Supplementary Information for

Mapping cost competitiveness of African green hydrogen exports to Europe

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Contains Figures 1-8 and Tables 1-6.

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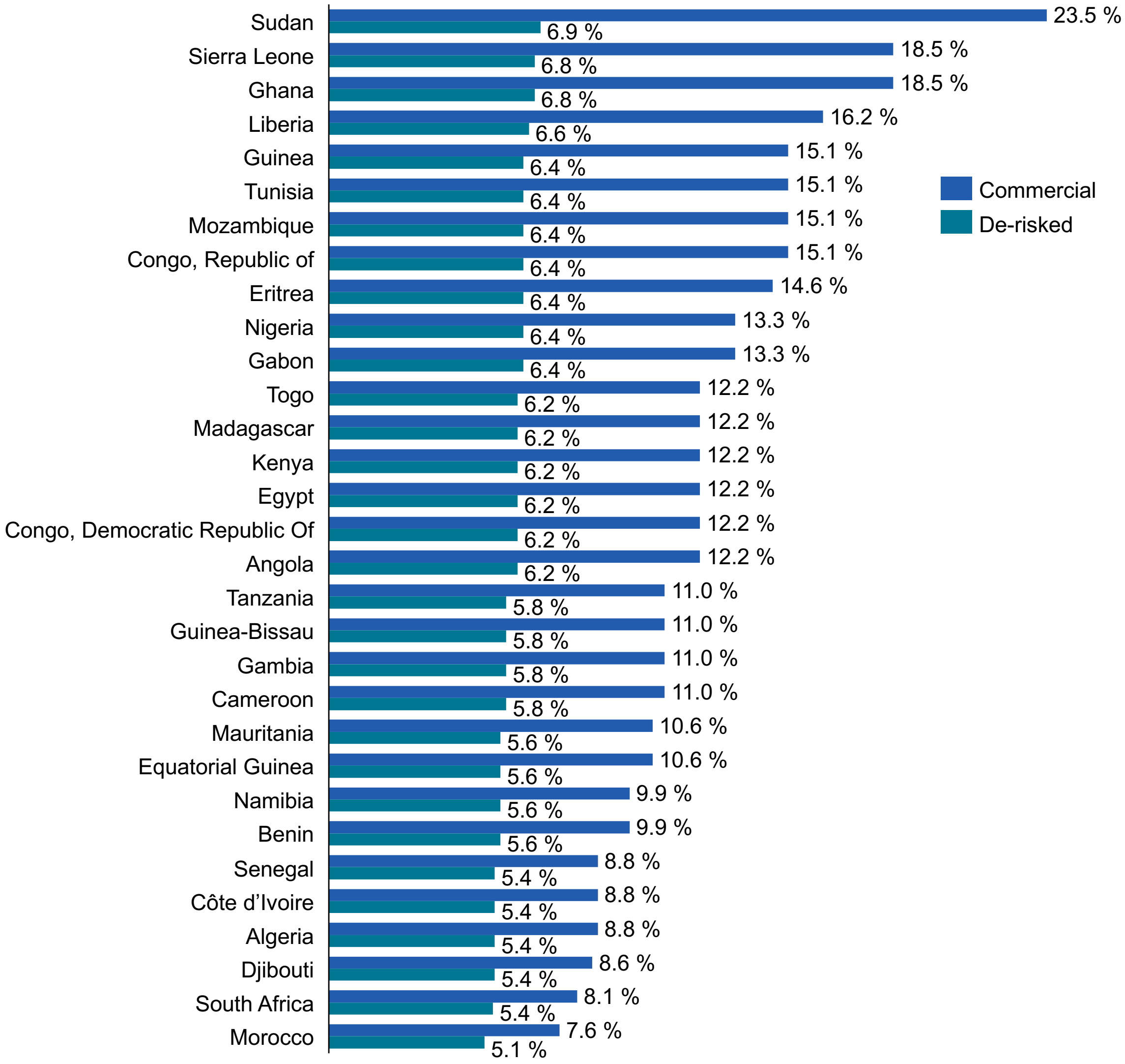

Fig. 1 | Cost of capital (COC) by country and policy scenarios. a. CoC for a private commercial and a public de-risked scenario in a low general interest environment (scenarios 3 and 4). Country differences result from different investment risks based on default spreads[1], while differences between policy scenarios, i.e., commercial versus de-risked, are the result of different sources of capital and premia (see Methods).

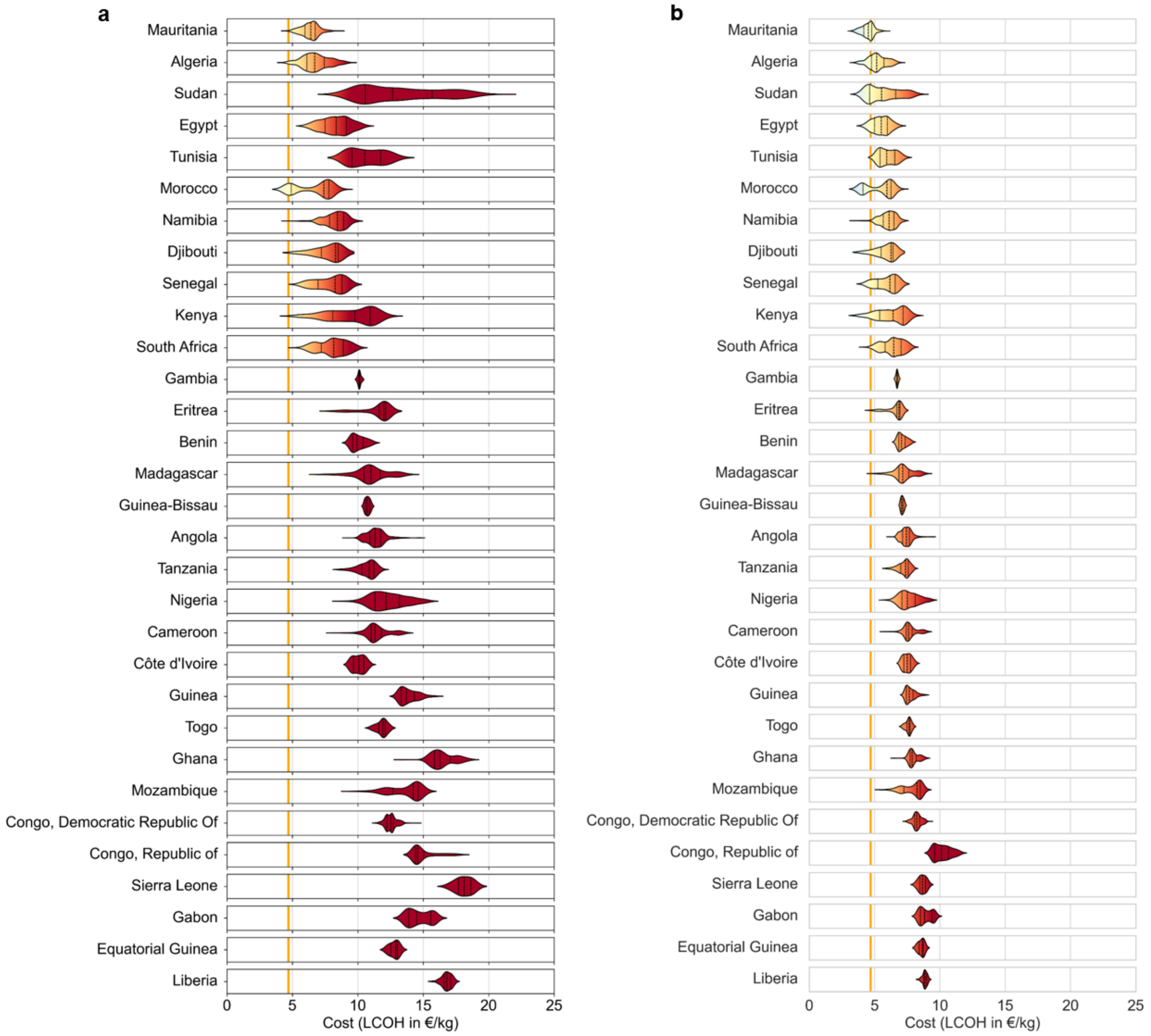

Fig. 2 | LCOH distribution by country. a. LCOH for scenario 3, *investment-friendly private.* **b.** LCOH for scenario 4, *investment-friendly de-risked*. The orange line represents the cost of producing green H2 in Rotterdam by 2030 as described in Methods. Colours indicate the cost competitiveness with European green H_2 projects, where blue is “in the money” compared to the cost of hydrogen produced in Rotterdam, yellow is near the European cost, and red is likely to be uncompetitive. The dotted line on the colour bar denotes the mean modelled cost of hydrogen produced in Rotterdam across the four scenarios. LCOH is in €/kg. Dashed black lines within the violin plots indicate the median and dotted black lines indicate the 25th and 75th percentiles.

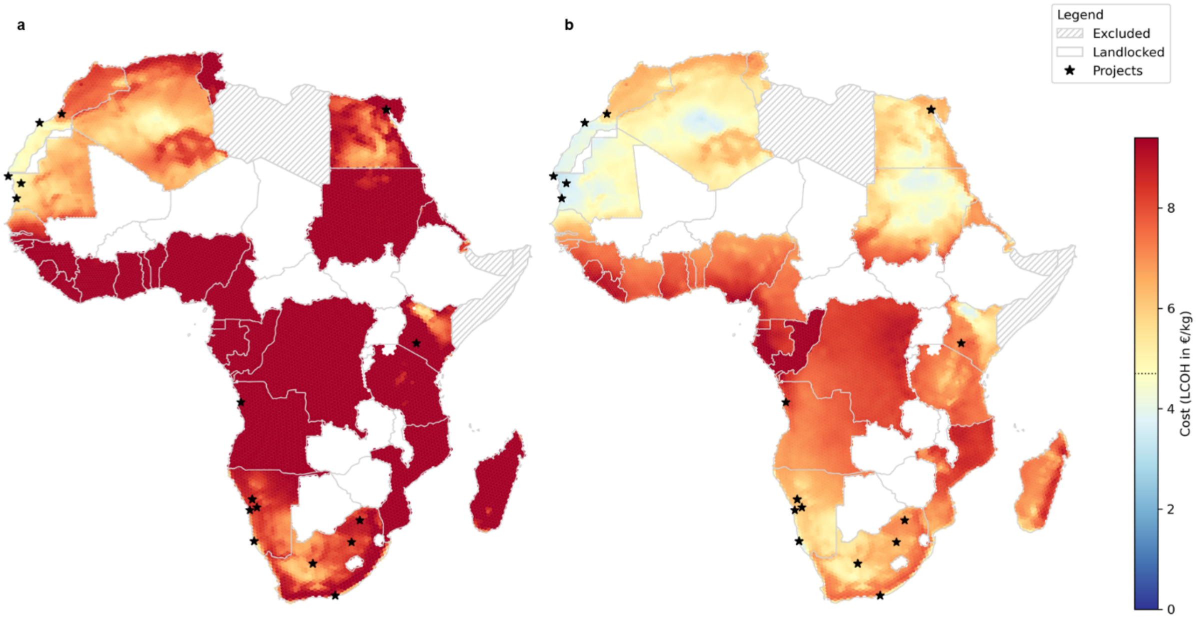

Fig. 3 | LCOH for Africa. a. LCOH for scenario 3, *investment-friendly private.* **b.** LCOH for scenario 4, *investment-friendly de-risked*. Colours indicate the cost competitiveness with European green H_2 projects, where blue is “in the money” compared to the cost of hydrogen produced in Rotterdam, yellow is near the European cost, and red is likely to be uncompetitive. The dotted line on the colour bar denotes the mean modelled cost of hydrogen produced in Rotterdam across the four scenarios. LCOH in €/kg H_2. Stars denote planned projects, as listed in Figure 1.

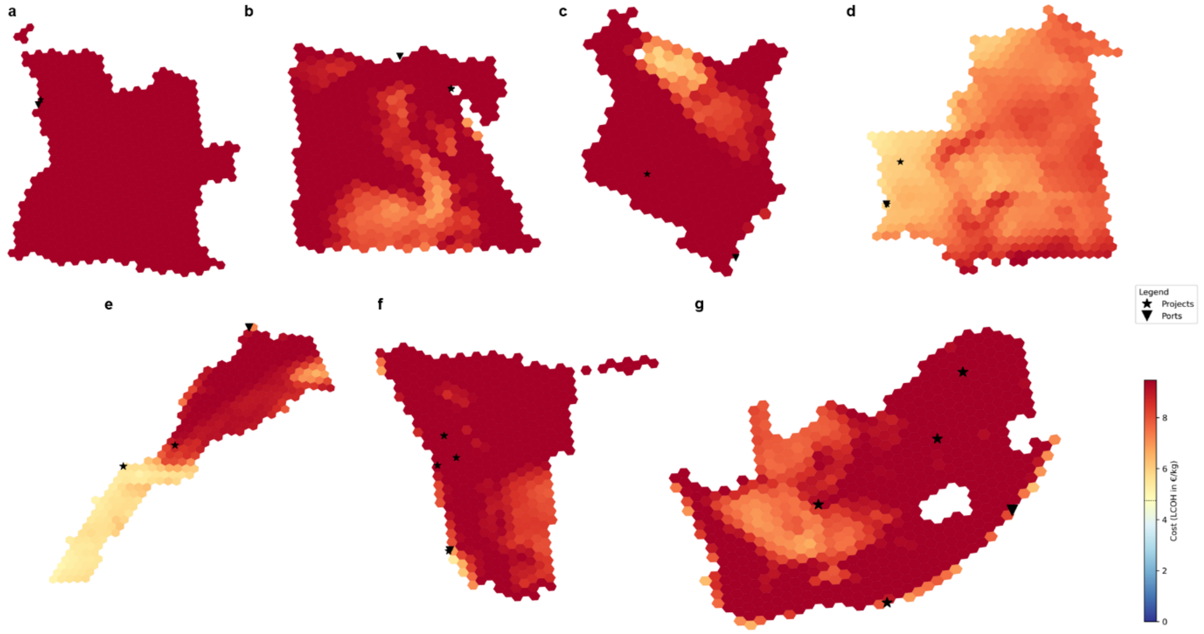

Fig. 4 | LCOH maps for **a.** Angola, **b.** Egypt, **c.** Kenya, **d.** Mauritania, **e.** Morocco, **f.** Namibia, and **g.** South Africa. Costs shown are for scenario 1, *cash-constrained private.* Countries are not shown to scale; however each hexagon is the same area across all sub-figures.

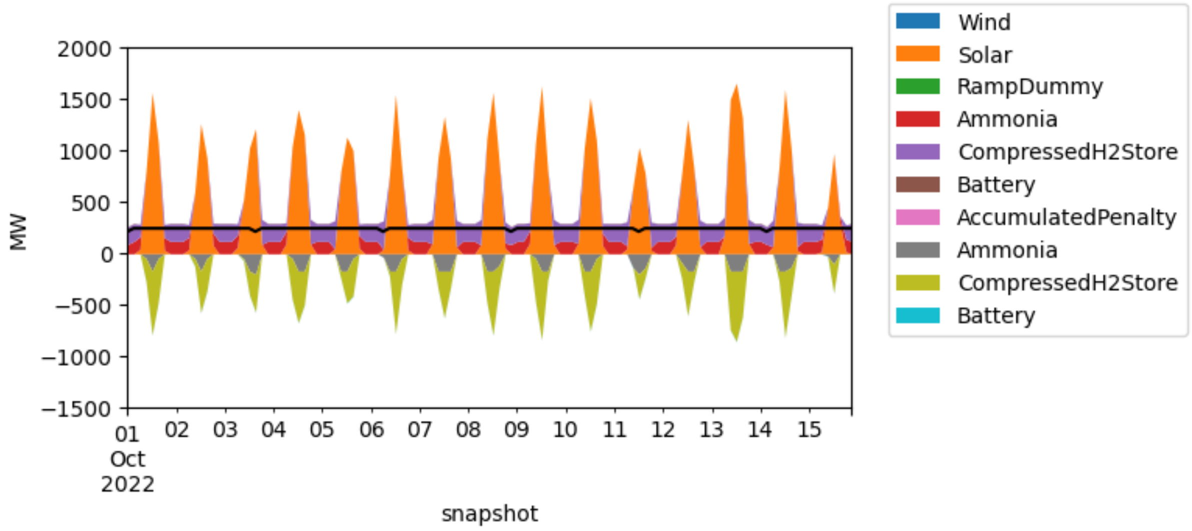

Fig. 5 | Hourly cost breakdown. Costs components with an hourly resolution for 15 days in Liberia as an exemplary high-cost country reliant on solar PV. This case illustrates that a mixture of compressed hydrogen and ammonia storage is deployed rather than battery storage to ensure a constant load to run the electrolyzer.

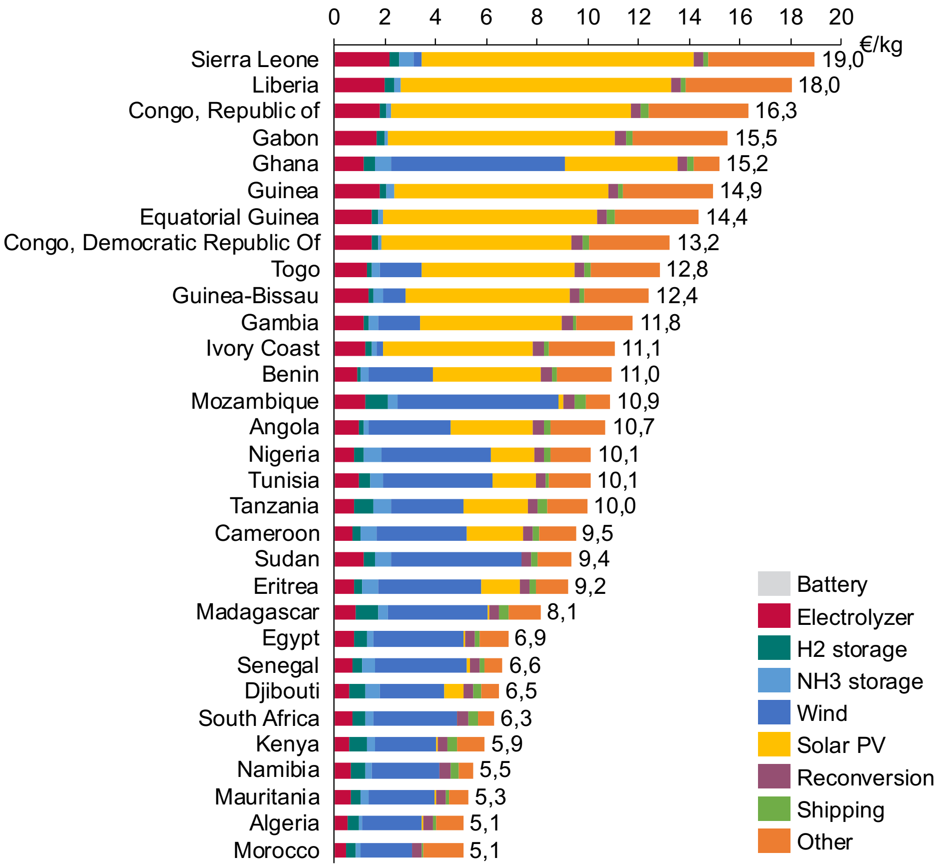

Fig. 6 | LCOH breakdown. Cost shown for scenario 1, *cash constrained private.*

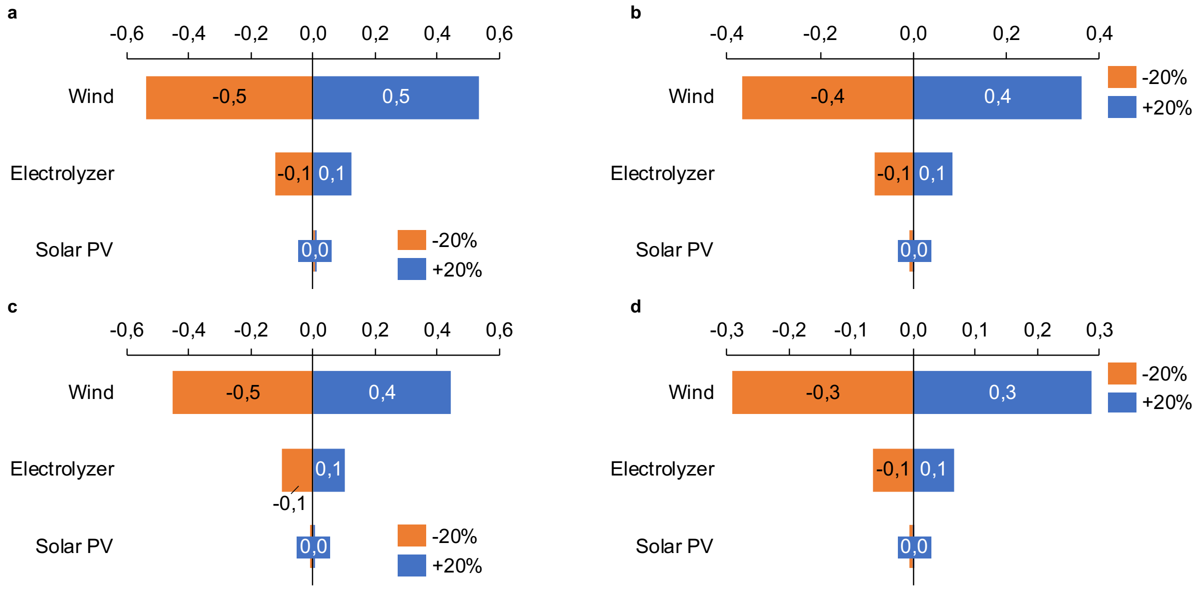

Fig. 7 | Sensitivity. Variation in least cost LCOH in €/kg green H_2 shown for Mauritania when key inputs change +/- 20% in each financing scenario where panel a shows scenario 1, b = scenario 2, c = scenario 3, and d = scenario 4.

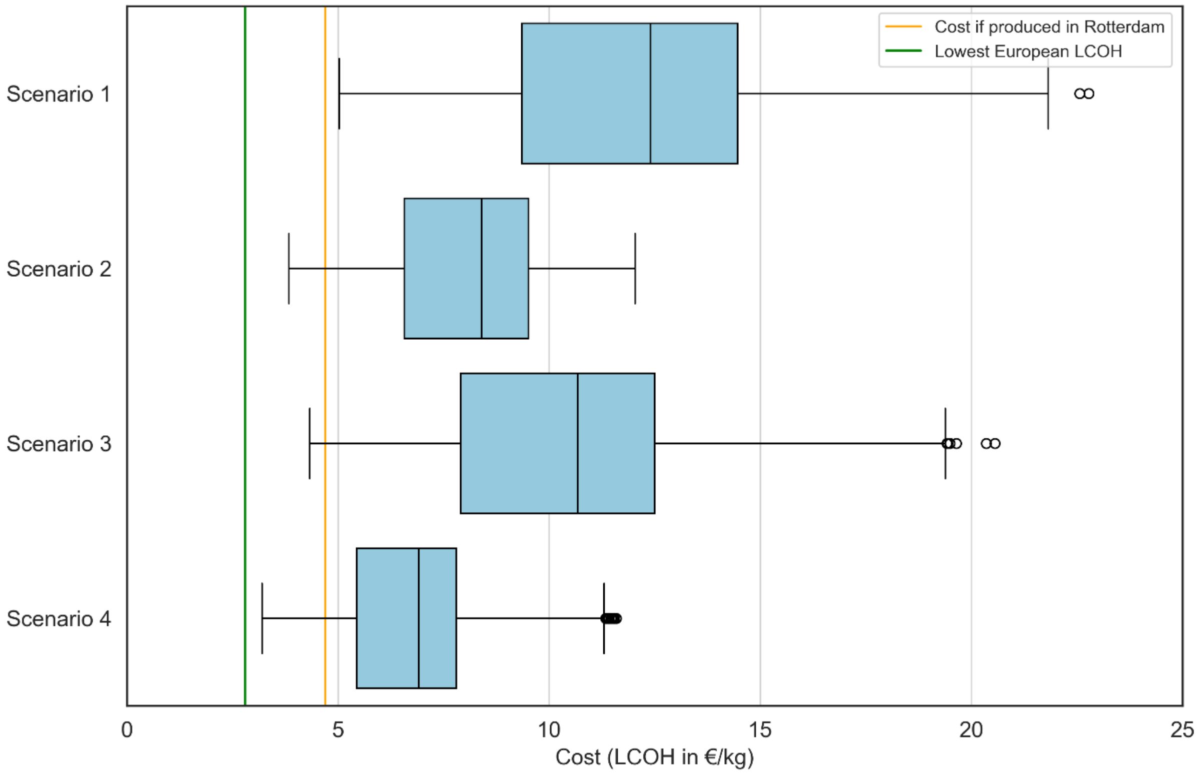

Fig. 8 | LCOH distribution by scenario. Depicts the same data as Figure 3 in the main text in a boxplot to show exact min. and max. values.

Table 1 | Key techno-economic parameters for GeoH$_2$ model. All model values are in 2023 euros.

Parameter	Component	Ref	Ref unit	Ref Value	Ref Year	Model Unit	Model Value
Capital cost	PV system	[2]	$/MW	1,470,000	2020	€/MW	1,415,544
Capital cost	Wind system	[2]	$/MW	1,489,000	2020	€/MW	1,529,568
Capital cost	Battery	[3]	$/MWh	151,000	2022	€/MWh	151,089
Capital cost[1]	Electrolyzer	[4]	$\$/\text{MW}_e$	364,000	2019	$€/\text{MW}_e$	382,084
Efficiency[2]	Electrolyzer	[5]	%	74	-	%	74
Capital cost	Hydrogen compression	[6]	€/MW	130,000	2021	€/MW	148,505
Electricity demand[2]	Hydrogen compression	[5]	$\text{MWh}_e/\text{MWh}_{H2}$	0.05	-	$\text{MWh}_e/\text{MWh}_{H2}$	0.05
Capital cost[1]	Ammonia production	[4]	$/MWe	2,890,000	2018	€/MW	2,908,055
Specific hydrogen consumption[2]	Ammonia production	[5]	$\text{MWh}_{H2}/\text{MWh}_{NH3}$	0.88	-	$\text{MWh}_{H2}/\text{MWh}_{NH3}$	0.88
Specific electricity consumption[2]	Ammonia production	[5]	$\text{MWh}_e/\text{MWh}_{NH3}$	6.25	-	$\text{MWh}_e/\text{MWh}_{NH3}$	6.25
Capital cost	Battery interface output	[5]	$/MW	148,000	2021	€/MW	142,909
Capital cost	Hydrogen fuel cell	[4]	$\$/\text{MW}_{H2}$	$1,000,000	2017	€/MW	1,070,732
Efficiency*	Hydrogen fuel cell	[5]	$\text{MWh}_{H2}/\text{MWh}_e$	0.5	-	$\text{MWh}_{H2}/\text{MWh}_e$	0.5
Capital cost	Ammonia storage	[4]	$\$/\text{MWh}_{NH3}$	800	2019	$€/\text{MWh}_{NH3}$	839.74
Capital cost	Compressed hydrogen storage	[7]	$€/\text{MWh}_{H2}$	21,700	2022	$€/\text{MWh}_{H2}$	22,873
Maximum capacity	Large pipeline	[8]	t_{NH3}/year	15,000,000	-	t_{NH3}/year	15,000,000
Minimum capacity	Large pipeline	[8]	t_{NH3}/year	8,262,000	-	t_{NH3}/year	8,262,000
Minimum capacity	Medium pipeline	[8]	t_{NH3}/year	1,775,000	-	t_{NH3}/year	1,775,000
Minimum capacity	Small pipeline	[8]	t_{NH3}/year	500,000	-	t_{NH3}/year	500,000
Capex constant	Large pipeline	[8]	$/t/year/ 100km	36.63	2021	€/t/year/ 100km	36.43
Capex flow coefficient	Large pipeline	[8]	$\$/t^2/\text{year}^2/100\text{km}$	-5.00E-07	2021	$€/t^2/\text{year}^2/100\text{km}$	-4.83E-07
Capex constant	Medium pipeline	[8]	$/t/year/ 100km	59.64	2021	€/t/year/ 100km	57.59
Capex flow coefficient	Medium pipeline	[8]	$\$/t^2/\text{year}^2/100\text{km}$	-3.15E-06	2021	$€/t^2/\text{year}^2/100\text{km}$	-30.4E-06
Capex constant	Small pipeline	[8]	$/t/year/ 100km	82.31	2021	€/t/year/ 100km	79.48
Capex flow coefficient	Small pipeline	[8]	$\$/t^2/\text{year}^2/100\text{km}$	-1.59E-05	2021	$€/t^2/\text{year}^2/100\text{km}$	-1.54E-05

[1] Scaled based on size of demand/infrastructure needed using formulae in ref.

[2] Values based on higher heating value of fuels.

Table 2 | LCOH summary statistics

	N	Min.	25th perc	Me-dian	Aver-age	75th perc	Max.	Rotter-dam	<=Rot-terdam	<=2.8
Scenario 1	10300	5.0	9.4	12.4	12.1	14.5	22.8	4.74	N=0; 0%	N=0; 0%
Scenario 2	10300	3.8	6.6	8.4	8.1	9.5	12.0	4.72	N=206; 2.0%	N=0; 0%
Scenario 3	10300	4.3	7.9	10.7	10.5	12.5	20.6	4.69	N=46; 0.4%	N=0; 0%
Scenario 4	10300	3.2	5.4	6.9	6.7	7.8	11.6	4.67	N=1091; 10.6%	N=0; 0%

Table 3 | Project Sample Overview

Project Name	Country	Date Online	Status	Dedicated End Uses	Capacity (MW)
Sonangol	Angola	2024	Concept	Ammonia	582
Ain Sokhna ammonia project	Egypt	2027	Feasibility study	Ammonia	1459
Ain Sokhna plant, Suez Canal Economic Zone (SCZone), phase 1	Egypt	2026	Feasibility study	Ammonia, mobility	253
EBIC - Ammonia plant	Egypt	2024	Feasibility study	Ammonia	100
Masdar Hassan Allam green hydrogen, phase 1	Egypt	2026	Feasibility study	Methanol, mobility	194
Masdar Hassan Allam green hydrogen, phase 2	Egypt	2030	Concept	Ammonia, other industrial applications	3806
ReNew Power - Egypt MoU, Ammonia phase 1	Egypt	2025	Concept	Ammonia	208
ReNew Power - Egypt MoU, Ammonia phase 2	Egypt	2029	Concept	Ammonia	2079
ReNew Power - Egypt MoU, Hydrogen, phase 1	Egypt	2025	Concept	Unspecified	231
ReNew Power - Egypt MoU, Hydrogen, phase 2	Egypt	2029	Concept	Unspecified	2078
Scatec Green Ammonia	Egypt	2025	Concept	Ammonia	1823
Total Eren, Enara green ammonia, phase 2	Egypt	2030	Concept	Ammonia	2188
Kenya Private Sector Alliance - FFI MoU, phase 1	Kenya	2025	Feasibility study	Ammonia	300
Aman - Green Hydrogen Project - phase 1	Mauritania	2030	Feasibility study	Ammonia	
Mauritania - Green Ammonia project - phase 1	Mauritania	2028	Concept	Ammonia	400
Project Nour	Mauritania	2030	Feasibility study	Unspecified	6906
Guelmim-Oued Noun project	Morocco	2027	Concept	Unspecified	
HEVO-Morocco	Morocco	2026	Feasibility study	Ammonia	689
Masen - KfW	Morocco	2025	Feasibility study		100
OCP Group	Morocco	2027	Concept	Ammonia	2079

Ammonia project					
Daures Green Hydrogen Village, phase 1	Namibia	2023	FID/Construction	Ammonia	0.5
Daures Green Hydrogen Village, phase 2	Namibia	2024	Feasibility study	Ammonia	3.5
Daures Green Hydrogen Village, phase 3	Namibia	2028	Feasibility study	Ammonia	38
Hyphen Hydrogen Energy - phase I	Namibia	2027	Feasibility study	Ammonia	1000
Hyphen Hydrogen Energy - phase II	Namibia	2029	Feasibility study	Ammonia	2000
O&L group - CMB.TECH hydrogen hub	Namibia	2023	FID/Construction	Mobility	4
Renewstable Swakopmund	Namibia	2025	Feasibility study	Power	24
Anglo-American Mogalakwena mine	South Africa	2022	Operational	Mobility	3.5
Eastern Cape MeOH plant	South Africa	2027	Concept	Methanol	120
Nelson Mandela Bay green ammonia plant, phase 1	South Africa	2025	Feasibility study	Ammonia	540
Nelson Mandela Bay green ammonia plant, phase 2	South Africa	2026	Feasibility study	Ammonia	2162
Prieska ammonia project, phase 1	South Africa	2025	Feasibility study	Ammonia	149
Prieska ammonia project, phase 2	South Africa	2030	Concept	Ammonia	5623
Sasolburg green hydrogen project	South Africa	2024	Feasibility study	Methanol, Iron & Steel, mobility, power	60

Table 4 | Interview Sample Overview

Interviewee Number	Location	Gender	Function	Organization Type
1	Johannesburg, South Africa	Male	Chief Legal Counsel, Energy & Sovereign Debt	Public
2	Luxembourg	Male	Technical Advisor Low Carbon Technologies	Public
3	Luxembourg	Male	Senior Climate Officer	Public
4	Luxembourg	Female	Senior Credit Officer	Public
5	Abidjan, Côte d'Ivoire	Female	Investment Administrator Private Sector Credit Enhancement Facility	Public
7	Paris, France	Male	Innovation R&D Director	Private
8	Zürich, Switzerland	Male	Key Account Manager Multilateral Development Banks	Private
9	Washington, DC, USA	Male	Senior Insurance Specialist	Public
10	London, UK	Male	Political and Sovereign Credit Risk Team Lead	Private
11	Geneva, Switzerland	Male	CEO	Public
12	Nairobi, Kenya	Male	Dean	Public
13	Windhoek, Namibia	Male	Head of Renewable Energy and Green Hydrogen Program	Public

Table 5 | Cost of Capital Components

Component	Description	Source
Risk-Free Rate ($r_{f_{low,high}}$)	The risk-free rate for each scenario is derived from looking at the average yield on 10-year US treasury bonds based on data from[9] in two five-year time periods: • $r_{f_{low}}$: In the aftermath of the 2008 financial crisis, central banks lowered interest rates overnight[10]. In July 2020, the US 10-year government bond yield reached a minimum of 0.62%[9] resulting in an average government bond yield of around 2.6% between 2009 and 2014. Using these findings as a benchmark, we assume $r_{f_{low}}$ to be 2% for simplicity. • $r_{f_{high}}$: We use the five-year period before the financial crisis (2003-2008) as a reference point for interest rates in "normal times." In this time period, long-term interest rates fluctuated around an average of 4.3%[9]. For simplicity, we assume $r_{f_{high}}$ to be 5%, which is more reflective of peaks in the long-term government bond yields as observed, for example, in January 2000 (6.66%)[9].	Link to OECD long-term interest rates.
Country Default Spread Host (CDS_{Host})	The country risk premium is often estimated using the default spread, which is the difference between the yields of a country's bonds and the US 10-year treasury bond.	Link to Damodaran Dataset

	However, not all countries issue bonds in USD or EUR, making this method impractical. The finance literature suggests two alternatives: If a country has a sovereign credit rating, the default spread of other countries with the same rating can be used[11]. If a country doesn't have a rating, we use a different method based on previous work[12]described below under Wikiratings.	
Country Default Spread Western EU $CDS_{WesternEU}$	Besides the individual country default spreads (CDS), [13] also provides average default spreads for regions weighted by each country's GDP. For this study, we used the weighted average CDS for Western Europe as of July 2023, which equals 0.96%.	Link to Damodaran Dataset. The data used in this paper is taken from the July 2023 update of the *“Risk Premiums for Other Markets"* estimates.
MIGA Guarantees	MIGA risk fees typically average 1%, but can vary from 0.5% to 1.75%[14]. However, public pricing data is not readily available. To address this, an alternative approach is suggested by aligning the distribution of MIGA pricing, as indicated by [14] with the distribution of country default spreads (CDS) from Damodaran's 2023 country sample . As described in equation (6) in the Methods the percentiles of the range suggested by ref.[14] are mapped to the percentiles of the country default spreads based on the estimates by ref.[13] to establish an approximate pricing mechanism for MIGA risks based on country risk.	Link to Damodaran Dataset.
Wikiratings	For countries not covered by [13], the Sovereign Wikirating Index[15] is considered and converted to an equivalent Moody's using Wikirating's credit ratings table[16]. This allows for calculating a country's default spread using a table provided by [13], linking Moody's ratings to default spreads.	Link to sovereign ratings. Link to the credit ratings table.
Equity Risk Premium (ERP)	For scenarios A and B, equity risk reflecting the weighted average of Western EU equity risk is used. Damodaran[13] calculates the total ERP for different regions weighted by the latest World Bank GDP estimates.	Link to Damodaran Dataset.
Country Risk Premium (CRP)	The CRP represents the risk of investing in a country relative to a mature market (US) ERP. They are based on the relative sovereign default spreads in the respective country, multiplied by the volatility of said country’s leading equity index. That is, multiplied by the ratio of the standard deviation of daily values of the leading national index over the past year relative to the standard deviation of the S&P 500[1,17].	Link to Damodaran Dataset.
Debt Share ($\frac{D}{V}$)	A recent OECD report provides a number of case studies of different green H_2 demonstration and/or large-scale projects in emerging economies[18]. In terms of financing, the authors find that companies are targeting a similar gearing ratio as typical CAPEX-intensive industry and infrastructures, with 20-30% equity and 70-80% debt. Hence, for this paper, a debt share of 75% is assumed.	Link to OECD report.
Technology Premium (Tp)	The technology premium (Tp) reflects the additional risk of green H_2 investments stemming from the fact that it there is a limited track record of successfully scaling the technology in large-scale projects. Following a recent IRENA report[17], Tp is set to 3.25%, reflecting a premium for new renewable energy markets.	Link to IRENA report.
Lender margin (Lm)	Following a recent IRENA report[17], a 2% lender margin to account for the additional risk of large private infrastructure debt investments is assumed. This 2% baseline is based on a 2019 report by the EDHEC Infrastructure institute[19] and corroborated with two additional reports from the grey literature.01/11/2024 16:08:00 PM	Link to IRENA report. Link to 2019 report by the EDHEC Infrastructure Institute.

Table 6 | Realized bids in European Hydrogen Bank auction (IF23) closed 8 February 2024 (in €/kg of green H_2)[20]

Country	# bids	Average LCOH	Min. LCOH	Max. LCOH
Spain	46	5.8	2.8	11.1
Germany	20	11.6	4.9	28.0
Norway	14	7.6	4.6	10.6
Portugal	7	8.8	5.3	22.6
Netherlands	7	9.8	7.6	13.9
Finland	5	7.6	n/a	n/a
Denmark	5	11.4	n/a	n/a
Austria	5	12.6	n/a	n/a
France	5	12.9	n/a	n/a
Lithuania	2	8.5	n/a	n/a
Belgium	3	11.0	n/a	n/a
Sweden	2	5.5	n/a	n/a
Greece	2	5.3	n/a	n/a
Italy	2	10.6	n/a	n/a
Poland	2	13.5	n/a	n/a

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