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Evaluating key early-stage tradeoffs in production of green ammonia

First Latam Meeting on Green Ammonia and Power-to-X

11.01.2024

Tomás Meyer Muñoz
tfmeyer@inodu.com

Prepared for:

IST LATAM MEETING ON GREEN AMMONIA AND POWER-to-X

Capabilities & clients

Inodú is focused on providing services related to:

- ✓ Electricity markets & regulation
- ✓ Energy market intelligence
- ✓ Energy data and analytics
- ✓ Renewable energy integration, flexibility, energy storage & grid transformation
- ✓ Decarbonization strategy and policy
- ✓ Distributed energy resources & services
- ✓ Green powerfuels
- ✓ Energy, environment & social nexus

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Inodú covers the following energy markets: **U.S., Chile, Perú and Colombia.**

Agenda

1 Approach to site selection & key early-stage tradeoffs

2 Evaluating energy supply for green hydrogen and ammonia production

3 Chilean study case of reliability premium cost dynamics

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1

Approach to site selection & key early-stage tradeoffs

Robust and comprehensive site selection can lead to more competitive green hydrogen and green ammonia projects

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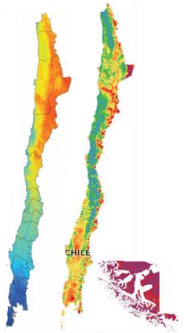
Site selection methodology

Energy sourcing

Analysis of renewable generation hubs

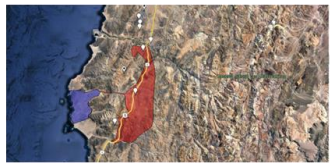


Grid connection or SAPS development

Critical infrastructure

Water sourcing

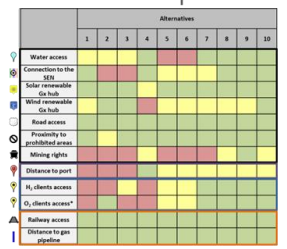
Client analysis



Other infrastructure

Zone analysis

Criteria comparison

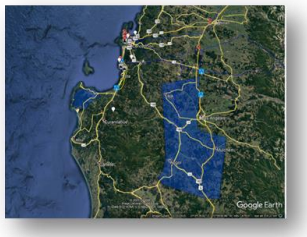


Analysis includes:

- Water sourcing
- Connection to the SEN
- Renewable generation hubs
- Road access
- Proximity to prohibited areas
- Mining rights analysis
- Distance to port
- H2 client access
- H2 derivatives client access
- Railway access
- Distance to gas pipelines
- Others

Selection of sites inside the zones

Site selection



The competitiveness of a green H_2 and derivatives production facility is highly influenced by the capacity to have access to favorable energy resources, to the end consumer and exiting infrastructure, which can lower distribution costs.

When developing a green H_2 and derivatives production facility it is important to evaluate multiple sites in order to have options and select a more competitive project.

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1.1

Supply alternatives for the Power-to-X project

Supply alternatives for a H_2/NH_3 facility

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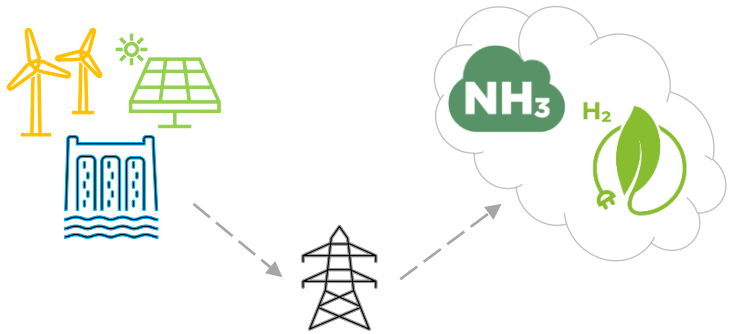
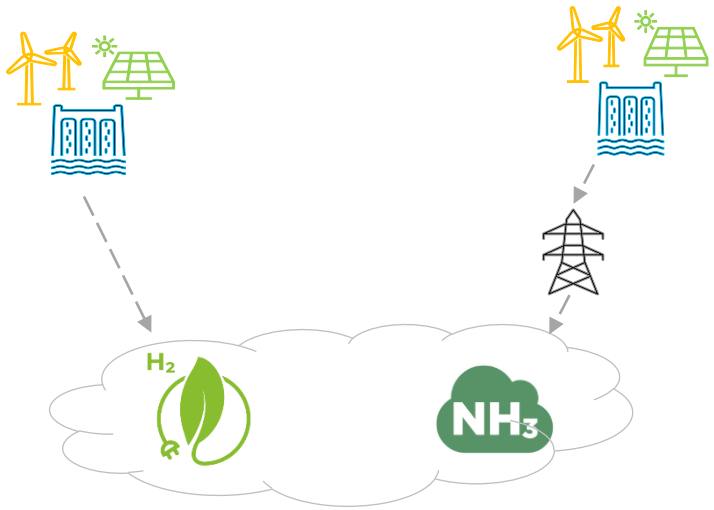
Full On-Grid supply



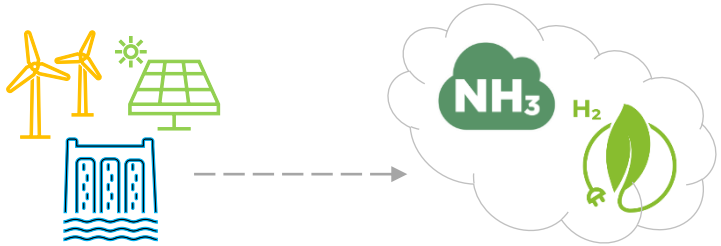
- Grid-connected H_2 plant
- Grid-connected NH_3 plant

Hybrid supply



- H_2 plant connected directly to VRE facility
- Grid-connected NH_3 plant

Full Off-Grid Supply



- H_2 and NH_3 plants connected directly to VRE facility
- Development of a stand-alone power system (SAPS)
- Project exposed to a higher risk in variability of supply
- Energy storage could be considered to firm supply to the H_2/NH_3 plant

Full **on-grid** supply cost breakdown

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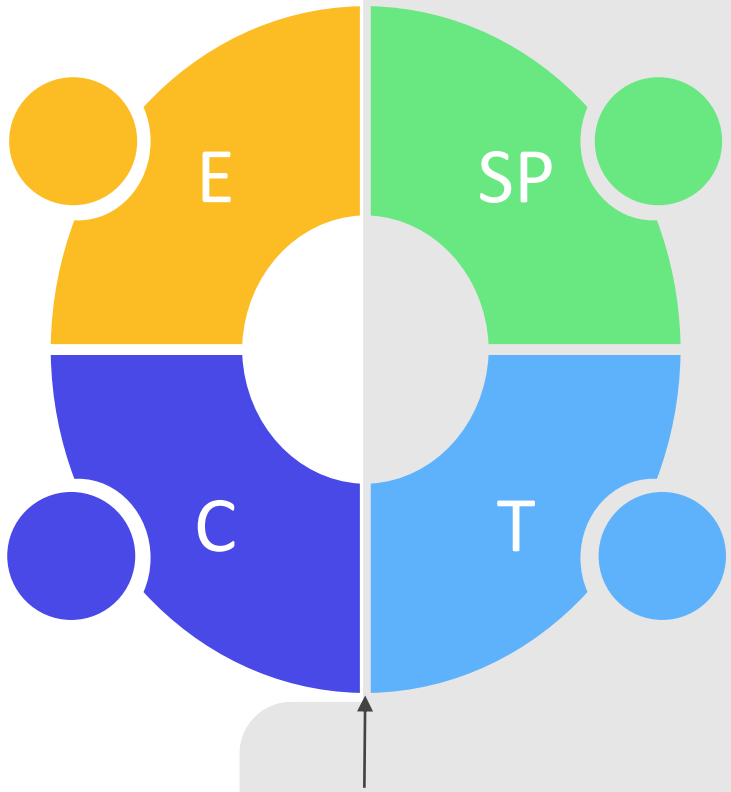
Energy

Is the price the energy consumer pays for each MWh consumed. The energy price can be a function of a price defined in the Power Purchase Agreement or energy spot prices.

Capacity charge

Is a reliability charge that is associated with the grid's capacity to supply the consumer at all times, particularly during periods of maximum demand.



Sidepayments

Are costs which are passed on to the end consumer. They include costs of ancillary services and other grid costs that are not included in other categories. Side payments can vary monthly.

Transmission

(National + Zonal + Distribuition)

Used to pay for the existing transmission system and new works. These costs might depend on the voltage level and location of the client. These costs are passed on to the end consumer.

ISO Fees - ISO fees are paid by all clients.

Grid & reliability costs

Full **off-grid** supply costs to be considered

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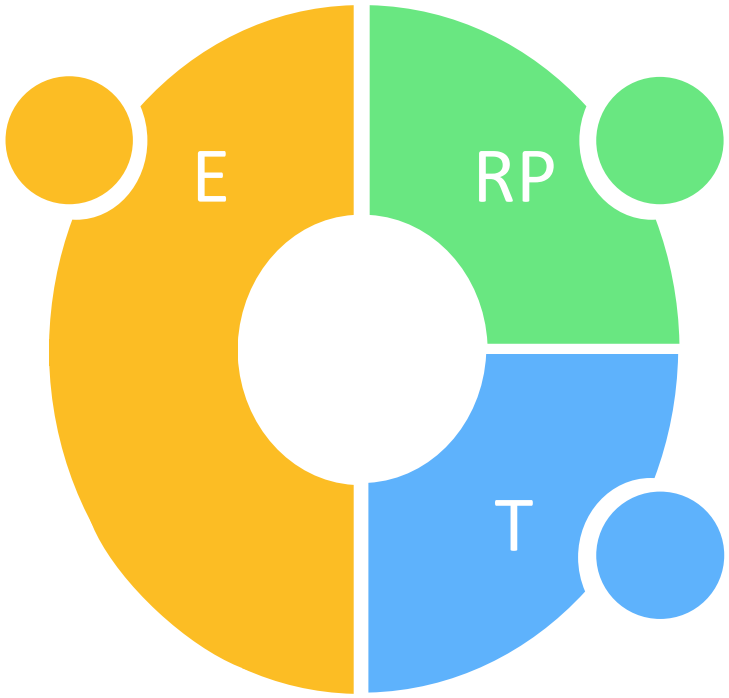
Energy

Energy price is the fixed price agreed with the supplier or developer of the off-grid VRE project. There are different options available for the structure of an off-grid supply agreement.



Reliability premium

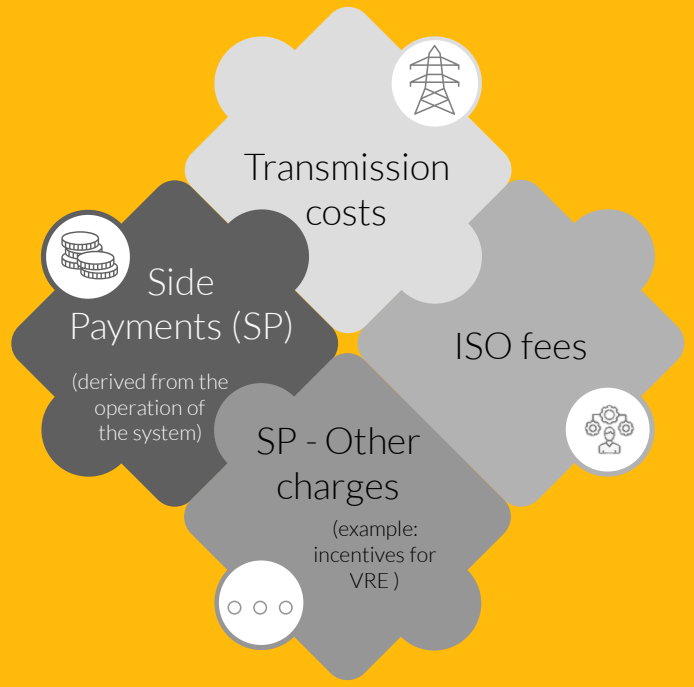
Cost related to an off-grid reliable supply. This could consider investment in energy storage, CSP and others. The investment will depend on the flexibility and reliability required by the H_2/NH_3 project.

Transmission

(Dedicated)

Transmission or transport costs associated to the dedicated line from the VRE facility to the H_2/NH_3 project.

Grid & reliability costs



Why are grid and reliability costs important?

Energy accounts for nearly **70-80%** of the cost to produce a kilogram of H_2 .

Grid costs are comparable to solar and wind LCOE, therefore can double energy costs.

Advantages of connection to grid

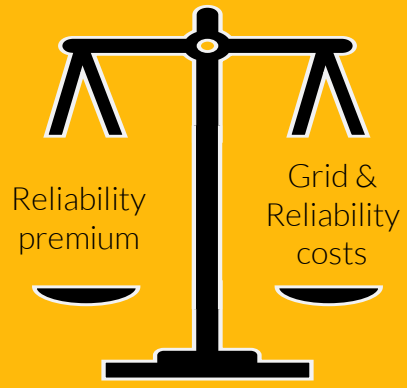
- ✓ Provides reliability of supply for the projects, and stability to H_2 / NH_3 processes.
- ✓ Allows higher utilization factors of the electrolyzers.
- ✓ Reduces pressure for flexibility for the H_2 / NH_3 plant.

Evolution of grid and reliability costs

Renewable energy transition is significantly changing grid & reliability costs.
Drivers include:

- Renewable energy integration
- Transmission investment
- Transformation and limitations of thermal generation facilities.

Off-grid vs. On-grid tradeoff



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1.2

Architecture alternatives for the Power-to-X project

Architecture alternatives for a Power-to-X project

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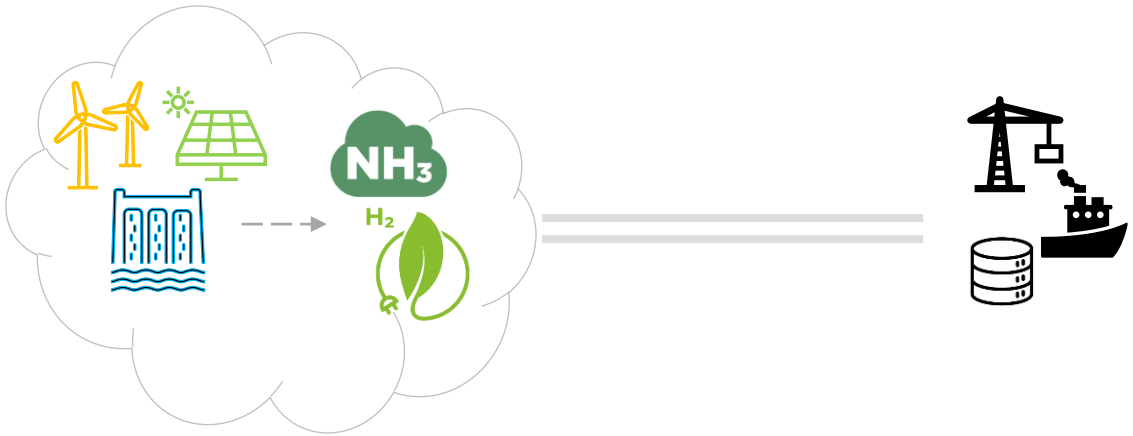
Renewable generation coupled with Power-to-X plant



- NH_3 must be transported as a pressurized fluid for longer distances.
- NH_3 liquefaction equipment need at the port facility.
- Site selection, permitting and easements considerations.
- Opportunity for creating or using shared infrastructure with multiple projects feeding one pipeline.

Source: Nustar.

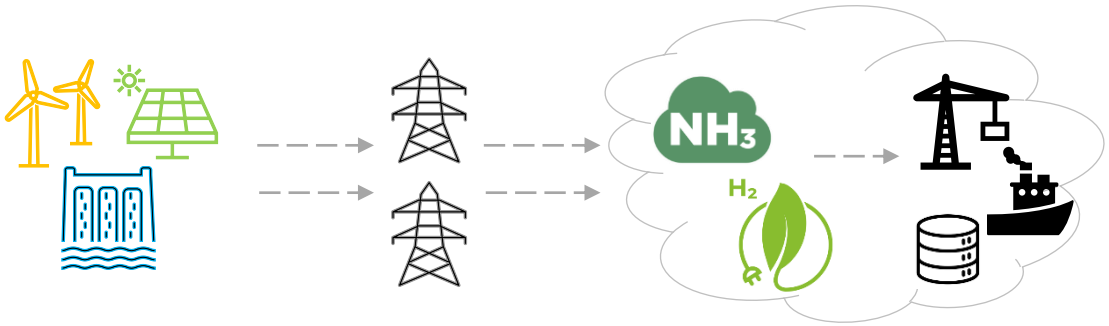
Nustar's Ammonia Pipeline System

Transports anhydrous ammonia over 2,000 miles for third parties, in liquid form.

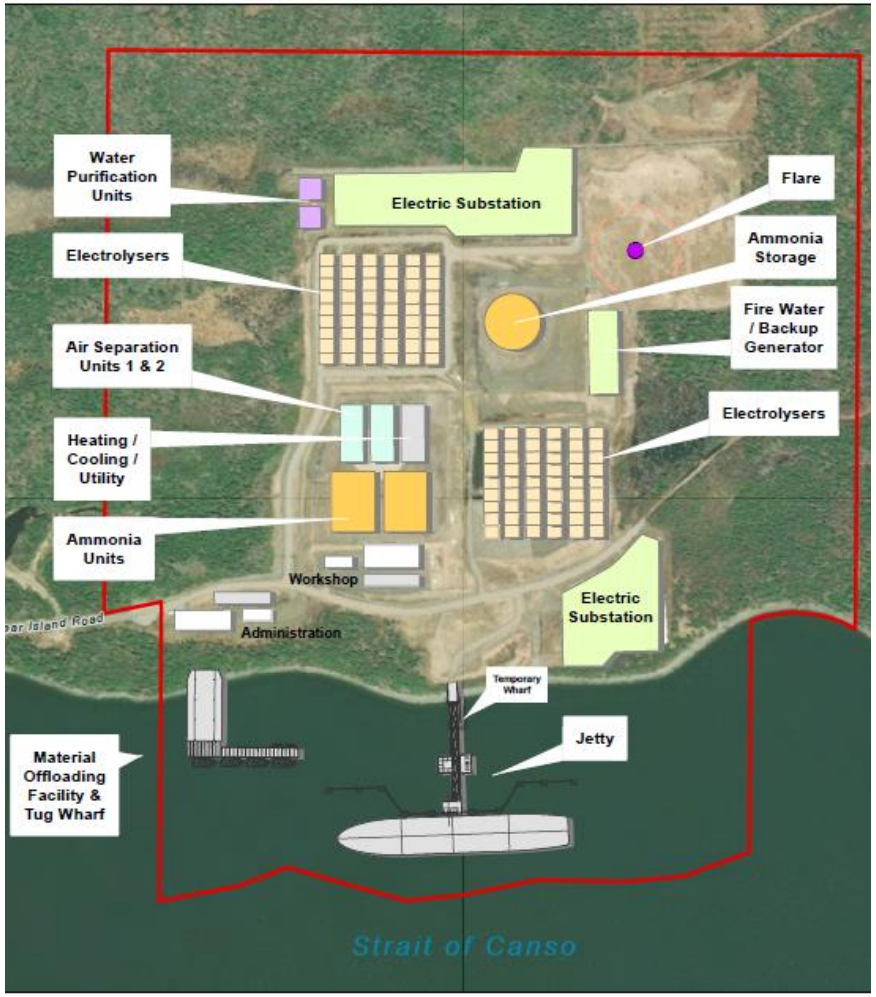
From Louisiana and other various points to the Corn Belt region.

Architecture alternatives for a Power-to-X project

Renewable generation separated from the Power-to-X plant



- Flexibility requirements for the Haber-Bosch plant.
- Transmission losses over long distances.
- Challenges related to large-scale H_2 storage (if needed).
- Easier access to port infrastructure and export capabilities.
- Energy storage could be considered to firm supply to the plant.
- Development near urban areas needs to be carefully addressed.



Source: Bear Head Energy.

Bear Head Energy – Nova Scotia

Production of up to 2,000,000 tons of ammonia per year.

Renewable energy sourcing still under review.

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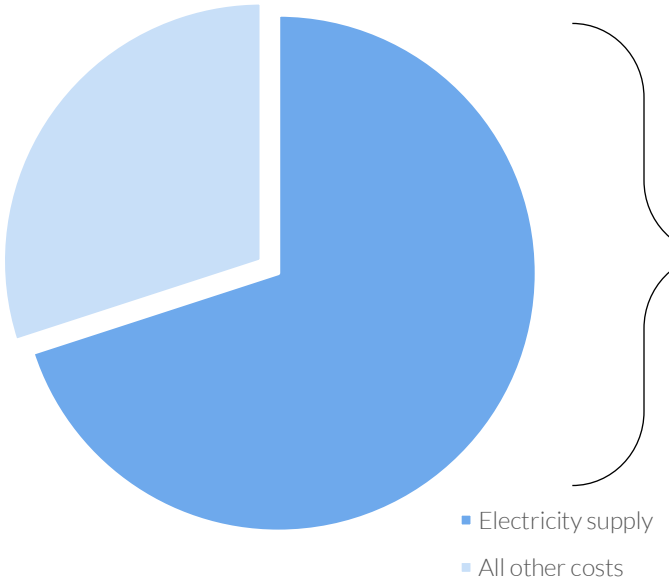
2

Evaluating energy supply for green hydrogen and ammonia production

Key energy sourcing tradeoffs for green hydrogen and ammonia production

Current cost breakout green referential large-scale green hydrogen project



Electricity accounts for up to 70%-80% of the cost to produce a kg of green hydrogen.

Drivers of electricity costs

Capacity Factor of renewable energy	Flexibility of energy requirements & grid connection costs	Firmness and availability of renewable energy throughout the day	Tradeoffs plant design such as hydrogen storage capacity and energy prices at night	Timing - cost declines in renewable energy

Renewable energy capacity factors have an impact in hydrogen and ammonia production competitiveness

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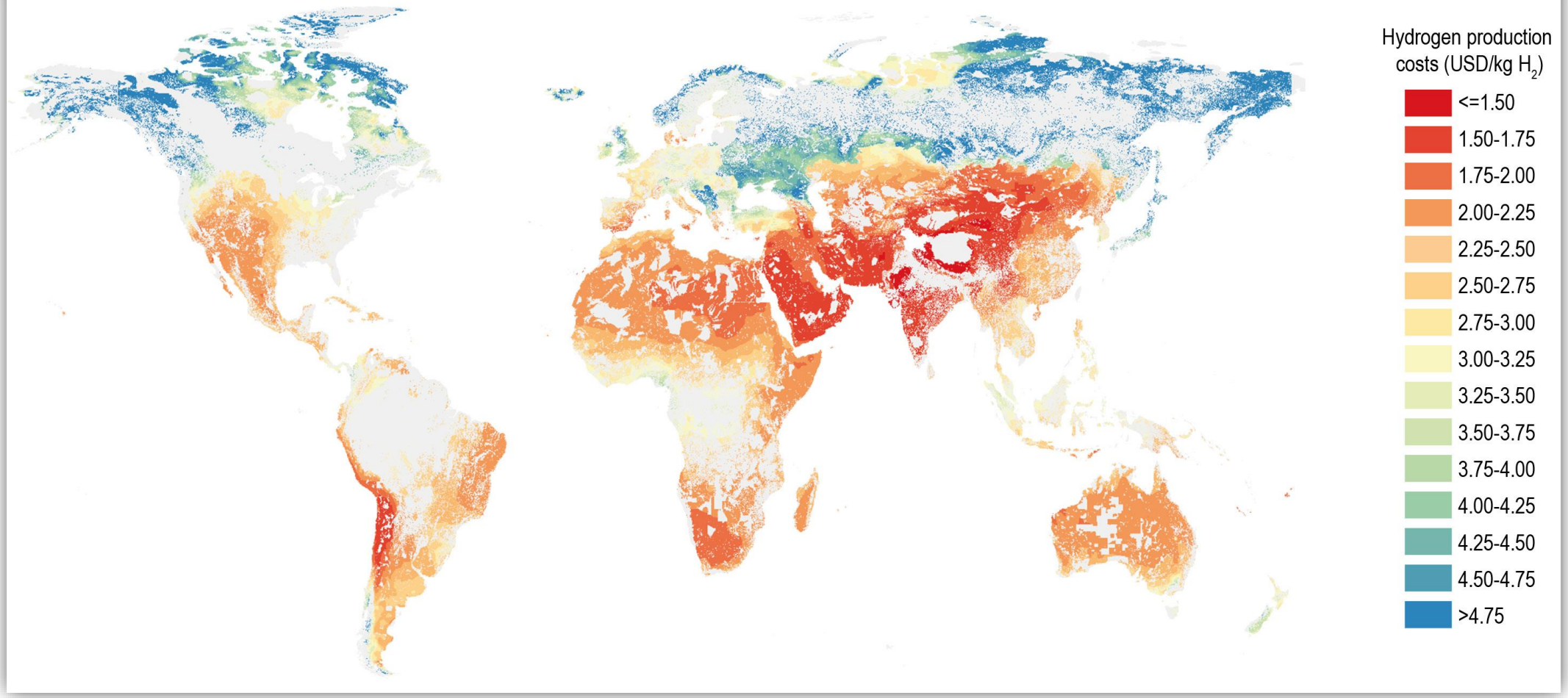
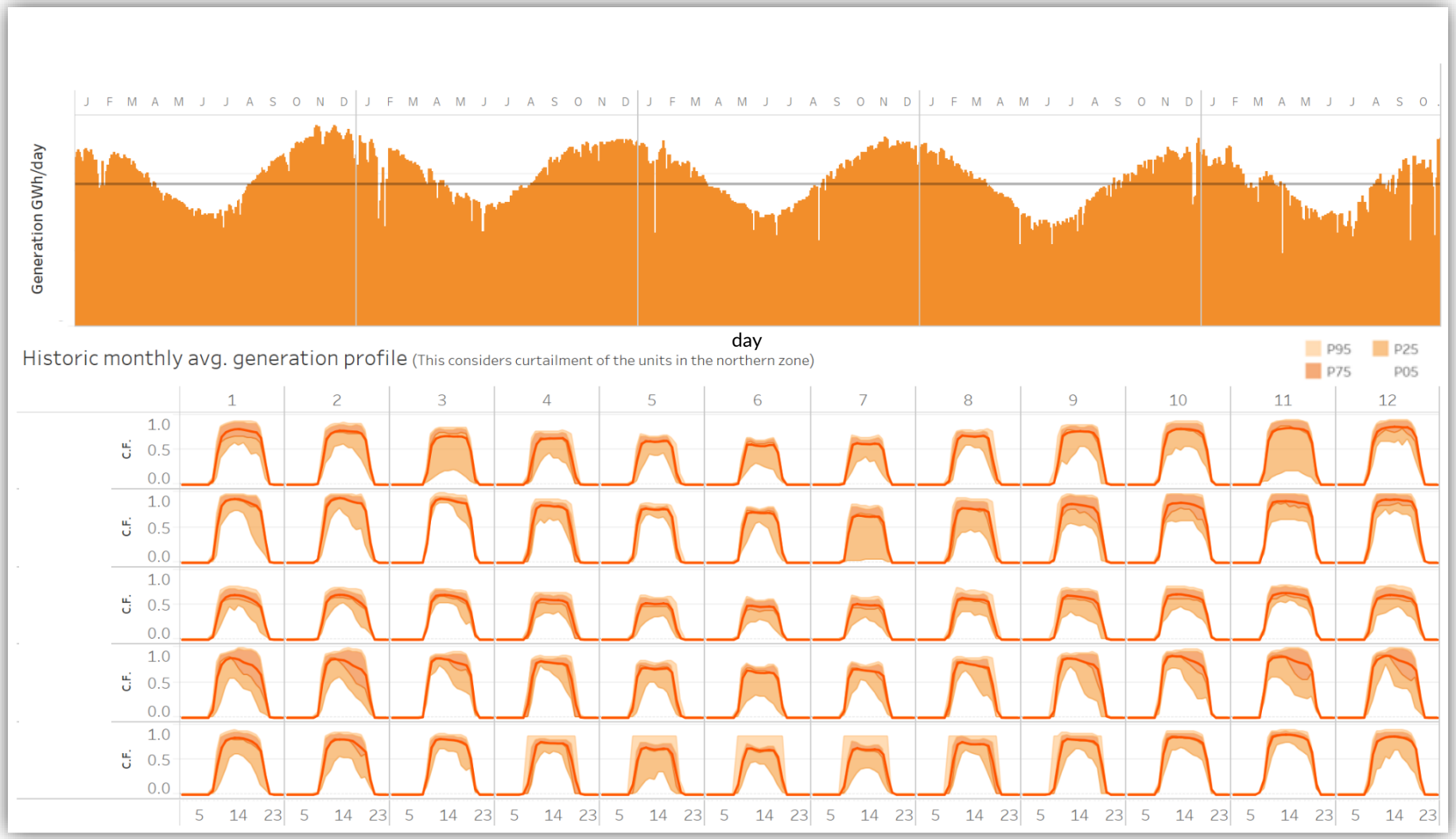
Hydrogen production costs from hybrid solar PV and wind systems for a minimum load of 40% by 2030



Source: IEA Hydrogen Review

Analysis of solar generation variability across the years for power plants connected to the Chilean Electricity System – historic generation



Source: Inodú Analytics

Analysis of solar generation variability across the years for power plants connected to the Chilean Electricity System – historic generation

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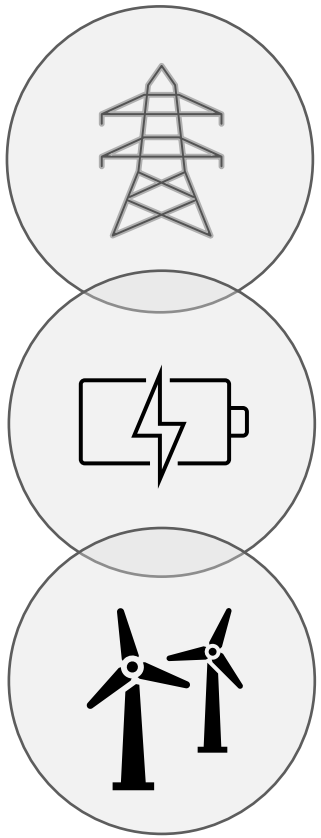
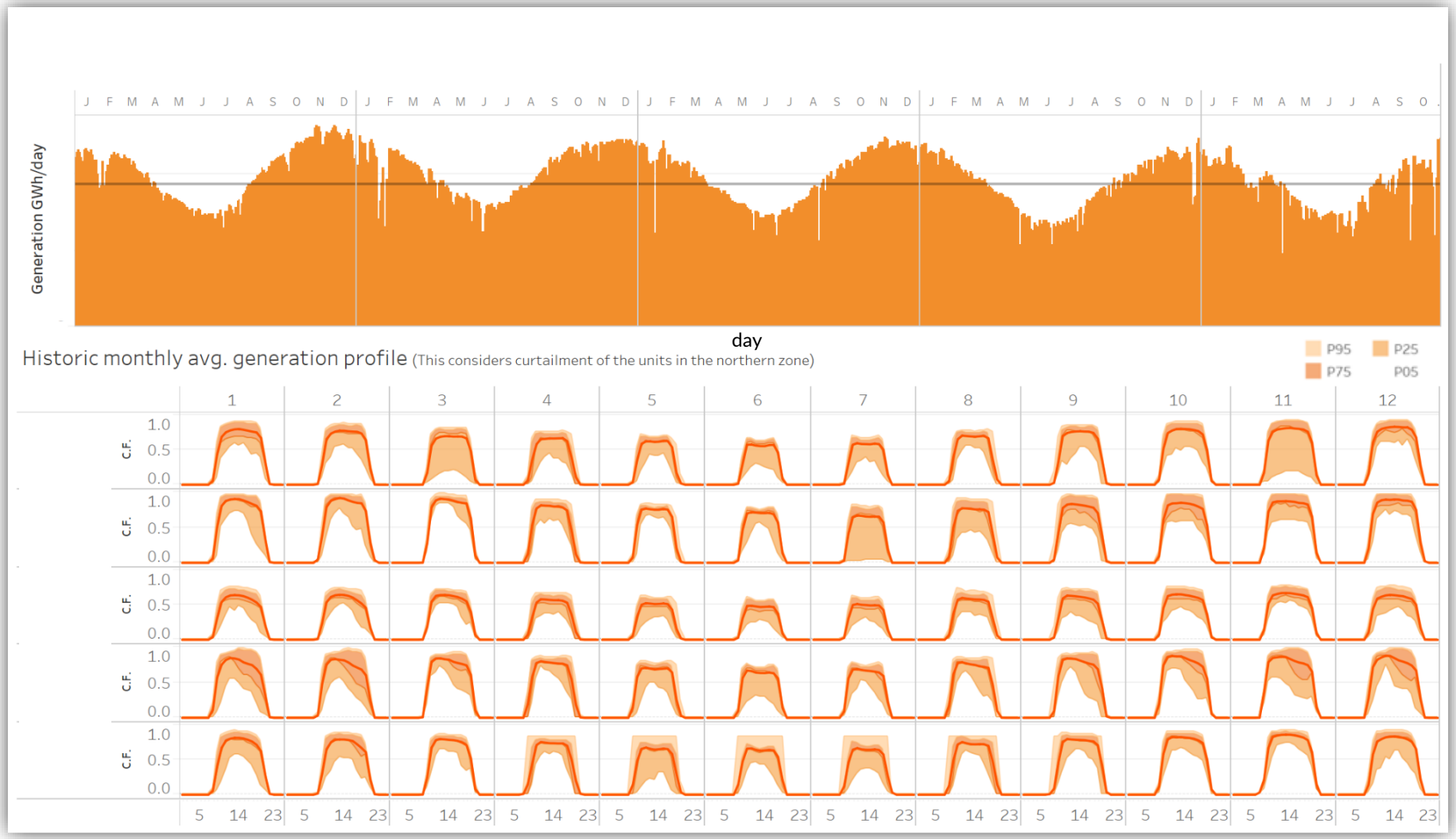
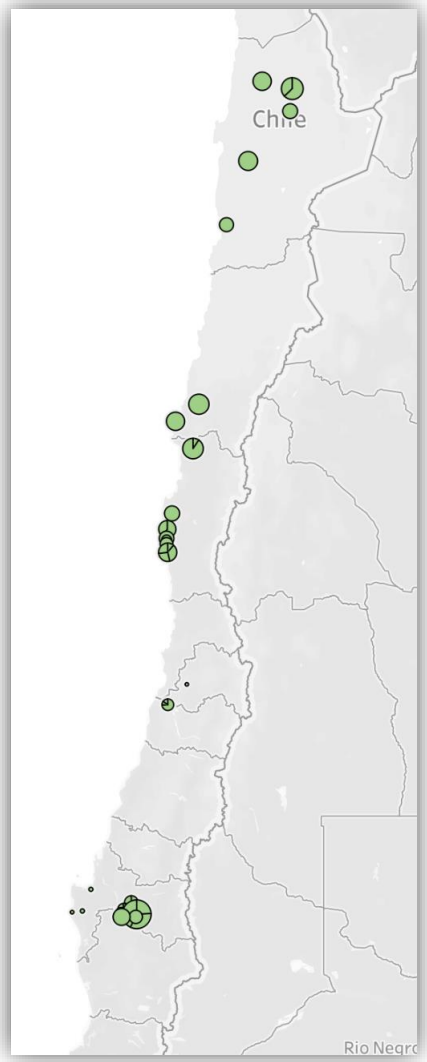
Impacts on green Ammonia production cost

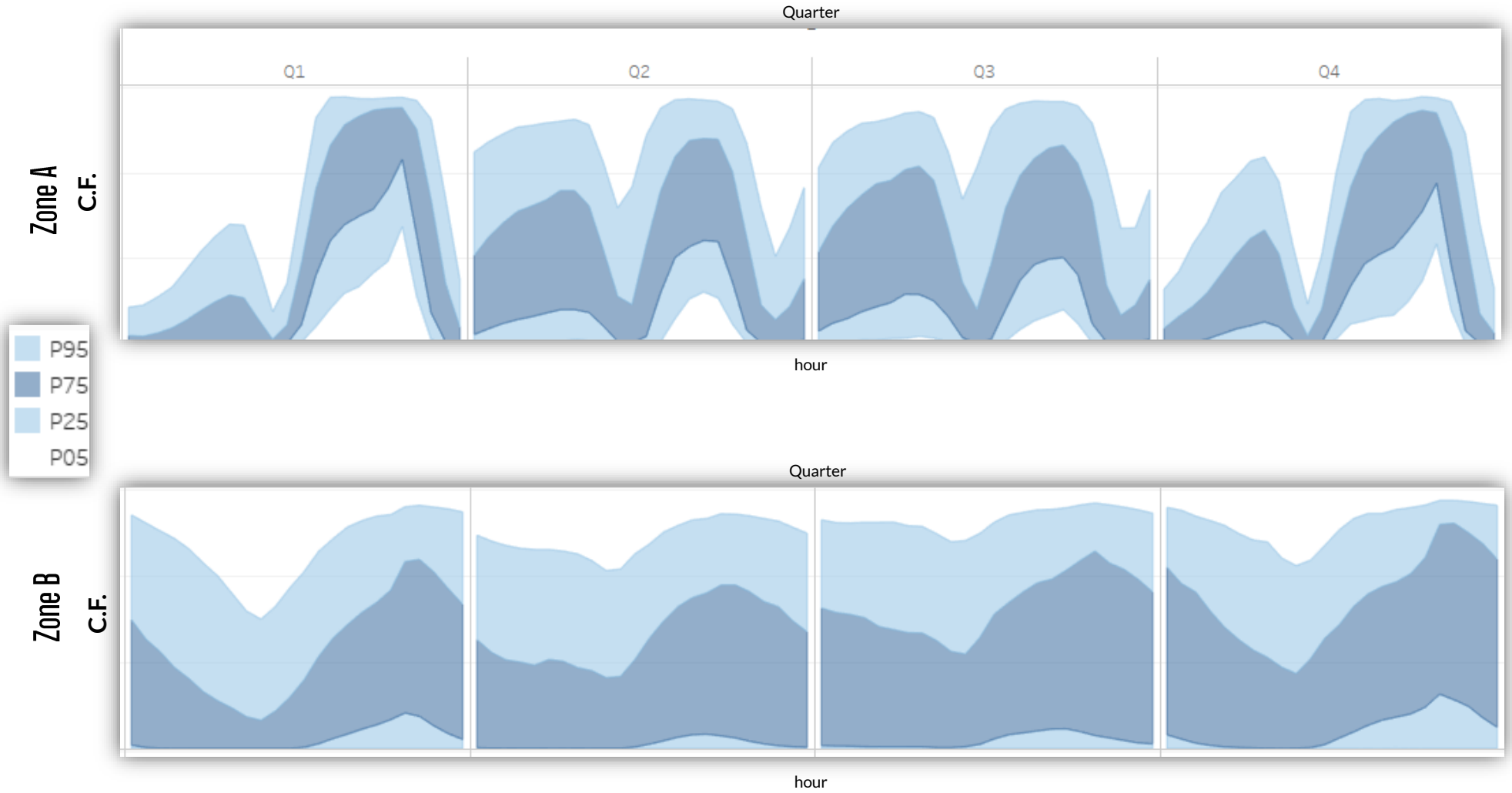




Source: Inodú Analytics

Analysis of wind generation variability across the years for power plants connected to the Chilean Electricity System – historic generation





Source: Inodú Analytics

Analysis of wind generation variability across the years for power plants connected to the Chilean Electricity System – historic generation

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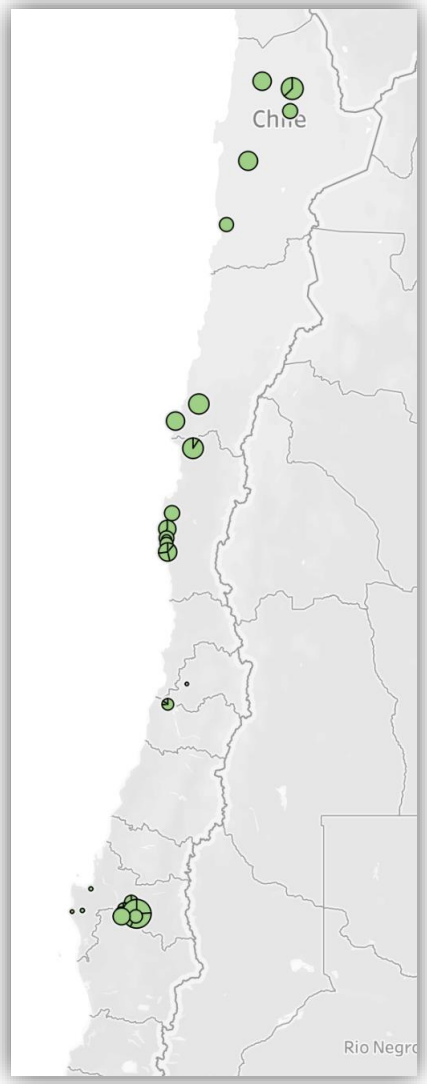
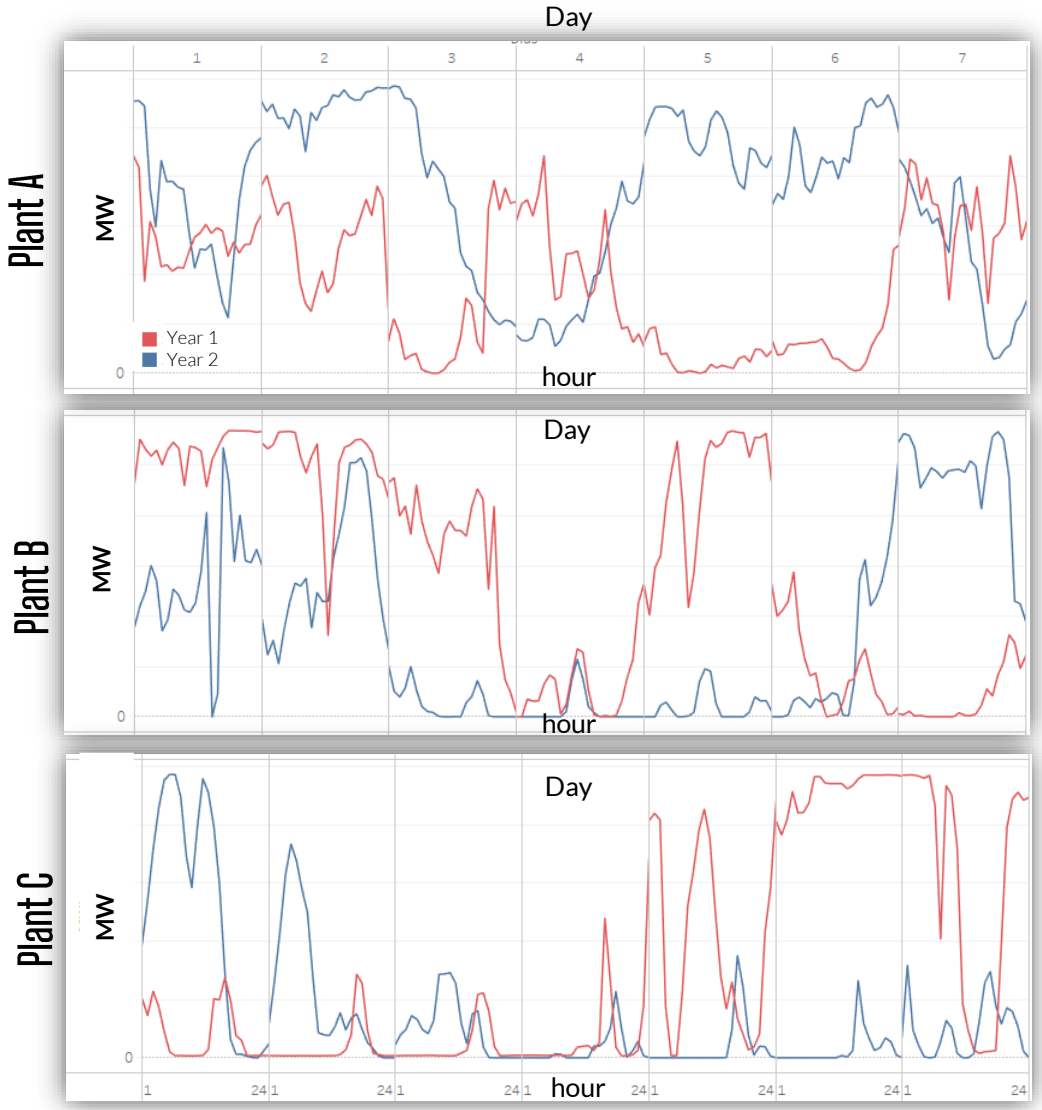
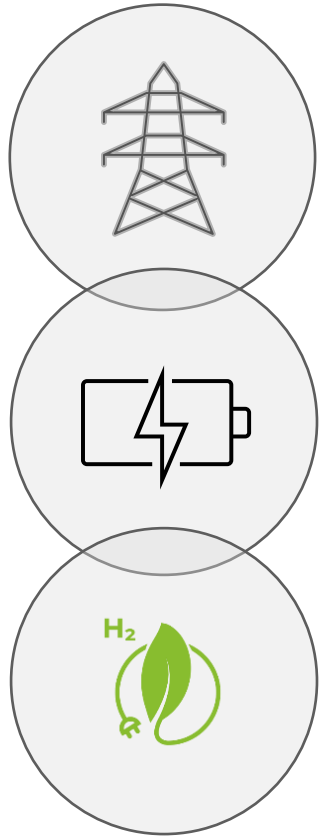




Impacts on green Ammonia production cost



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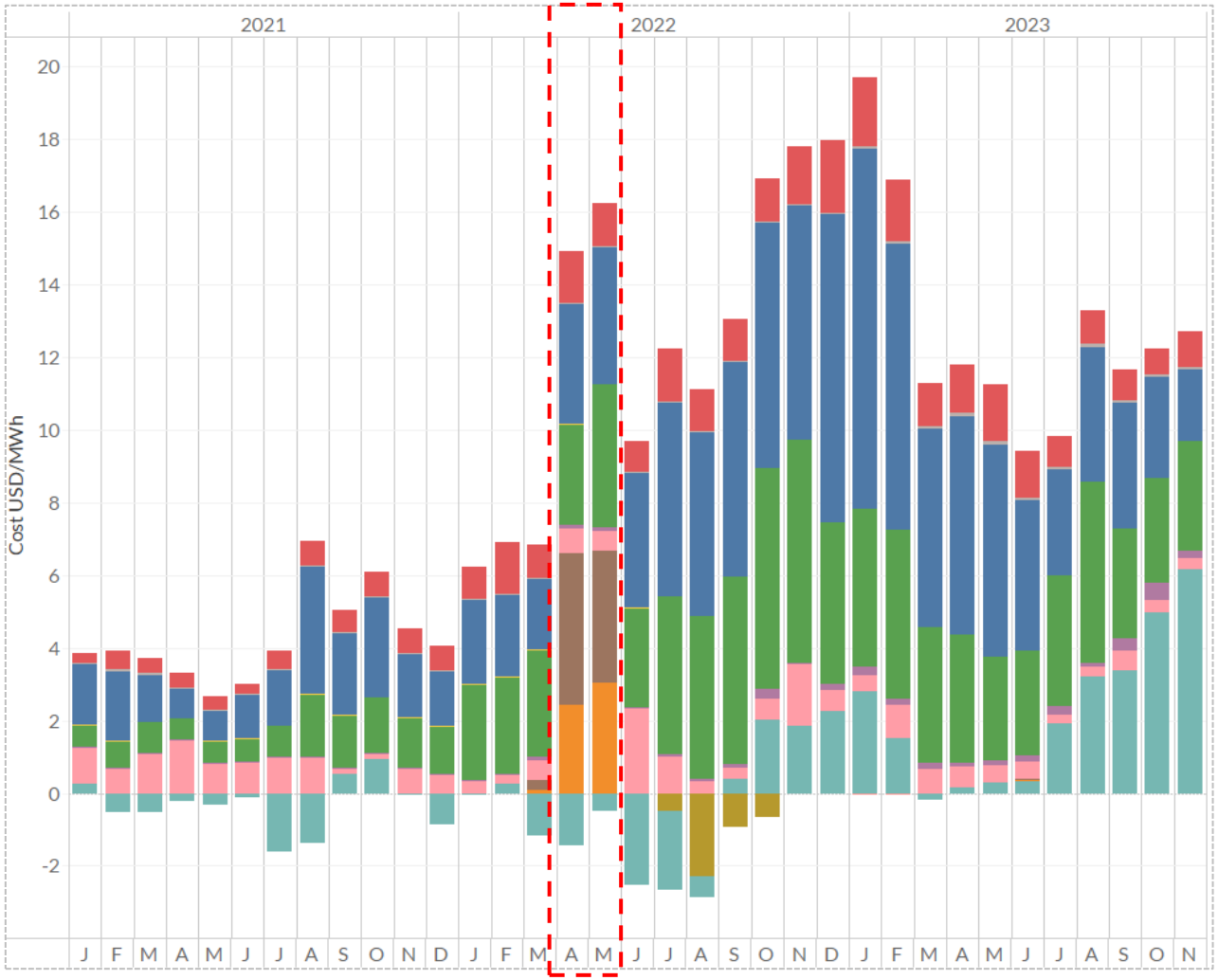
Chilean study case of reliability premium cost dynamics

Side payments are highly influenced by the energy transition



Renewable energy transition is significantly changing grid & reliability costs

During 2022 water reserves have been active due to a rationing decree, because of water scarcity conditions.

Water scarcity rationing decree

Minimum operational level at termal units

Side payments of thermal units whose variable cost (VC) of production is higher than the spot price and operating at *minimum* operational level conditions have increased in 2022.

Water scarcity	Ancillary services	System inflexibilities	Other
OCHR	SSCC	SCML	PE
SSCCRD	SPRD	SCPD	Other
RHR	SSCC/PDO		

In Chile, side payments have been increasing in the past years, reaching amounts above 18 USD/MWh per month in January 2023.

Summary of grid & reliability costs in Chile

Cost item	≥ 200 kV	Zonal Systems
National Transmission (USD/MWh)	8.2	8.2
Zonal Transmission (USD/MWh)	-	2.7 – 14.6 *
Side Payments derived from the operation of the system (USD/MWh)	2.4 – 15.8	2.4 – 15.8
ISO cost (USD/MWh)	0.63	0.63
Grid connection costs (USD/MWh)	11.2 – 24.6	13.9 – 39.2

* Differences are related to location where energy is withdrawn and voltage level at point of connection.
**Indicated values do not consider costs associated with sufficiency capacity and distribution grid costs.
*** Values are based on estimations for 2022.

In Chile, grid and reliability costs are only counted when energy is withdrawn from the system.

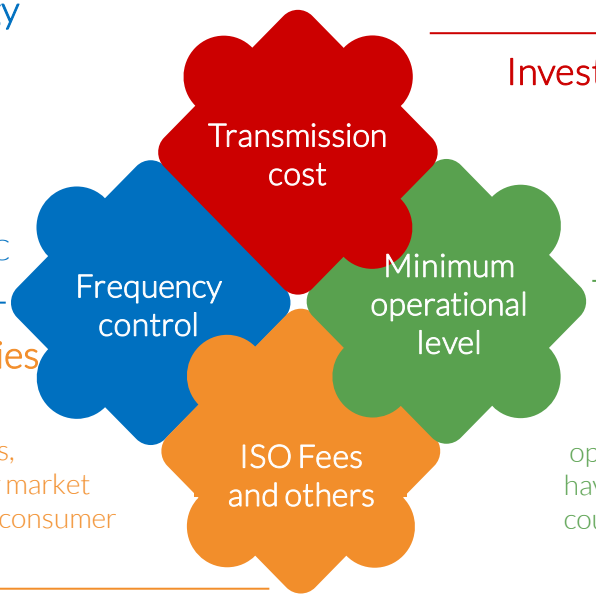
Future grid & reliability cost drivers

Variable Renewable Energy (VRE) could lower cost of frequency control

PV solar projects are starting to provide frequency control (FC) services by default, which will increase supply and lower cost of FC ancillary service.

ISO Fees and other subsidies

A price stabilization surcharge could be included as part of ISO fees, increasing them. Inflation and other market incentives could affect rates to end consumer in the future.



Investment in transmission assets

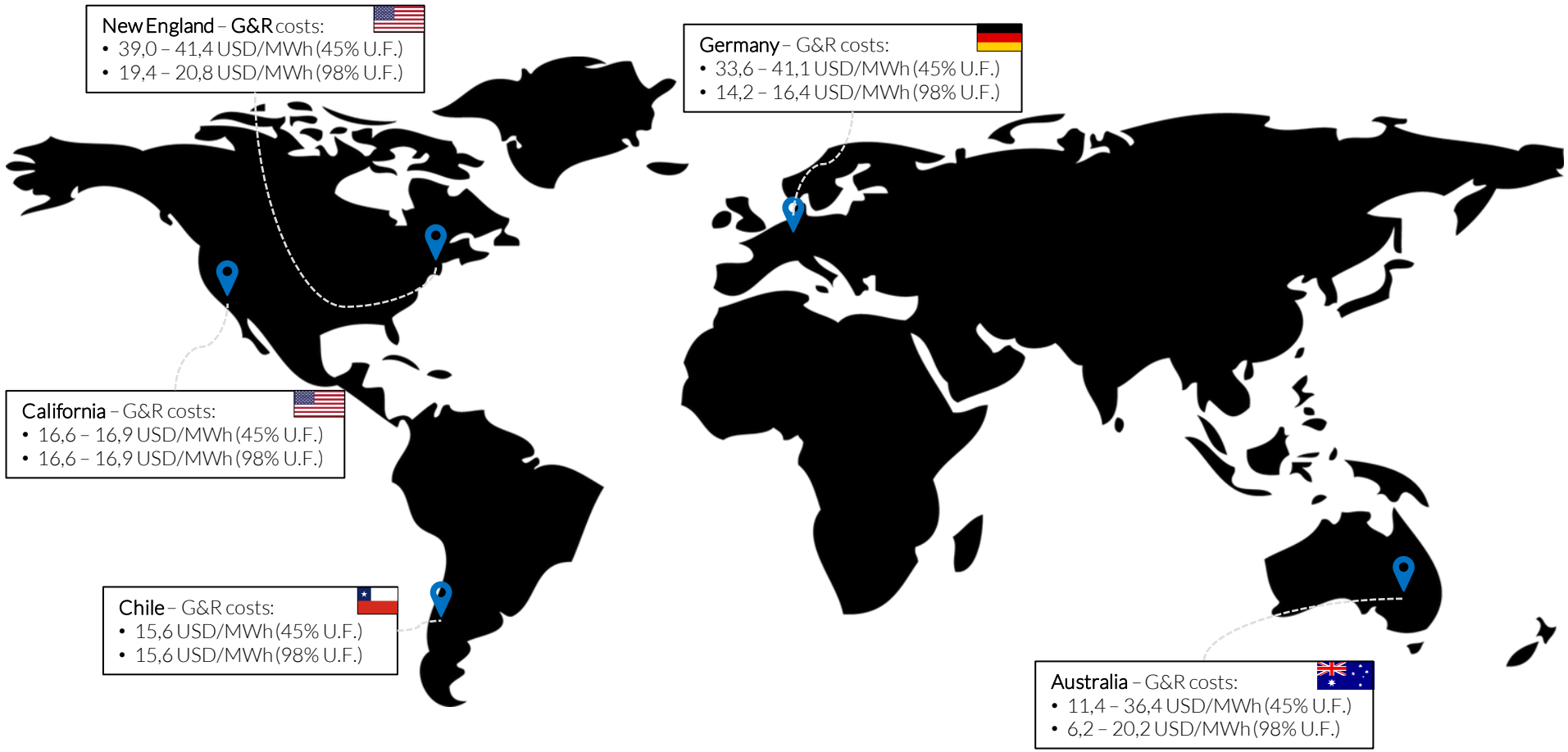
Due to high integration of VRE and congestion issues, new investments in transmission assets could increase costs for final consumers.

Minimum operational level at thermal units

Side payments for thermal units operating at minimum operational level have increased during 2022-2023. This could keep increasing. Variability of fuel prices could also affect this cost.

International benchmark of grid & reliability costs

Costs estimated based on information from 2nd semester 2021 and 1st semester 2022



Transmission charges in some markets are heavily affected by localization.

Germany is a potential green H_2 importer.

Australia and Chile are potential green H_2 exporters.

Connecting large projects to the grid can lead to develop grid infrastructure improvements.

U.F.: Utilization factor

Grid & reliability (G&R) costs* = Transmission costs + Side payments + ISO costs + other systemic charges

* Does not include capacity charge.

Grid & reliability costs are increasing in other markets

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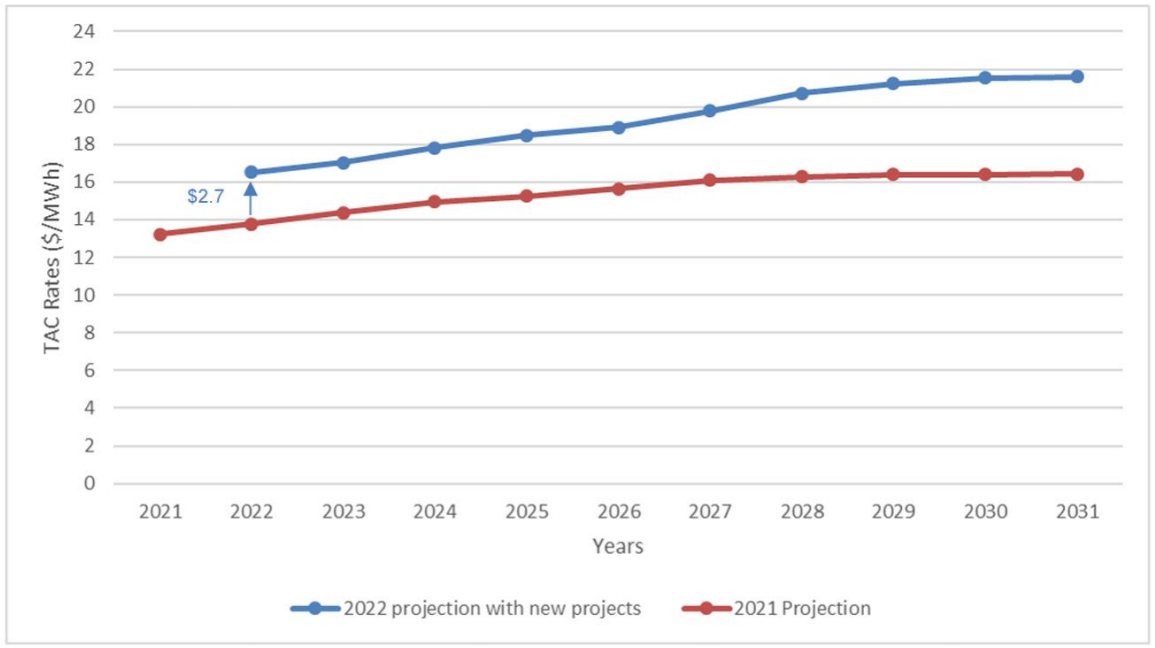
Transmission costs in California should increase over time

ISO 2021-2022 Transmission Plan **March 17, 2022**

Figure 8.5-1 Forecast of ISO High Voltage Transmission Access Charge Trending from First Year of Transmission Plan



Source: CAISO.

Australia plans *massive* investments in transmission…

Who is going to pay for them and how?

NEWS

Australia's AU$20 billion transmission initiative supports Tasmania's 'Battery of the Nation'

By Andy Colthorpe

October 19, 2022

Asia & Oceania, Southeast Asia & Oceania | Connected Technologies, Grid Scale | Policy

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Anthony Albanese at a wind farm in New South Wales. Image: Anthony Albanese's office via Twitter.

Source: Energy storage news.

Regulators reinforce need for 'massive investment' in energy sector

Australian energy regulators have called for urgent investments in renewable energy capacity and the transmission infrastructure needed to connect new projects to the grid as they look to ensure an orderly transition as coal-fired generation exits the National Electricity Market.

SEPTEMBER 30, 2022 DAVID CARROLL

COMMERCIAL & INDUSTRIAL PV | DISTRIBUTED STORAGE | GRIDS & INTEGRATION | MARKETS | POLICY | RESIDENTIAL PV | SUSTAINABILITY | UTILITY SCALE PV | UTILITY SCALE STORAGE | AUSTRALIA

Source: PV Magazine

Sustainability

Australian government unveils first step towards 'rewiring the nation'

The new government's partnership with state governments to roll out billions in concessional finance is expected to accelerate Australia's energy transition.

Tharshini Ashokan - 21 October 2022

Share | A- | A+ | 100%

Source: Infrastructure Investor

In California, investments in new infrastructure are expected to drive cost increases. Australia is also planning massive investments in transmission assets. How will these investments impact the total grid & reliability costs?

Cost differences lead to opportunities for load flexibility and reliability premium technologies

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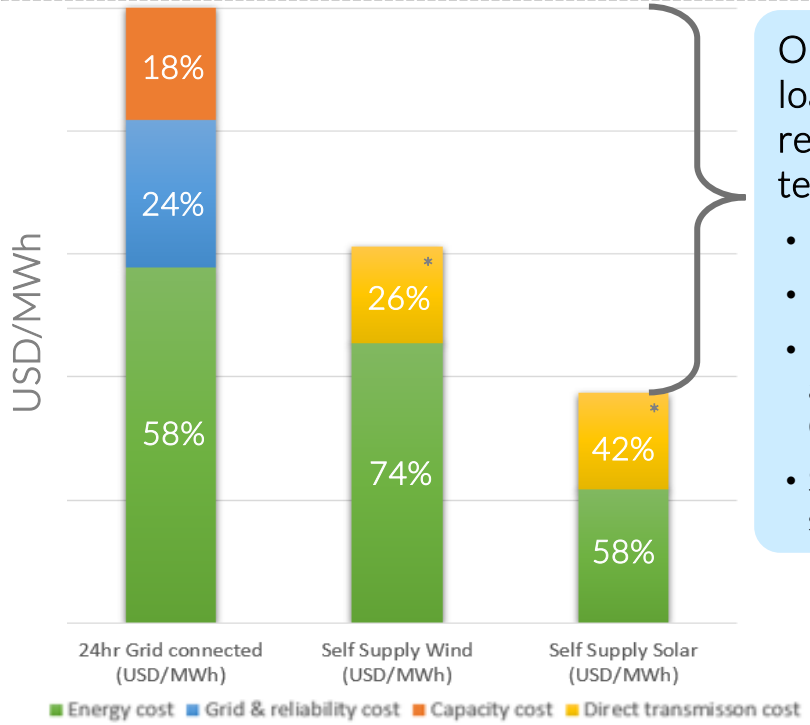
Load characteristics for production process

- Low-temperature electrolysis is highly adaptable to variable supply.
- Electrolyzer capacity and hydrogen storage can be used to avoid 24/7 supply.
- Supply distribution over day/year can be optimized to minimize LCOH.

- Haber-Bosch (HB) to produce ammonia accounts for approximately 10% of H_2 electrolysis energy requirements.
- Load and HB process inflexibilities lead to need for 24-hour supply.
- Development is focused on making HB process and load more flexible.

Supply cost breakdown

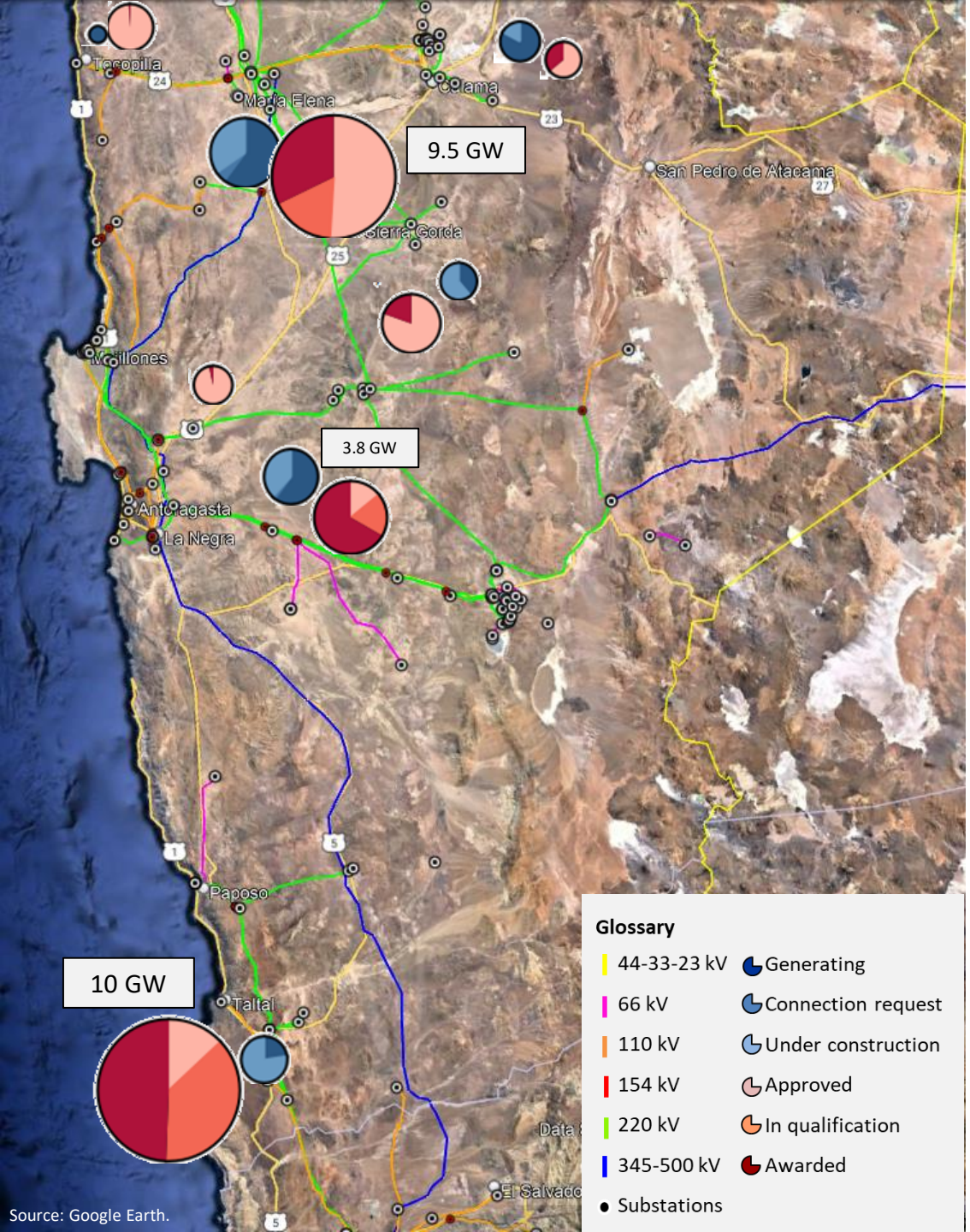


Opportunities for load flexibility and reliability premium technologies

- NH_3 process flexibility
- H_2 process flexibility
- Energy storage alternatives (BESS, CSP, etc.)
- Strategic hydrogen storage alternatives

* Direct Tx connection considers a line of 100km, for a 500 kV line for 3,000MW load and a 35% U.F. Referential costs considers 500kV lines in the north of Chile.
**Values are based on estimations for 2022.

Off-grid supply implies reliability and security risks. Nevertheless, there is a big difference in cost between off & on grid supply, which could drive investments in load flexibility and reliability premium technologies.



Source: Google Earth.

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Stand Alone Power Systems (SAPS) might be favored because of increasing grid & reliability costs and the difficulty to integrate H_2 – at scale – with legacy systems

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