

KYOS Webinar

Green hydrogen business cases

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KYOS approach to renewable energy assets



- Apply advanced financial models combined with experience of the energy markets to value and optimize assets and contracts.
 - Models developed by experienced quant team, over past 20 years.
 - KYOS is at the forefront of new developments, understanding the market's needs.
 - Continuous feedback from our clients helps us to stay ahead.
- Calculate the market value of an asset by optimizing it in the market
 - Use realistic simulations and trading/operational strategies





Green hydrogen – facts & figures

Global hydrogen production and trends








- Hydrogen use: currently, hydrogen is mostly used in refinery, chemical processes and the production of ammonia (fertilizer)
- Global and EU production: current production of grey hydrogen worldwide is ~95 mln tons, of which 10 mln tons in Europe
- Production process: most of the hydrogen is produced via steam reforming of natural gas and coal, responsible for around 1200 mln ton of CO₂ emissions globally (around twice total German CO₂ emissions)
- EU production targets: EU ambition is to produce 10 mln ton of green hydrogen by 2030, and to import another 10 mln ton
- Capacity requirement: just replacing current grey hydrogen production by electrolysis would require ~1500 GW renewable generation capacity globally, of which 158 GW in Europe (assuming 50 kWh/kg efficiency and 50% load factor)

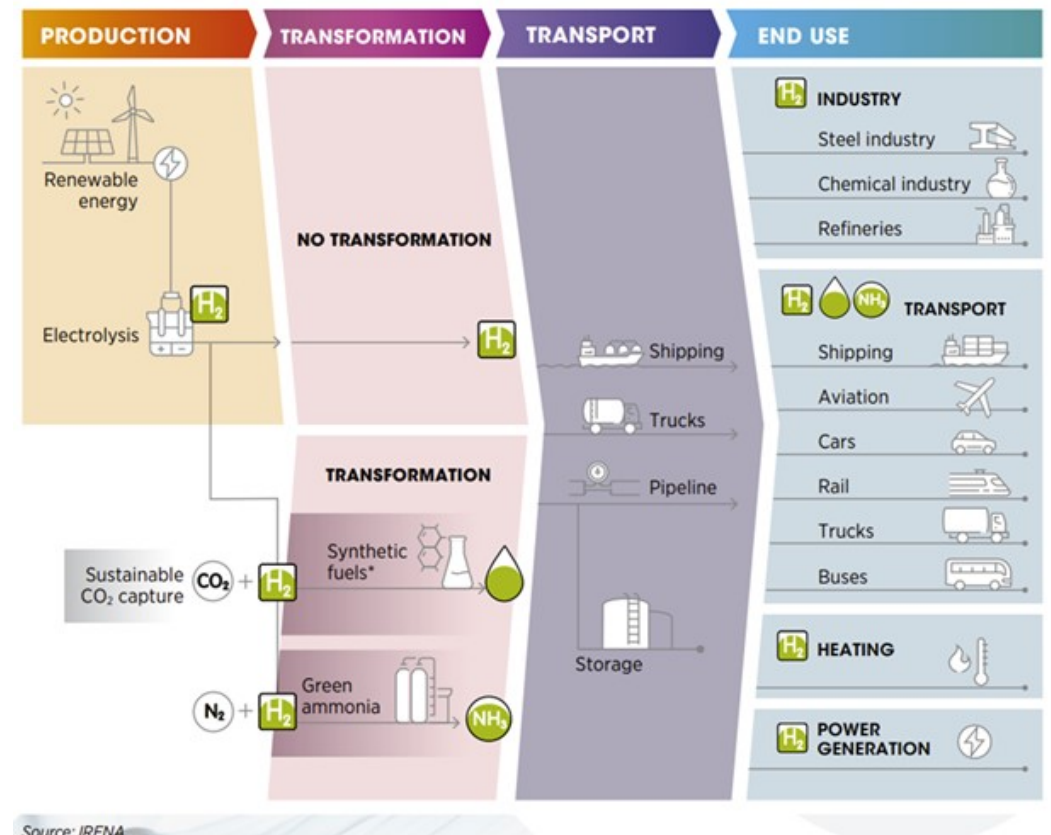


Grey, blue, green, pink, white

Hydrogen labels based on origin

-  Grey: produced from fossil fuels, no CCUS
-  Blue: produced from fossil fuels, with CCUS
-  Pink: produced from nuclear energy
-  Green: produced from renewable energy
-  White: found in nature

Value chain of green/renewable hydrogen



Hydrogen production - electrolysis



- Electrolysis technologies:
 - Alkaline: Fuel Cells
 - PEM: Proton Exchange Membrane Fuel cells
 - SOEC: Solid Oxide Exchange Cells
- Both Alkaline and PEM operate at low temperature (~70°C for Alkaline, ~100°C for PEM). The investment cost for PEM is higher than for Alkaline but they provide quicker ramp times.
- SOEC have higher efficiency but operate at high temperature (~1000°C), which means they require heat from another process (nuclear, industry)



When is hydrogen green?



EU Commission Delegated Act from February 2023:

1. *Direct line between renewable asset and electrolyser*

2. *High share of renewable power option:*

The clean power asset is located in a bidding zone with average proportion of renewable electricity of more than 90% in previous calendar year.

3. *PPA option:*

Additionality:

Renewable power asset became operational less than 3 years prior to the electrolyser (beyond 2028)

Geographical correlation:

The renewable power asset has to be in the same bidding as the electrolyser **OR** in a neighboring zone with higher or equal electricity price **OR** in an adjacent offshore bidding zone.

Temporal correlation:

H₂ is produced during the same hour as the electricity is produced under the PPA **OR** day-ahead price below 20 €/MWh **OR** below **0.36 * CO₂ price**

Transitional phase for temporal correlation: monthly matching is allowed until end of 2029



When is hydrogen green?



EU Commission Delegated Act from February 2023:

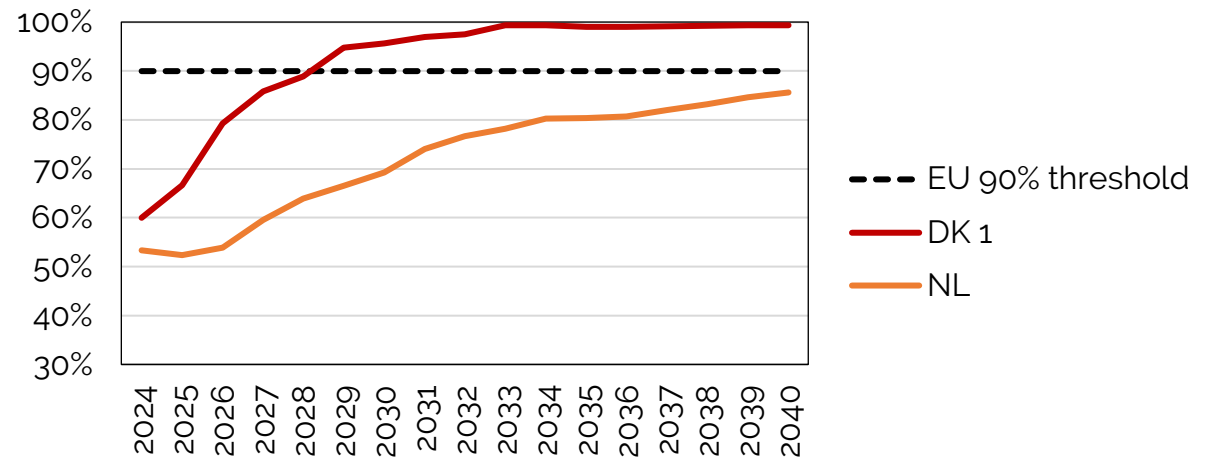
1. *High share of renewable power option:*

The clean power asset is located in a bidding zone with average proportion of renewable electricity of more than 90% in previous calendar year.

Current situation: Norway, SE1 & SE2 Swedish bidding zones fit the criterium

Future expectation: Denmark and Austria are good candidates to reach 90% renewable share and fit the criterium

Share of renewable* power production in the mix



Forecasts from KYOS power fundamental model.
Imports/exports excluded

* Renewable = wind, solar & hydro production



Why care about green hydrogen?



- Compliance targets: the industry & transport sectors are required to use a growing share of green hydrogen.
- Upcoming EU hydrogen bank auction:
 - Opens on 23rd November 2023
 - Awards 800 mln € of fixed premium in €/kg over 10 years; more auctions to follow
- Other government support schemes



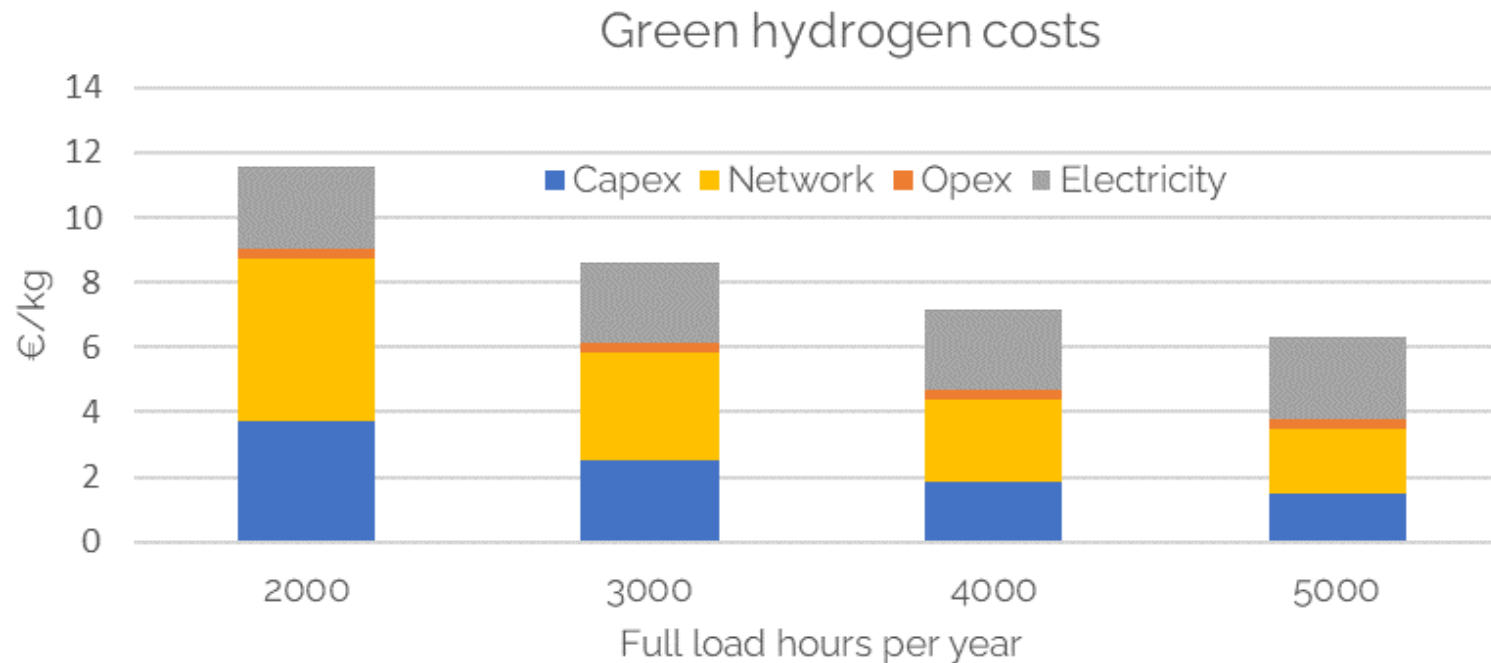


Green hydrogen – Business Cases

Cost estimate green hydrogen



- A high number of full load hours is key to reduce the green hydrogen price
- Network fees for grid access are easily overlooked
- First projects are likely to have higher costs, capex and opex, but also provide learning
- Additional revenue generated with flexible trading (DA, ID) and balancing services



Assumptions:

Capital 150 €/kW/yr
Network 200 €/kW/yr
Opex 0.3 €/kg
Electricity 50 €/MWh
Efficiency 50 kWh/kg

Source: KYOS Analytics

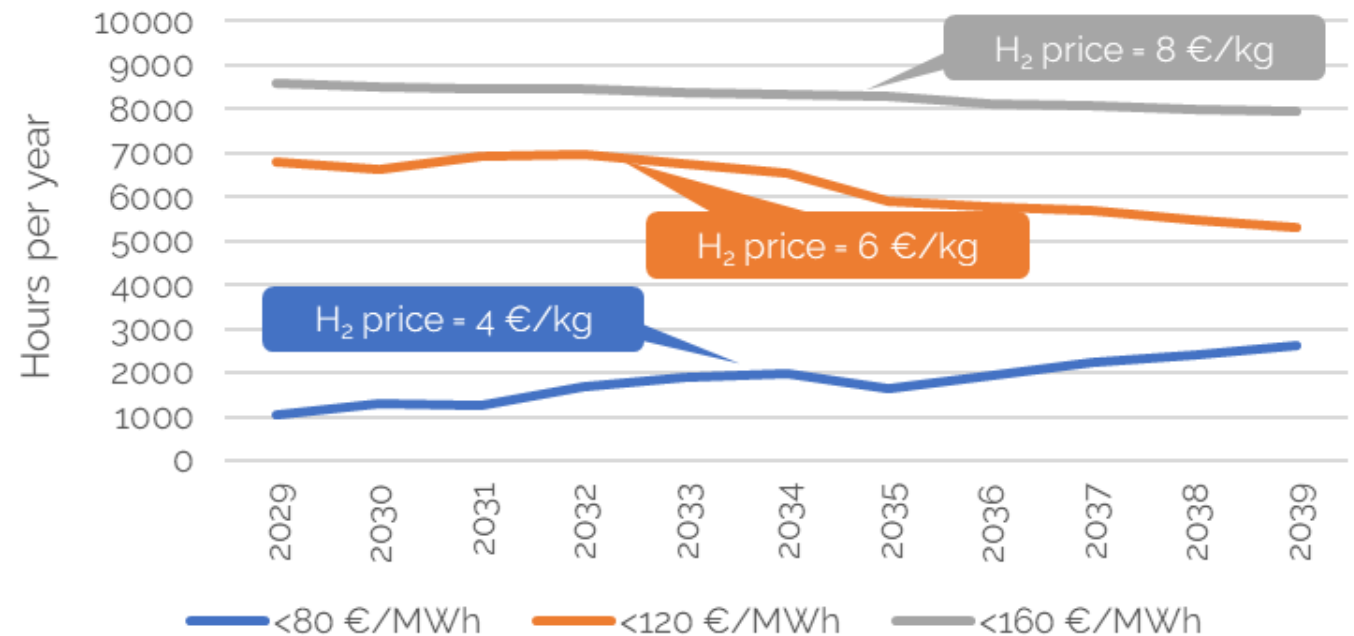


Case 1: DK1 with more than 90% renewables



- Suppose DK1 has more than 90% RES in 2029
- Then from 2030, electrolysis in DK1 is green
- With a green hydrogen price of e.g. 4 €/kg, and 50 kWh/kg efficiency, the electricity cost threshold is 80 €/MWh
- An electrolyser will produce in hours where the power price is below this cost threshold

DK1: power price below H₂ cost threshold
Source: KYOS fundamental power price forecast

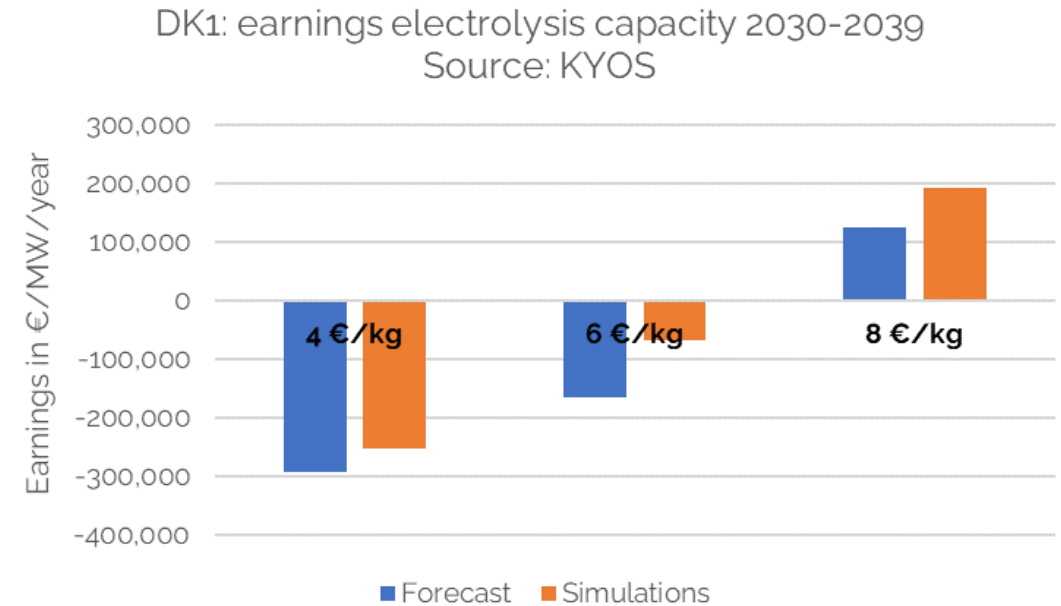
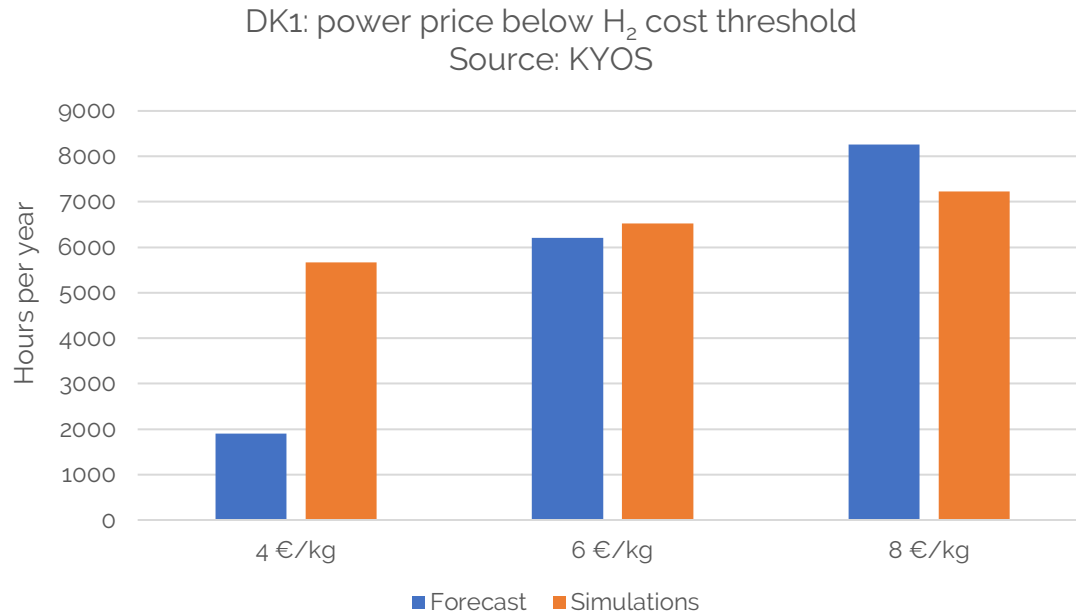


- To achieve a high enough load factor and generate positive earnings, using the KYOS **fundamental power price forecast**, the hydrogen price should at least be **7.15 €/kg**.
- But the forecast is not capturing volatility: **we need simulations!**



Case 1: DK1 with more than 90% renewables

- Same assumptions as before, but using realistic price simulations around the forecast
- All simulations have been generated with KySim, and reflect market volatility, e.g. due to variable renewables in the system, gas price volatility, etc.



- To achieve a high enough load factor and generate positive earnings, using the **KYOS power price simulations**, the **hydrogen price should at least be 6.53 €/kg**.
- Compared to the analysis with single price forecast, this is **0.62 €/kg lower!**

Lessons learnt



- There is considerable **flexibility value** for an electrolyser to optimise against short-term power prices
- A single price forward curve reflects expected future power prices
- However, prices fluctuate unexpectedly. That is why **a simulation methodology is needed to reveal the full value**, day-ahead or intraday

- Next: electrolysers connected to a renewable asset
- Additional challenge: correlation between renewable generation, market prices and the hydrogen production



Case 2: Spain electrolyser connected to renewables



- Similar assumptions as before
- Period: 2024 to 2033 (previously: 2030-2039)
- Two renewable generation assets in Spain:
 - Solar PV of 73.5 MW
 - Wind turbines of 84 MW
- Direct line: no power taken from the grid



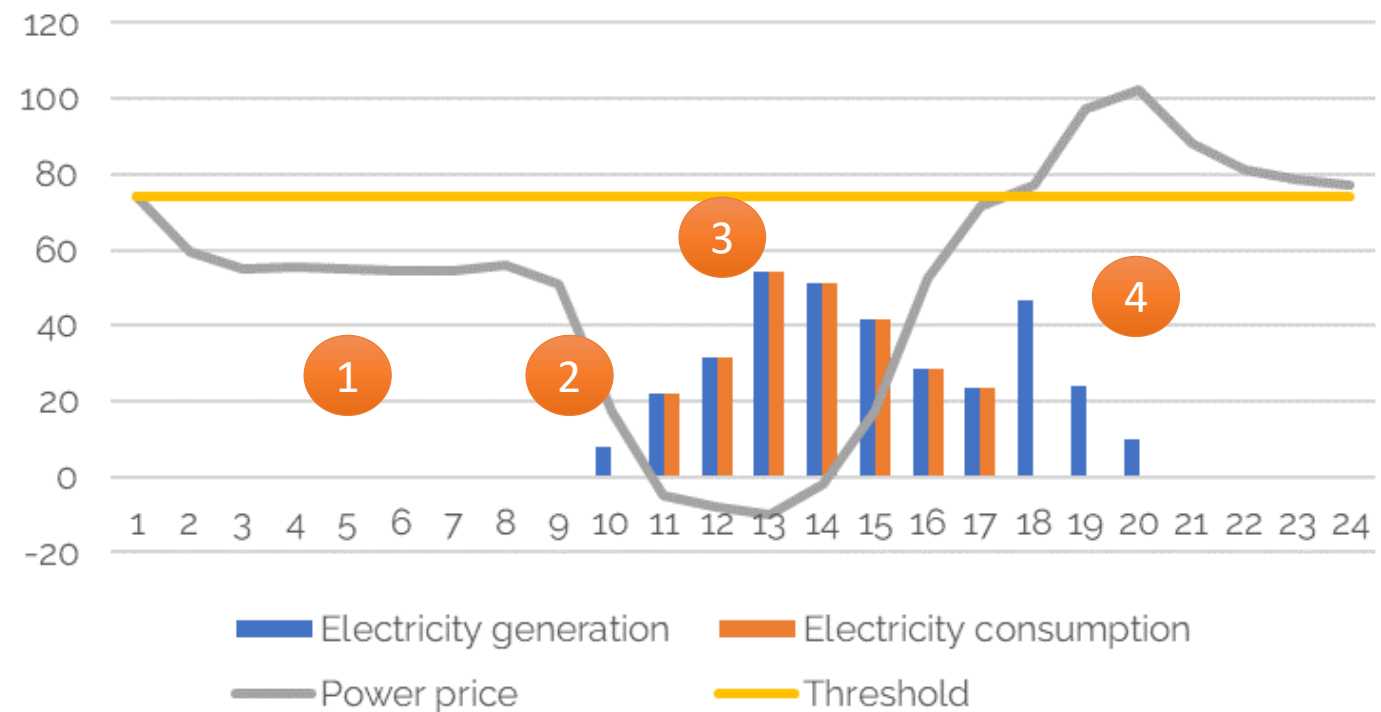
Case 2: Spanish electrolyser with PV



- The electrolyser (60 MW) produces:
 - When there is enough electricity output from the generation asset
 - And the power price is below the threshold of 74 €/MWh (assuming 3.7 €/net H₂ price and 50 kWh/kg)

- 1 No power
- 2 Not enough power
- 3 Max production (below Electrolyser capacity)
- 4 Power delivered to the grid

Hourly optimisation electrolyser with PV

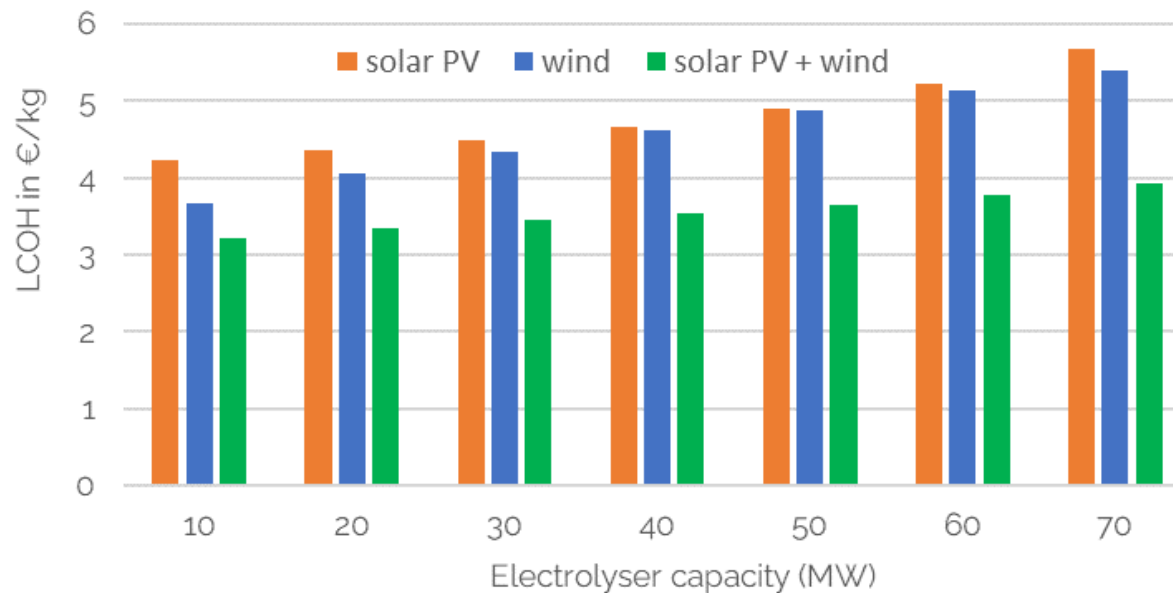


Case 2: Spanish electrolyser with renewables



- Is an electrolyser best combined with PV or wind, or both?
- And what is then the optimal sizing? Assess LCOH, levelized cost of hydrogen

Spain: hydrogen cost with solar and/or wind
KYOS simulations of prices and RES generation



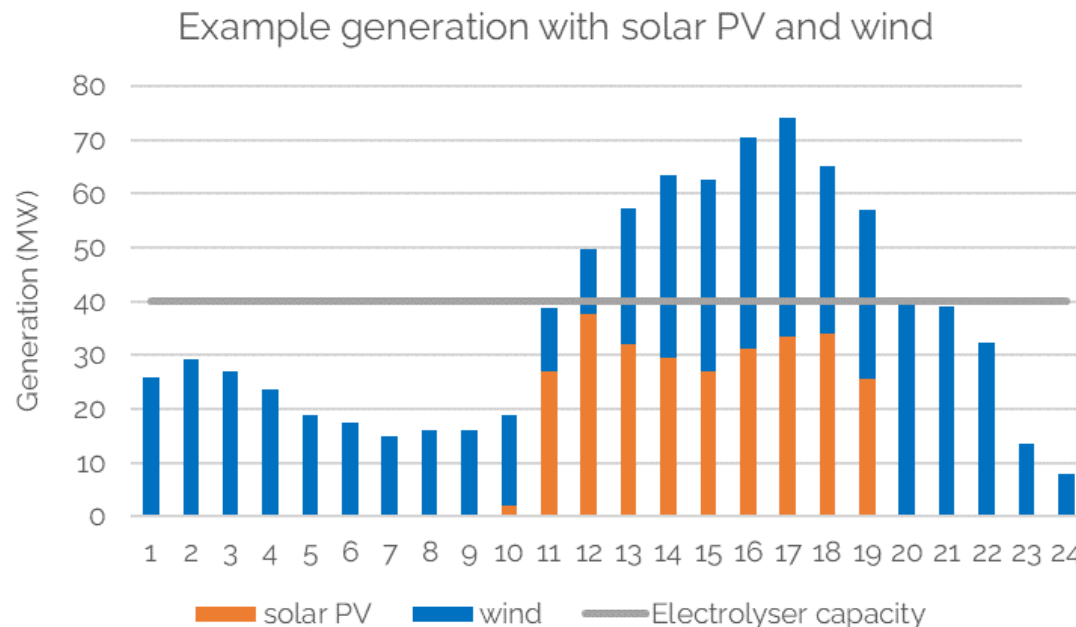
- Solar = 73.5 MW
- Wind = 84 MW
- Capex/yr = 150 €/kW
- Opex = 0.3 €/kg
- Efficiency = 50 kWh/kg

- Lower LCOH with wind than with solar, and even better combined
- Higher LCOH when electrolyser capacity becomes larger relative to RES capacity

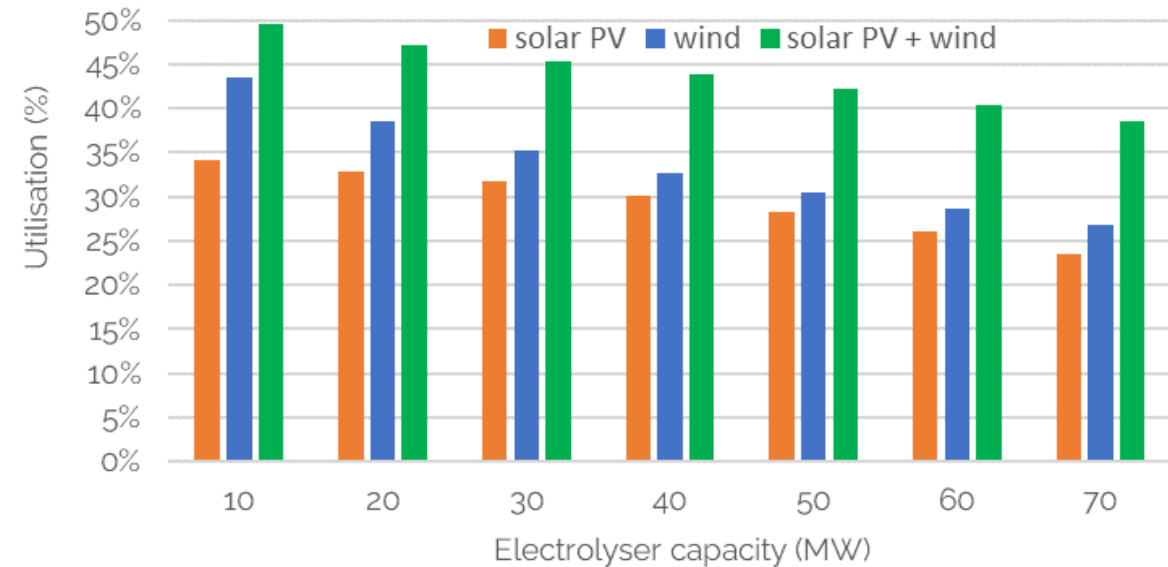


Case 2: Spanish electrolyser with renewables

- Solar PV and wind combined allows for high load factor, via direct line or PPA
- Of course, not trivial to combine via direct line



Spain: electrolyser utilisation with solar and/or wind
KYOS simulations of prices and RES generation



- PPA requires grid connection, but also allows for combining RES generation and produce at low power market prices

Lessons learnt

- A green hydrogen market is taking shape and will be big
- Important to obtain experience and assess business cases
- Optimisation of flexibility is key to achieve a low LCOH
- Realistic price and production simulations provide key insights and help to assess a variety of business cases



Some useful free publications



See: <https://www.kyos.com/knowledge-center/>



Questions and Answers



Q&A!

Contact Details



We look forward to supporting you with the right tools and advice in the rapidly changing energy sector!



info@kyos.com

<https://www.kyos.com/contact/>

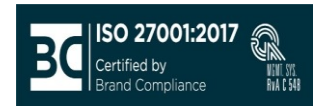
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KYOS Energy Analytics

- International client base across Europe, plus Americas and Japan
- 35+ people, headquartered in Haarlem (NL)
- More than 100 corporate clients for its software services

Trusted by organizations all over the world



Our analytics – your advantage



Software for energy valuation & optimization

Solutions for valuation, optimization and risk management, coupled with advanced forecasting and price simulations.

Power plants
Renewable generation
Gas storage
Gas swing contracts
Batteries
Options
.....



Software for multi-commodity exposures

The Commodity Portfolio & Risk Management software combines physical commodity management with financial risk reporting and price analytics.

It swiftly reveals the company-wide financial risks in clear reports.



Consultancy

We offer a wide range of top analytical services to companies in the energy and commodity markets. We are specialists in valuation, optimization and risk management.

Our expert services range e.g. from a one-off deal valuation to a complete solution for the risk management of a portfolio of assets and contracts.



Price data

Live or End-of-day market price forward curves are essential for trading, structuring and risk management.

In addition, we have a fundamental model for long-term (>30 year) power prices..