Levelised Cost of Green Ammonia in Chile: A System-level Perspective

David Pozo

1st LATAM Meeting on Green Ammonia and Power-to-X

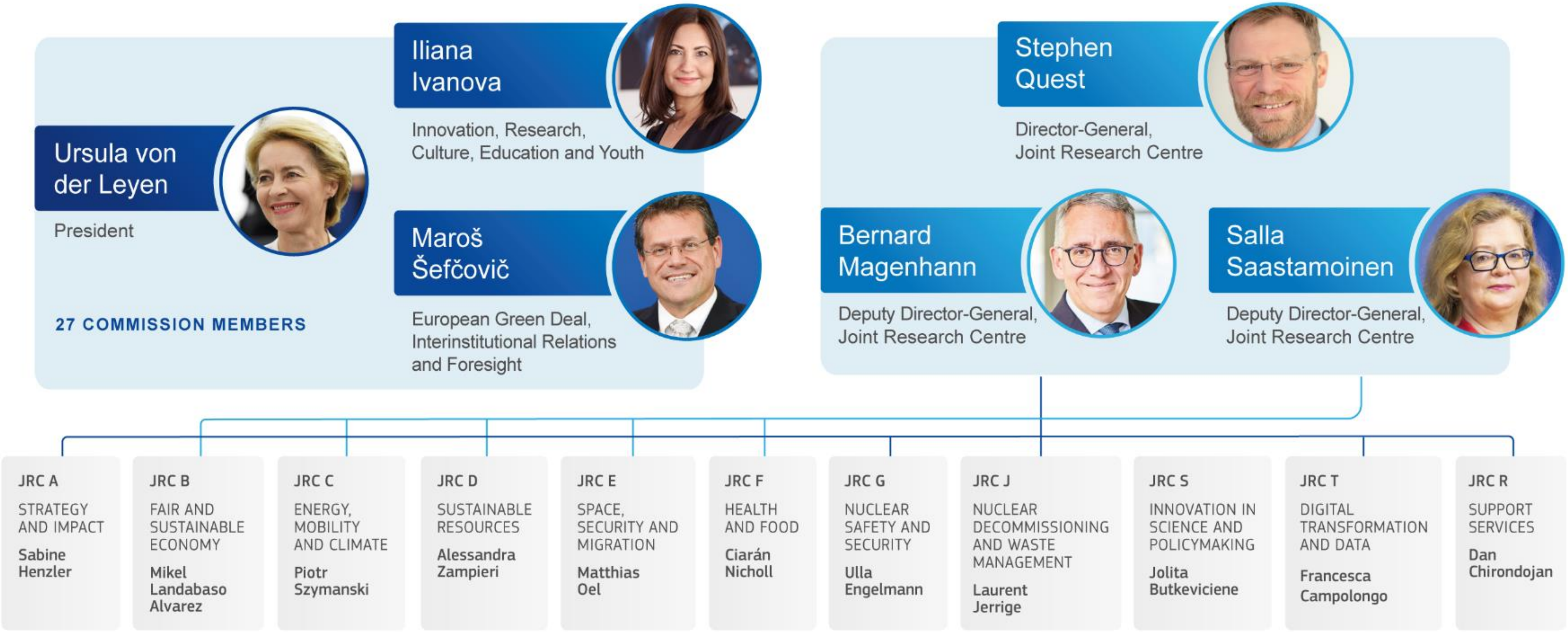
11 January 2024

European Commission

Disclaimer

The views and opinions expressed in this presentation are solely those of the presenter and do not necessarily reflect the views, positions, or policies of any other person or entity.

The Joint Research Centre within the Commission



European Commission

JRC sites

Headquarters in **Brussels** and research facilities located in **5 EU Countries:**

- Belgium (Geel)
- Germany (Karlsruhe)
- Italy (Ispra)
- The Netherlands (Petten)
- Spain (Seville)

European Commission

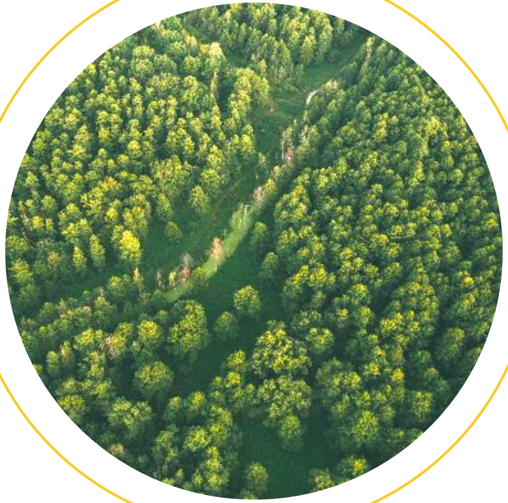
Connecting aspects of the Green Deal

50%

of our scientific work programme is devoted to the Green Deal

Transport and clean energy

Geospatial systems to assess infrastructures and land available



Biodiversity and healthy ecosystems

Knowledge Centre on Biodiversity
Global deforestation observatory

European Commission

Scientific performance

- Nearly 8.000 peer-reviewed publications in Scopus
- 40-50% of articles published in the top 10 % most cited journals (KPI)
- 5-7 % among the top 1% most cited journals

European Commission

Impact on policy-making

Analysis of 2.800 reports on tangible effects on policymaking 2014-2020

70% implementing, monitoring and evaluating policy
30% preparation of policy

88% report use by other Commission departments

Increasing impact on central policy-making processes e.g., better regulation, instruments (e.g. European semester) and crisis response (COVID-19)

86% JRC instrumental for shaping and implementing policies & **14%** moderate impact on policy-making

Introduction

Motivation

- The global production of ammonia is above 150 million metric tonnes and is projected to increase by 2.3% per year.
- The Haber-Bosh process, however, is currently one of the largest global energy consumers and greenhouse gas emitters, responsible for 1.4% of the global anthropogenic CO2 emission.
- Green ammonia can be used as an energy carrier, helping to cope with long-term storage and hard-to-abate sectors.
- Today, **more than 50 countries have hydrogen roadmap or strategy plan**. Green ammonia is in almost all plans.

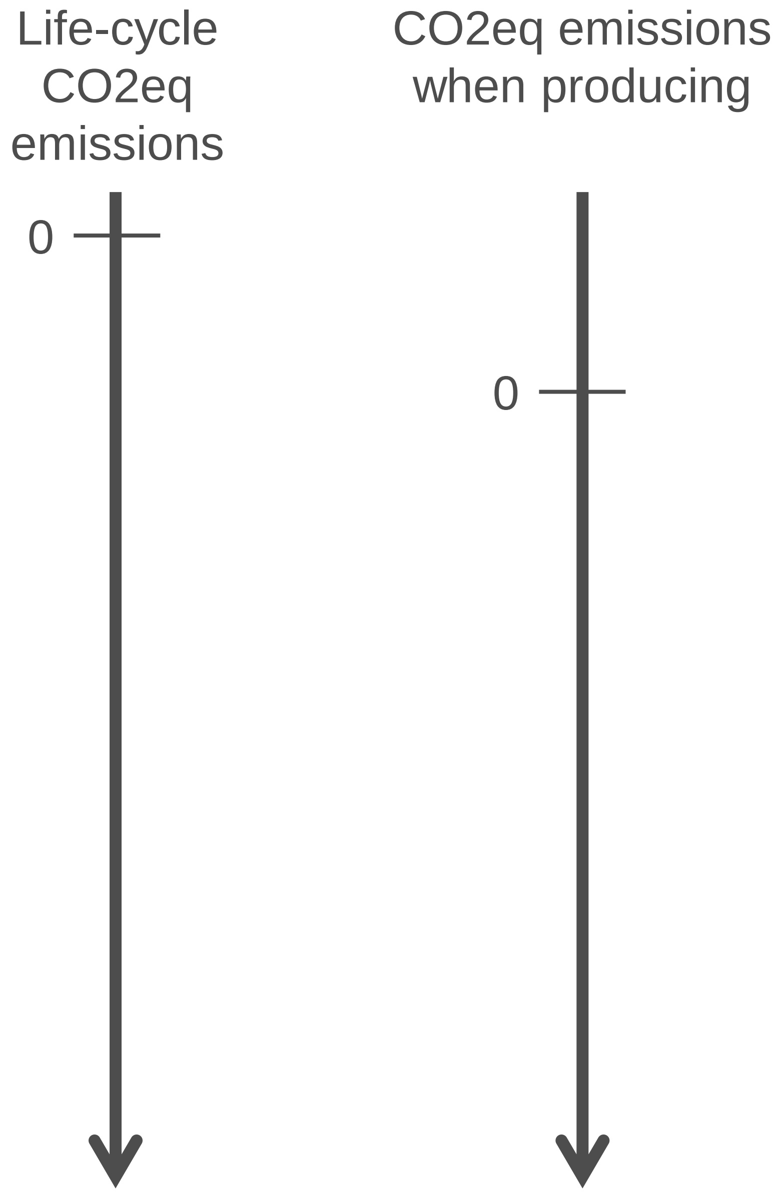
A macro-scale perspective

µg NH3

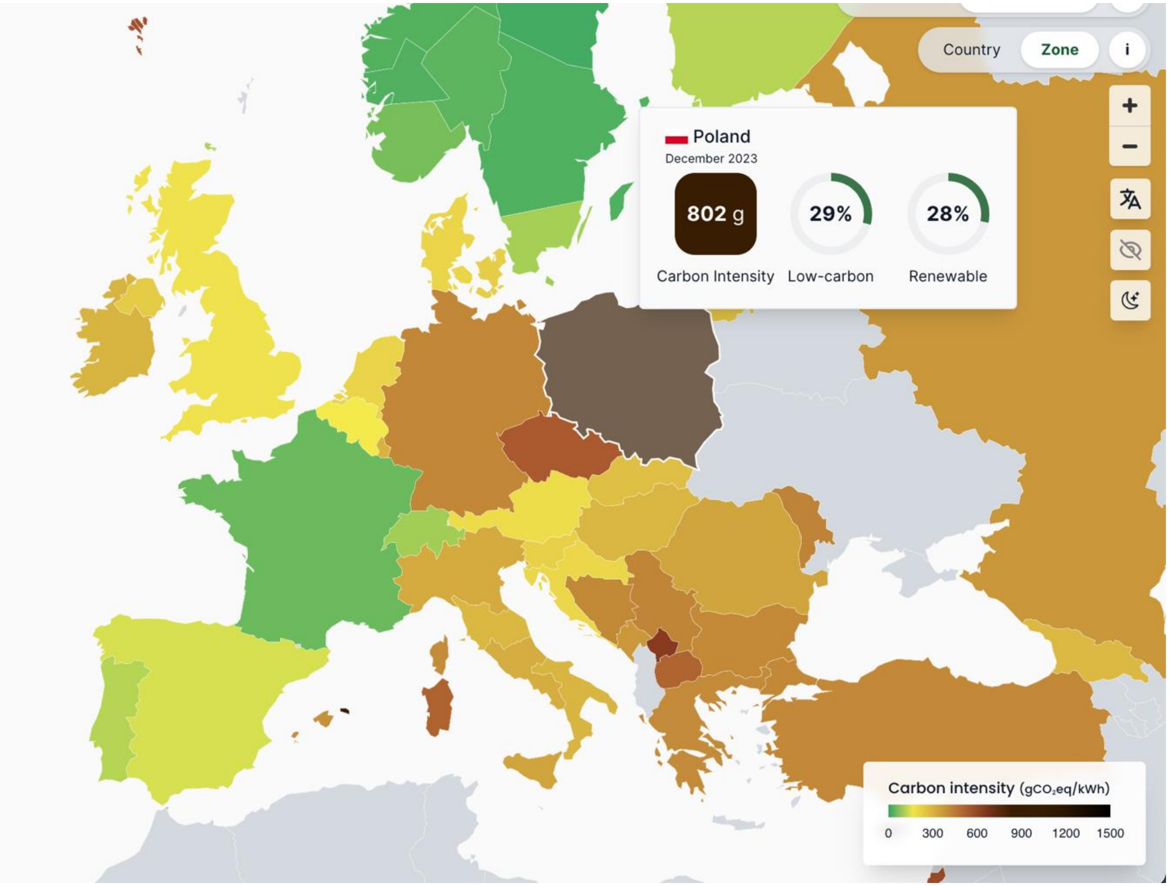
Mt NH3

What is Green Ammonia?

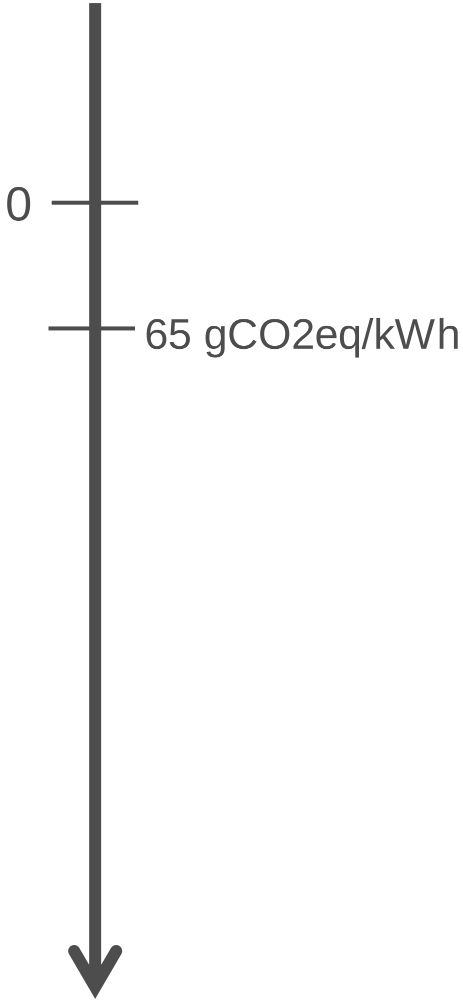
Matching technical and regulatory definition

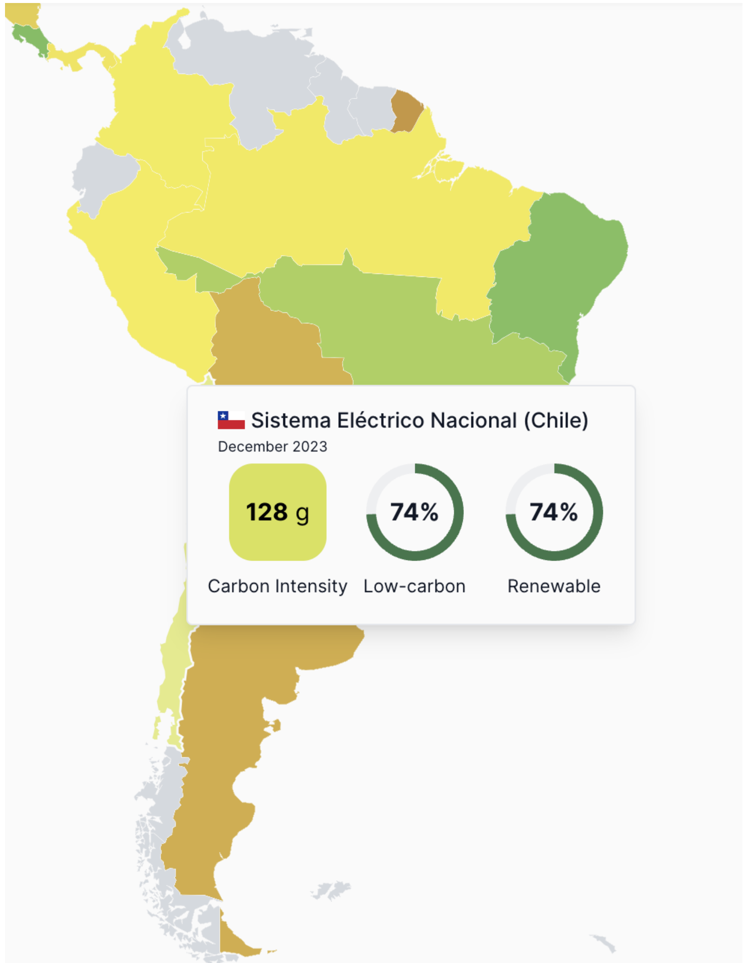

Life-cycle CO2eq emissions
CO2eq emissions when producing
0
0

CO2eq emissions when producing

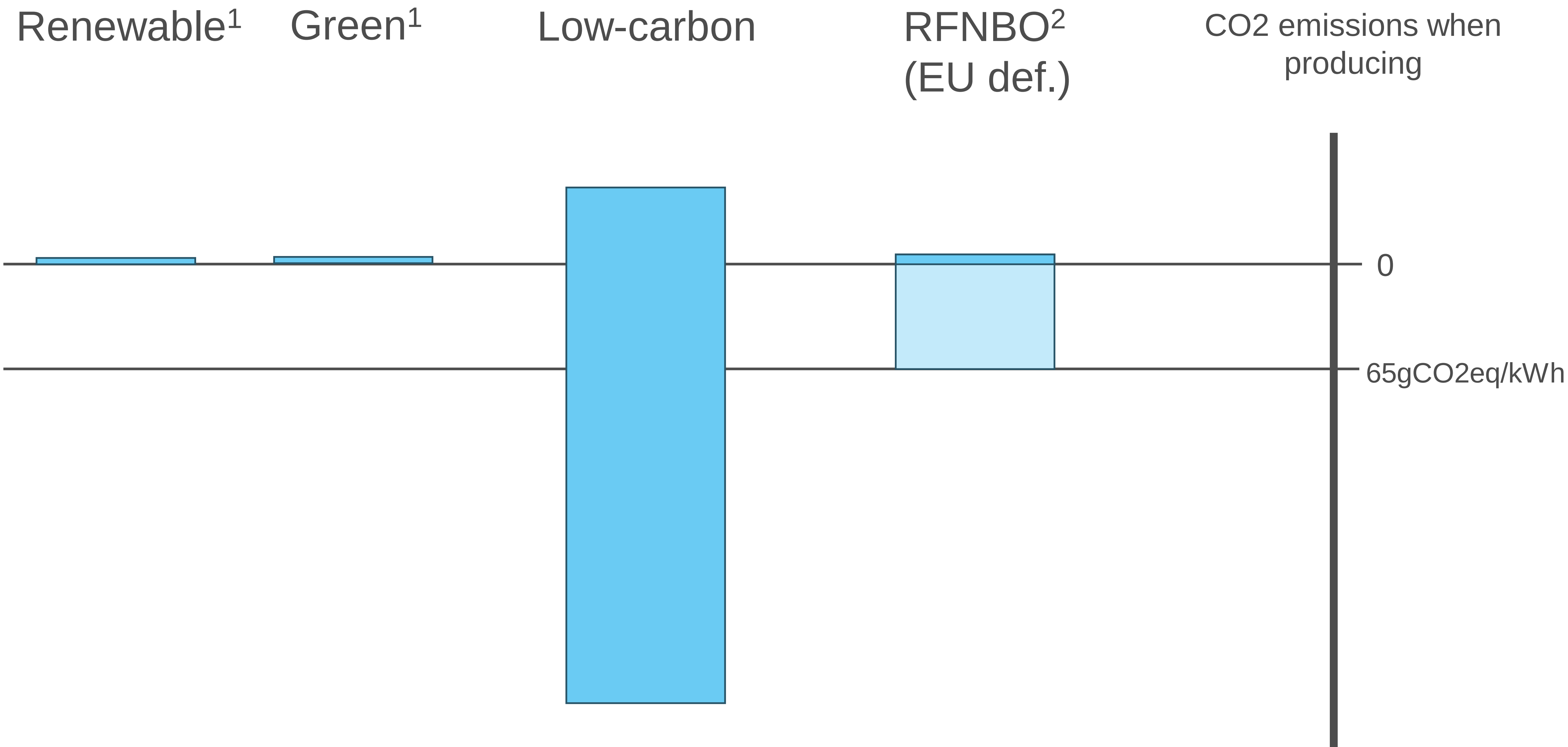


Emissions intensity in the last 12 months
https://app.electricitymaps.com/map





Emissions intensity in the last 12 months
https://app.electricitymaps.com/map



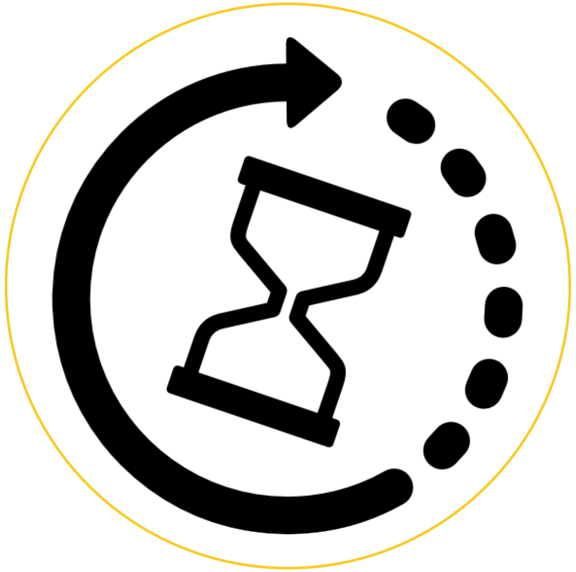
[1] if “renewable” electricity is used (wind, solar, hydro). It excludes nuclear

[2] RFNBO = Renewable Fuel from Non-biological Origen

Three pillars for the definition of “renewable” fuel

Additionality

The electricity needed for ammonia production is generated exclusively from renewable sources



Hourly matching

The electricity generated during a specific hour by renewable resources dedicated to ammonia production.

Geographic correlation

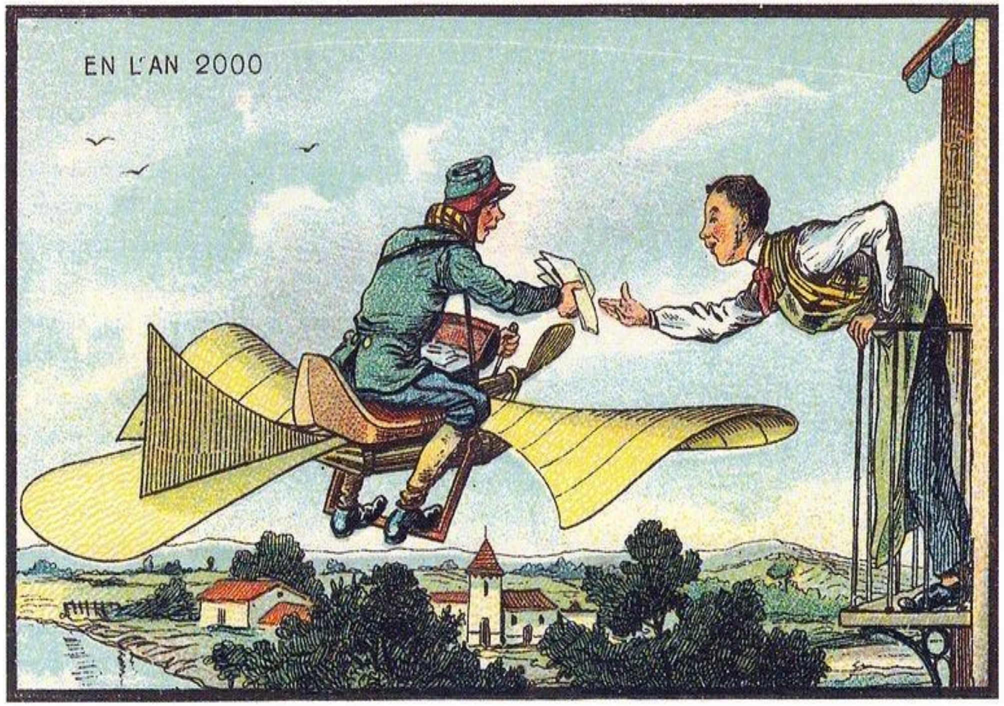
The electricity must be generated in close proximity to the green ammonia facility.

When is “Green” Ammonia/Fuel considered fully renewable?

Off-grid operation	Grid-connected operation		
Direct connection of H2/NH3 generation and electricity generation installation / production within the same installation. No grid connection / proof of no use of grid electricity for production.	**>90% rule** Bidding zone >90% RE share Specifically identified share determines the number of annual operating hours	**Low-carbon bidding zone** < 18g CO2/MJ RE-PPA needed Hourly Matching Geographical correlation	**General grid electricity** RE-PPA needed Additionality Hourly Matching Geographical correlation

A model for computing the LCOA

Predicting the future … is difficult



The Rural Postman

I think there is a world market for maybe five computers, 1943

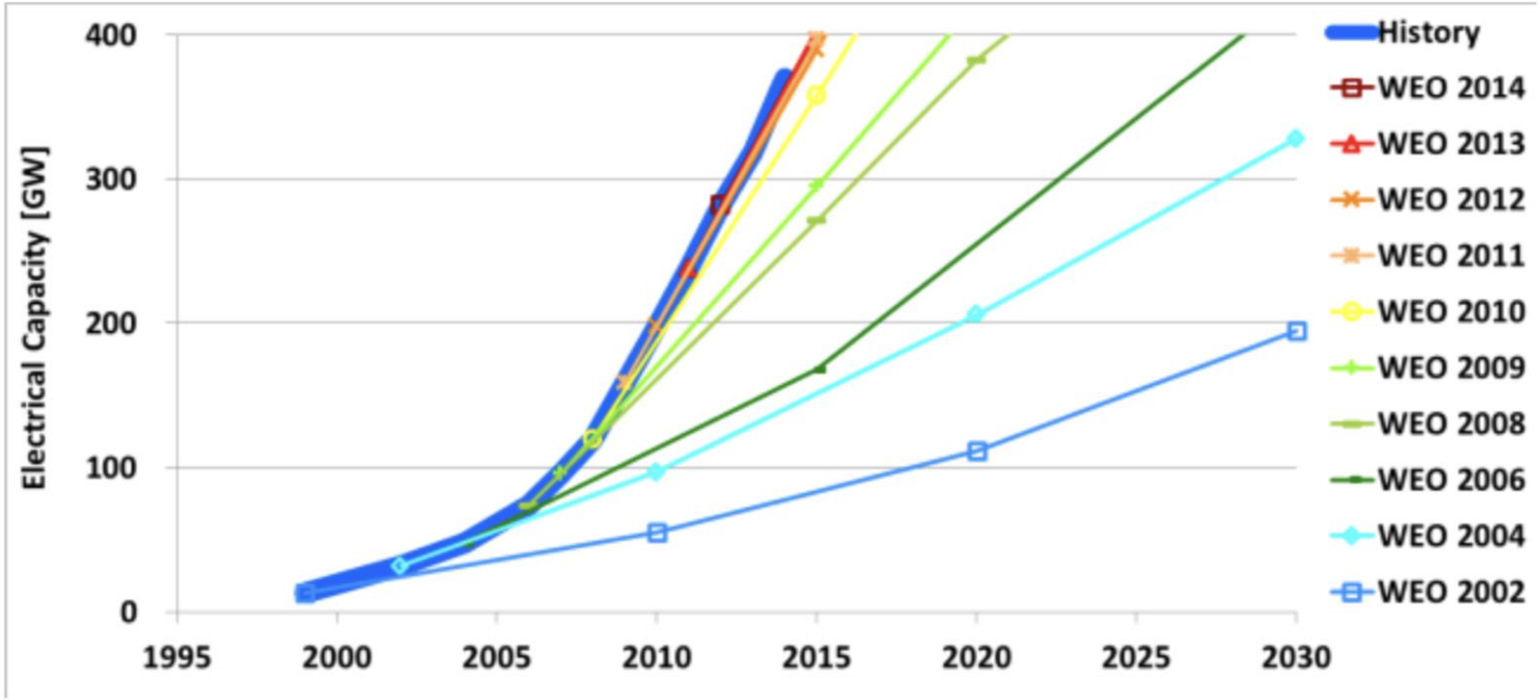
*Thomas Watson, **chairman** of IBM,*

There is no reason anyone would want a computer in their home, 1977

*Ken Olson, **president**, chairman and founder of Digital Equipment Corp. (Compaq)*

European Commission

Predicting the future … is difficult

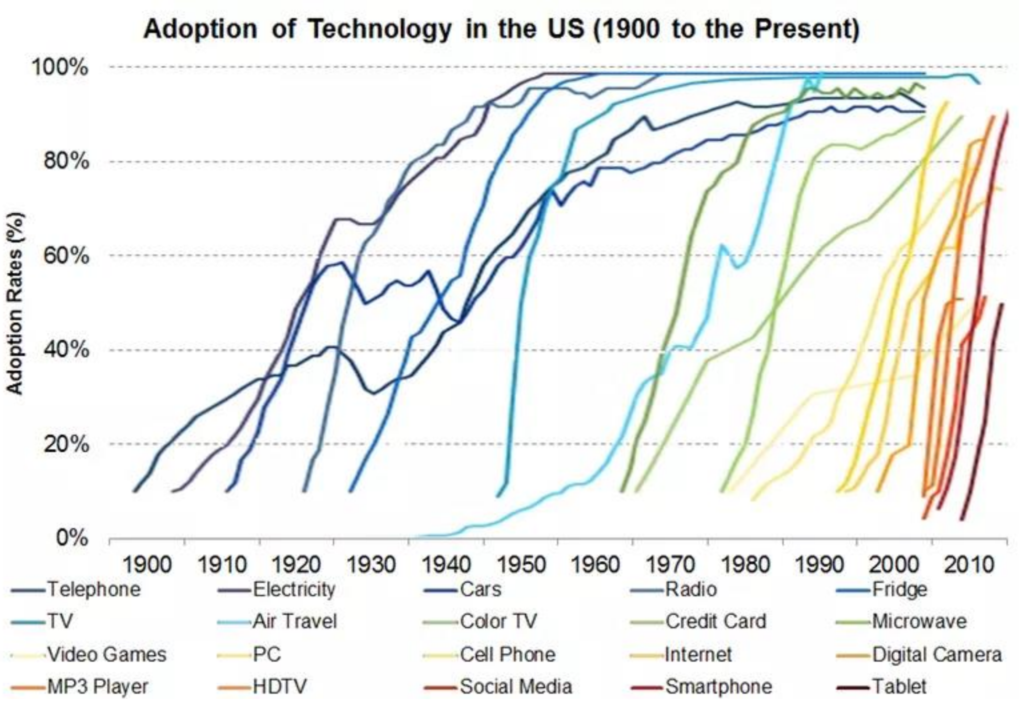


Wind generation capacity investment projection. World Energy Outlook

Technology S-curve

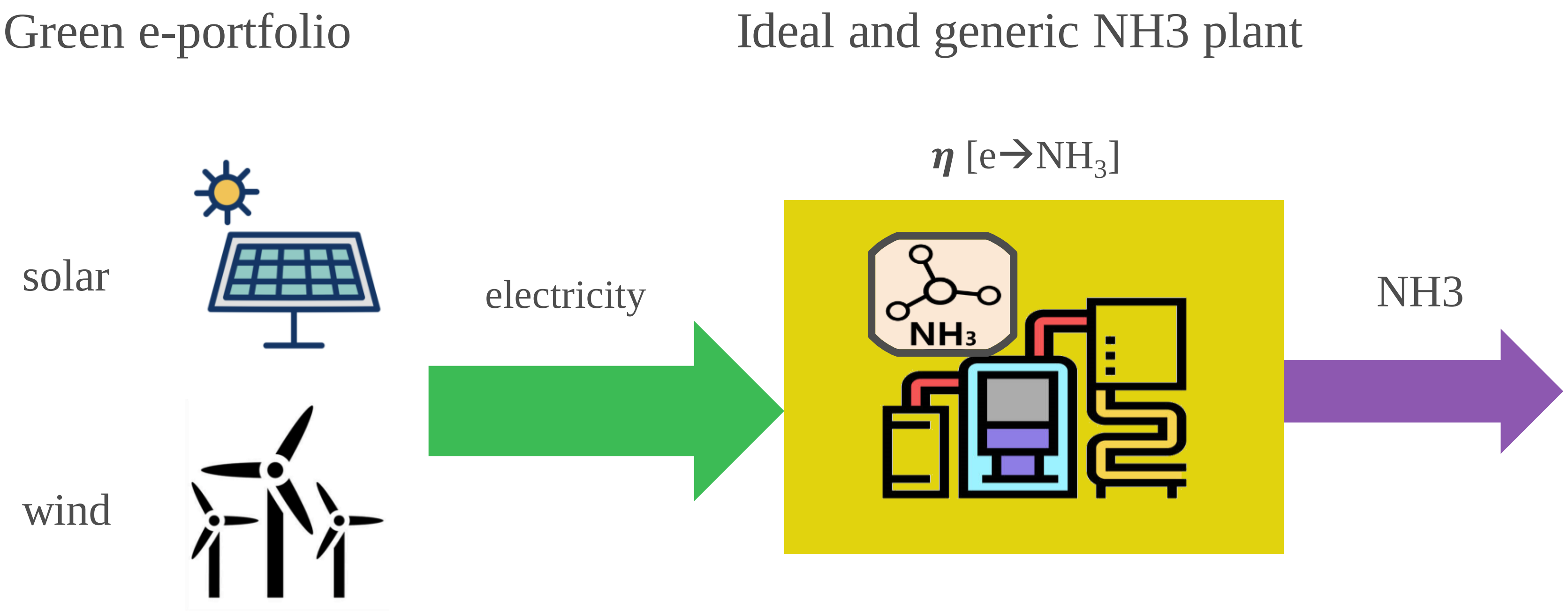
It is difficult to predict the future cost of a technology.

Models supports anything: garbage in, garbage out



… but, we have experiences of may other technologies → S-curve

Generic and ideal green ammonia facility



Generic and ideal green ammonia facility

Key elements:

(a) System-level approach: The emphasis is on evaluating mass and energy balances at the facility level. The model accepts renewable electricity as input and yields ammonia as an output, independent of the specific technologies utilized.

(b) Constant efficiency of transformation: It is expressed in as kg/kWh, indicating the amount of NH3 produced per kWh of electricity consumed.

(c) Absence of ramps: The model allows for the facility to switch from offline to full-capacity production within the temporal resolution of the mathematical model (1 hour).

(d) Modular design and constant capital costs: It is assumed modular construction of any capacity (continuous decision variables).

LCOA

LCOA is calculated in a techno-economic assessment of green ammonia production in an islanded facility, disconnected from the main power grid.

$$\mathrm{LCOA} = \frac{\mathrm{C\&O}^{\mathrm{w}} + \mathrm{C\&O}^{\mathrm{s}} + \mathrm{C\&O}^{\mathrm{NH_3}}}{P^{\mathrm{tot,NH_3}}}$$

LCOA is computed in USD using the reference value of 2023

$$\text{minimize} \quad \left(\text{C\&O}^{\text{w}} + \text{C\&O}^{\text{s}} + \text{C\&O}^{\text{NH}_3} + \Gamma\right)$$

subject to:

Cost terms definition

$$\text{C\&O}^{\text{w}} = \left(c^{\text{inv,w}} + c^{\text{ope,w}}\right)\overline{P}^{\text{w}}$$

$$\text{C\&O}^{\text{s}} = \left(c^{\text{inv,s}} + c^{\text{ope,s}}\right)\overline{P}^{\text{s}}$$

$$\text{C\&O}^{\text{NH}_3} = \left(c^{\text{inv,NH}_3} + c^{\text{ope,NH}_3}\right)\overline{P}^{\text{NH}_3}$$

$$\Gamma = \frac{1}{|\Omega|}\sum_{\omega=1}^{|\Omega|}\sum_{t=1}^{8760} c^{\text{curt}}\rho^{\text{s}}(\omega) + \rho^{\text{w}}(\omega)$$

Electricity balance

$$p_t^{\text{e}}(\omega) = p_t^{\text{w}}(\omega) + p_t^{\text{s}}(\omega), \qquad \forall t, \omega$$

$$\rho_t^{\text{w}}(\omega) = \gamma^{\text{w}}(\omega)\overline{P}^{\text{w}} - p_t^{\text{w}}, \qquad \forall t, \omega$$

$$\rho_t^{\text{s}}(\omega) = \gamma^{\text{s}}(\omega)\overline{P}^{\text{s}} - p_t^{\text{s}}, \qquad \forall t, \omega$$

Green ammonia facility

$$p_t^{\text{NH}_3}(\omega) = \eta^{\text{e}\rightarrow\text{NH}_3} p_t^{\text{e}}(\omega), \qquad \forall t, \omega$$

$$p_t^{\text{NH}_3}(\omega) \leq \overline{P}^{\text{NH}_3}, \qquad \forall t, \omega$$

$$P^{\text{tot,NH}_3} = \frac{1}{|\Omega|}\sum_{\omega=1}^{|\Omega|}\sum_{t=1}^{8760} p_t^{\text{NH}_3}(\omega)$$

The temporal resolution is one hour, so the LP model consists of 8760 periods, representing a full year of operation.

Year 2050, as a reference.

We use climate scenarios indexed by ω, for representing wind and solar availability according to historical data.

This model is run for 1 locations. This location is connected with solar and wind availability.

This model is run several times, for each location.

We establish an expected annual NH3 production target of 1 million tons.

Numerical Analysis

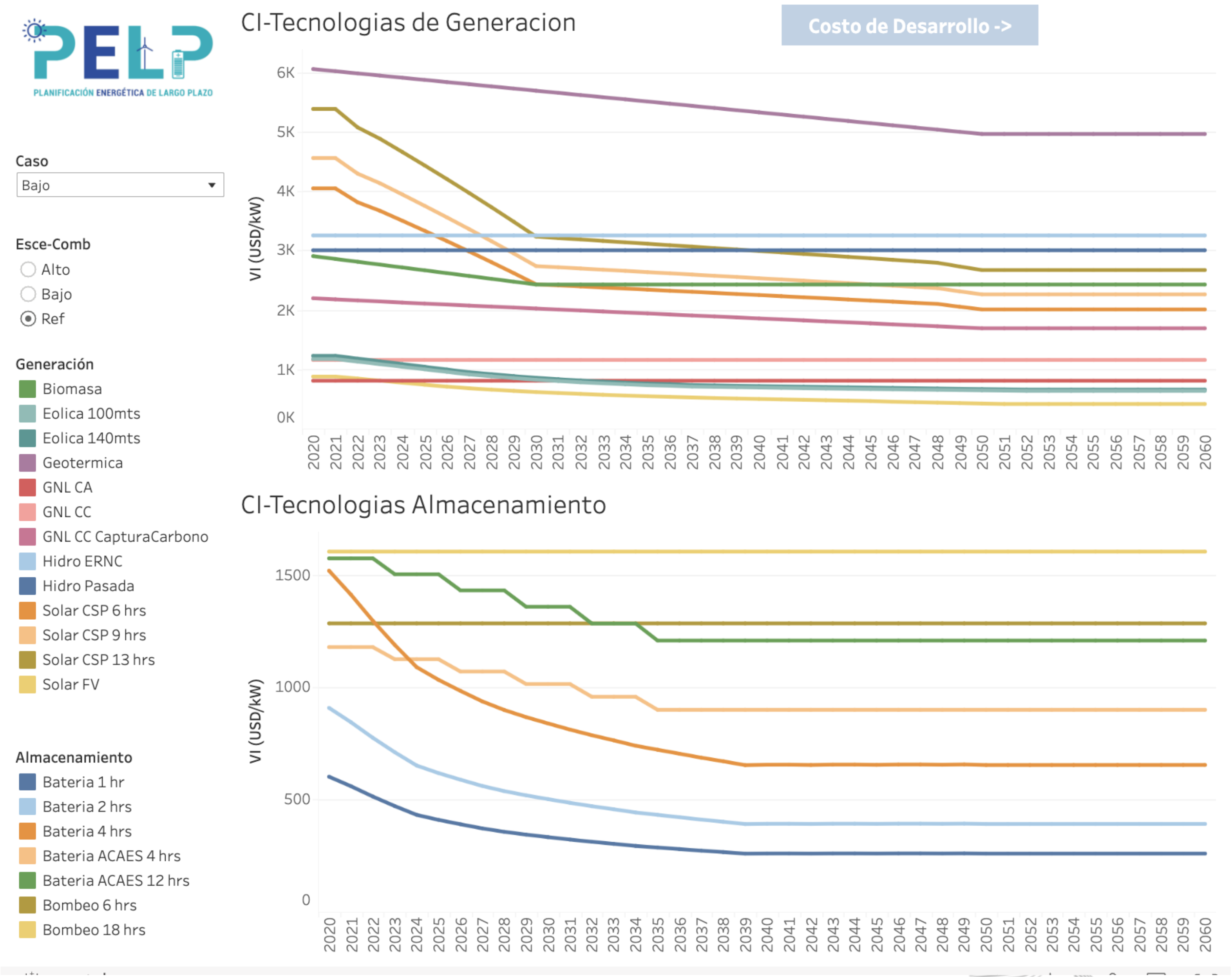
Simulation setup

- Green ammonia production in Chile, targeting the year 2050
- 24 selected locations
- 3 technology costs according to the Chilean Long Term Energy Planning (PELP from the Spanish): Low, Ref, and High.
- Sensitivity analysis, examining the impact of changes in the capital cost of the ammonia facility and the efficiency of the ammonia production process.

CAPEX

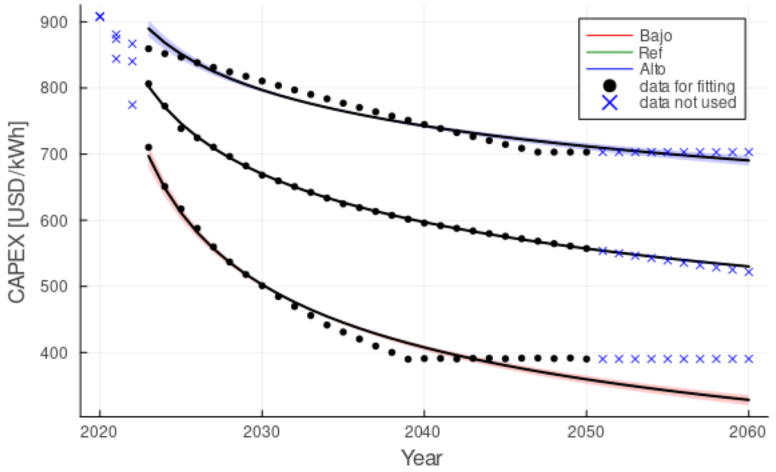
CAPEX Solar =
PELP scenarios “Solar FV”

CAPEX Wind =
PELP scenarios “Eolica 140mts”

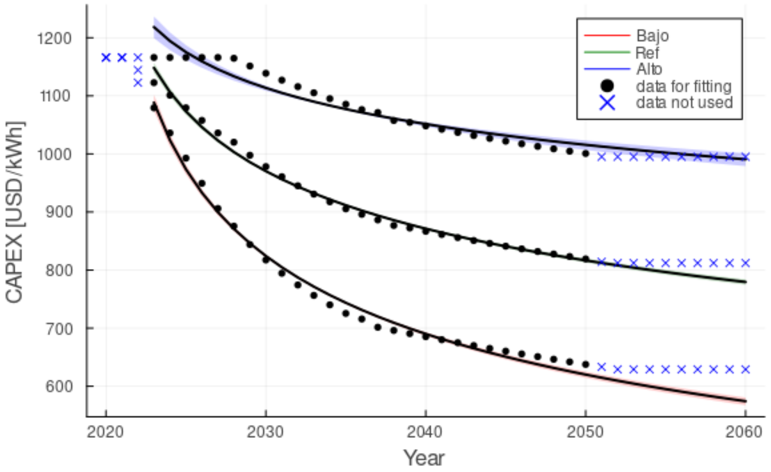


European Commission

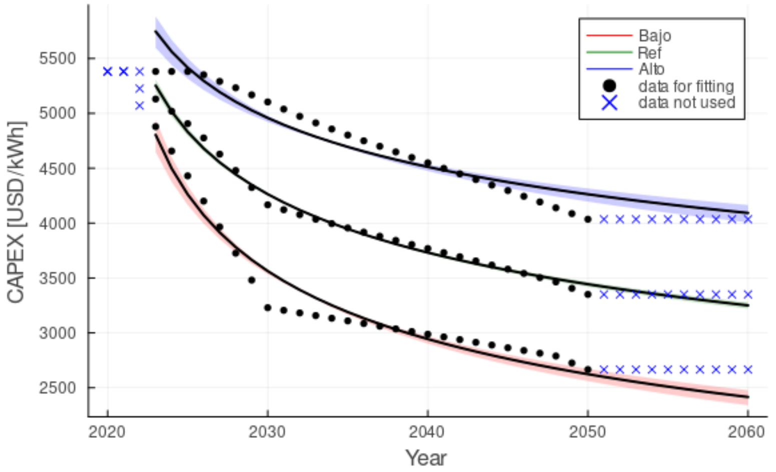
CAPEX for Bateria 2 hrs in USD/kWh



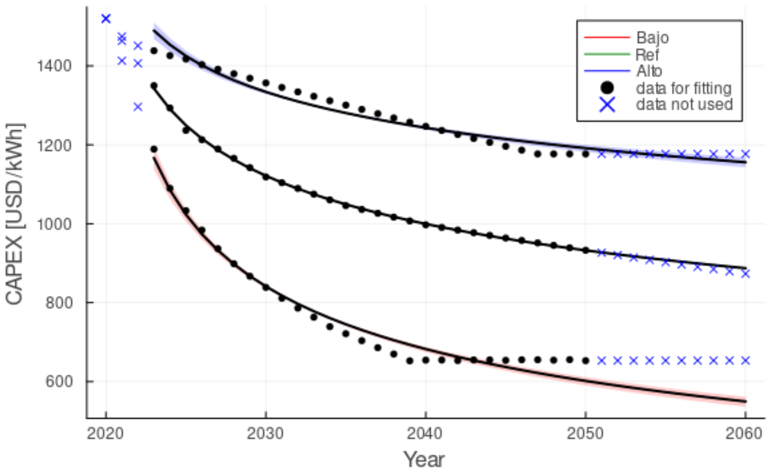
CAPEX for Eolica 100mts in USD/kWh



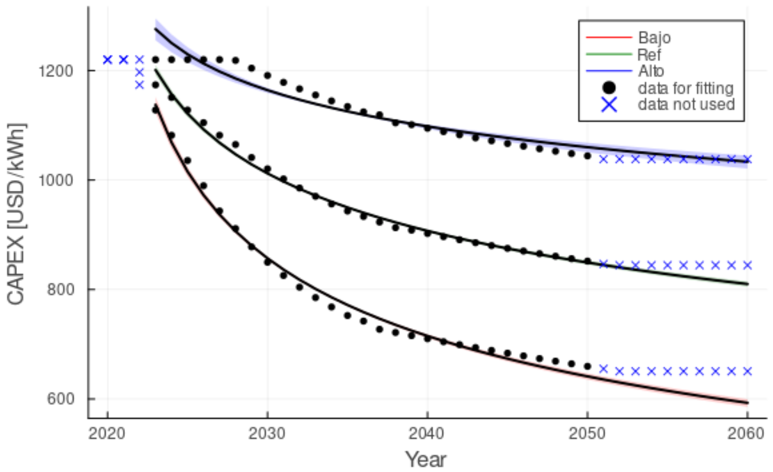
CAPEX for Solar CSP 13 hrs in USD/kWh



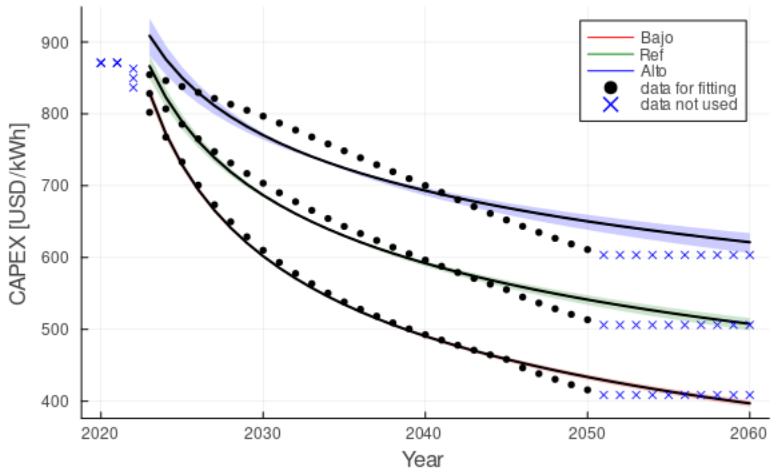
CAPEX for Bateria 4 hrs in USD/kWh



CAPEX for Eolica 140mts in USD/kWh

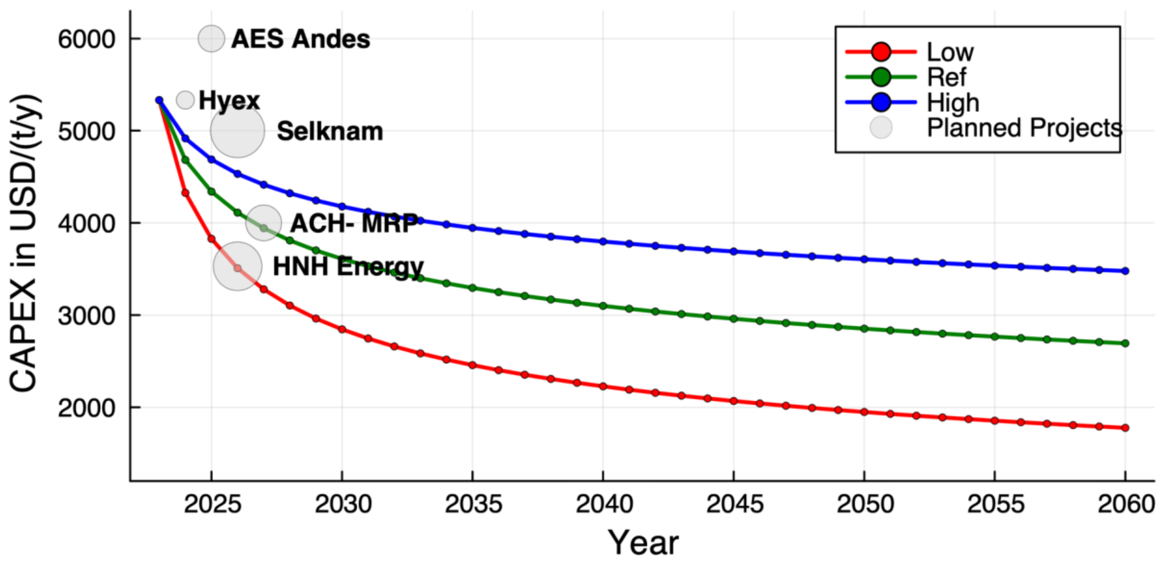


CAPEX for Solar FV in USD/kWh



CAPEX(year,a,b) = a * (year - year0)^log2(b)

CAPEX NH3



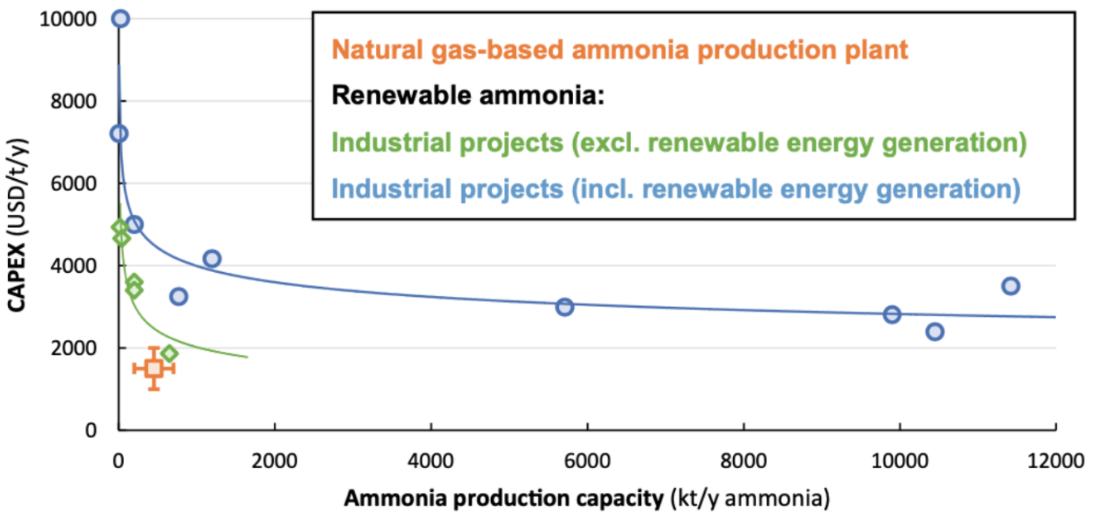
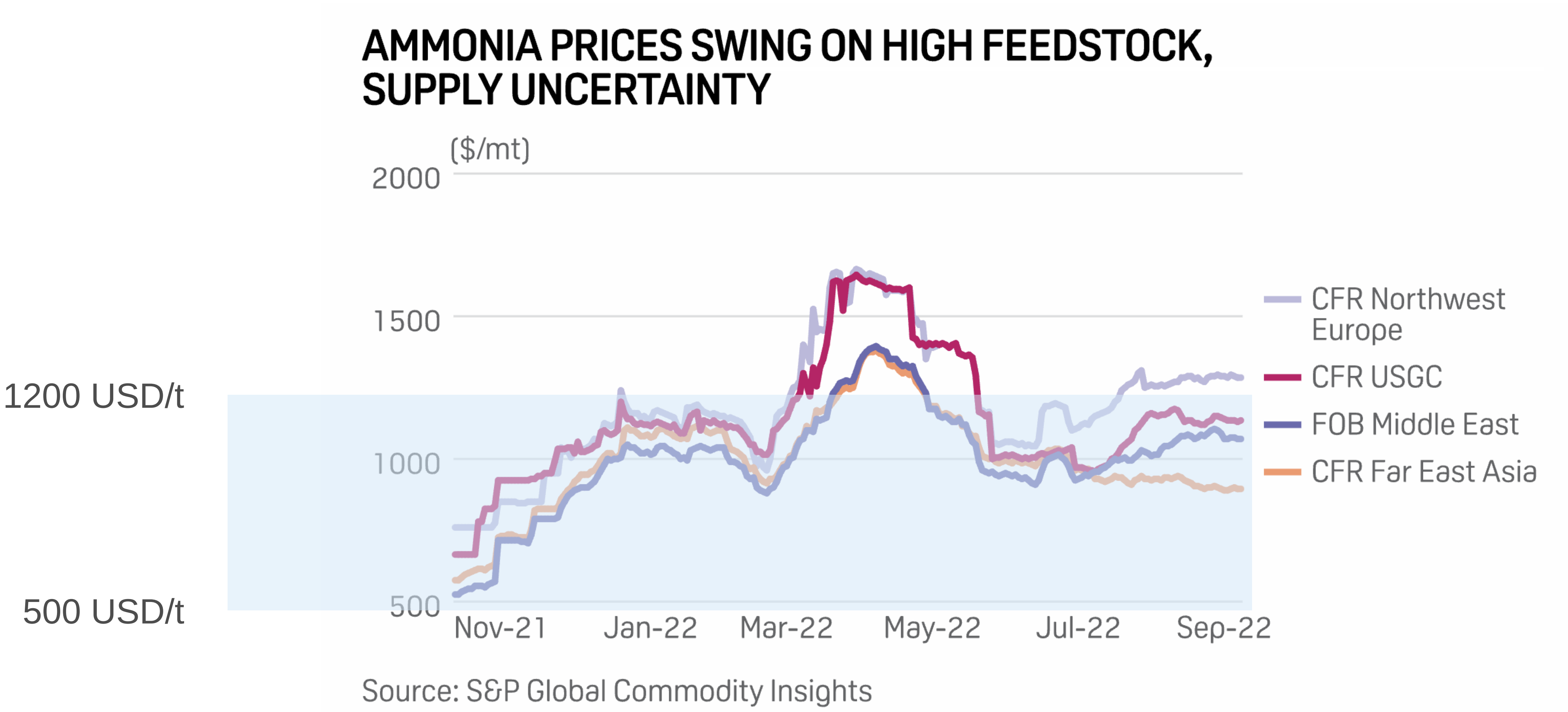


Fig. 47.6 Capital intensity of ammonia synthesis plants versus ammonia production capacity. Adapted and modified from IRENA [2]

IRENA Innovation Outlook Ammonia 2022

NH3 price for benchmark



Other considerations

Curtailment: 25 USD/MWh

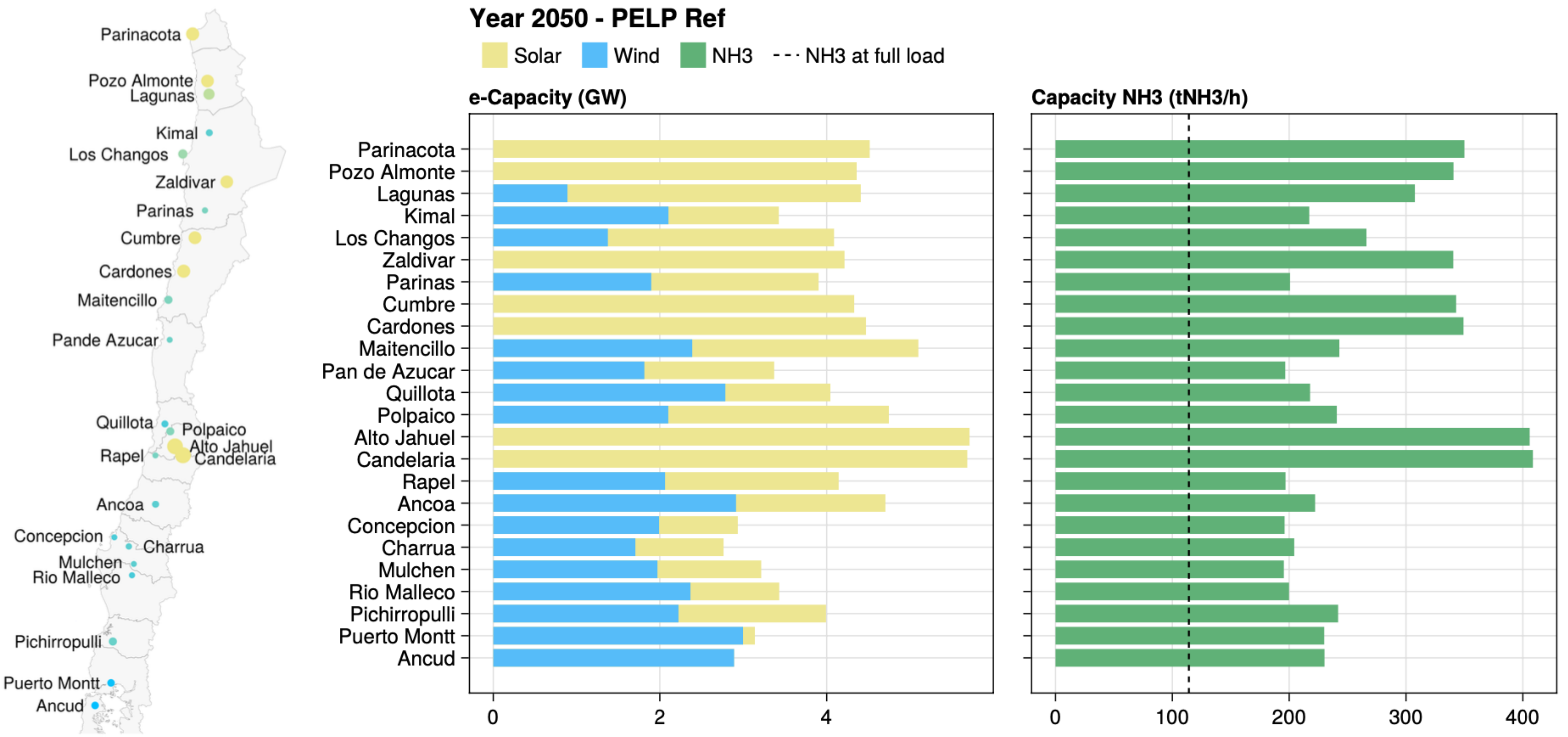
$\eta^{\mathrm{ref}}_{e \rightarrow NH3} = 1/8.3$

Climatic years (scenarios of wind and solar profiles): 2030 to 2040

PELP-ref

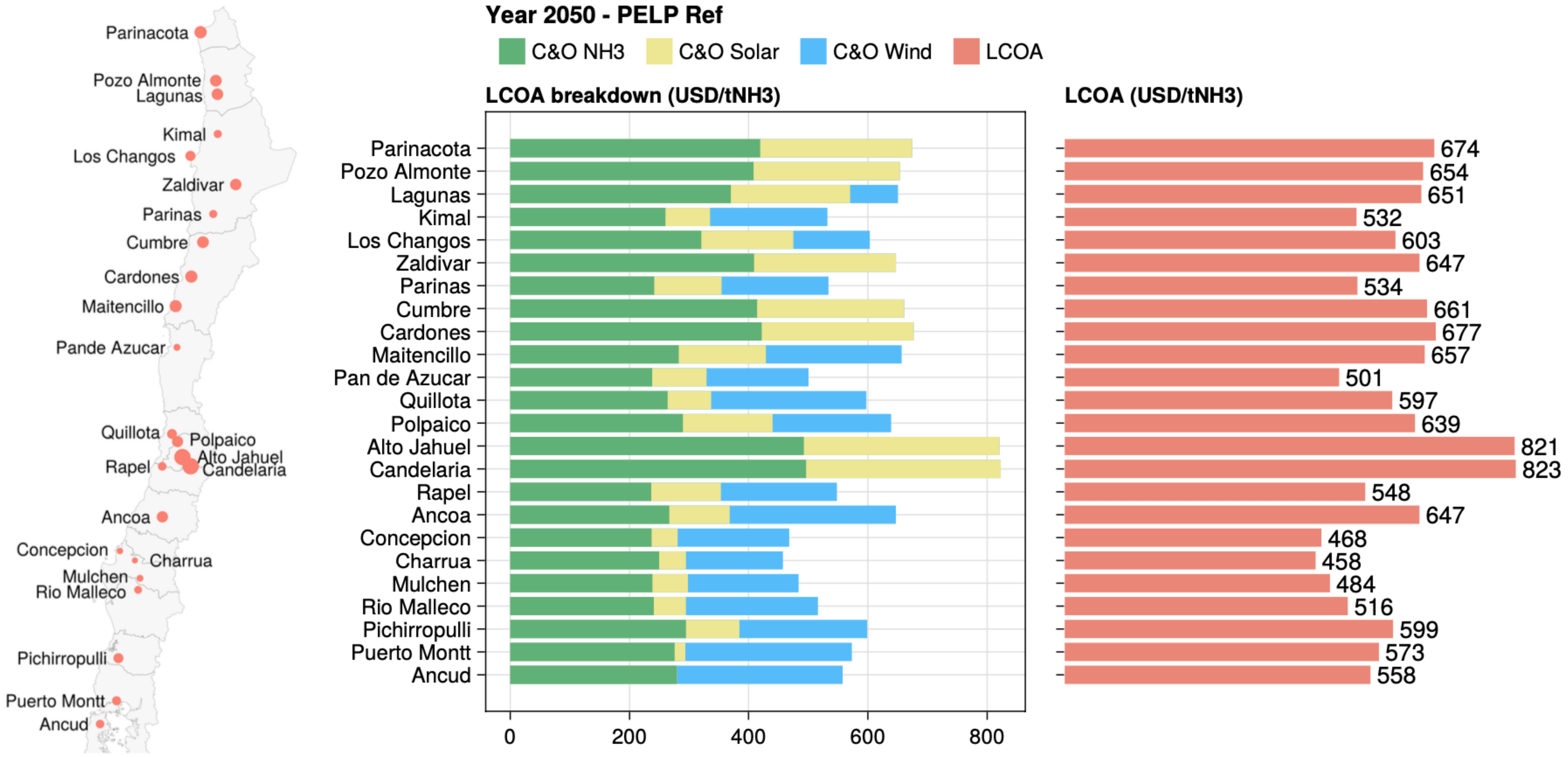
Analysis for 24 location

Total capacity installed by location



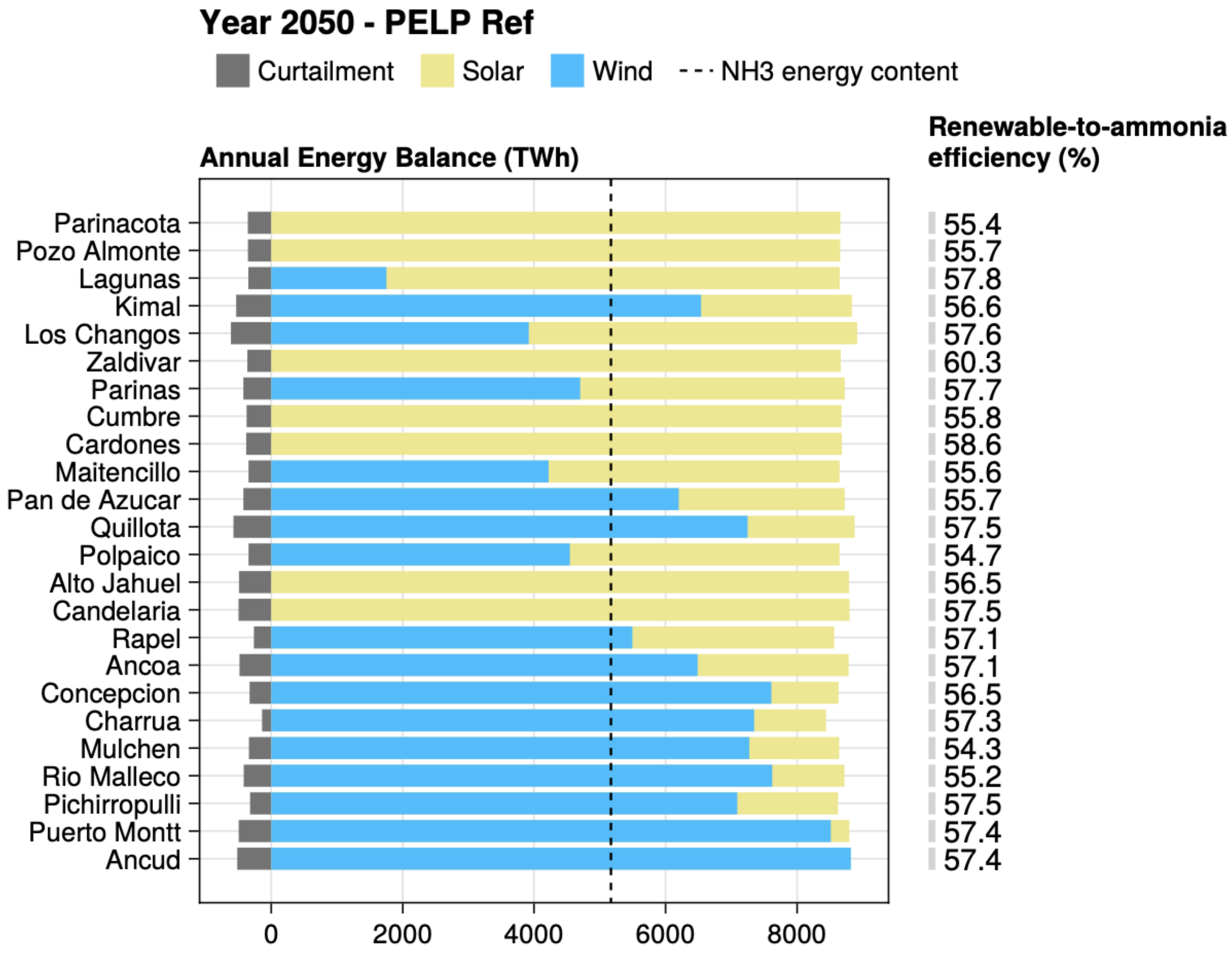
European Commission

LCOA by location



European Commission

Annual energy balance

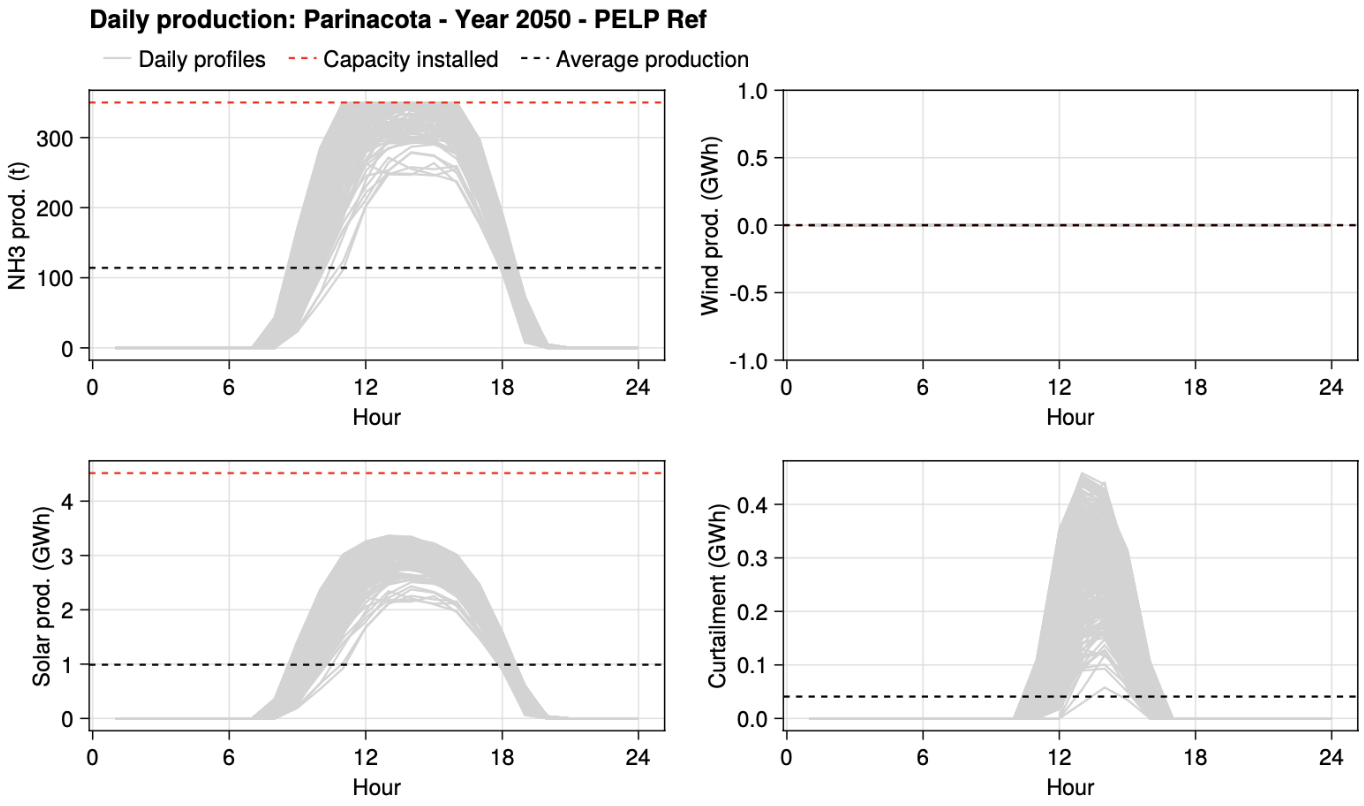


A close look at Parinacota and Charrua locations

PELP-ref

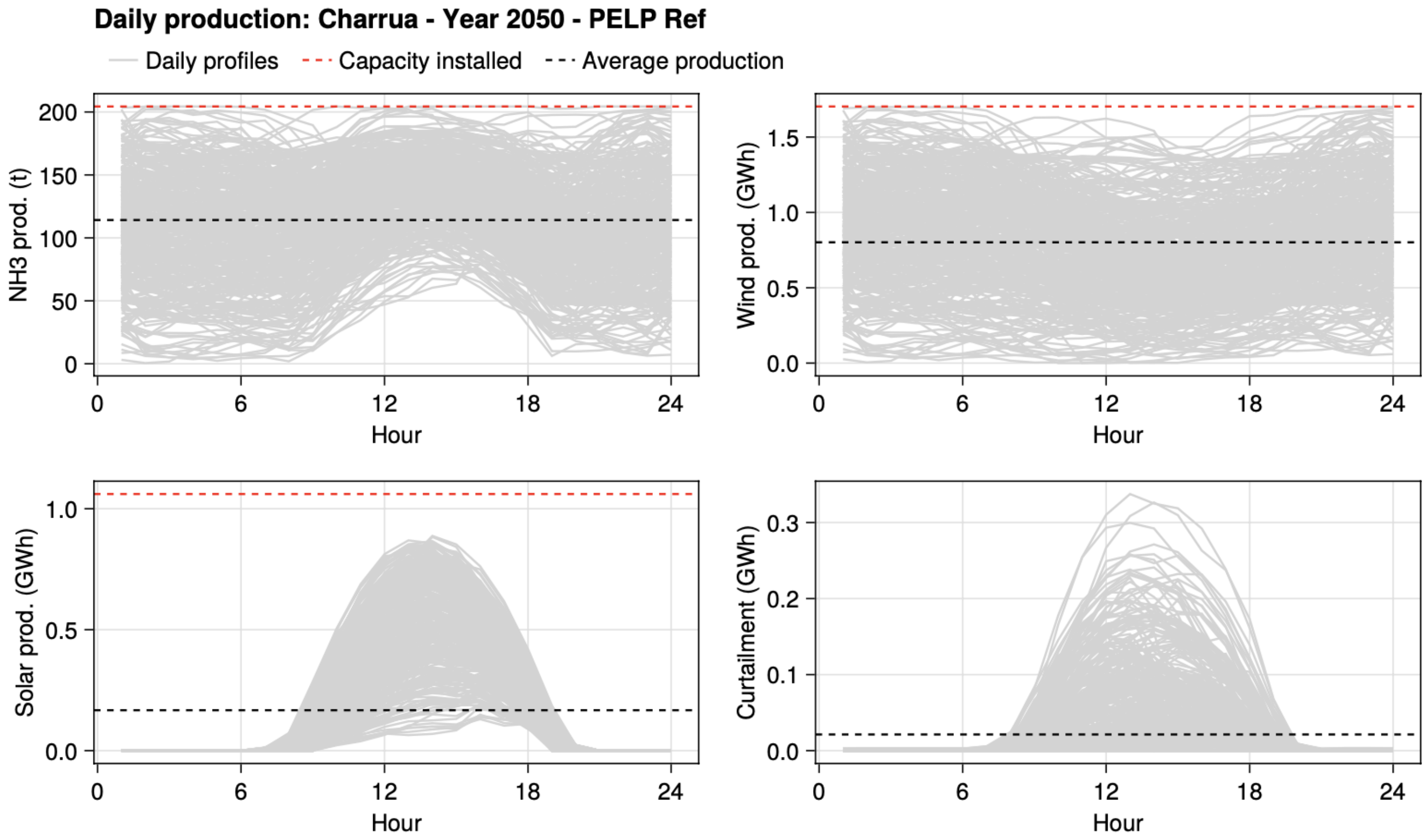
Daily profiles for production of NH3, wind, and solar as well as curtailment

Curtailment is unavoidable

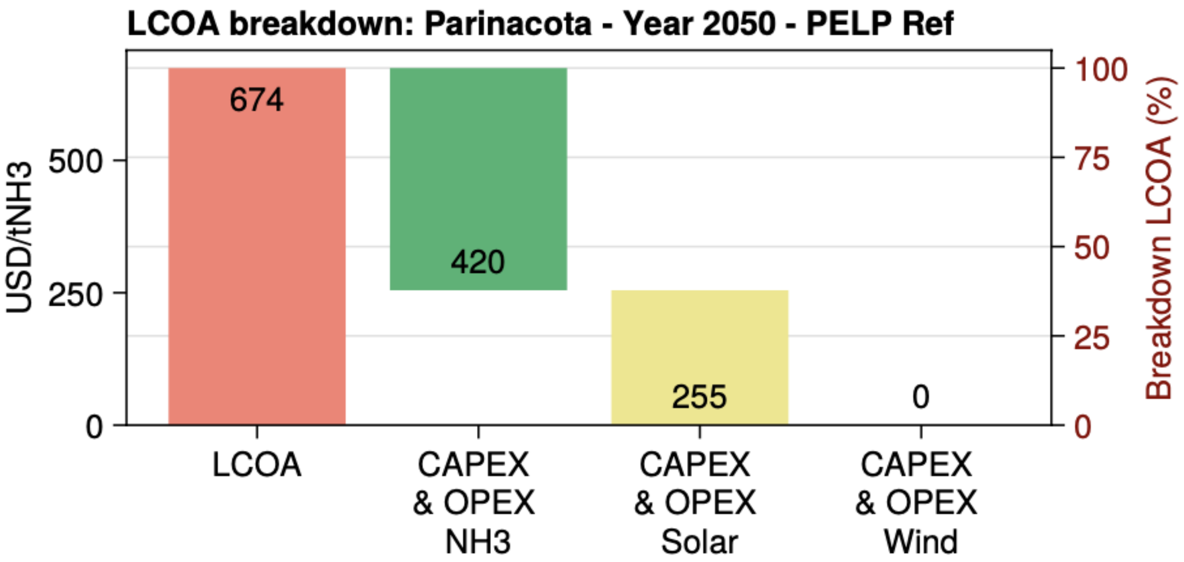


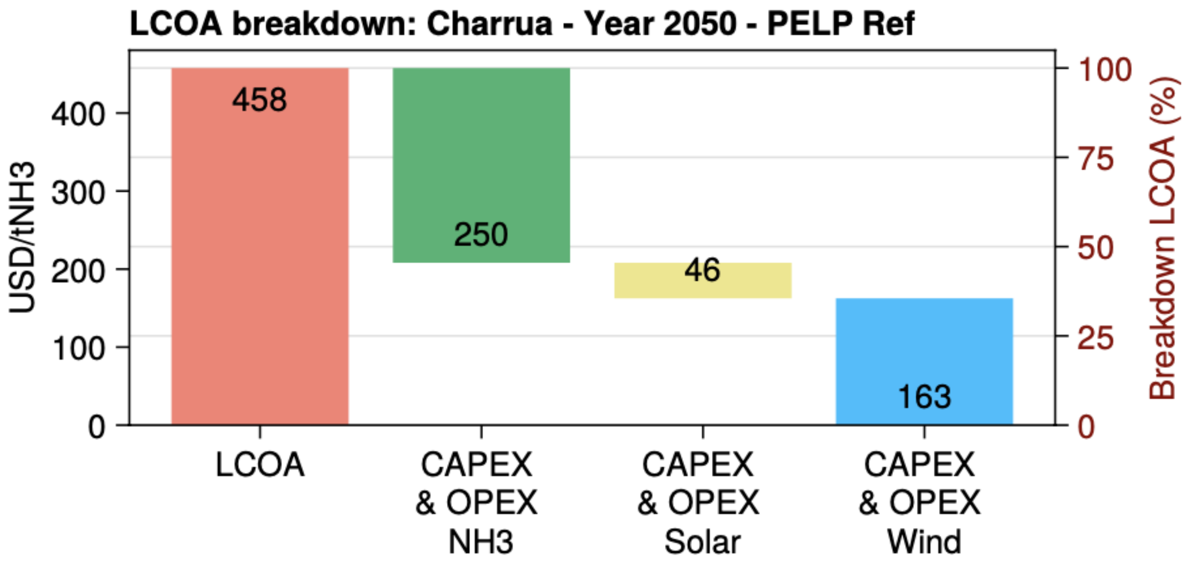
Daily profiles for production of NH3, wind, and solar as well as curtailment

Curtailment is unavoidable



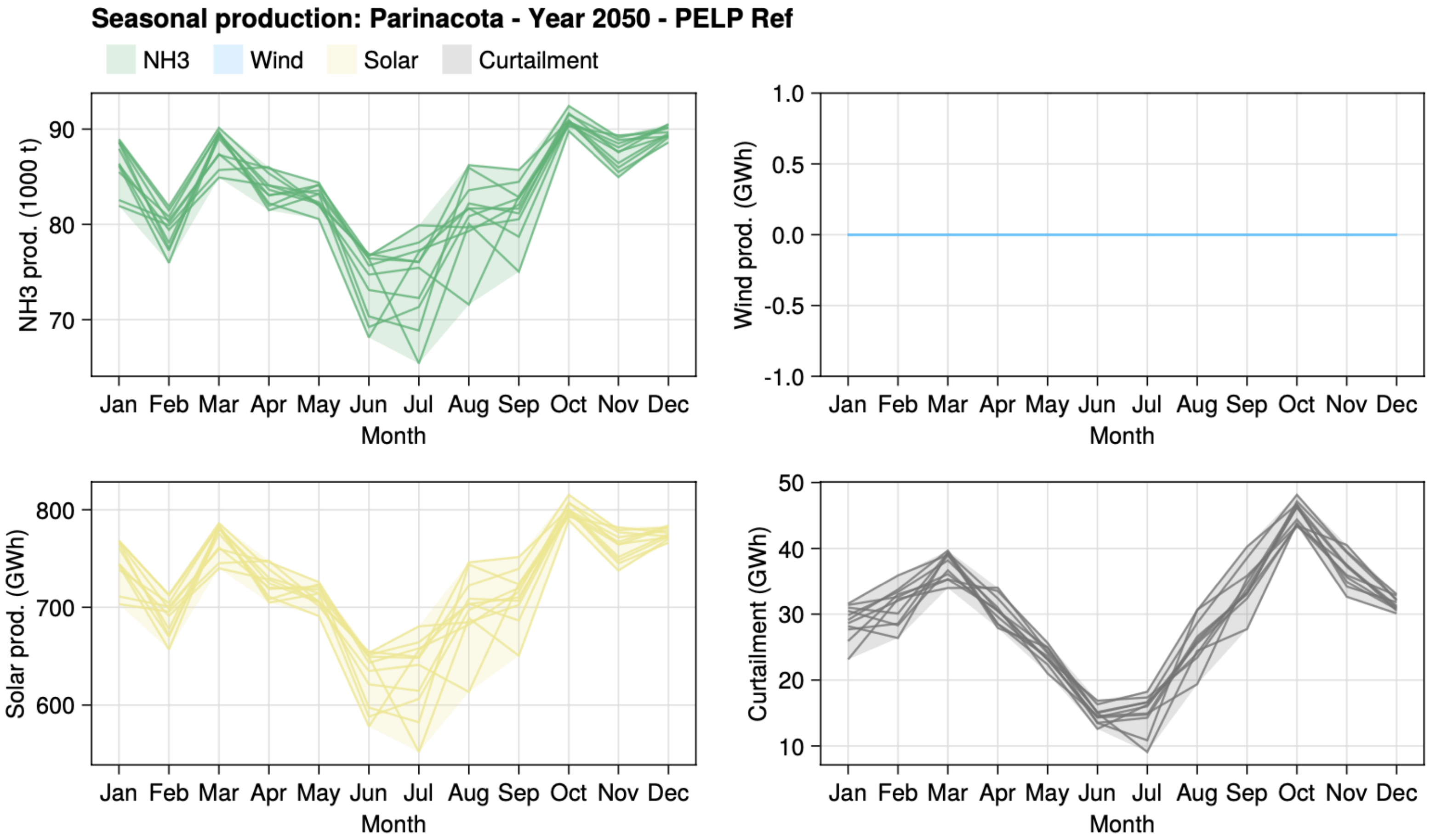
LCOA and its breakdown for Parinacota location (left), and Charrua location (right)



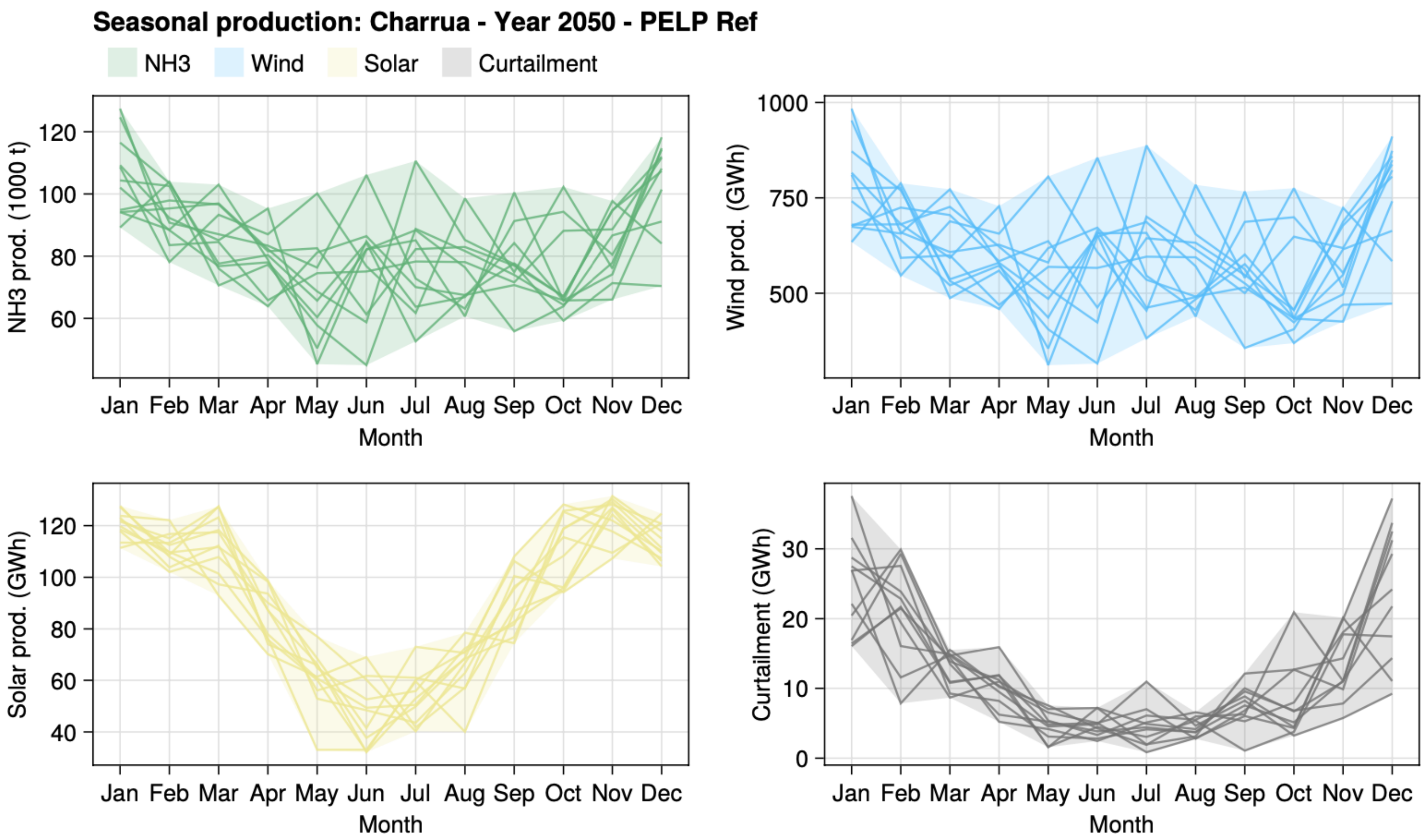


CAPEX & OPEX from NH3 can represents 50-65% of the LCOA

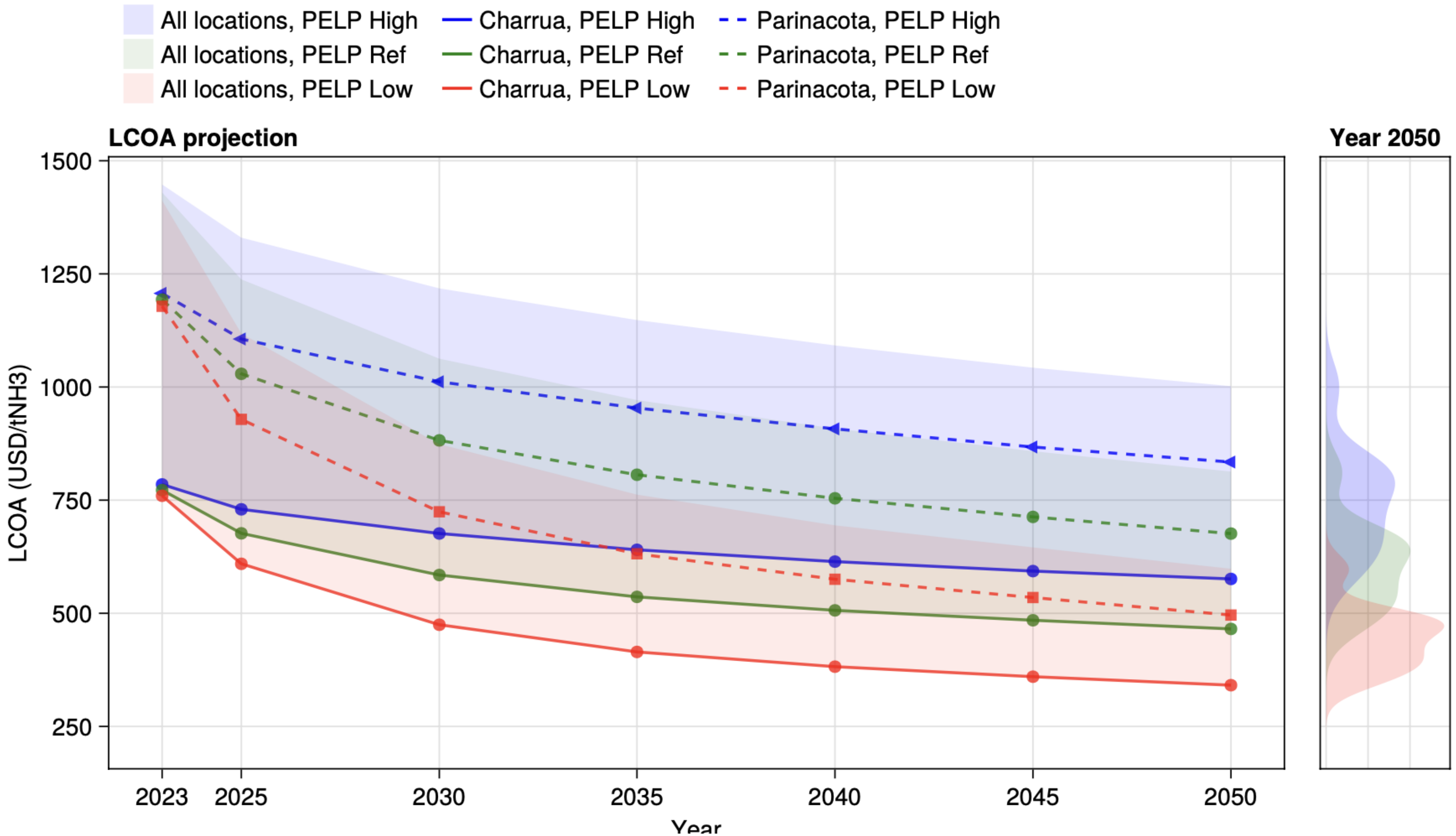
Seasonal profiles for production of NH3, wind, and solar as well as curtailment



Seasonal profiles for production of NH3, wind, and solar as well as curtailment

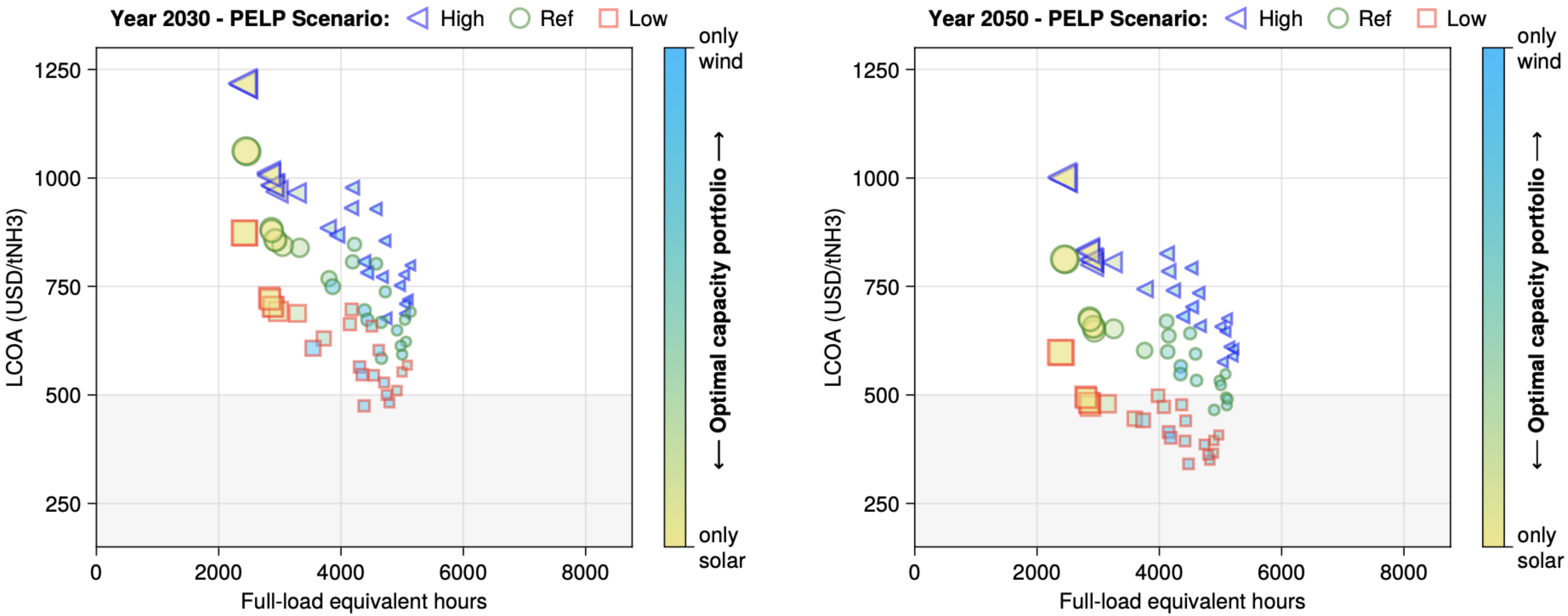


European Commission



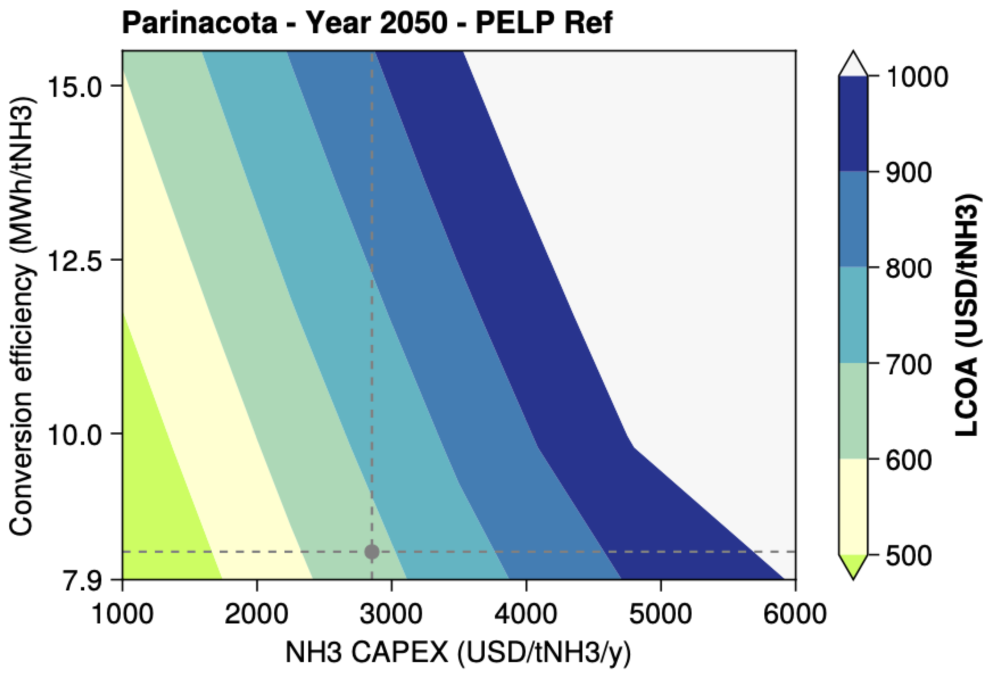
Geographical considerations for technology selection. The North of Chile is not the best location

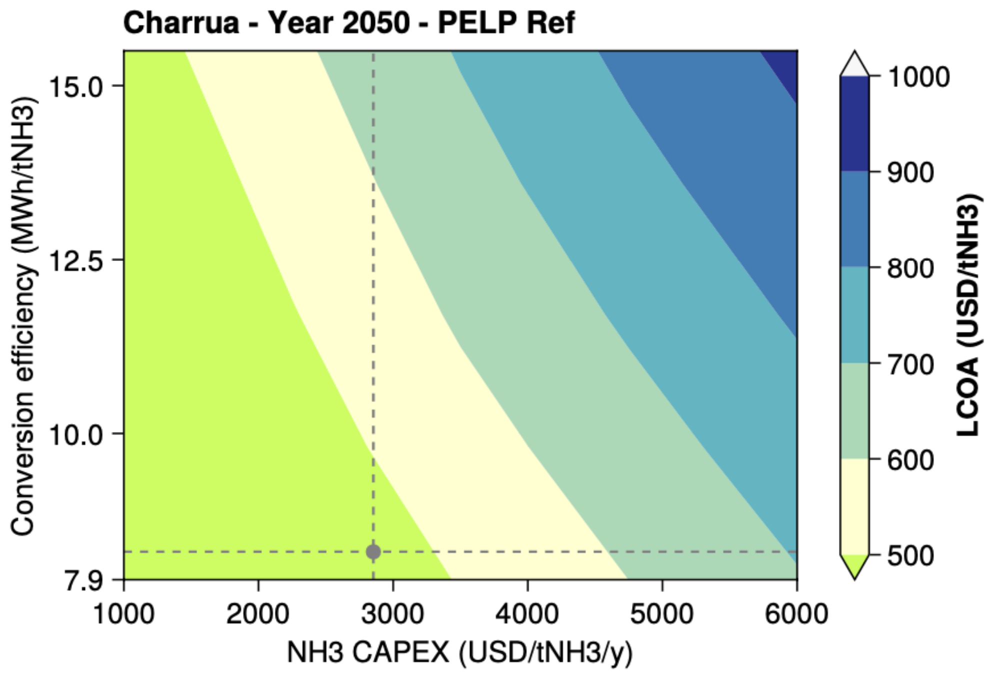
LCOA vs. the equivalent FLH



Inverse relation between LCOA and equivalent full-load hours (FLH).

Sensitivity CAPEX vs conversion efficiency





Sensitivity analysis on efficiencies and CAPEX for Parinacota location (on the left), and Charrua location (on the right). The gray dot is the reference efficiency and CAPEX used in the simulations of the previous subsections. The light green color is used for LCOA below 500 USD/tNH_3.

Conclusions

Conclusions

- Since 2023, there is a first definition of “renewable” ammonia EU regulation.
- We have proposed a stochastic LP model for computing the LCOA of a green ammonia production facility.
- The model is agnostic to the technology used for producing green ammonia: system level approach.
- Application is done for Chilean case, year 2050.
- Several conclusions are derived from the analysis.

Conclusions

1) Projects in the **north** of Chile exhibit superior performance using solar technology due to abundant sunlight. Conversely, the **southern** regions, exposed to stronger and more consistent winds, benefit more from wind technology.

2) Despite excellent solar production conditions in the north, **solar-only projects do not always yield the best outcomes**.

3) The optimal capacity of an ammonia plant, as determined by our analysis, is 2 to 3 times larger than a plant that operates at full load for 8760 hours annually

4) As FLH hours increase, the ammonia plant size can be reduced, leading to a corresponding decrease in LCOA.

Conclusions

5) **The C&O for the ammonia** plant consistently forms a substantial portion of the overall LCOA, always constituting more than 50%.

6) **Unavoidable curtailment.**

7) Rollout depending on the CAPEX vs conversion efficiency

Future

Layout of ammonia facility (storage + production)

Thank you
and keep in touch

EU Science Hub
Joint-research-centre.ec.europa.eu

European Commission