H2 Summit 2026

Beyond Levelised Cost: A Techno-Economic Optimisation and Risk Framework for Designing Market Support Mechanisms for Green Hydrogen Deployment

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Industrial Competitiveness & Strategic Autonomy

THE PROBLEM

Green hydrogen faces an investment problem, not only a cost problem

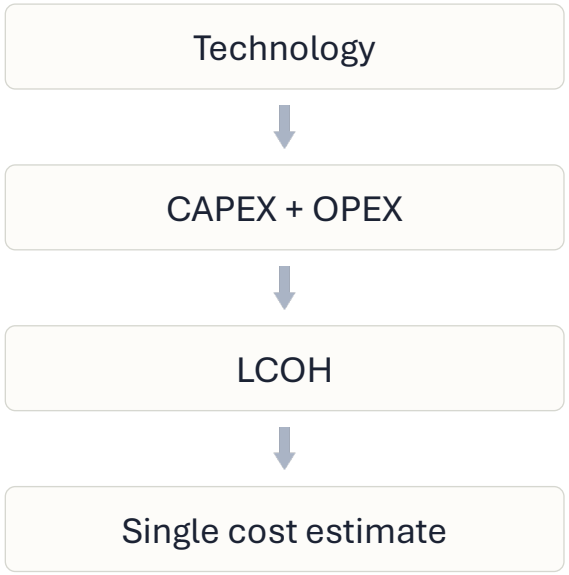
Technology	Market	Finance	Policy
Electrolyser cost	Demand uncertainty	WACC	Support design
Renewable availability	Electricity prices	Cost of capital	Revenue stability
Efficiency	Price volatility	Investment risk	Policy credibility

A single LCOH value does not capture how these four dimensions interact.

RESEARCH GAP

Where conventional hydrogen assessment falls short

CONVENTIONAL



01 **Deterministic assessment**

Fixed assumptions produce a single-point LCOH.

02 **Limited integration**

Finance, electricity-market uncertainty and policy are often assessed separately.

03 **Policy judged mainly on cost**

A mechanism can lower expected LCOH without lowering downside risk.

RESEARCH QUESTION

Under what conditions does green hydrogen become investable?

> Under what technical, financial, market and policy conditions can green hydrogen become economically feasible in early-adoption markets — and which combinations of support mechanisms most effectively improve investment viability while reducing cost and risk?

Integrated Techno-Economic and Risk Framework (ITERF)

Systematic scenarios + uncertainty + risk + policy → decision support

THE FRAMEWORK — ITERF

From levelised cost to risk-informed decision support

01	**Inputs**	Technical, financial, market, policy	
02	**Model**	Hourly dispatch, deterministic LCOH	**Baseline**
03	**Scenarios**	Systematic sweep of configurations	**Solution space**
04	**Archetypes**	Cost-optimal, Green-lead, Zero-policy	**Pathways**
05	**Monte Carlo**	Uncertainty around each design	**P10 · P50 · P90**
06	**Policy**	CAPEX · OPEX · CfD · CCfD	**Effectiveness**
07	**Stress test**	Power at €60, 80, 100, 150/MWh	**Robustness**

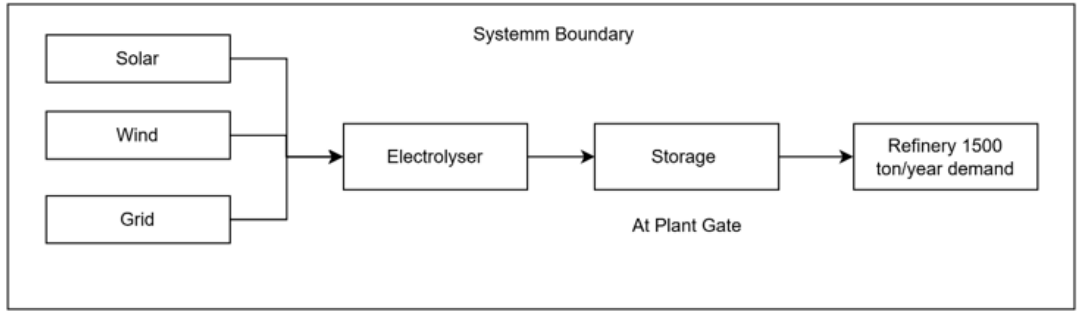
OUTPUT

Cost
+ Risk
+ Robustness

Decision support, not a single number

CASE STUDY · WHITEGATE REFINERY

Model 1: €4.92/kg at the best wind–solar mix



€4.92/kg

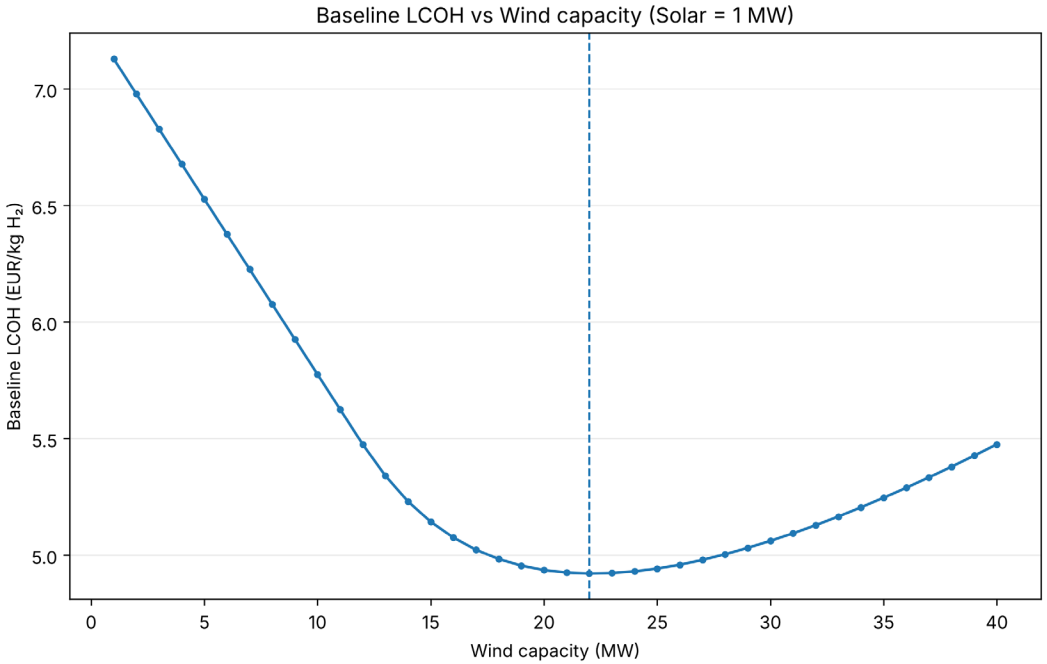
Minimum LCOH: 22 MW wind + 1 MW solar + 11.9 MW PEM; 69% renewable, 31% grid

≈ €9.5/kg

Same plant at today's Irish costs (grid price, electrolyser and wind CAPEX)

+ €0.27/kg

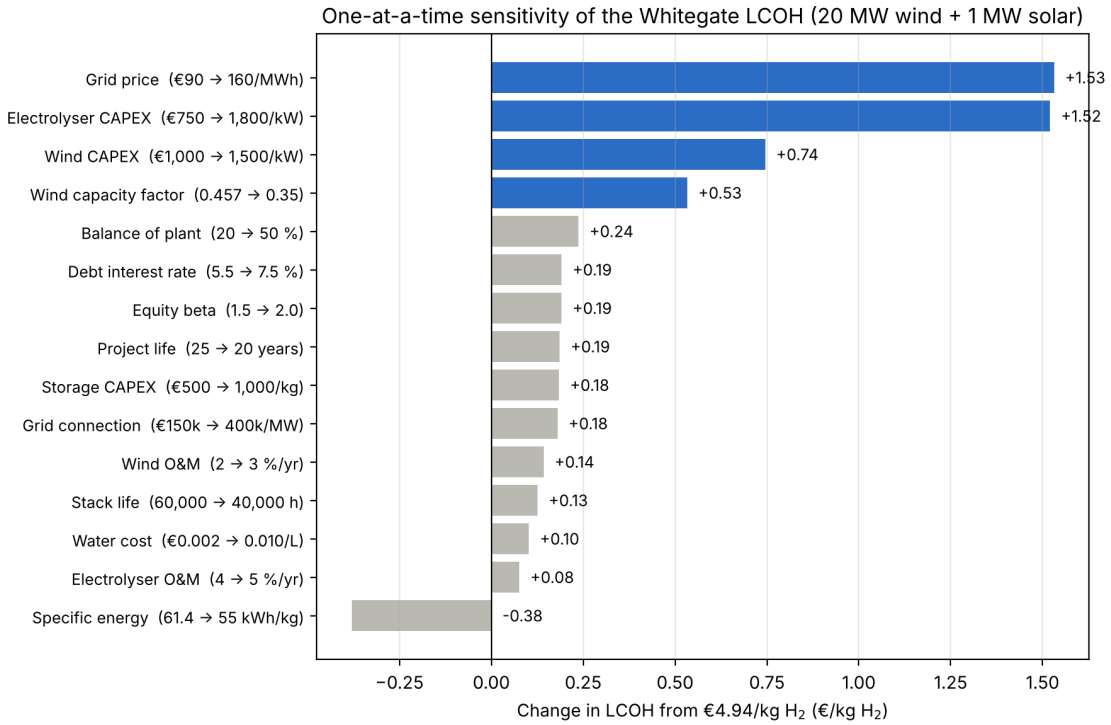
To meet the EU RFNBO carbon limit: 34 MW of wind instead of 22 MW



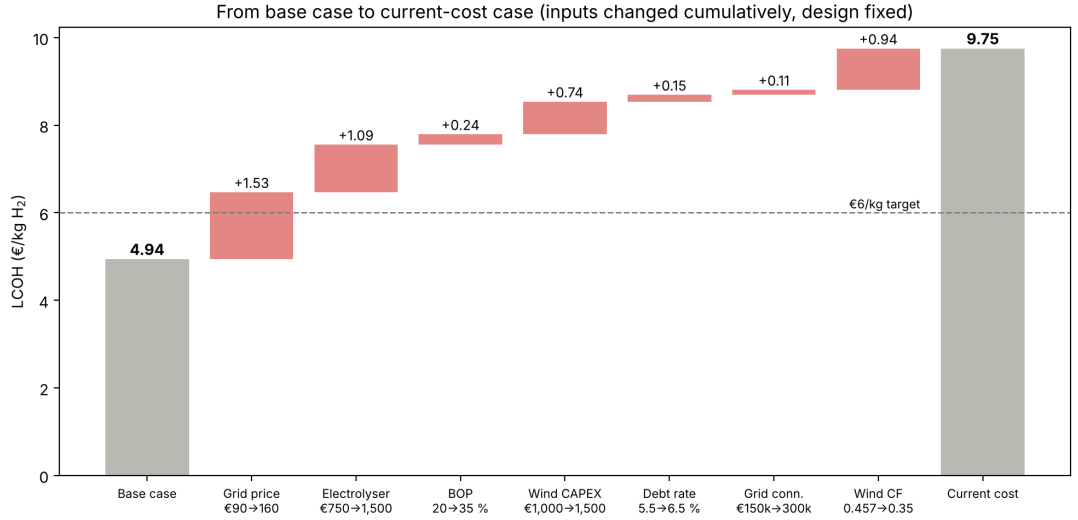
LCOH falls with wind up to 22 MW, then rises as more output is curtailed (19% at the optimum). 1,500 t H_2/yr, hourly dispatch, 2019 Whitegate wind and solar profiles.

WHITEGATE · HOW REALISTIC IS €4.92/kg?

At today's Irish costs the LCOH roughly doubles



Each input changed on its own from the base case (20 MW wind + 1 MW solar, €4.94/kg). Only a more efficient electrolyser (55 kWh/kg) lowers the cost.

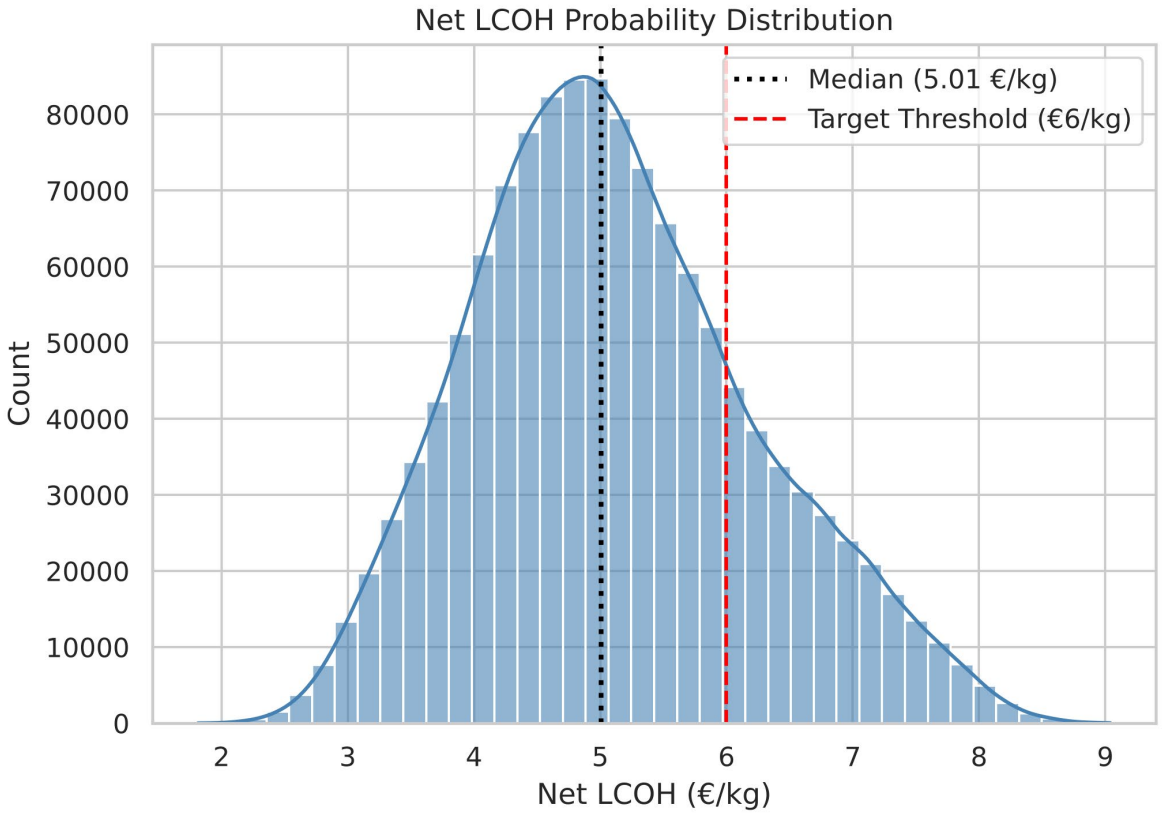


€9.75/kg with current Irish costs, design fixed; **€9.51/kg** even after re-optimising (27 MW wind + 2 MW solar).

Four inputs explain ~90% of the gap: grid price (€90 → 160/MWh) and electrolyser CAPEX (€750 → 1,800/kW) each add ≈ €1.5/kg; wind CAPEX and capacity factor add €0.5–0.75/kg.

ITERF · SCENARIO SPACE

From one optimum to a solution space



€5.01

median Net LCOH per kg

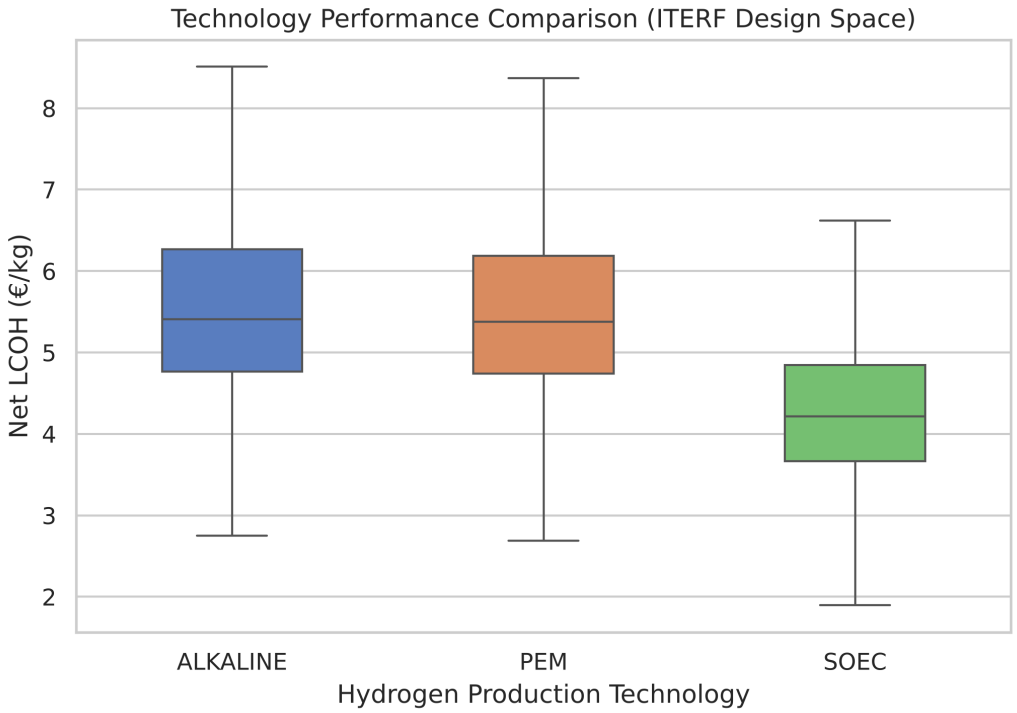
79%

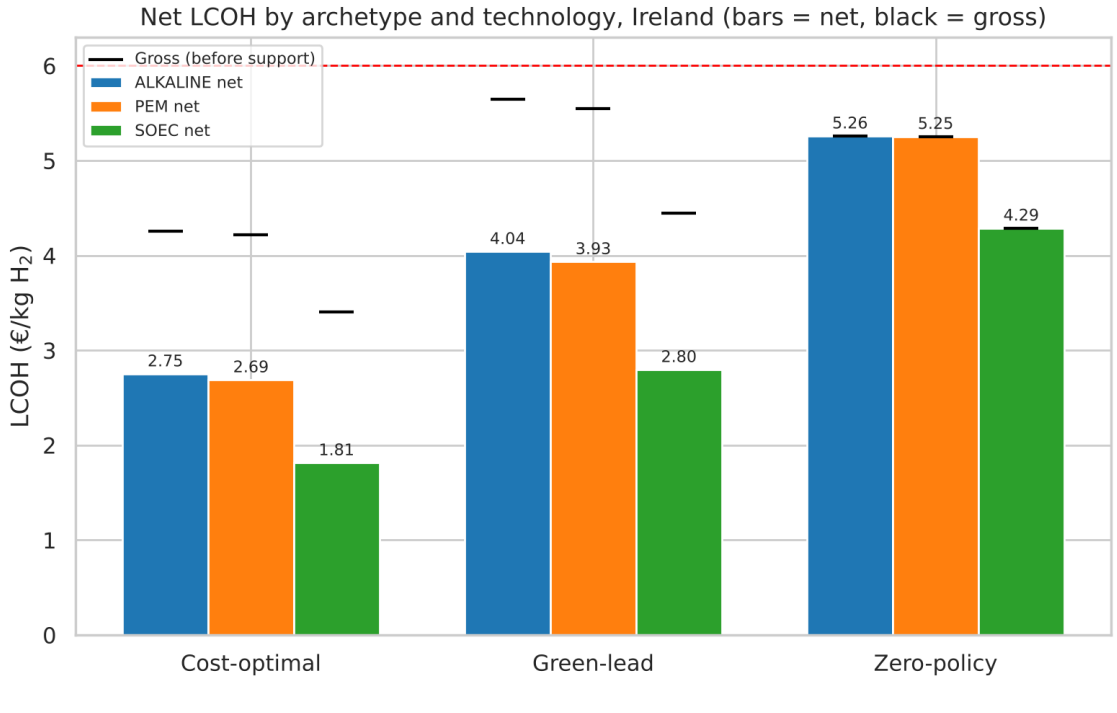
of configurations at or below €6/kg

> Each observation is a deterministic configuration — not yet a probability.

ITERF · TECHNOLOGIES AND ARCHETYPES

Support moves cost more than technology does



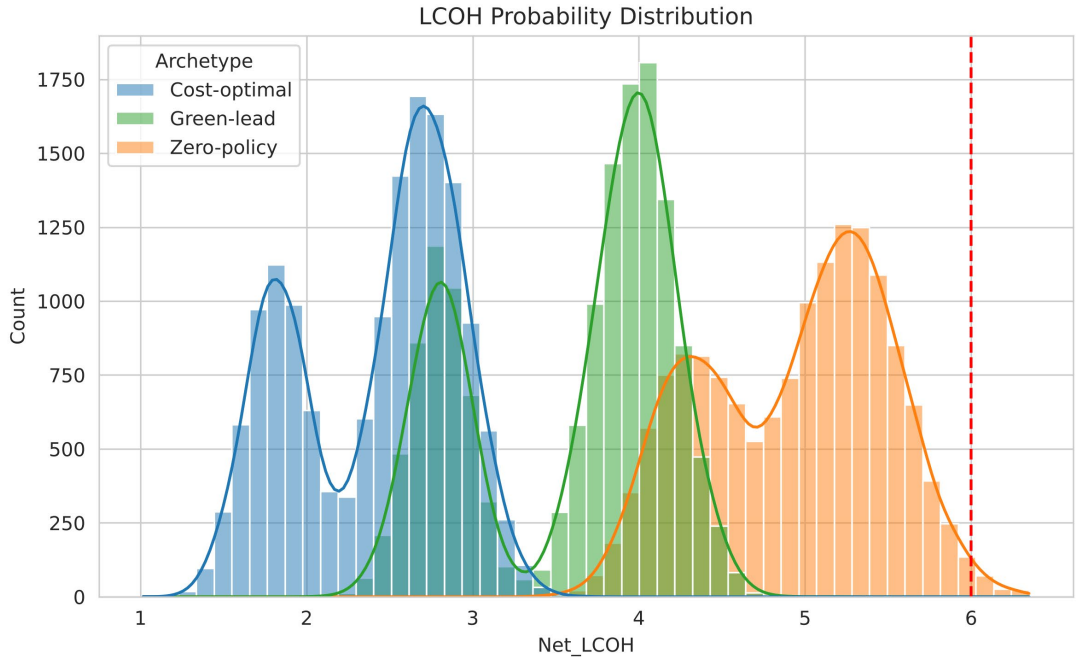


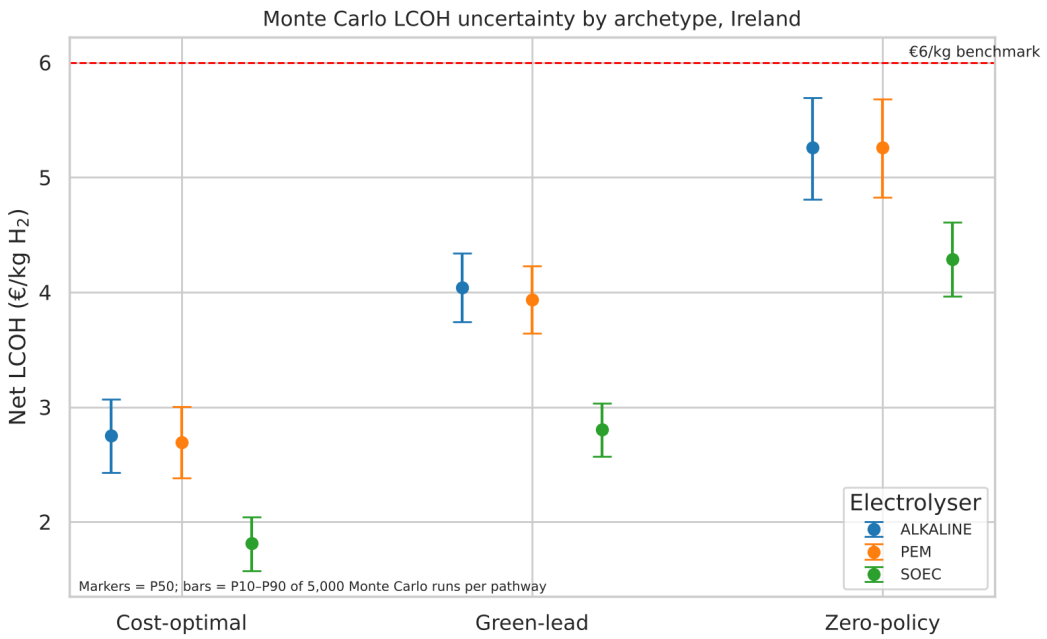
Technology medians: SOEC €4.22, PEM €5.38, alkaline €5.41/kg (SOEC assumes free waste heat).

Archetypes (PEM): Cost-optimal €2.69 with stacked support (50% grant, €2/kg OPEX, CfD, CCfD); Zero-policy €5.25/kg.

ITERF · MONTE CARLO

Uncertainty widens costs, but most designs hold





5,000 runs per pathway: CAPEX ±10%, electricity ±15%, OPEX ±8% (1σ). **Even without support,** Irish PEM stays at or below €6/kg in 98.8% of runs. The real threat is a sustained price shock - next slides.

POLICY MECHANISMS

Four support mechanisms, four different risks

CAPEX grant

Reduces upfront investment

Risk addressed

Capital-cost exposure

OPEX support

Reduces operating cost

Risk addressed

Operating-cost exposure

CCfD

Pays the carbon-price gap

Risk addressed

Carbon-price exposure

CfD

Caps the grid power price at a strike price

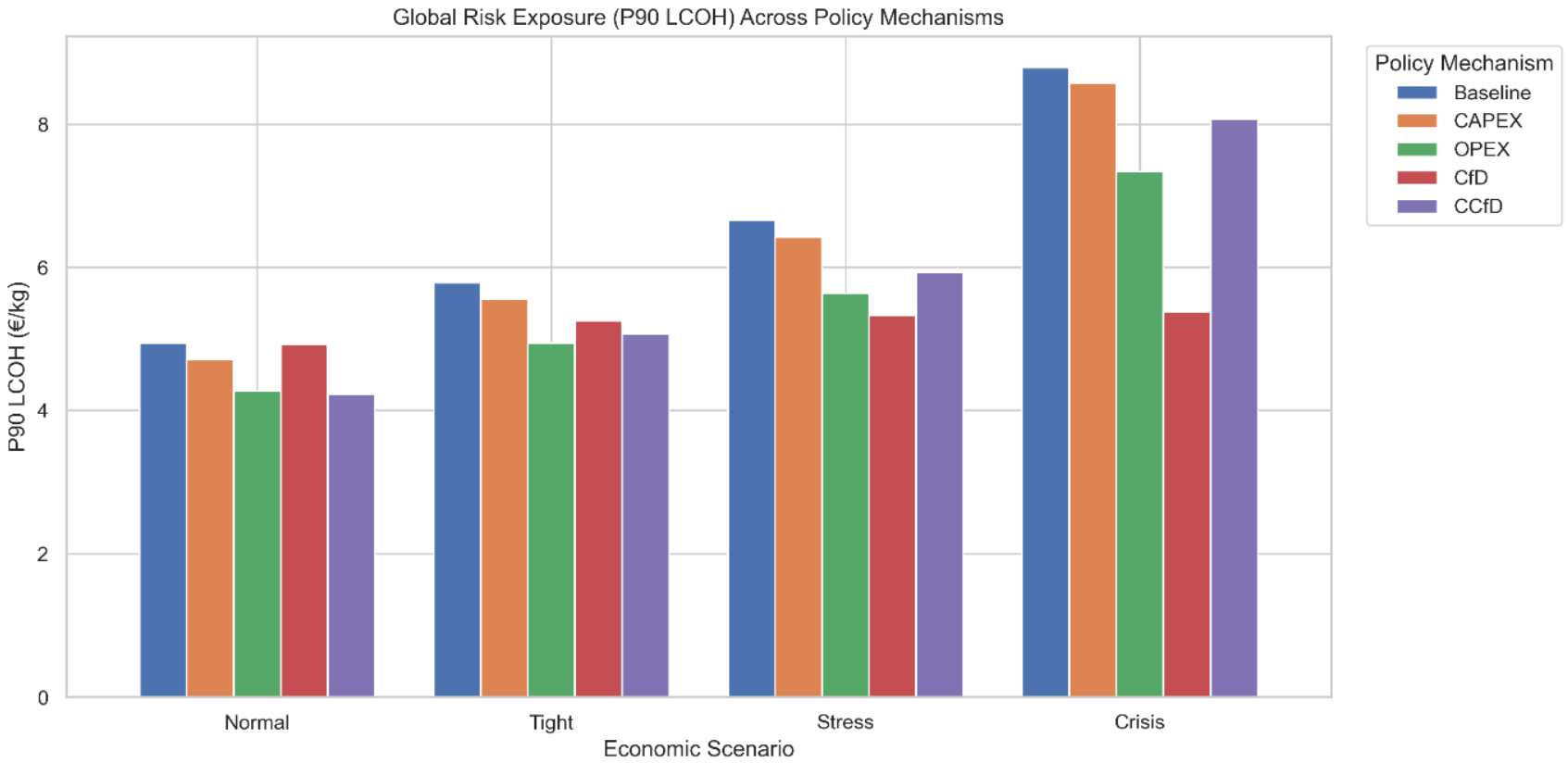
Risk addressed

Electricity-price exposure

Each is evaluated on expected cost, probability of meeting €6/kg, and efficiency per unit of support.

ITERF · POLICY STRESS TEST

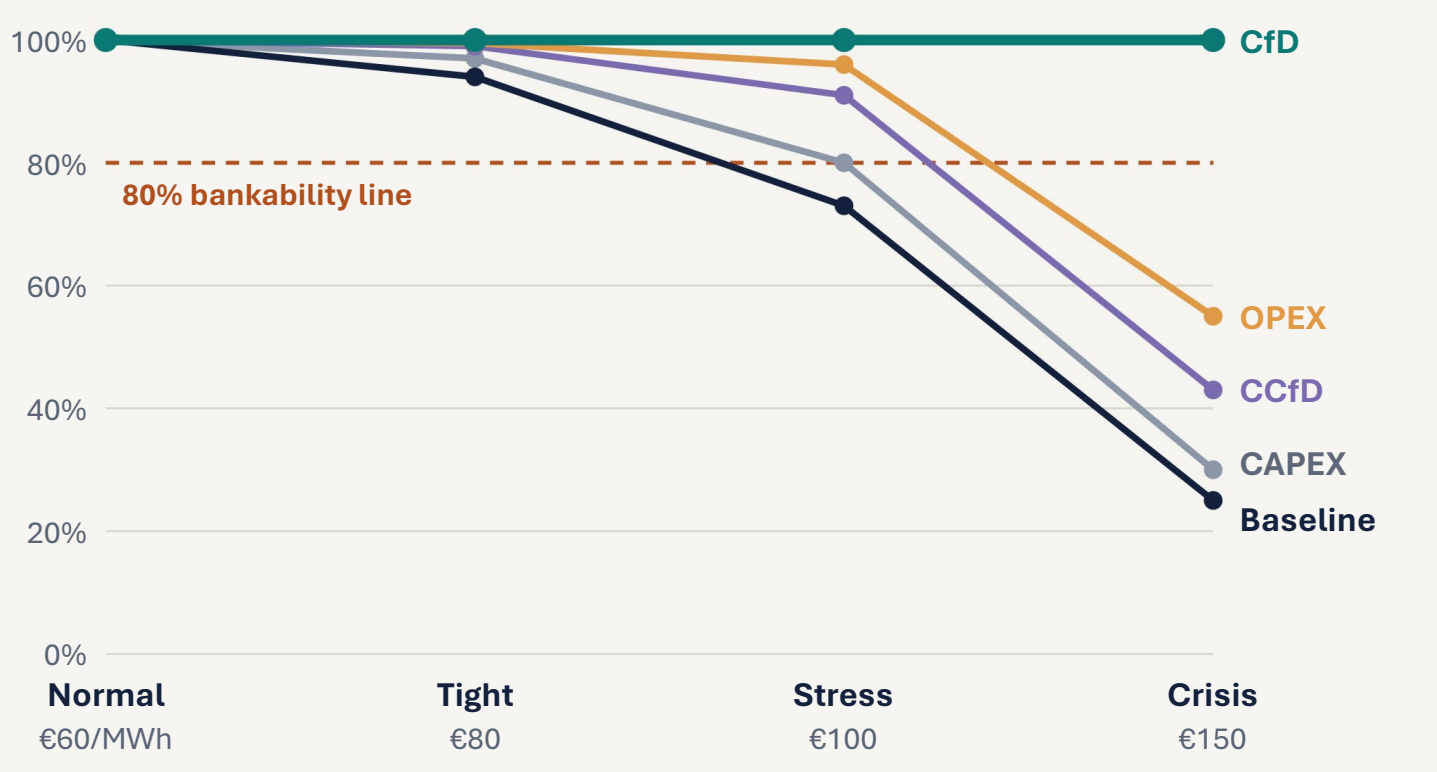
Downside cost (P90) as power prices rise



P90 = the cost exceeded in only 1 run in 10. Crisis (€150/MWh): ≈ €8.8/kg baseline vs ≈ €5.4/kg with a CfD.

STRESS TEST

What happens when electricity markets turn adverse?



CRISIS · €150/MWH

≈25%

Baseline chance of ≤ €6/kg

100%

With a CfD — in every scenario

P90 LCOH in crisis: ≈€8.8/kg baseline vs ≈€5.4/kg with CfD

ELECTRICITY-PRICE CfD

Most robust — but the risk moves to the state

- **100% probability** of LCOH at or below €6/kg in all four scenarios, including Crisis (€150/MWh).
- **How it works:** the CfD caps the grid price the electrolyser pays at the €70/MWh strike, so the stress variable is hedged directly.
- **Risk more than cost:** lowest P90 in Crisis (≈ €5.4 vs ≈ €8.8/kg), but OPEX support cuts average cost more per euro of support.
- **Across 38 countries:** each €1 of CfD support lowers P90 LCOH by €1.42, against about €1.0 for the other instruments.
- **The catch:** the public budget carries the price risk — the CfD pays out most exactly when power prices spike, so its cost must be budgeted in the crisis case.

FINDINGS

What the framework tells us

01 Cost is not enough

LCOH alone misses exposure to electricity prices, financing and policy uncertainty.

02 Cheapest is not greenest

The lowest-cost designs lean on grid power and stacked support; meeting the EU RFNBO limit at Whitegate adds €0.27/kg.

03 Policy ranking depends on the metric

OPEX support cuts average cost most per euro; the CfD protects best against price spikes (100% at or below €6/kg in Crisis).

04 Electricity exposure dominates risk

Grid price and electrolyser CAPEX move the Whitegate LCOH most (about +€1.5/kg each); power-price shocks separate robust policies from fragile ones.

BEYOND LEVELISED COST

From “What does hydrogen cost?”

To “How does the project perform under uncertainty — and which policy makes deployment robust?”

Thank you · Questions?

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Assumptions and boundary conditions

Project and electrolyser assumptions

PROJECT

Annual H_2 demand	**1,500 t**
Project lifetime	**25 years**
Volume conversion	**11.13 Nm^3/kg**
Operating hours	**12–24 h/day**
Annual hours	**4,380–8,760 h**

ELECTROLYSER TECHNOLOGIES

Technology	Stack kWh/Nm^3	Loss factor	CAPEX €/kW	kWh/kg H_2*
Alkaline	4.8	1.25	700	66.8
PEM	4.6	1.20	1,000	61.4
SOEC	3.7	1.10	1,400	45.3

* Derived: stack consumption × 11.13 Nm^3/kg × loss factor. Model 1 (Whitegate) uses PEM at €750/kW.

Demand is fixed at 1,500 tonnes a year over 25 years. Operating hours are swept from 12 to 24 hours a day. Three technologies are modelled with their own stack consumption, system loss factor and CAPEX; electricity use per kg is derived from these, not entered separately.

Financing and operating costs

CAPITAL STRUCTURE	
Debt / equity	**70% / 30%**
Cost of debt	**5.5%**
Cost of equity	**CAPM 3% + 1.5 × 7% = 13.5%**
WACC (Ireland)	**6.94%**
Tax in financing	**25%**

FORMULATION

WACC = 0.3·Re + 0.7·Rd·(1 − T)

OPEX = 4% electrolyser CAPEX + 2% RE CAPEX

LCOH = (CAPEX + OPEX + Power + Finance) ÷ discounted H_2

Financing = LCOH at WACC − LCOH at 0%, split into after-tax debt interest and equity return; no separate interest line.

Country risk is added to the cost of equity, so WACC is country-specific. Each LCOH component is divided by discounted hydrogen output, not annual output.

Policy levels tested at each stage

Mechanism	Core optimisation	Policy Monte Carlo	Stress test
CAPEX grant	0 / 30 / 50% of electrolyser CAPEX	0–40%, 5-point steps	20%
OPEX support	€0 / 1 / 2 per kg H_2	0–30%, 5-point steps	20% of electricity cost
CfD	Strike €0 / 60 / 80 per MWh	Strike €50–90/MWh; price N(€80, 20%)	Strike €70/MWh
CCfD	Strike €0 / 80 / 120 per tCO_2; ETS €80	Strike €60–150/tCO_2; ETS €65	Strike €80/tCO_2

Support duration: 10 years (core)

CO_2 intensity: 9 kg CO_2/kg H_2

CfD applied as min(power price, strike)

Electricity-price stress test design

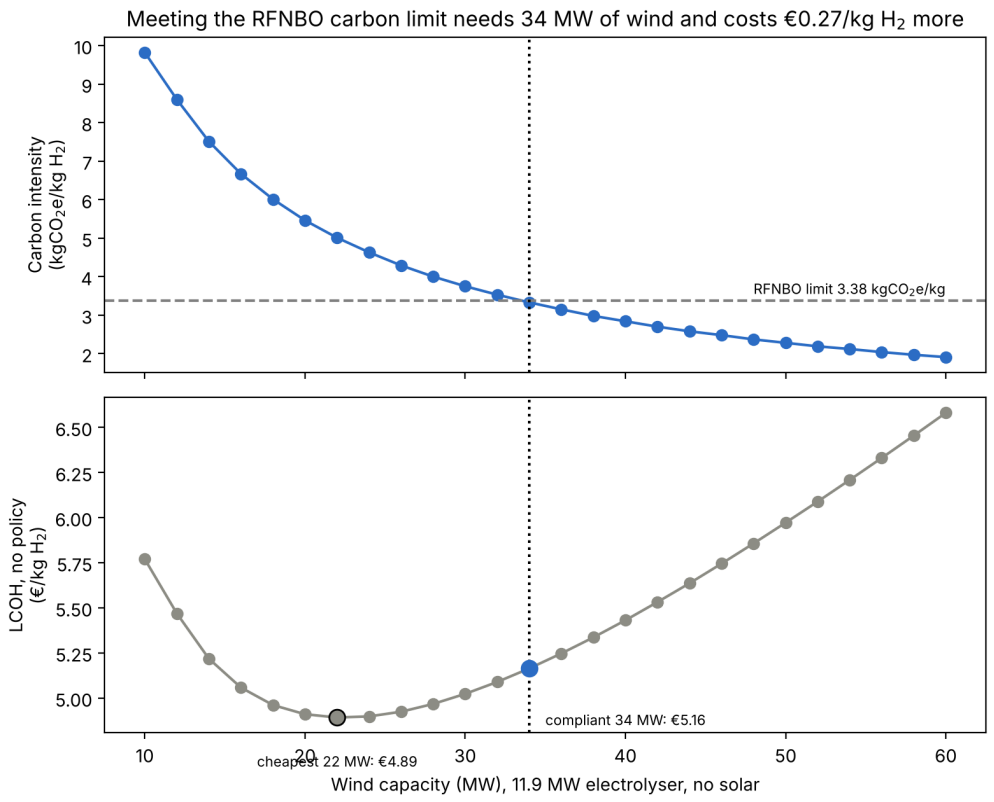
SCENARIOS · 30% VOLATILITY

Scenario	Mean price
Normal	€60/MWh
Tight	€80/MWh
Stress	€100/MWh
Crisis	€150/MWh

STYLISED PROJECT

H_2 output	**1,000 t/year**
Lifetime	**20 years**
Electricity use	**52 kWh/kg H_2**
Operating hours	**5,000 h/year**
Fixed OPEX	**€0.40/kg H_2**
CO_2 intensity	**9 kg/kg H_2**

Sensitivity test values and the RFNBO check



RFNBO limit 3.38 $kgCO_2e/kg$ = 94 g/MJ × (1 − 0.70) × 120 MJ/kg. At 20 MW wind, 33.5% grid power (259 g/kWh) gives 5.3 kg. Compliance needs 34 MW wind: €4.89 → €5.16/kg, curtailment 19% → 39%.

Input	Base (Model 1)	Test value
Grid electricity price	€90/MWh	€160/MWh
Electrolyser CAPEX	€750/kW	€1,800/kW
Balance of plant	20% of stack	50%
Wind CAPEX	€1,000/kW	€1,500/kW
Wind capacity factor	0.457	0.35
Electrolyser specific energy	61.4 kWh/kg	55 kWh/kg
Debt interest rate	5.5%	7.5%
Equity beta	1.5	2.0
Project life	25 years	20 years
Storage CAPEX	€500/kg	€1,000/kg
Grid connection	€150k/MW	€400k/MW
Wind O&M	2%/yr	3%/yr
Stack life	60,000 h	40,000 h
Water cost	€0.002/L	€0.010/L
Electrolyser O&M	4%/yr	5%/yr

Sources for test values: Eurostat Irish non-household prices (≈ €255/MWh, H2 2025), IEA electrolyser costs outside China (USD 1,900–2,500/kW), IRENA onshore wind (USD 1,041/kW, 2024), Irish wind fleet capacity factor ≈ 31% (2025).