COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

# Cogeneration concept in green hydrogen production

**S. Nárdiz[1], J.I. Linares[1,2], E. Arenas[1,2,3], J.R. Pérez-Domínguez[1,3]**

[1] Rafael Mariño Chair in New Energy Technologies, COMILLAS-ICAI, Spain
[2] Repsol Foundation Chair in Energy Transition, COMILLAS-ICAI, Spain
[3] Institute for Research and Technology, COMILLAS-ICAI, Spain

ICP 2025

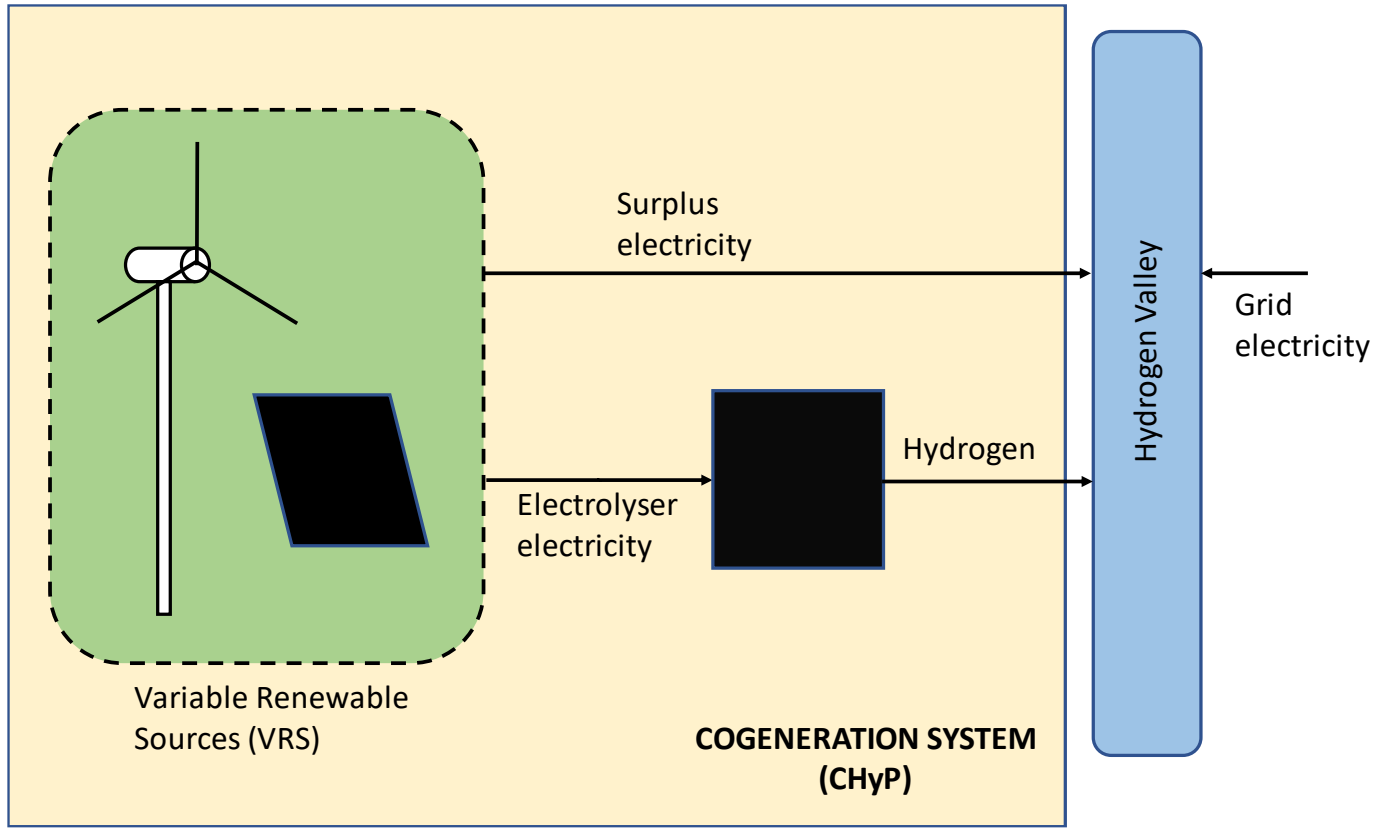
comillas.edu

# INTRODUCTION



- Currently **97 Mt $H_2$** are produced in the world, the vast majority coming from fossil sources
- European Hydrogen Strategy (2020) forecasts **40 GW of electrolyzers in 2030**
- **Hydrogen valleys** are promoted to integrate production, storage and utilization
- IBHYX (Iberian Mainland hydrogen cost index) quotes **6.09 €/kg** at this moment
- Levelized Cost of Hydrogen (**LCOH**) depends of:
  - CAPEX: **investment** on electrolyzer (ELY) and **capacity factor**
  - OPEX: mainly levelized cost of electricity (**LCOE**)
- European regulation encourage to connect directly the electricity source to the electrolyzer

# METHODS




- Integration of Photovoltaic (PV) and wind farm (WF) allows to reach a trade-off between LCOE and capacity factor
- The matching between ELY size and VRS produces electricity surpluses

Cogeneration: power + hydrogen (Combined Hydrogen & Power: CHyP)

**Key concept: Hydrogen valley to connect production with both demands: power & hydrogen**

# METHODS

## Assumptions (from IBHYX)

| Variable | Value | Units |
|---|---|---|
| $INV_{ELYe}$ | 1,600 | €/kW |
| $\bar{g}$ | 57.44 | kWh/kg |
| $INV_{PVe}$ | 500 | €/kW |
| $OM_{PV}$ | 5 | €/kW-year |
| $INV_{WFe}$ | 1,100 | €/kW |
| $OM_{WF}$ | 50 | €/kW-year |
| $N$ | 25 | years |
| $H_{stack}$ | 80,000 | h |
| $f_{rs}$ | 15 | % |
| wacc | 7.74 | % |

**Overall VRS: 500 MW (PV & WF)**

## Model

$$LCOH = CAPEX_{ELY} + CAPOPEX_{feedstock} + OPEX_{om\ ELY} + OPEX_{rep\ stack} + REVENUES_{surpluses} \quad (1)$$

$$CAPEX_{ELY} = \frac{INV_{ELYe} \cdot \bar{g} \cdot CRF}{H} \quad (2)$$

$$CAPOPEX_{feedstock} = \frac{LCOE \cdot \bar{g} \cdot (E_{PV} + E_{WF})}{1000 \cdot E_{ELY}} \quad (3)$$

$$LCOE = CAPEX_E + OPEX_E \quad (4)$$

$$CAPEX_E = \left(\frac{INV_{PVe} \cdot P_{PV} + INV_{WFe} \cdot P_{WF}}{E_{PV} + E_{WF}}\right) \cdot CRF \cdot 1000 \quad (5)$$

$$OPEX_E = \left(\frac{OM_{PV} \cdot P_{PV} + OM_{WF} \cdot P_{WF}}{E_{PV} + E_{WF}}\right) \cdot 1000 \quad (6)$$

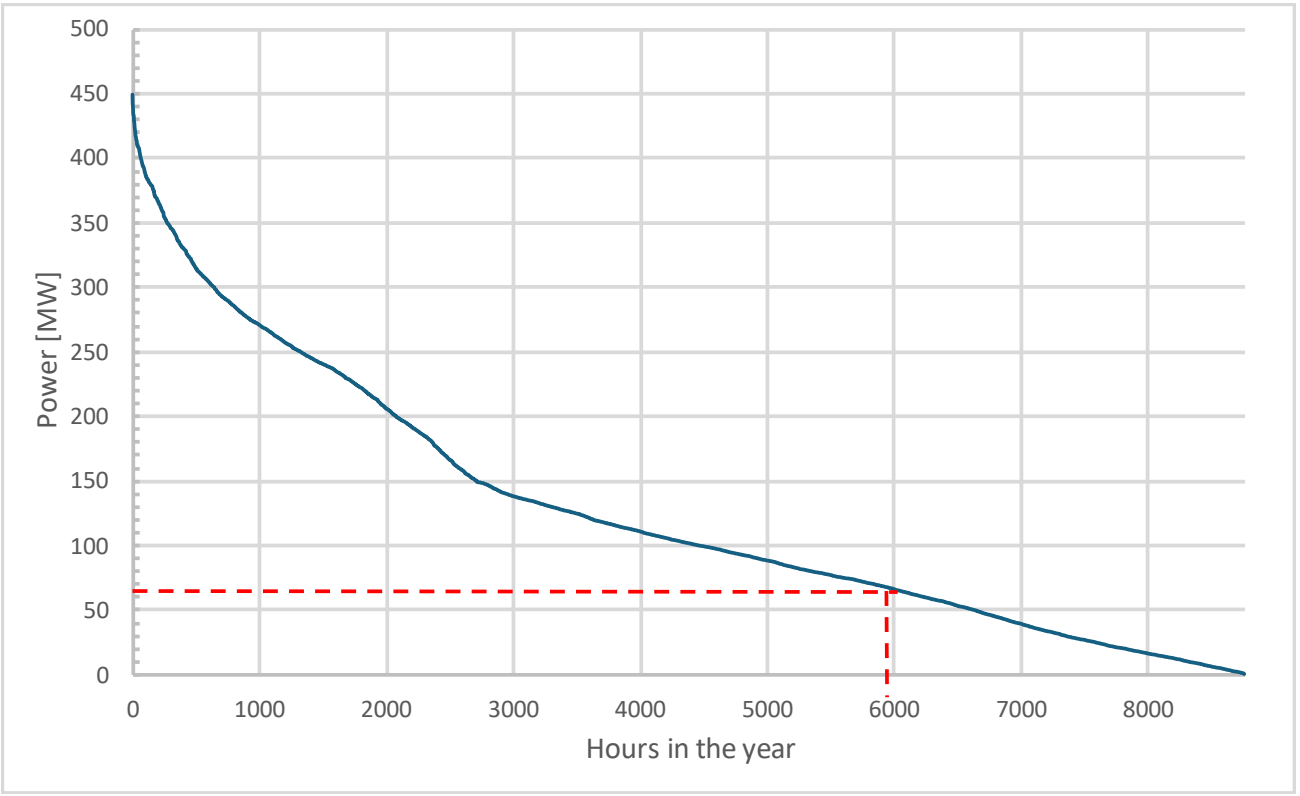
$$OPEX_{om\ ELY} = \frac{INV_{ELYe} \cdot \bar{g} \cdot f_{om}}{H} \quad (7)$$

$$OPEX_{rep\ stack} = \frac{floor\left(\frac{H \cdot N}{H_{stack}}\right) \cdot INV_{ELYe} \cdot \bar{g} \cdot f_{rs}}{H \cdot N} \quad (8)$$

$$REVENUES_{surpluses} = -T_{se} \cdot \left(\frac{\bar{g}}{1000}\right) \cdot \left(\frac{E_{PV} + E_{WF} - E_{ELY}}{E_{ELY}}\right) \quad (9)$$

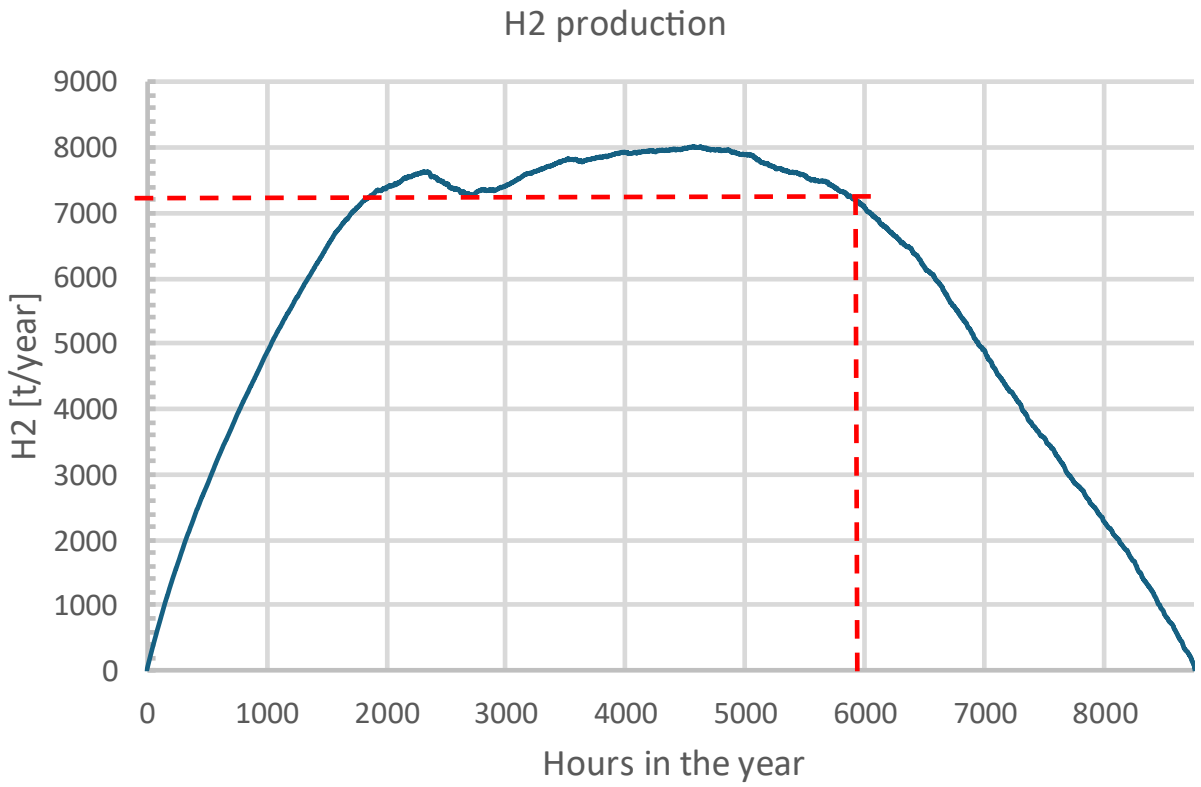
$$CRF = \frac{wacc \cdot (1 + wacc)^N}{(1 + wacc)^N - 1} \quad (10)$$

# RESULTS

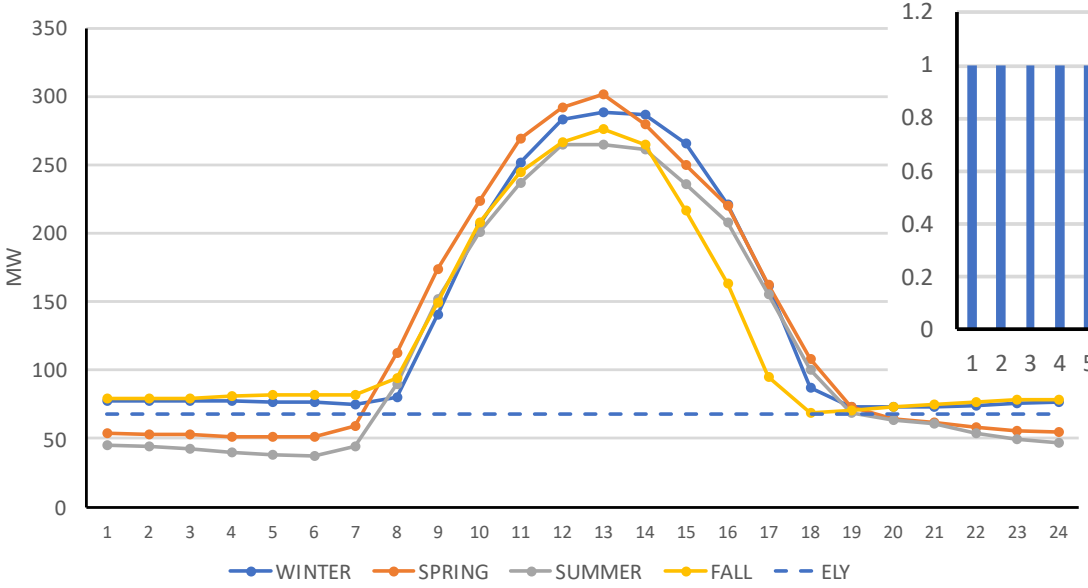


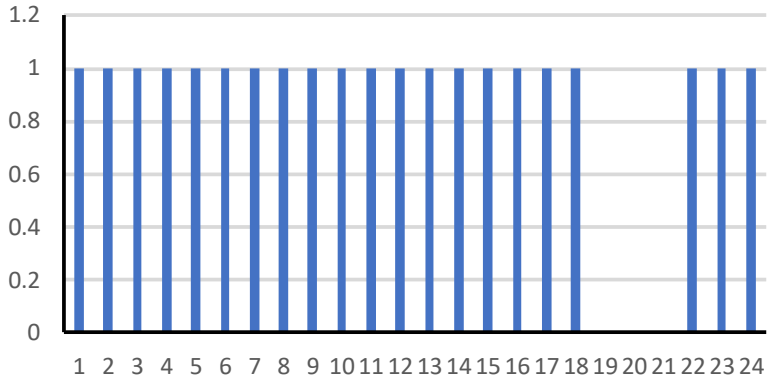

**Aragón**
**WF share: 30%**

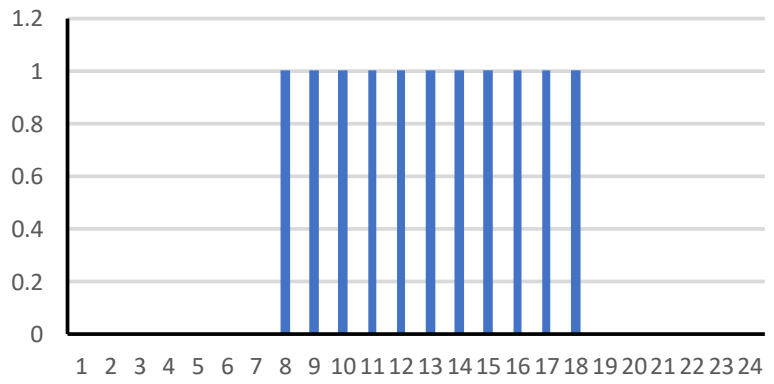
- Electrolyzer: 68 MW
- Operation hours: 5915
- Annual hydrogen production: 7209 t (106 t/h / MW)
- Annual surpluses: 716 GWh (64% of production)
- Annual electricity produced: 1118 GWh

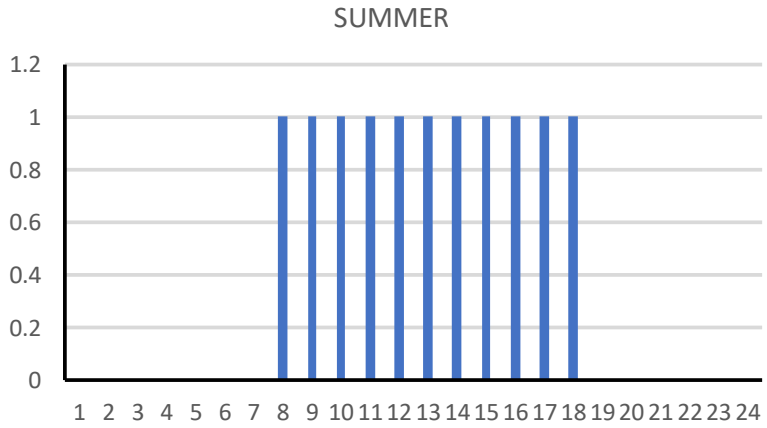


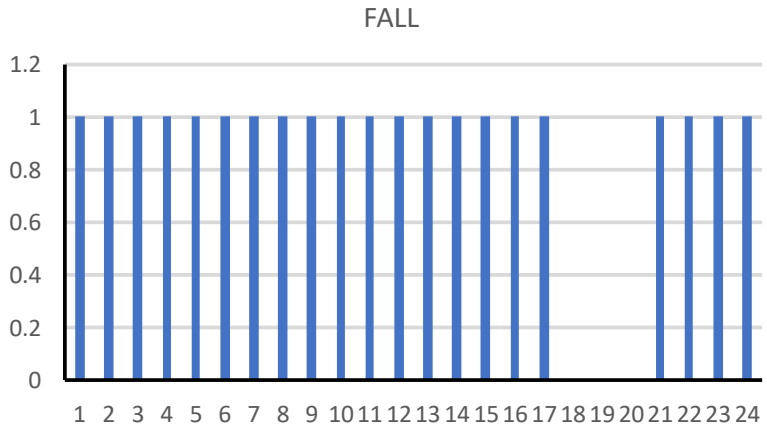
# RESULTS



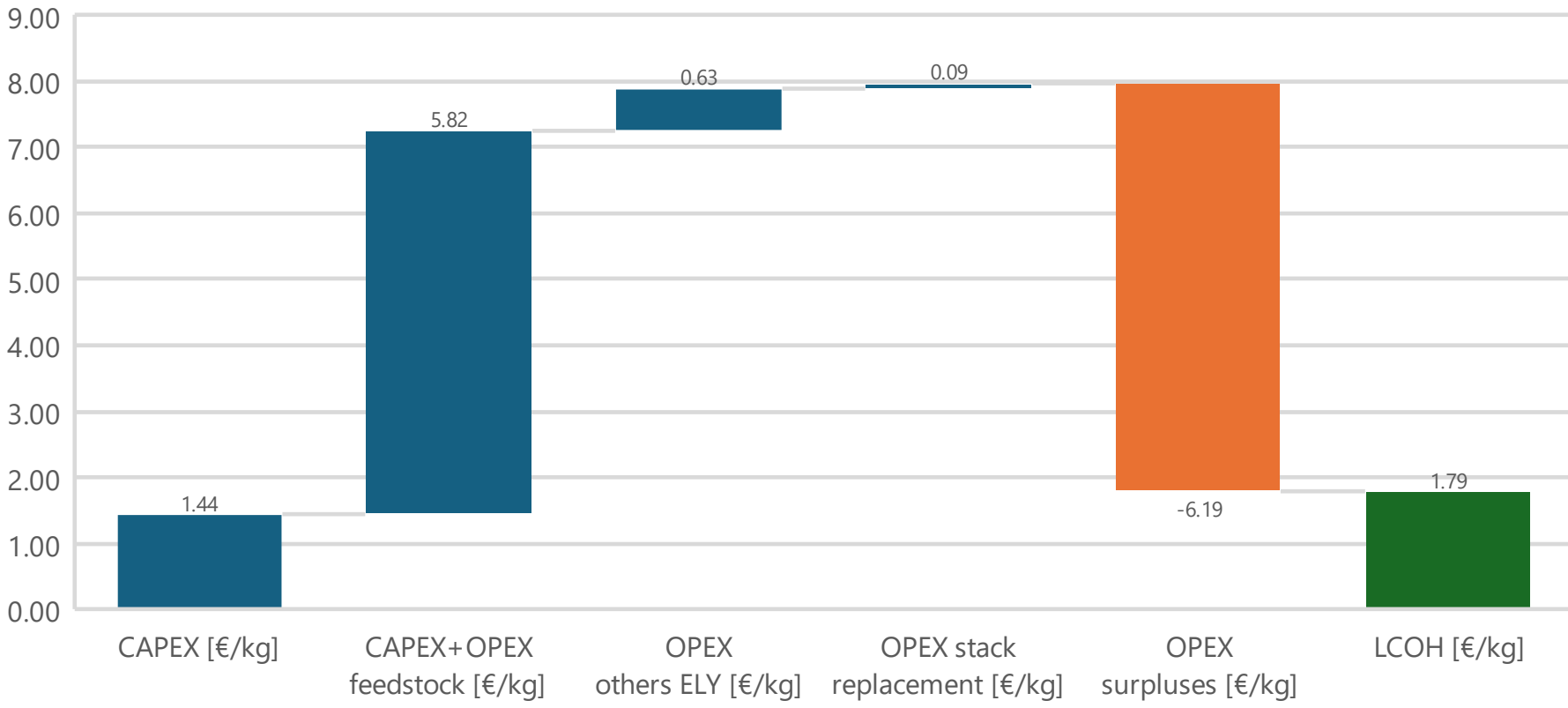



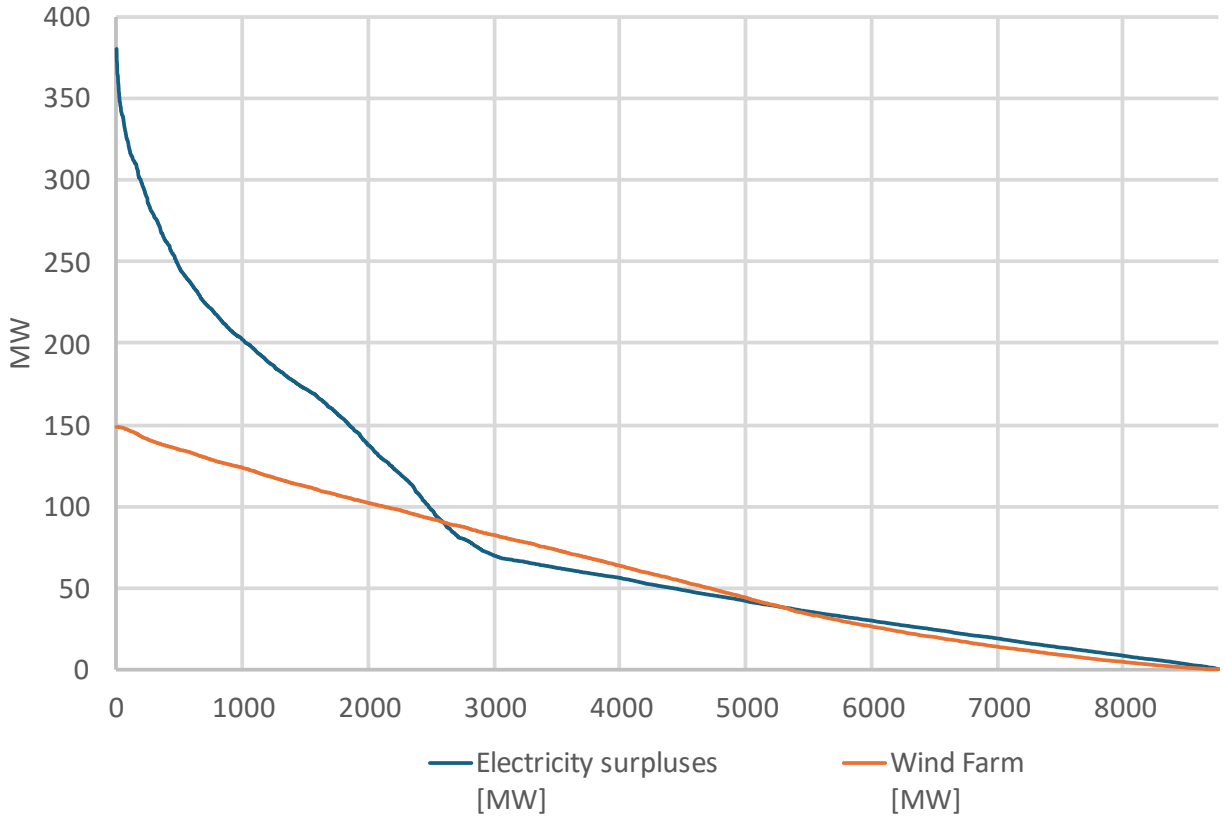

**Aragón**
**WF share: 30%**

# RESULTS




**Aragón**
**WF share: 30%**

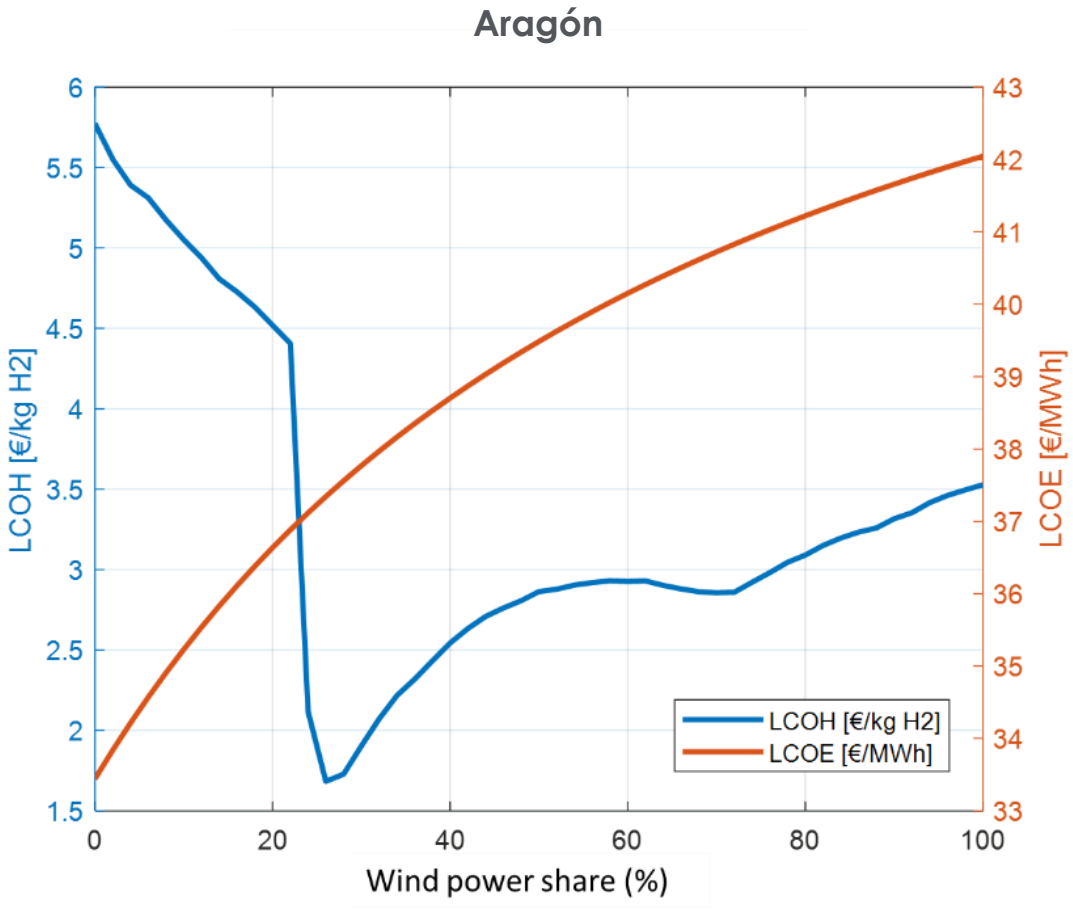
# RESULTS




**Aragón**
**WF share: 30%**

- The accumulated profile of the electricity surpluses:
  - Exhibits PV influence
  - Lasts 8760 hours, as WF
- **The price assigned to surpluses is set at 60 €/MWh, lower than current PPA for WF**

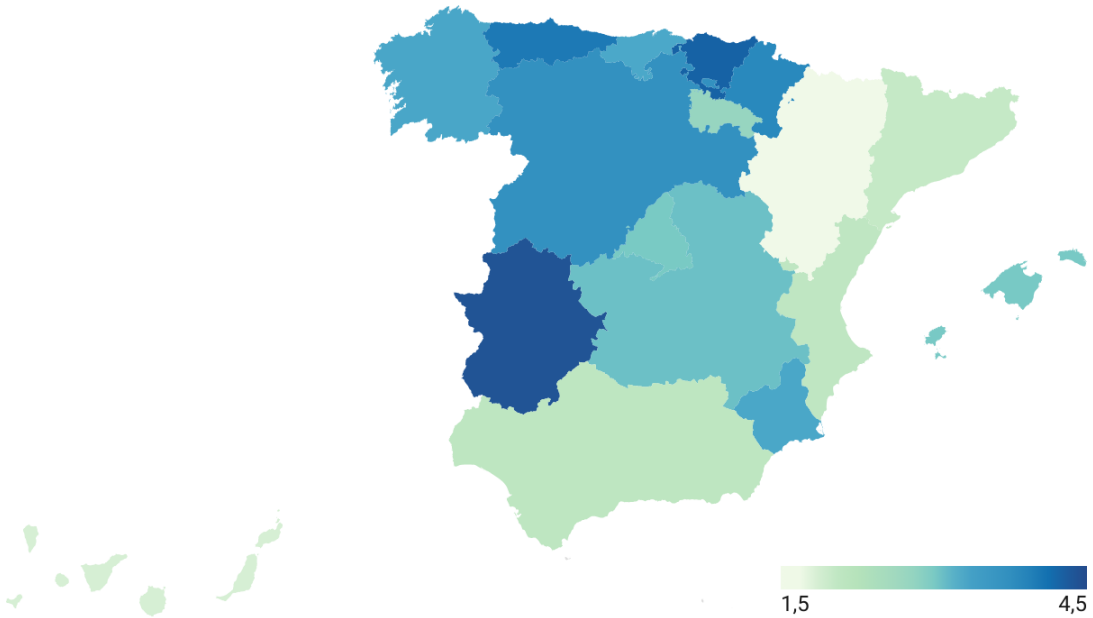
# RESULTS



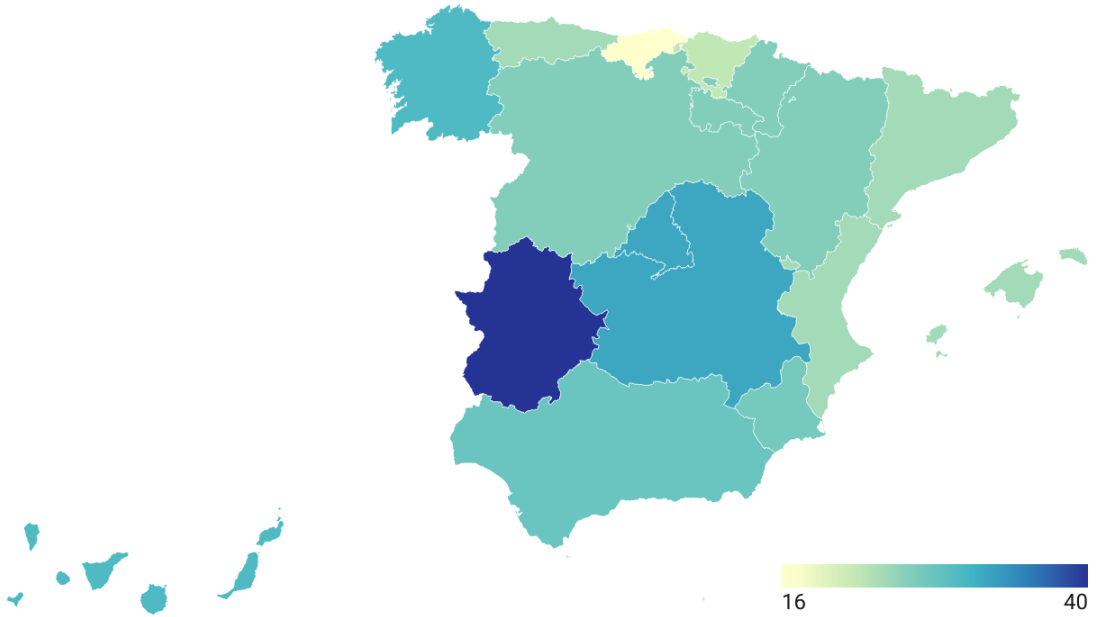

| | Minimum LCOH (€/kg H2) | Wind share [%] | LCOE [€/MWh] |
|---|---|---|---|
| Aragón | 1.68 | 26 | 37.34 |
| Canarias | 1.86 | 30 | 37.03 |
| Cataluña | 1.98 | 24 | 37.18 |
| Comunidad Valenciana | 2.08 | 24 | 36.43 |
| Andalucía | 2.1 | 28 | 36.11 |
| La Rioja | 2.78 | 26 | 41.36 |
| Comunidad de Madrid | 3.01 | 32 | 42.27 |
| Islas Baleares | 3.02 | 24 | 39.44 |
| Castilla-La Mancha | 3.17 | 32 | 40.43 |
| Galicia | 3.24 | 30 | 45.62 |
| Cantabria | 3.4 | 18 | 46.36 |
| Región de Murcia | 3.45 | 28 | 43.52 |
| Castilla y León | 3.73 | 26 | 42.80 |
| Comunidad Foral de Navarra | 3.84 | 26 | 45.86 |
| Principado de Asturias | 4.05 | 24 | 46.21 |
| País Vasco | 4.23 | 22 | 49.85 |
| Extremadura | 4.4 | 40 | 48.04 |

# RESULTS

## Minimum LCOH [€/kg]




## Wind share [%]



# CONCLUSIONS

- Green hydrogen is a key enabler for energy transition, specially in hard-to-abate industries
- LCOH is usually high, being conditioned by capacity factor and electricity costs
- Cogeneration business model is proposed:
  - Allocation in a Hydrogen Valley
  - Understanding the hydrogen facility as a two-products factory: power & hydrogen
  - Integration of PV (low LCOE) with WF (high capacity factor)
- With WF shares about 30% the LCOH ranges from 1.7 €/kg to 4.5 €/kg, well below the IBHYX index (> 6 €/kg)

COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

# THANKS FOR YOUR ATTENTION

## Questions?

linares@comillas.edu

ICP 2025

comillas.edu