

Optimizing Wind Energy Revenue through Hydrogen Arbitrage

A Techno-Economic Analysis of a Hybrid 50MW Electrolyzer System in Germany

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The Challenge: Cannibalization & Curtailment

- **Price Cannibalization:** As renewable penetration rises, market prices drop during high-wind hours.
- **Grid Congestion:** Northern Germany faces significant grid bottlenecks.
- **Curtailment:** Wind farms are frequently turned off, wasting potential green energy.

Research Question:

Can a hybrid Hydrogen system monetize this "lost" energy while remaining profitable without massive subsidies?

Data Insight

Analysis confirms a divergence between **Market Average Price** and the realized **Capture Price** for wind assets [1].

System Design & Technical Parameters

Parameter	Value / Description
Wind Asset	210 MW Onshore Capacity
Location	Reußenköge, Germany (ERA5 Data) [3]
Electrolyzer	50 MW PEM System
Model	Siemens Energy Silyzer 300 [4]
Efficiency	52.2 kWh / kg H ₂ (Nominal)
Min. Load	10% (5 MW)

Configuration: Co-located system ("Behind-the-Meter") to minimize grid fees.

Methodology: The "Smart Arbitrage" Logic

Objective: Maximize Net Present Value (NPV) via dynamic dispatch.

The Switching Threshold

We calculate a dynamic Breakeven Price (P_{switch}) to decide operation modes:

$$P_{switch} = \frac{1000}{\eta_{el}} \times P_{H2}$$

Where $\eta_{el} = 52.2 \text{ kWh/kg}$ and $P_{H2} = €5.00/\text{kg}$.

The Decision Rule:

- If Grid Price < **€95.79 / MWh** → **Produce Hydrogen**
- If Grid Price > **€95.79 / MWh** → **Sell Electricity**

Data Sources & Validation

- **Electricity Prices:** Day-Ahead Auction prices (DE-LU Zone, 2024) [1].
- **Wind Resource:** ERA5 Reanalysis data (ECMWF), processed via Xarray [3].
- **Grid Stress:** Historical Redispatch 2.0 data (TenneT TSO) [2].
- **Financials:** CAPEX (€1,800/kW) and WACC (7%) aligned with IEA Global Hydrogen Review [6].

Simulation Results: Financial Viability

Revenue Uplift

- Hybrid system generated **€10.96 Million** in extra annual revenue vs. baseline.
- Driven by avoiding low/negative price hours.

Cost Competitiveness

- **LCOH:** €4.87 / kg
- **Sales Price:** €5.00 / kg
- **Margin:** €0.13 / kg

Final Investment Verdict

APPROVED

NPV: €7.04 Million

IRR: 8.0%

Project clears the 7% WACC hurdle.

Revenue Diversification

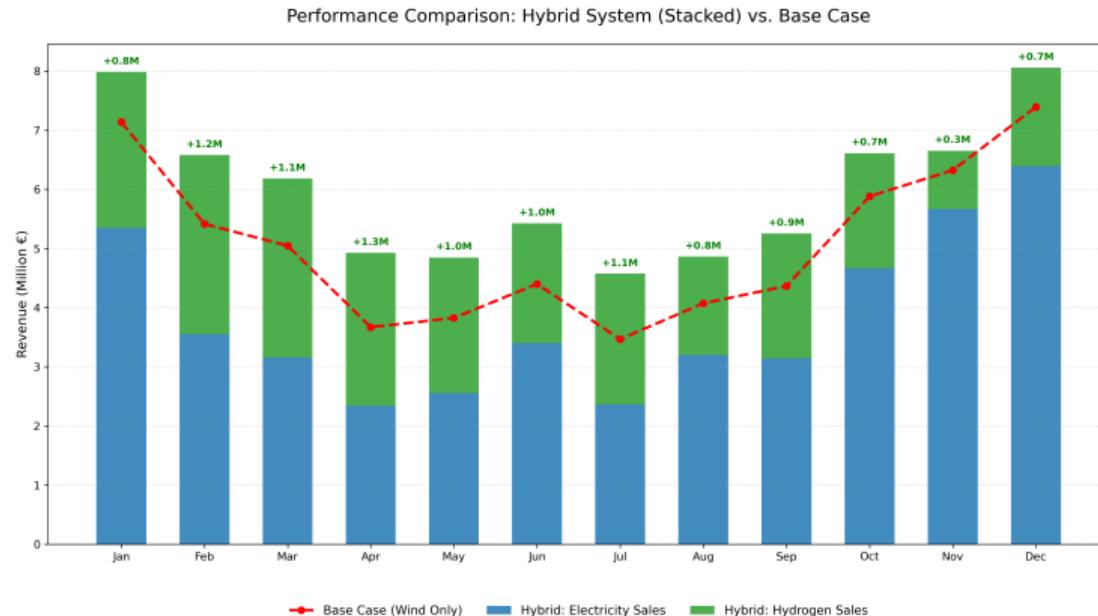


Figure: Monthly revenue comparison showing Hydrogen (Green) as a revenue floor during summer months.

Critical Risk Factor: Hydrogen Offtake Price

- The project operates on a thin margin (€0.13/kg).
- A price drop of just **€0.15/kg** (to €4.85) turns NPV negative.

Mitigation Strategy:

- ① **Long-Term PPA:** Securing a fixed-price offtake agreement $> \text{€}5.00/\text{kg}$ is mandatory for FID.
- ② **Grid Services:** Future qualification for Frequency Containment Reserve (FCR) could provide ancillary revenue.

- ① **Feasibility Confirmed:** A 50MW Electrolyzer co-located with 210MW wind is economically viable in Germany (8.0% IRR).
- ② **Value of Flexibility:** The dynamic switching logic (curtailing H₂ when power > €96/MWh) is critical to profitability.
- ③ **Grid Impact:** The system acts as a flexible load, reducing physical curtailment and aiding grid stability.

Thank You! Questions?

References I

- [1] Fraunhofer ISE. (2024). *Energy-Charts: Public Net Electricity Generation in Germany*.
- [2] TenneT TSO. (2024). *Redispatch 2.0 Data Downloads*.
- [3] ECMWF. (2024). *ERA5 Reanalysis Data*. Copernicus Climate Change Service.
- [4] Siemens Energy. (2023). *Silyzer 300 PEM Electrolyzer Datasheet*.
- [5] EEX. (2024). *HYDRIX - European Green Hydrogen Index*.
- [6] IEA. (2024). *Global Hydrogen Review 2024*. International Energy Agency, Paris.