystein Ulleberg* [d], *Sabrina Sartori* [a]

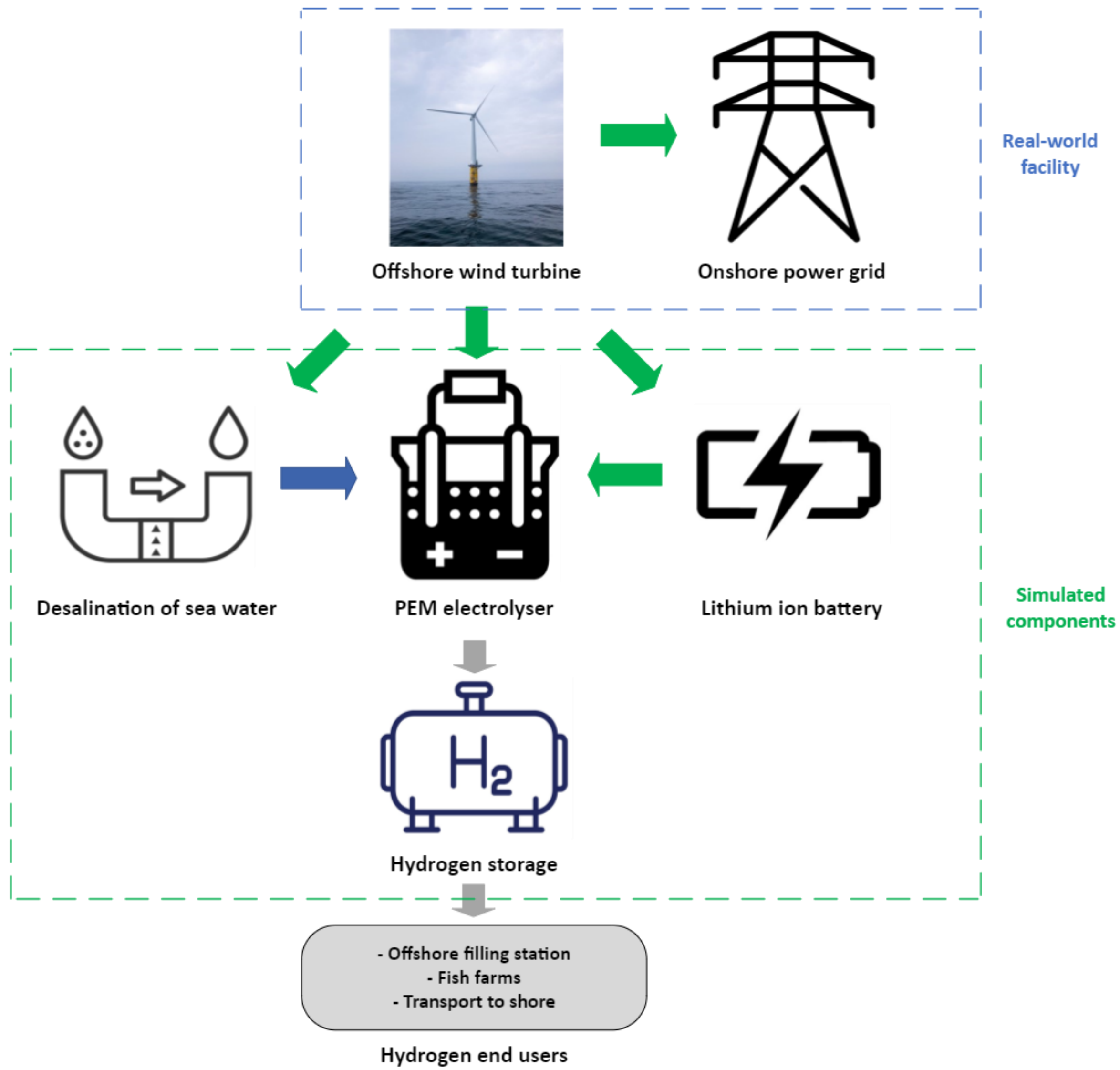
[a] *Department of Technology Systems, University of Oslo, Gunnar Randers Vei 19, 2007, Kjeller, Norway*
[b] *NORCE Norwegian Research Centre AS, Sørhauggata 128, 5527, Haugesund, Norway*
[c] *UNITECH Energy Research and Development Center AS, Spannavegen 152, 5535, Haugesund, Norway*
[d] *Institute for Energy Technology, Instituttveien 18, 2007, Kjeller, Norway*

HIGHLIGHTS

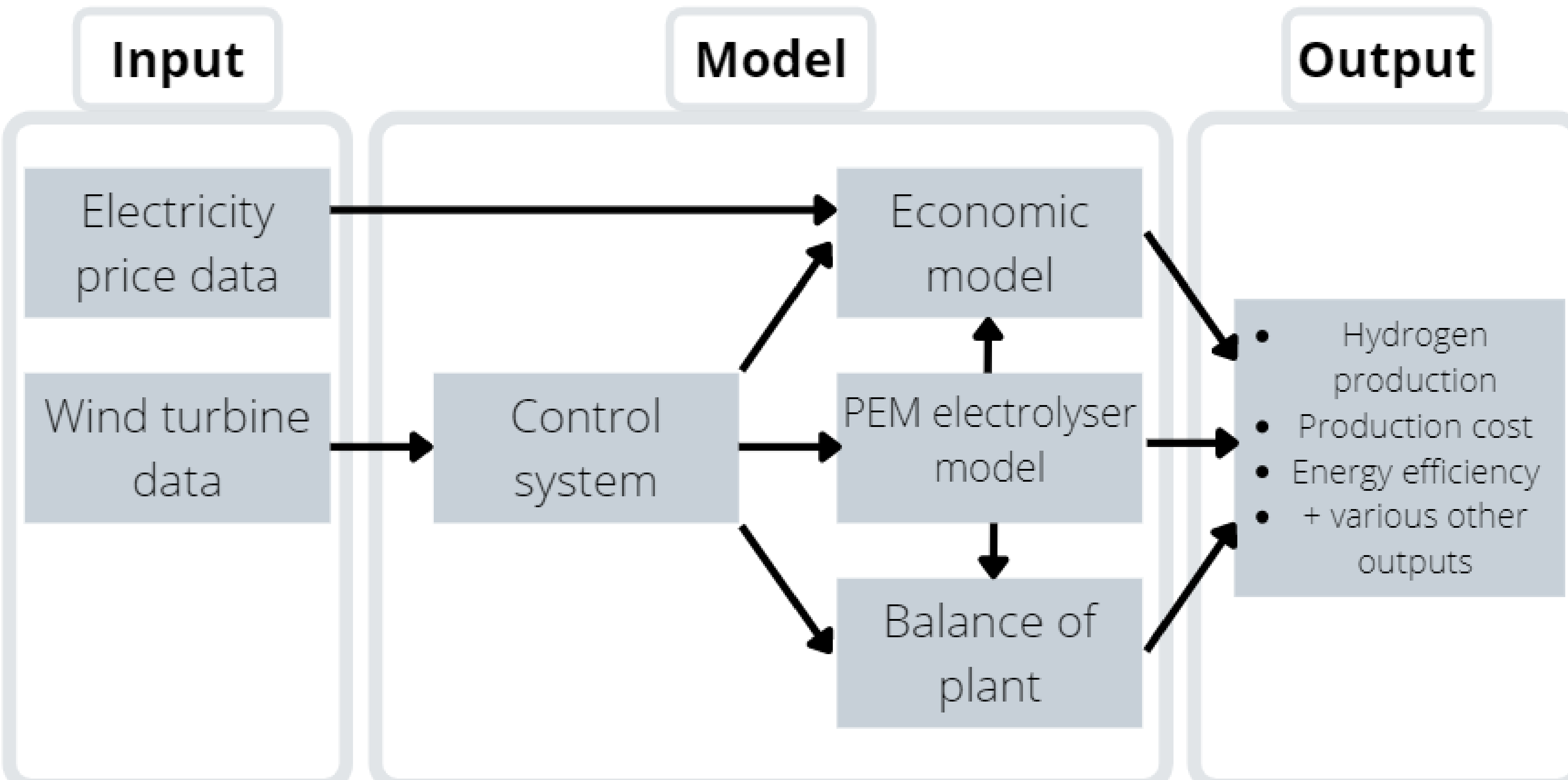
- Simulations of H_2 produced with electricity from real-world offshore wind turbine.
- Novel combination of electrolyzer model + wind power and electricity price data.
- H_2 production and cost vary by a factor of three between different periods.
- Highest H_2 production in a 31-day period was 17 242 kg with a 1.852 MW electrolyzer.
- The lowest H_2 production cost achieved was 4.53 \$/kg H_2.

1 Hy School.no

Zefyros hydrogen system overview



Schematic of Simulink model

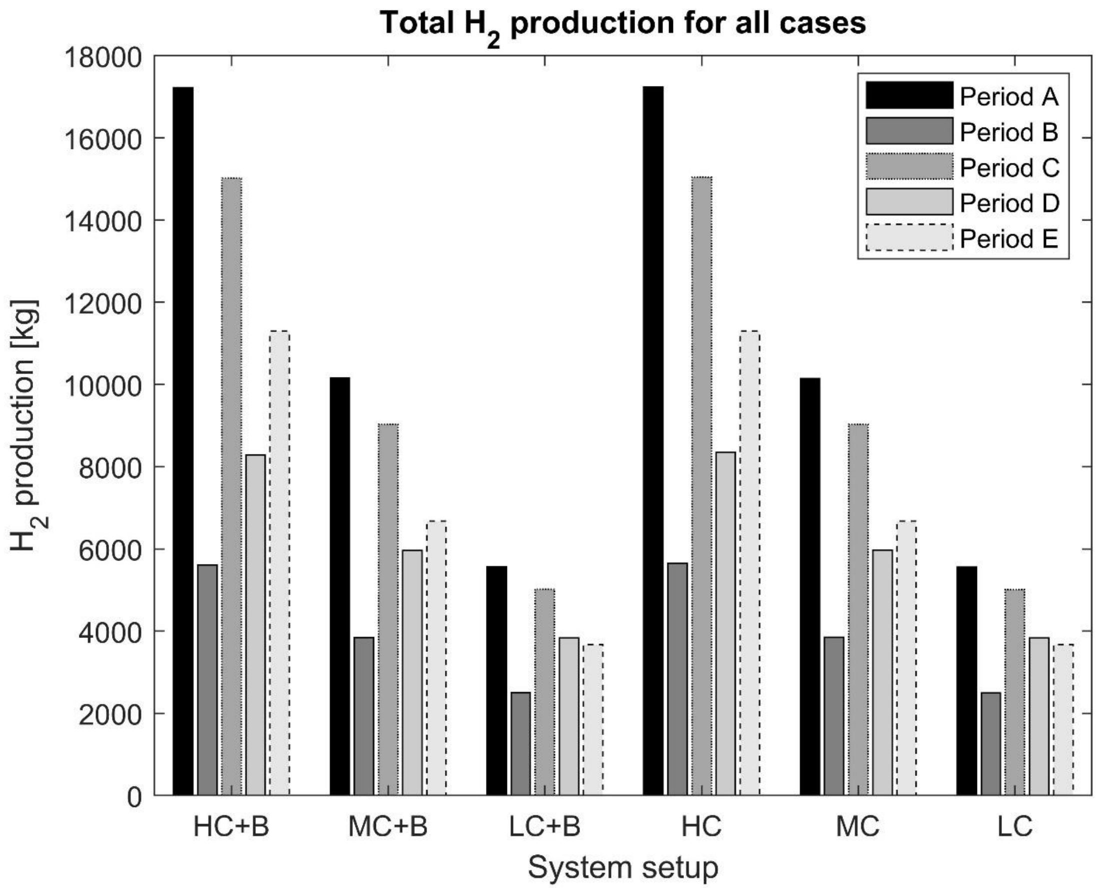


Five time periods and six system designs

Time period	Tag	Wind turbine capacity factor [%]	Average electricity price [$/kWh]
07.03-06.04.2020	A	63.6	0.0091
20.12.2020-19.01.2021	B	21.3	0.0440
01.01-31.01.2022	C	55.1	0.1609
01.06-01.07.2020	D	30.9	0.0018
01.12-31.12.2020	E	41.7	0.0245

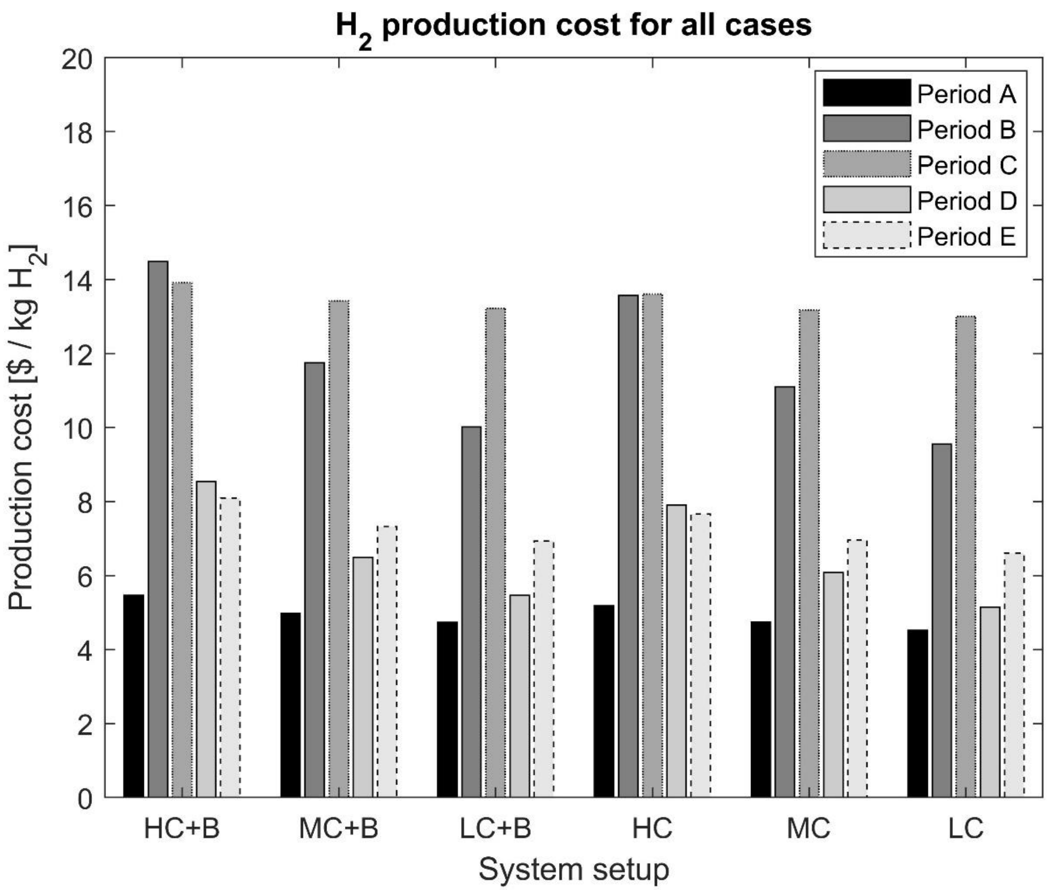
System design	Electrolyzer power [kW]	Combined electrolyzer and compressor power [kW]	Li-ion battery energy/power [kWh/kW]	Grid-connected
High capacity with battery (HC+B)	1852	2000	1000 / 200	Yes
Medium capacity with battery (MC+B)	926	1000	500 / 100	Yes
Low capacity with battery (LC+B)	463	500	250 / 50	Yes
High capacity without battery (HC)	1852	2000	No battery	Yes
Medium capacity without battery (MC)	926	1000	No battery	Yes
Low capacity without battery (LC)	463	500	No battery	Yes

Hydrogen production



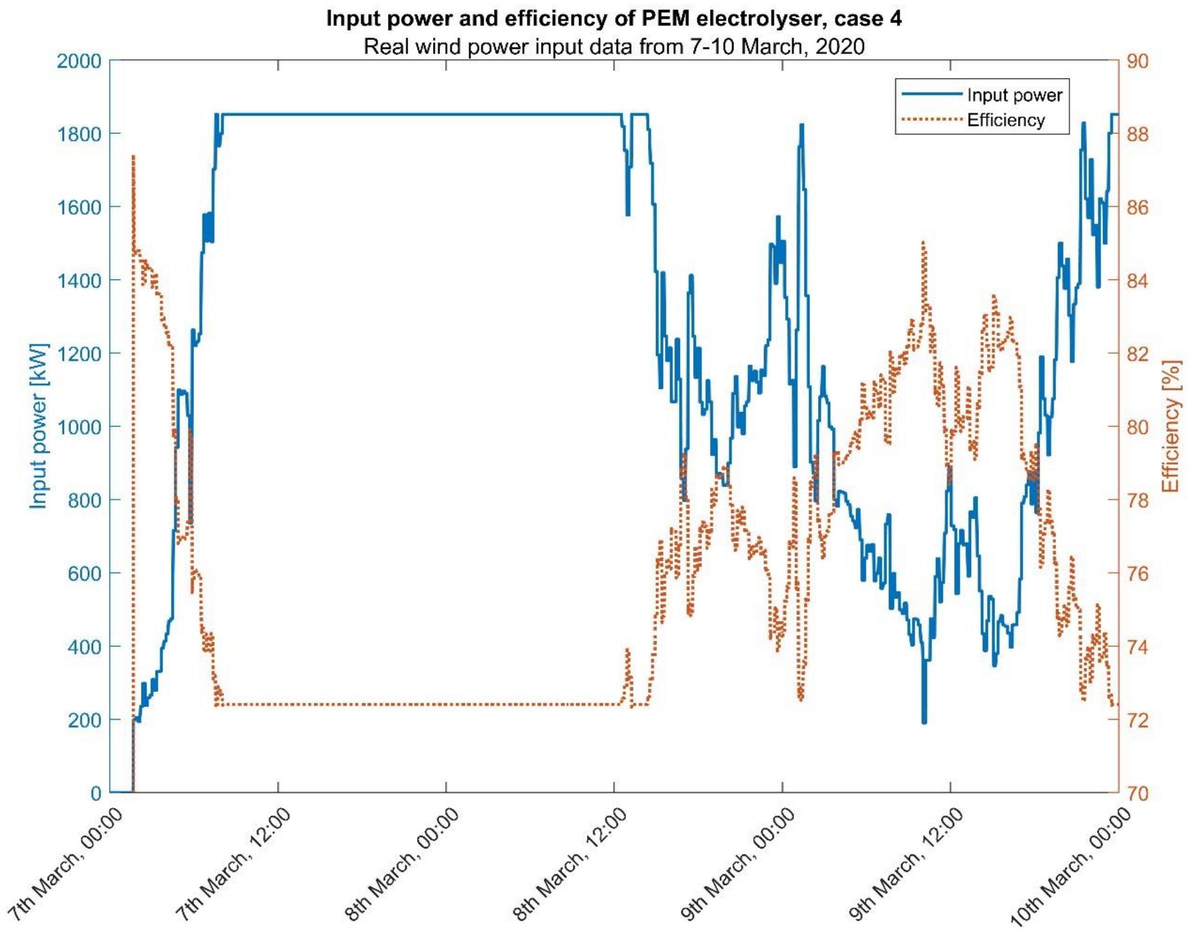
- Very large differences (factor of three) between different time periods
- Depends mostly on the capacity factor of the wind turbine, which is decided by the wind speed and the amount of turbine downtime

Hydrogen production cost



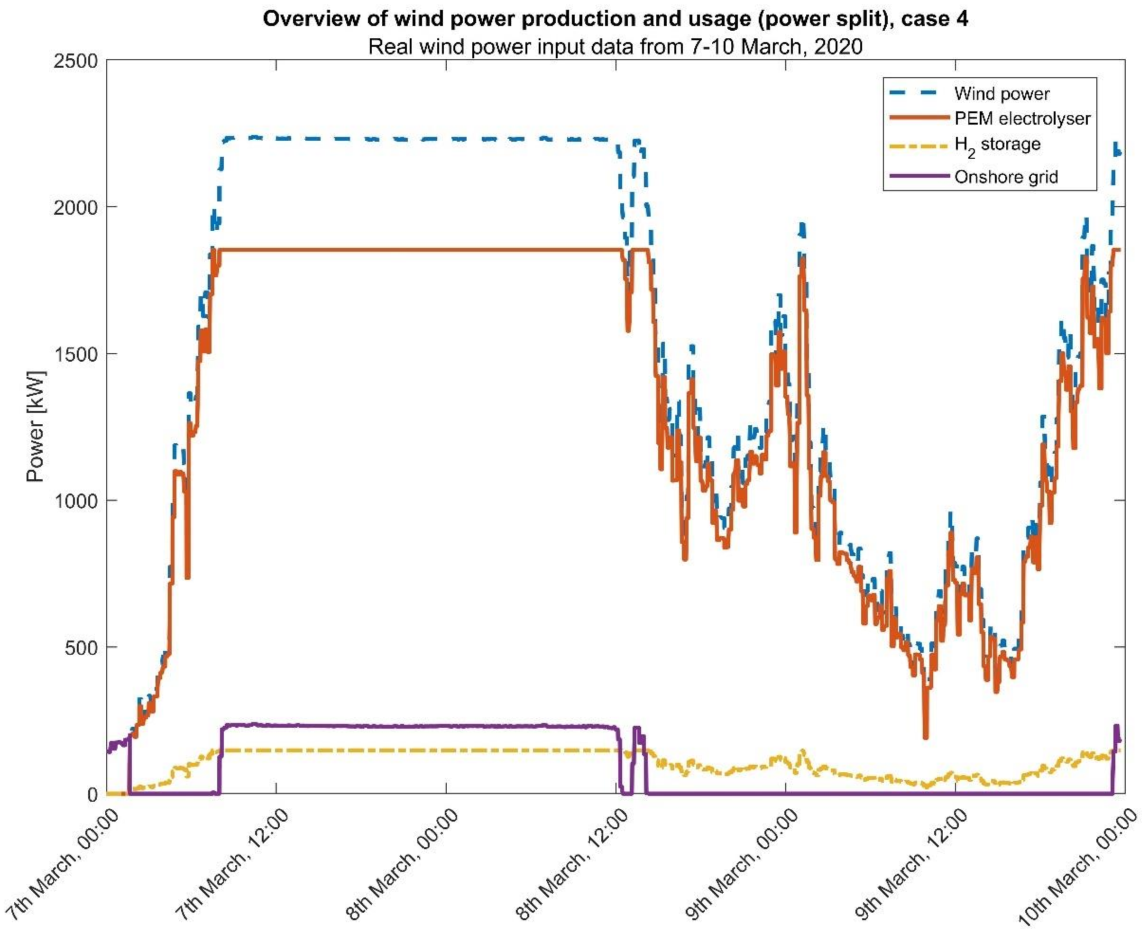
- Again: very large differences (almost factor of three) between different time periods
- Depends mostly on the capacity factor of the wind turbine and the electricity price
- Needs both high capacity factors and low electricity prices to be viable

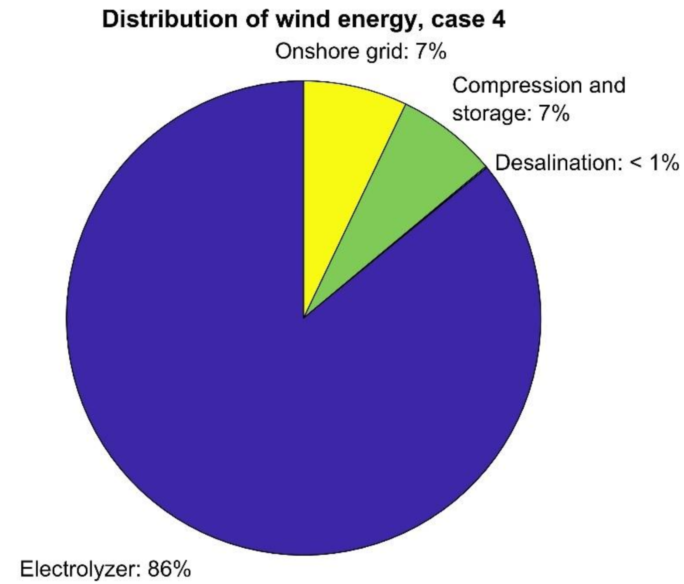
Electrolyzer power and efficiency

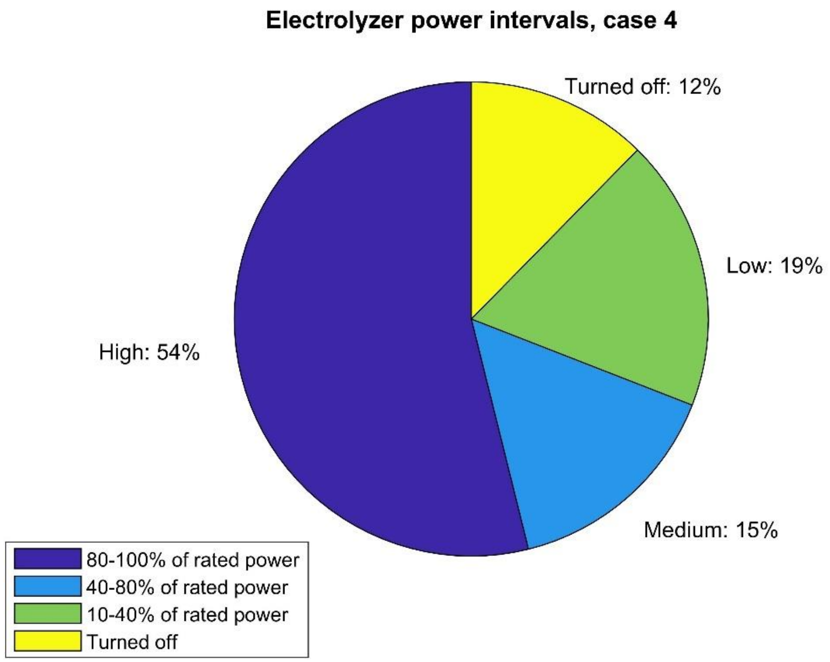


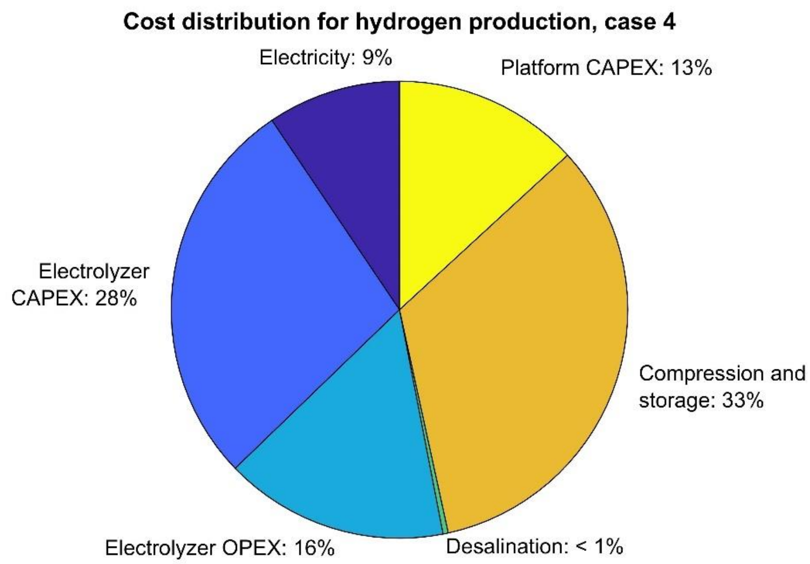
- Input power and efficiency of PEM electrolyzer are inversely correlated
- Electrolyzer handled power fluctuations well
- Electrolyzer efficiency in the range 72-88% (using the higher heating value of hydrogen)
- Overall process efficiency around 57% (using the lower heating value of hydrogen)

Wind power distribution






Electrolyzer power intervals, case 4
Turned off: 12%
Low: 19%
High: 54%
Medium: 15%
80-100% of rated power
40-80% of rated power
10-40% of rated power
Turned off


Cost distribution for hydrogen production, case 4
Electricity: 9%
Platform CAPEX: 13%
Electrolyzer CAPEX: 28%
Compression and storage: 33%
Electrolyzer OPEX: 16%
Desalination: < 1%

Conclusions

- Cost range was 4.5-14.5 $/kg H2
- Large variations in both production and cost (factor of 3)
- Overall average energy efficiency was around 57%
- Green hydrogen is extremely dependent on the price of electricity => only produce hydrogen when the price is low
- IEA estimate that the price of hydrogen from natural gas with CCS (blue hydrogen) is in the range 1.2-2.1 $/kg H2 (both now and in 2050) so green hydrogen has a long way to go to be competitive
- The choice between green and blue hydrogen will most likely be decided by the natural resources available in each region:
  - Regions with large amounts of relatively cheap natural gas => blue hydrogen
  - Regions with large amounts of cheap low-emission electricity => green hydrogen

UiO University of Oslo

NORCE

Thanks for listening!

HySchool.no