IMPERIAL

Climate Compatible Growth

Hydropower-Enhanced Spatial Modelling for Green Hydrogen in Data-Constrained Countries

A Case Study of Lao PDR

Lukas Schirren, Vignesh Sridharan, Adam Hawkes

IMPERIAL

Identifying the least-cost green H2 production sites

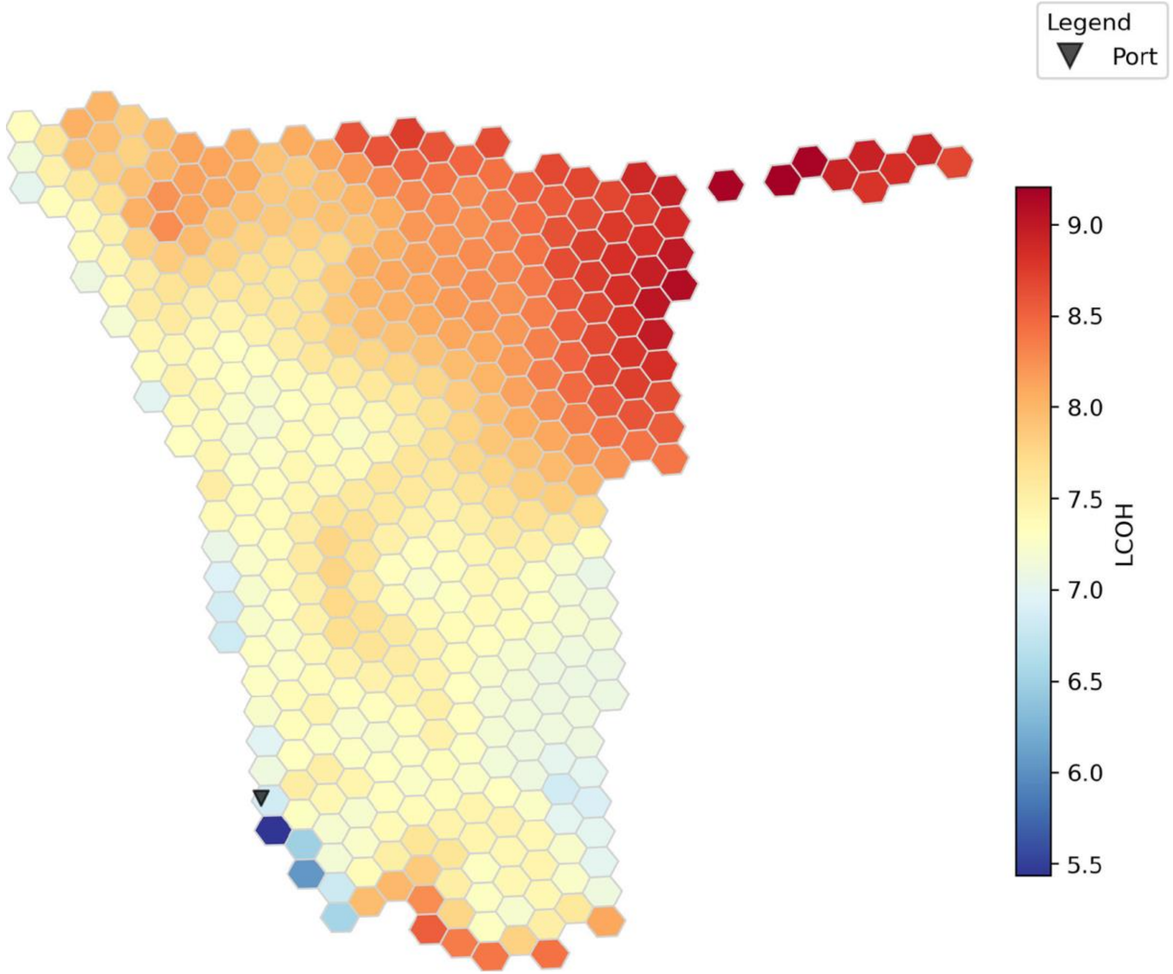
GeoH2

Optimises green hydrogen production systems to meet specified demand profiles

Focuses exclusively on wind and solar resources for electricity generation

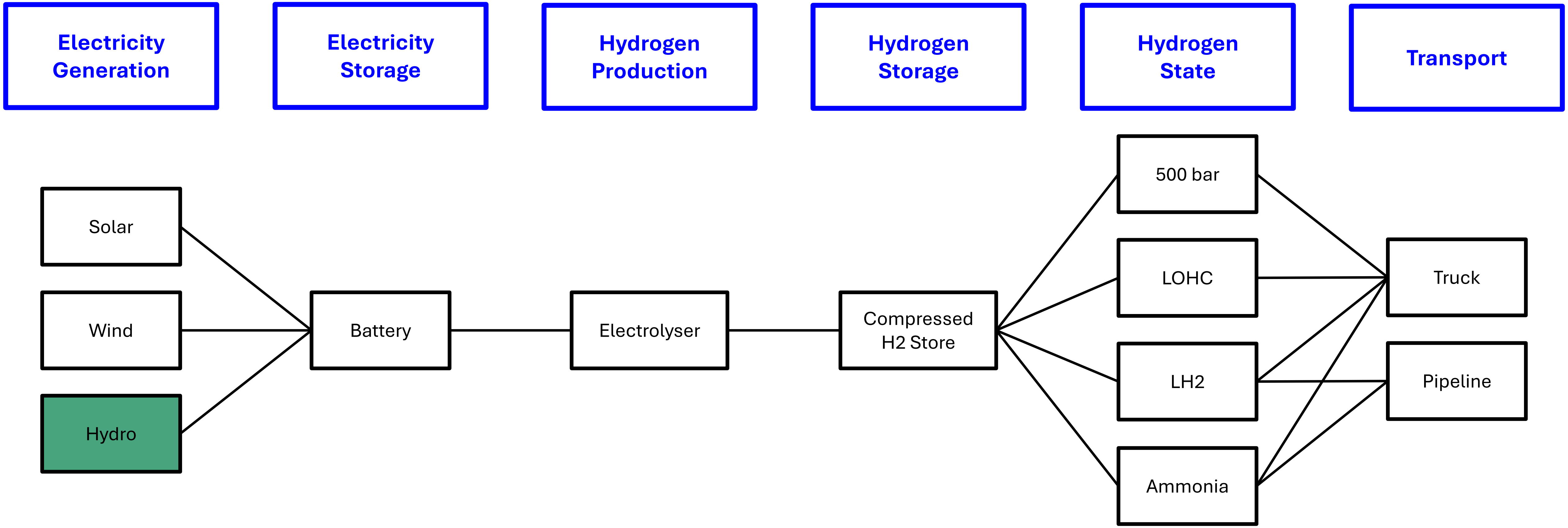
Models production, storage, and transport within hexagons

Open-source and applicable globally with focus on data-constrained countries



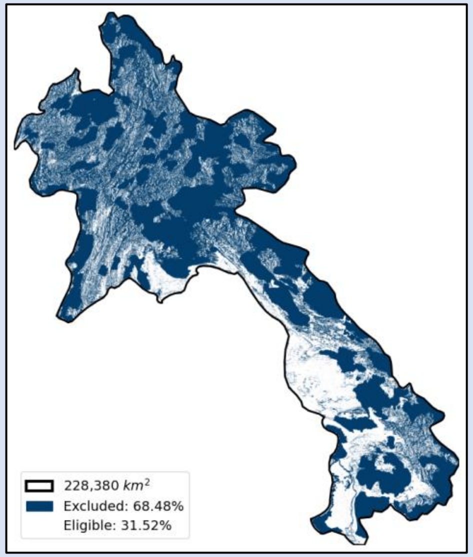
IMPERIAL

Optimised variables in GeoH2



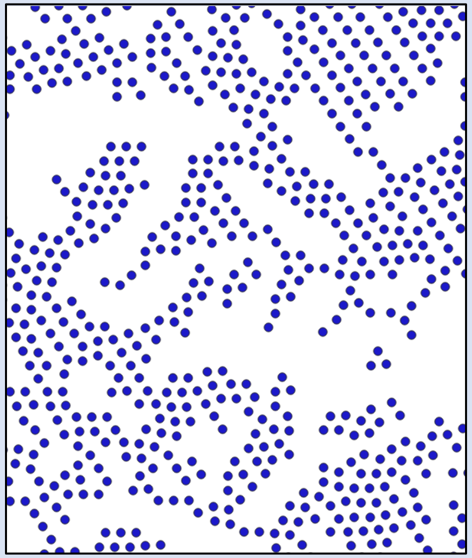
Spatial-Temporal Optimisation in GeoH2

Eligible area for renewables



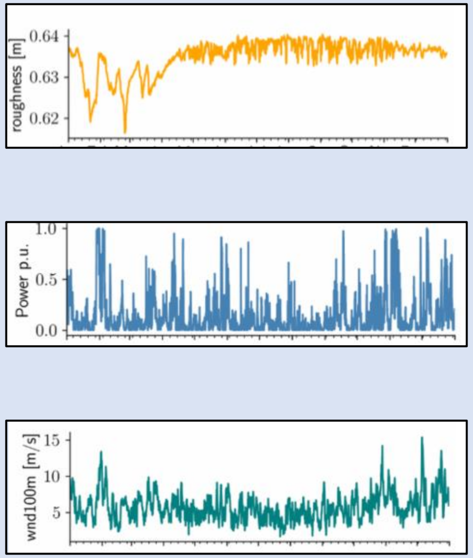
Slope-based

Placement of renewable generation



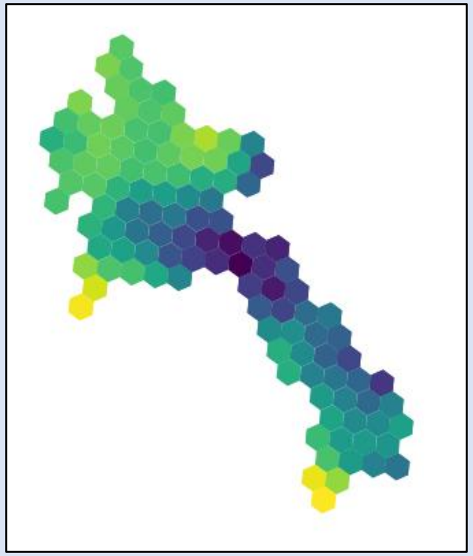
Re-adjustment

Computation of capacity factors



Hydropower Integration

Hourly optimisation of power system

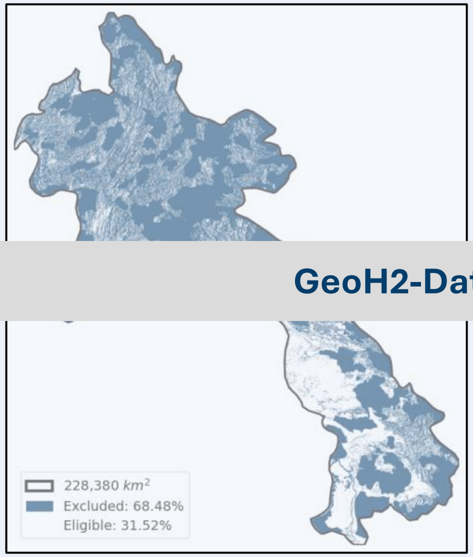


Optimised Hexagon Coverage

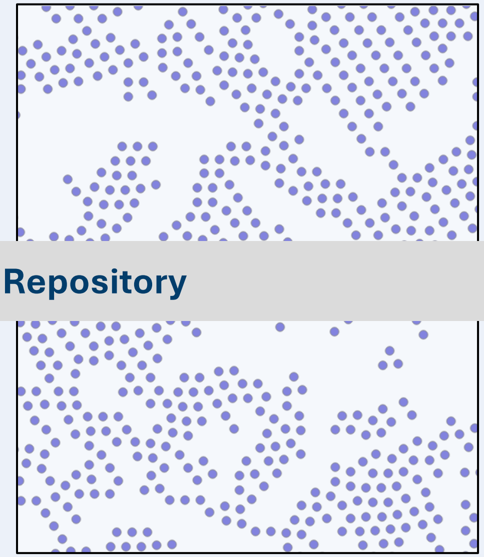
IMPERIAL

Spatial-Temporal Optimisation in GeoH2

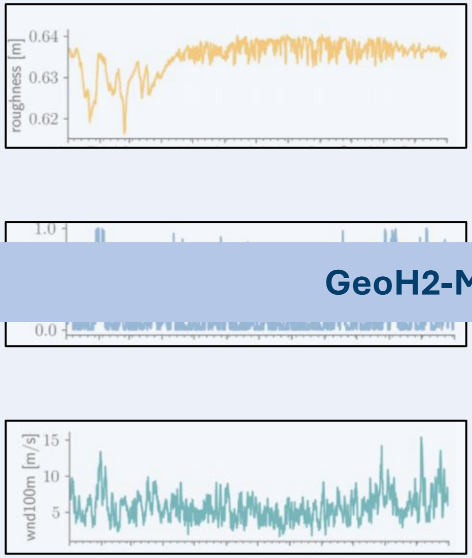
Eligible area for renewables



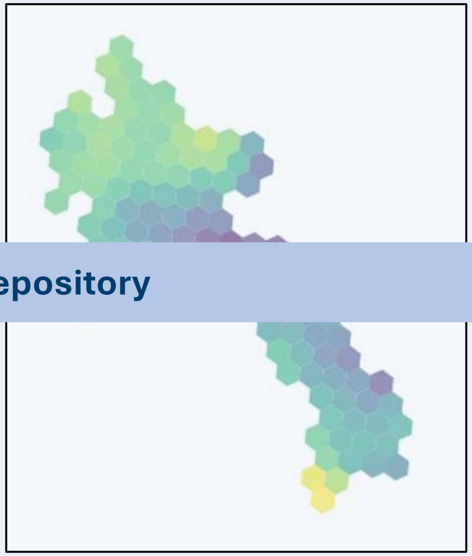
Placement of renewable generation



Computation of capacity factors



Hourly optimisation of power system



GeoH2-Data-Prep Repository

GeoH2-Master Repository

Data

GLAES
Geospatial Land Availability for Energy Systems

SPIDER
Aggregate to hexagons

ATLITE
ERA5 dataset

PyPSA
Python Power System Analysis

The integration of hydropower in GeoH2-Master

File with hydro-power location and data

hydro x (capacity, head)

File with hexagon and data on solar, wind, and hydro capacity

hexagon x (capacities)

→ Set to NULL

→ Set to value

→ Weighted average capacity factor

(hydro x hours) **(hydro x hours)** **(hexagon x hours)**

Runoff data from ATLITE based on hydro locations

Annual runoff profile

Calculation of the hydropower potential

$\eta * \rho * g * Q * H$

Annual hydro profile

Conversion to capacity factor

Annual capacity factor

Mean capacity factor per hexagon

Annual capacity factor

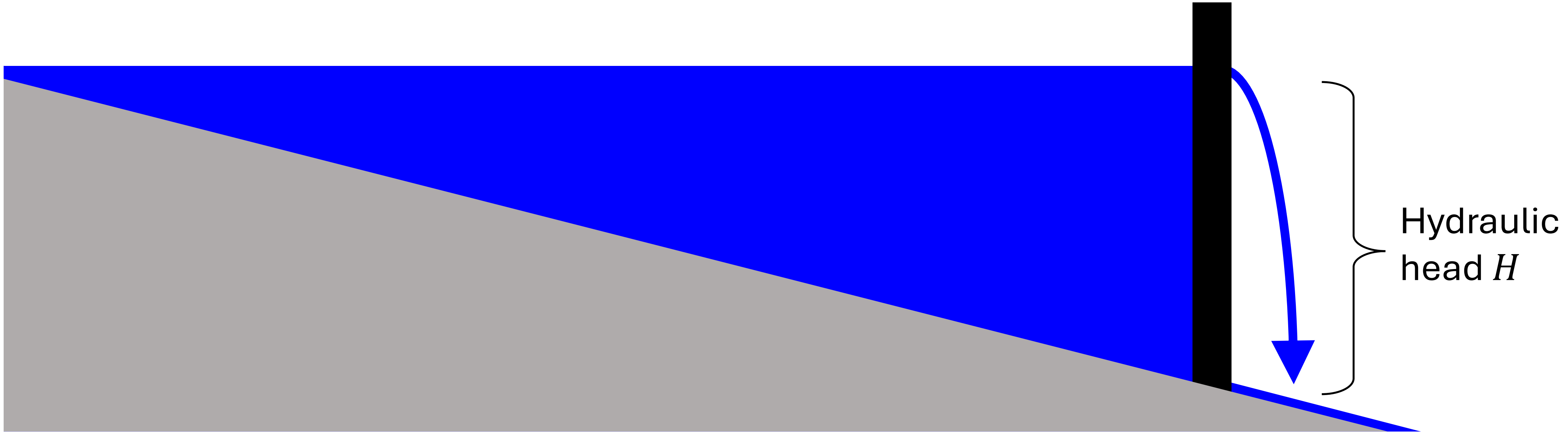
Input for Power system optimisation in PyPSA

The Integration of Hydropower

The estimation of hydropower output P is based on

$$P = Q \times \boxed{H} \times \eta \times \rho \times g$$

Q – Flow rate
H – Hydraulic head
η – Plant efficiency
ρ – Density of water
g – Gravitational acceleration

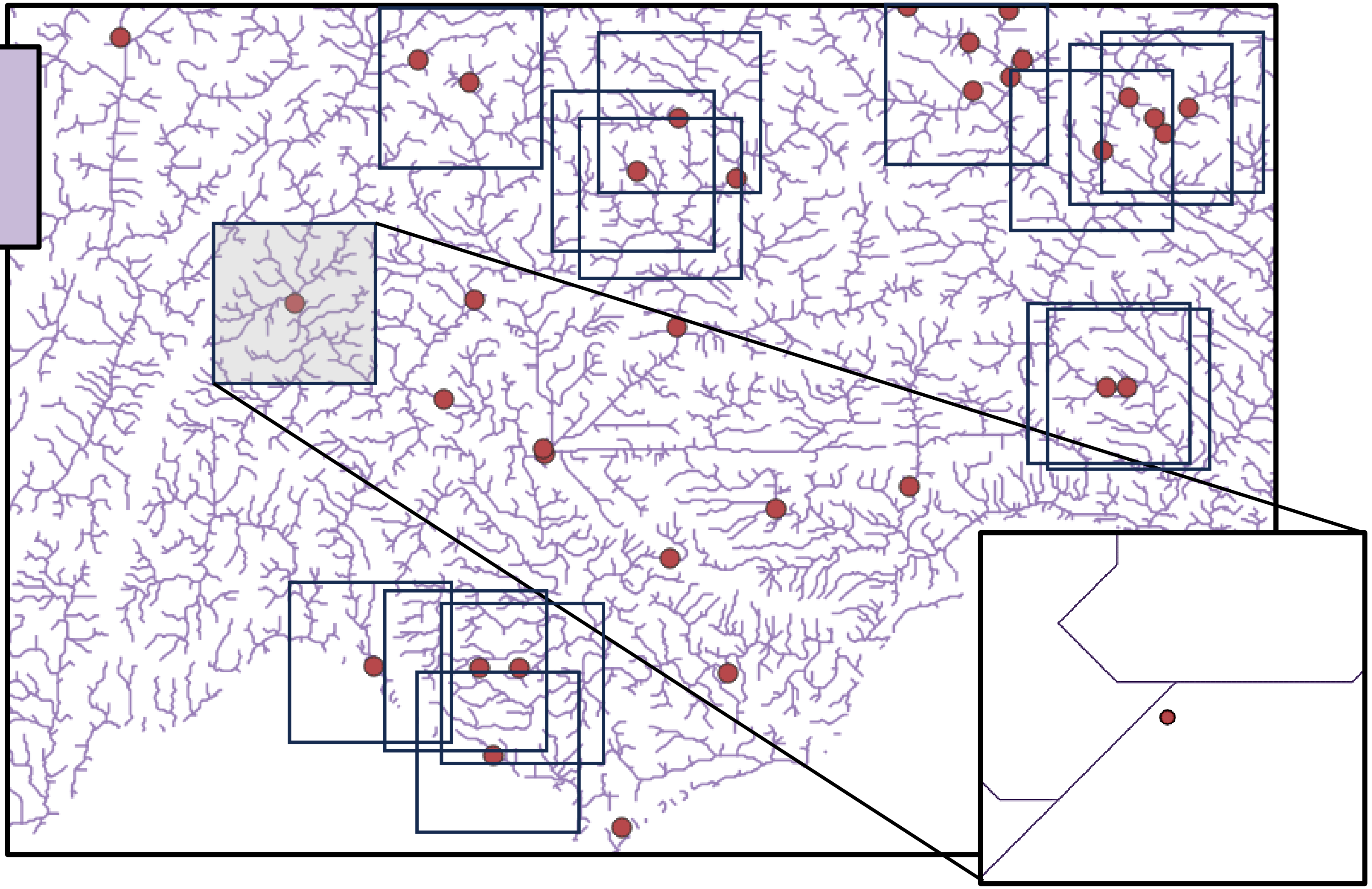


IMPERIAL

Calculate the hydraulic head for future hydropower

1

Extract Area:
Select an area around each hydropower plant from the DEM.



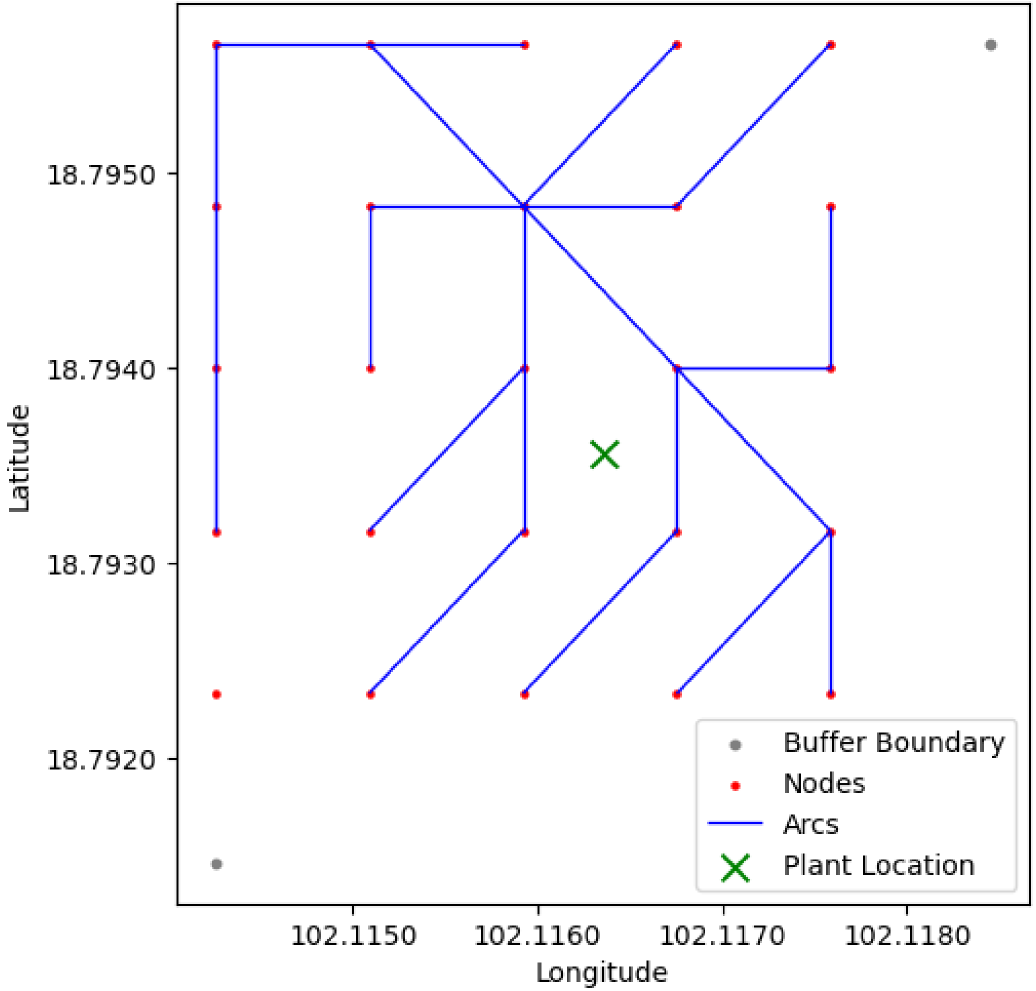
IMPERIAL

Calculate the hydraulic head for future hydropower

1. **Extract Area**: Select an area around each hydropower plant from the DEM.

2. **Calculate Head**: Create hydrological network to calculate head.

3. **Optimize**: Adjust area size to find minimal discrepancy between actual and calculated head.

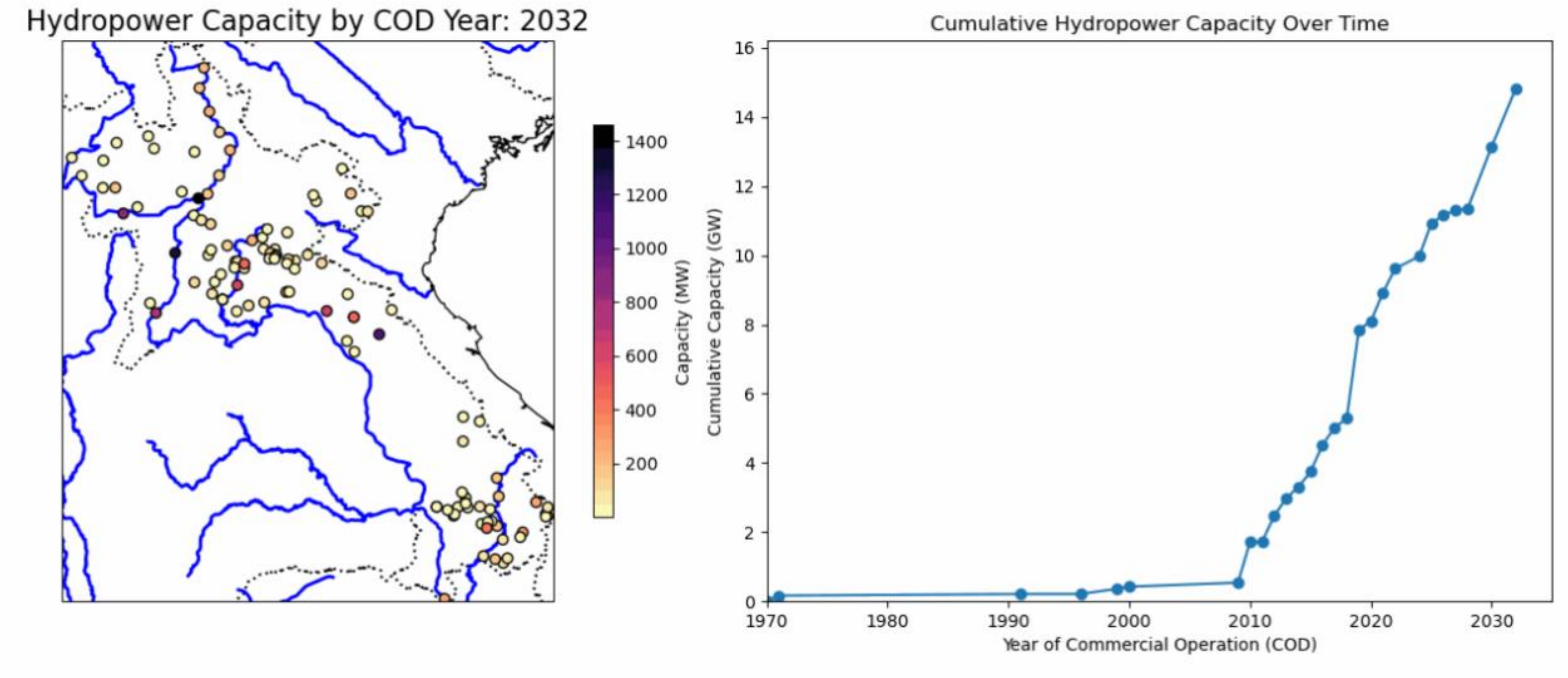


Case Study

Lao PDR

IMPERIAL

An increasing hydropower capacity



IMPERIAL

Low Profit from Electricity, High Cost for Fertiliser

Problem

Export
75%

Electricity Generation

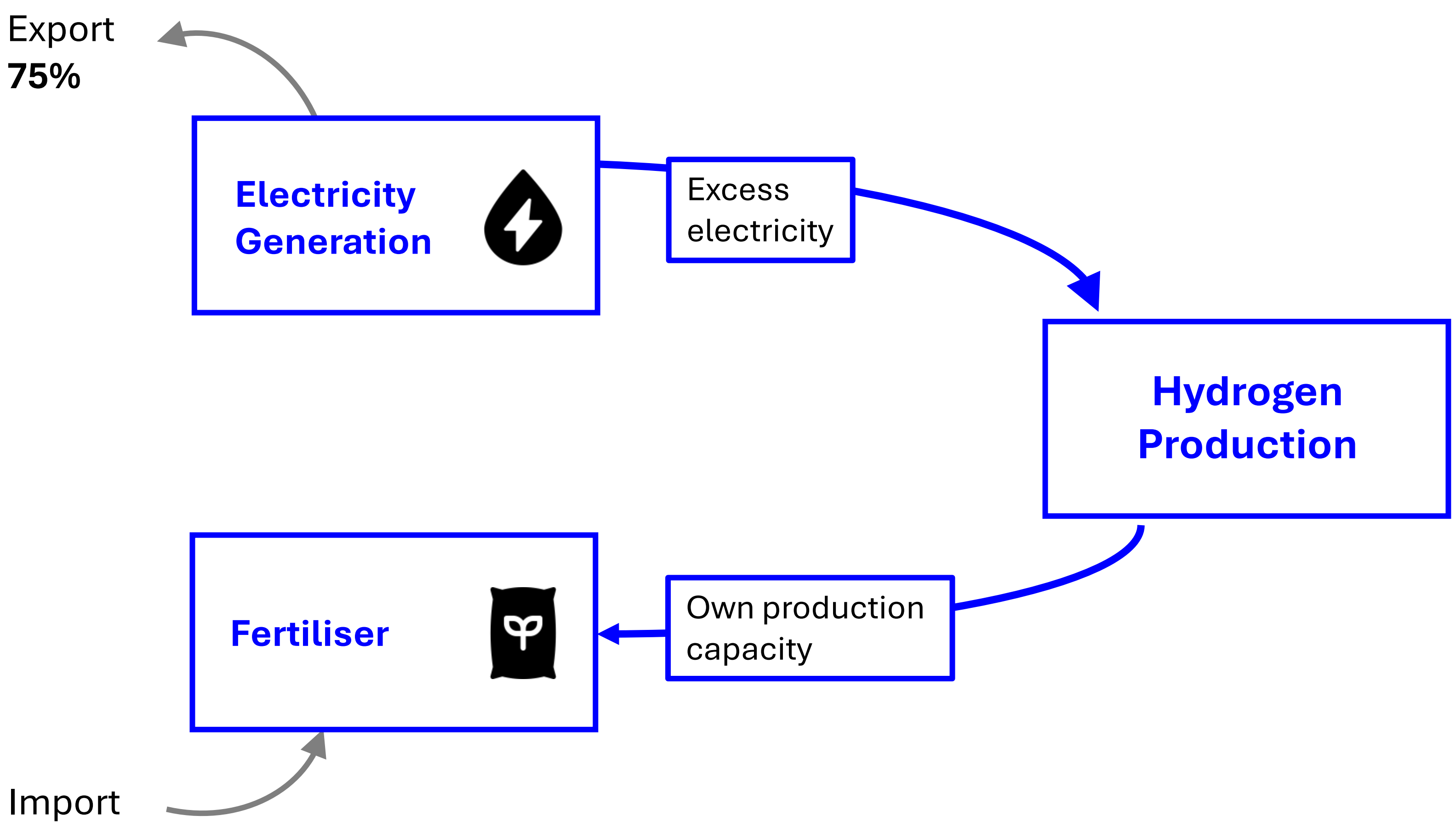
Fertiliser

Import

IMPERIAL

Low Profit from Electricity, High Cost for Fertiliser

Solution



Low Profit from Electricity, High Cost for Fertiliser

Solution

Export 75%

Electricity Generation

Excess electricity

Fertilizer

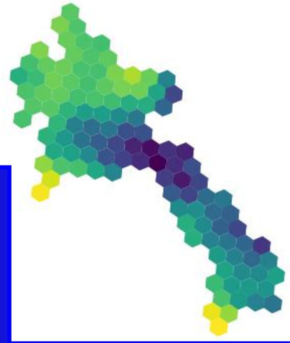
Own production capacity

Import

Research Area

Hydrogen Production

Least Cost hydrogen production model



Analysis of 4 drivers across 24 scenarios

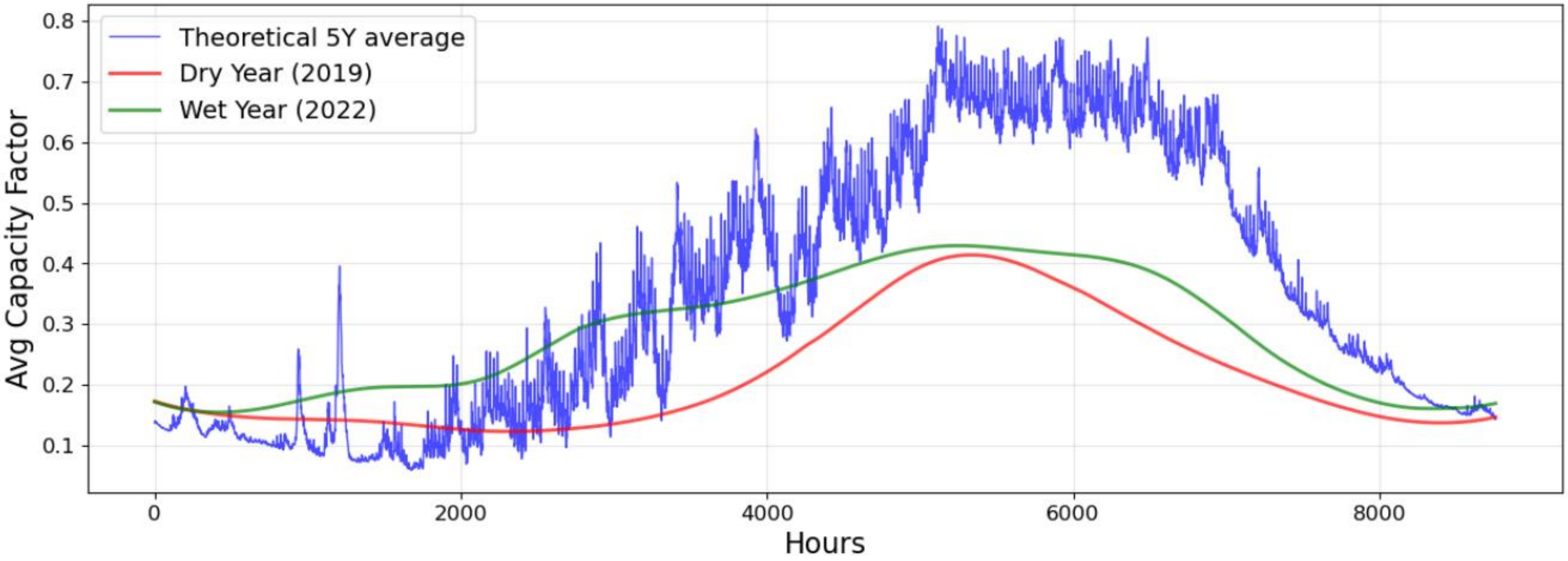
Scenario Analysis with 4 Drivers

- Electricity demand
- Electrolyser
- Runoff
- Year

	Electrolyser Technology	Runoff Variability	2025	2030
Total Generation	PEM	Dry	T1	T7
		Wet	T2	T8
		ATLITE	T3	T9
	ALK	Dry	T4	T10
		Wet	T5	T11
		ATLITE	T6	T12
Net Generation	PEM	Dry	N1	N7
		Wet	N2	N8
		ATLITE	N3	N9
	ALK	Dry	N4	N10
		Wet	N5	N11
		ATLITE	N6	N12

IMPERIAL

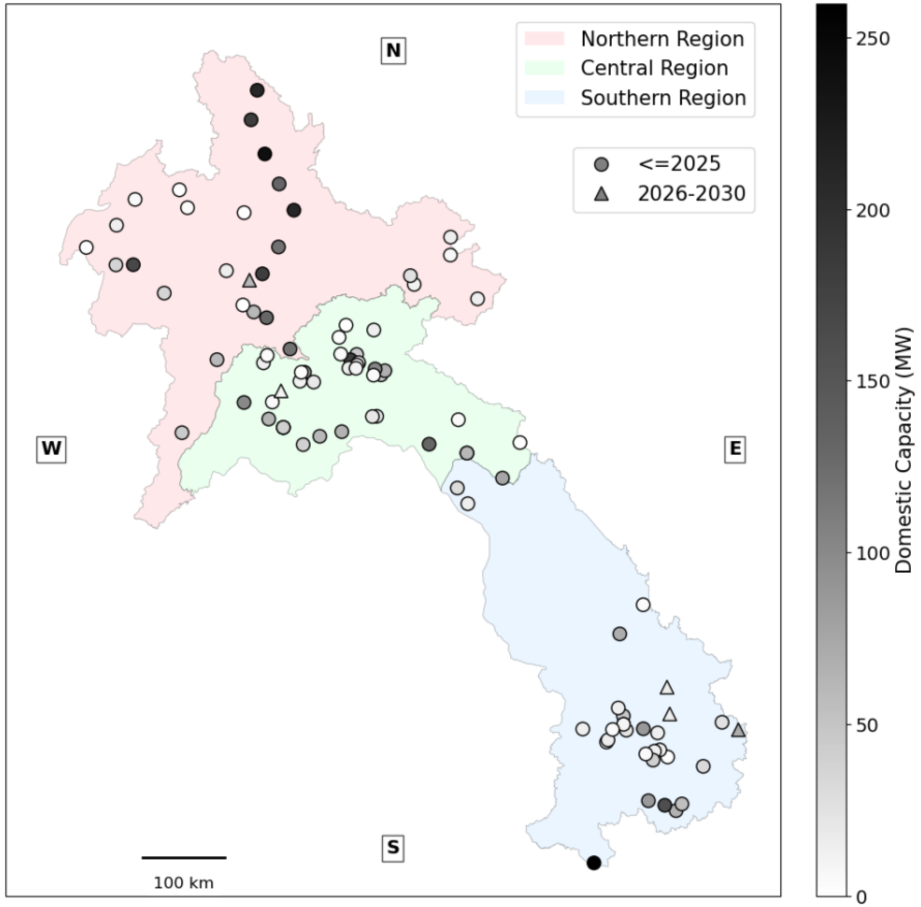
Runoff variability between dry, wet, and 5Y-average



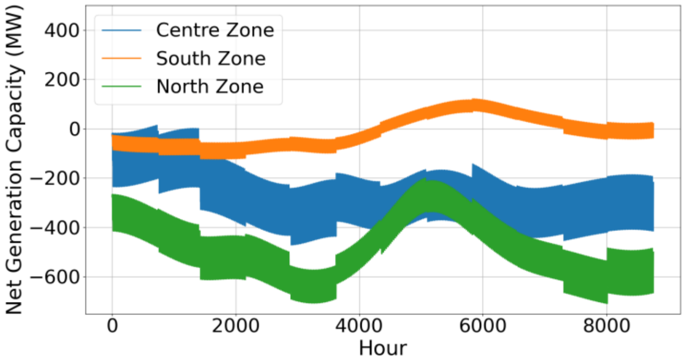
IMPERIAL

Electricity Demand in 2025 and 2030

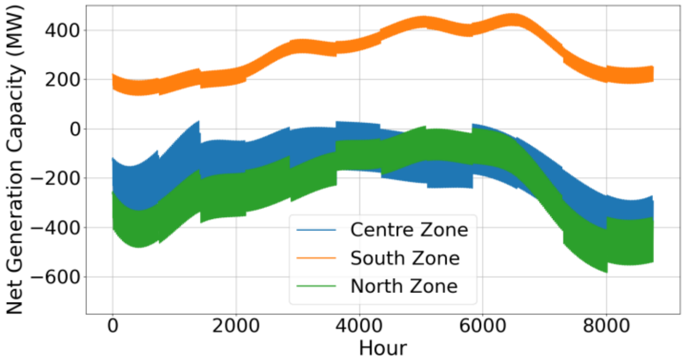
Split in 3 regions



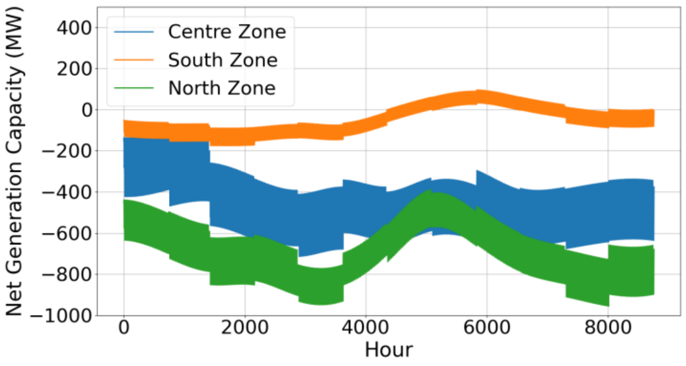
Available generation after electricity demand



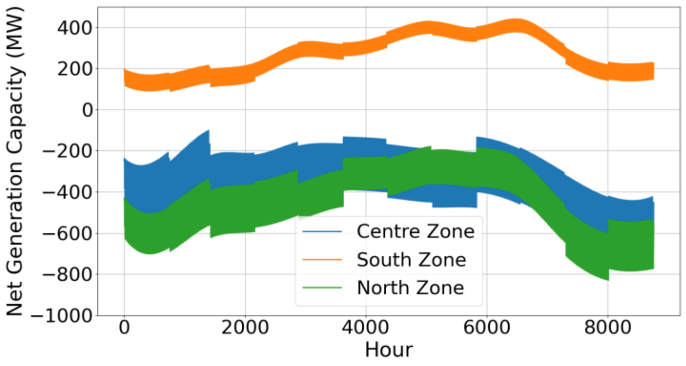
(a) Dry, 2025



(b) Wet, 2025



(c) Dry, 2030

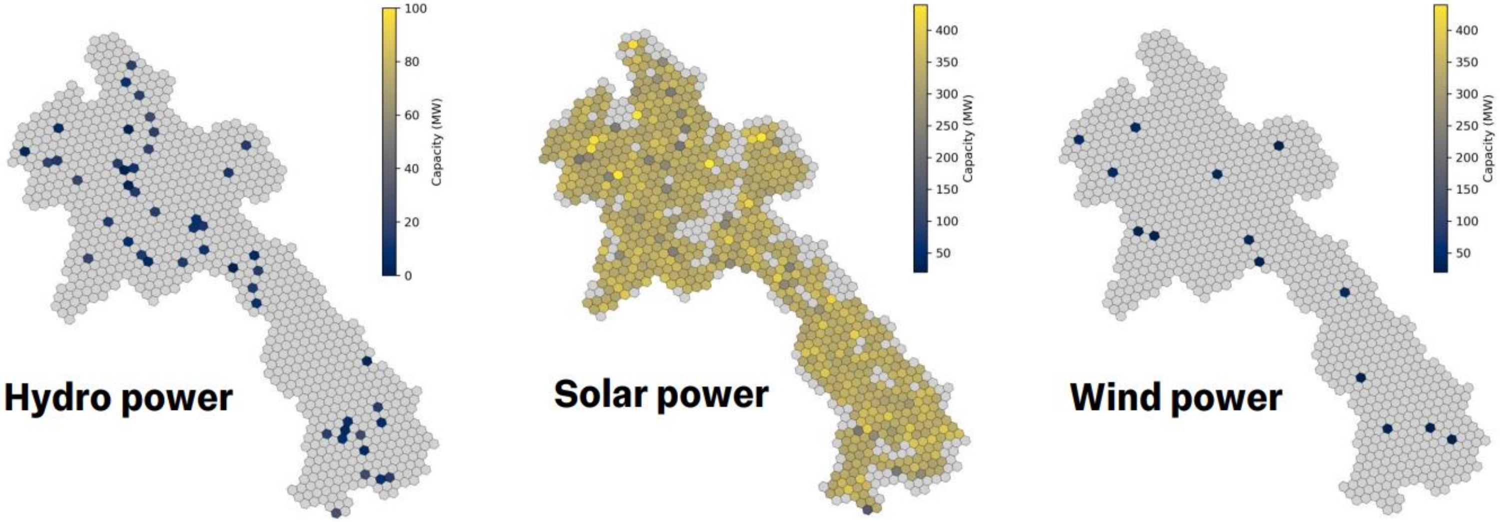


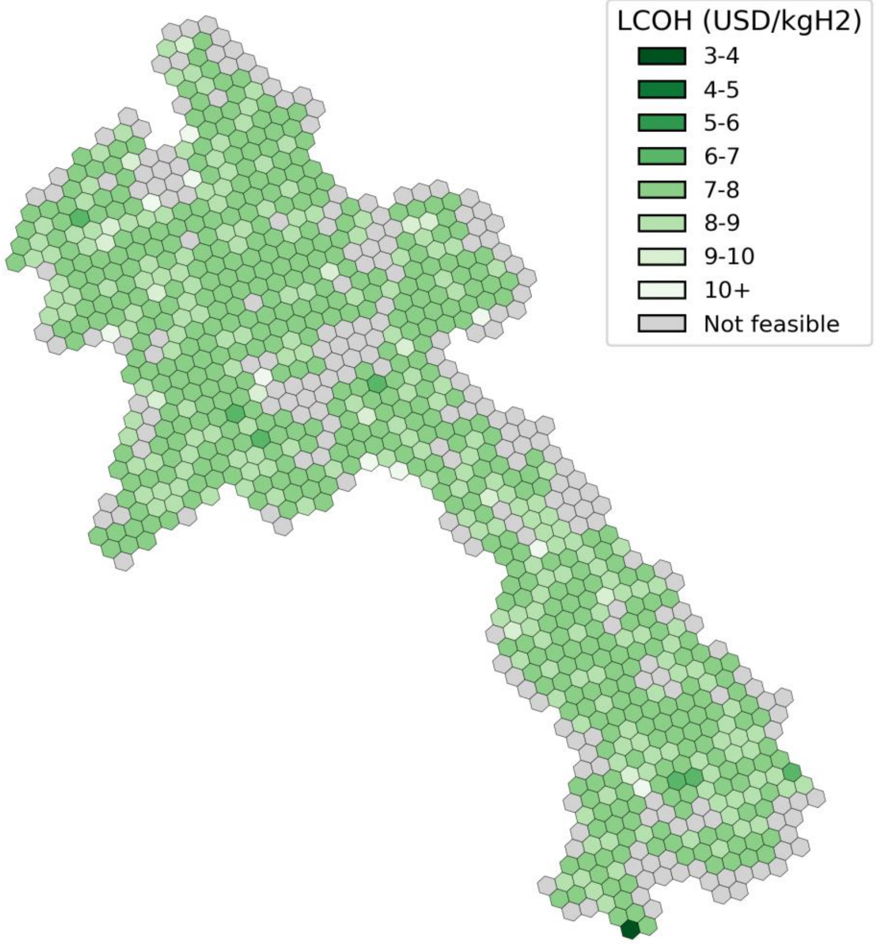
(d) Wet, 2030

IMPERIAL

Hexagonal Map of LCOH & Installed Capacity

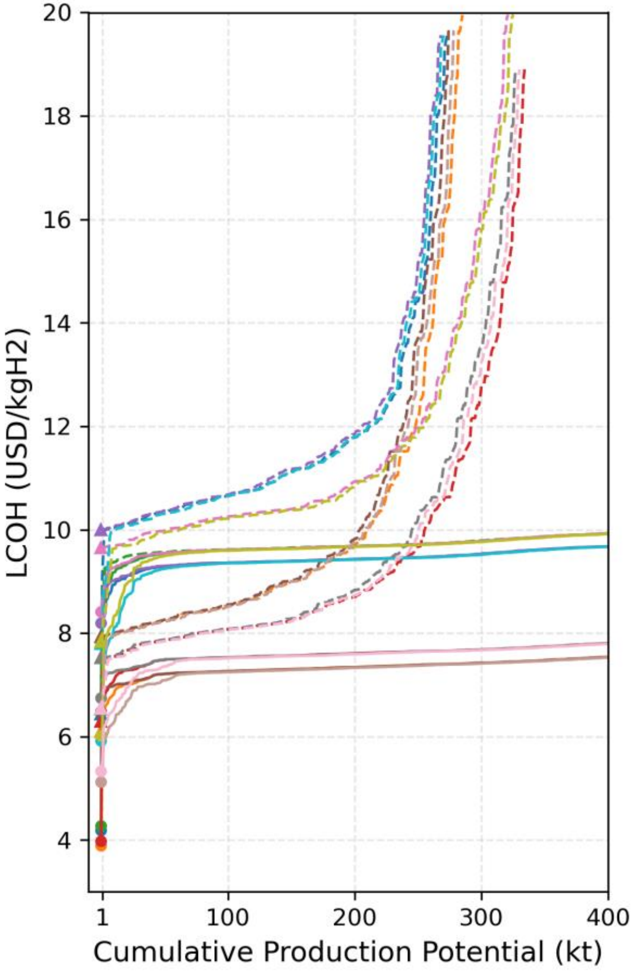
T8 **Total Generation, PEM, Wet, 2030**



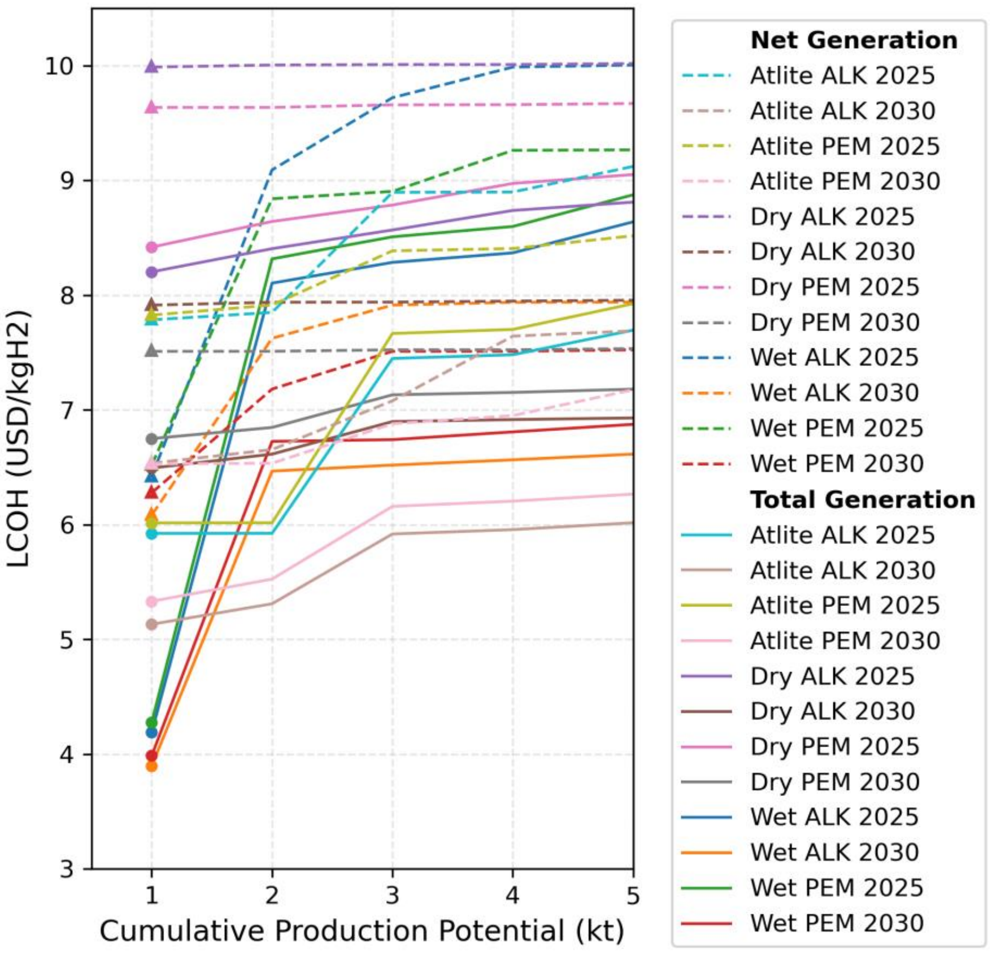


IMPERIAL

Results for All Scenarios

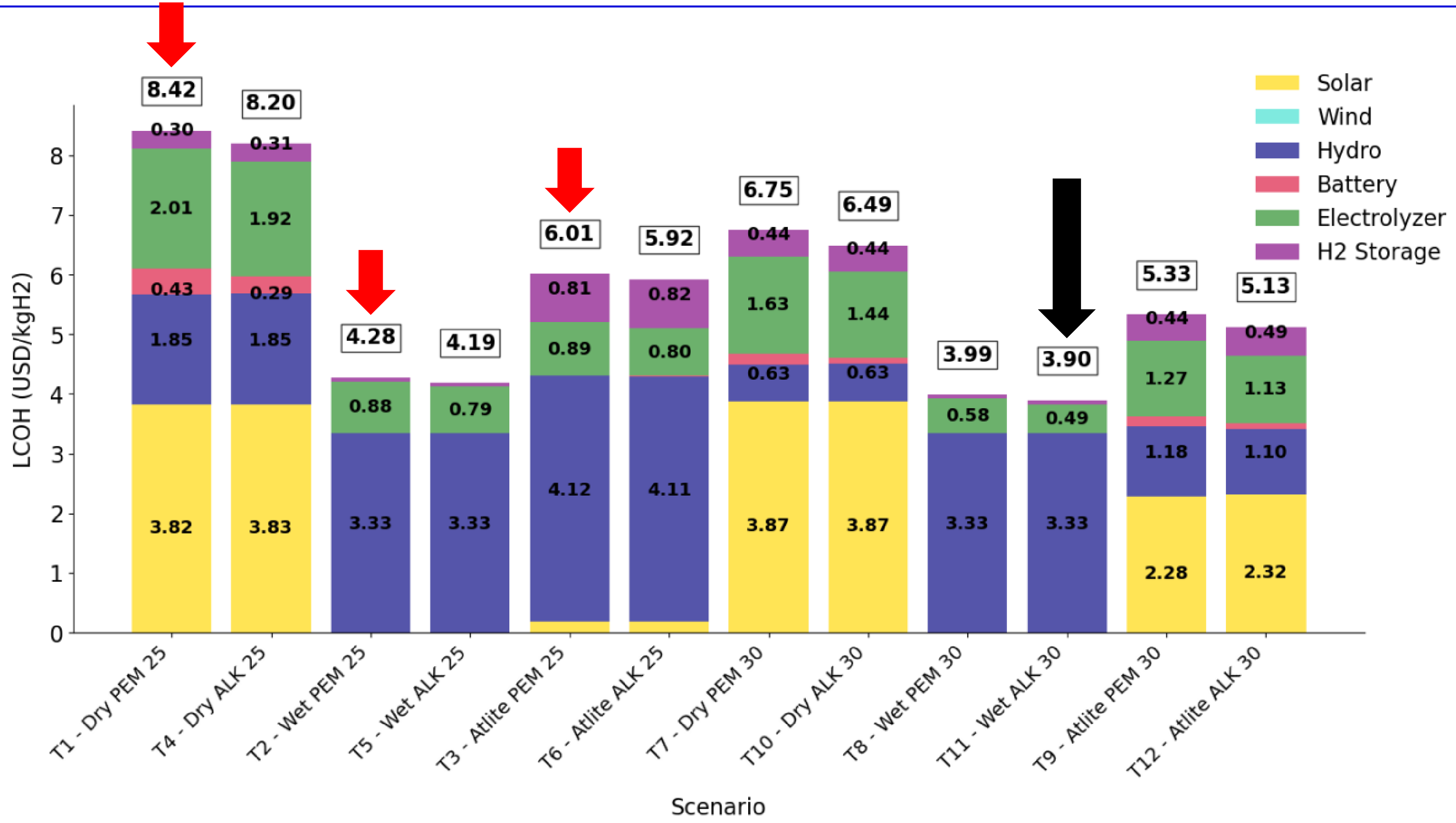


(a) Total overview

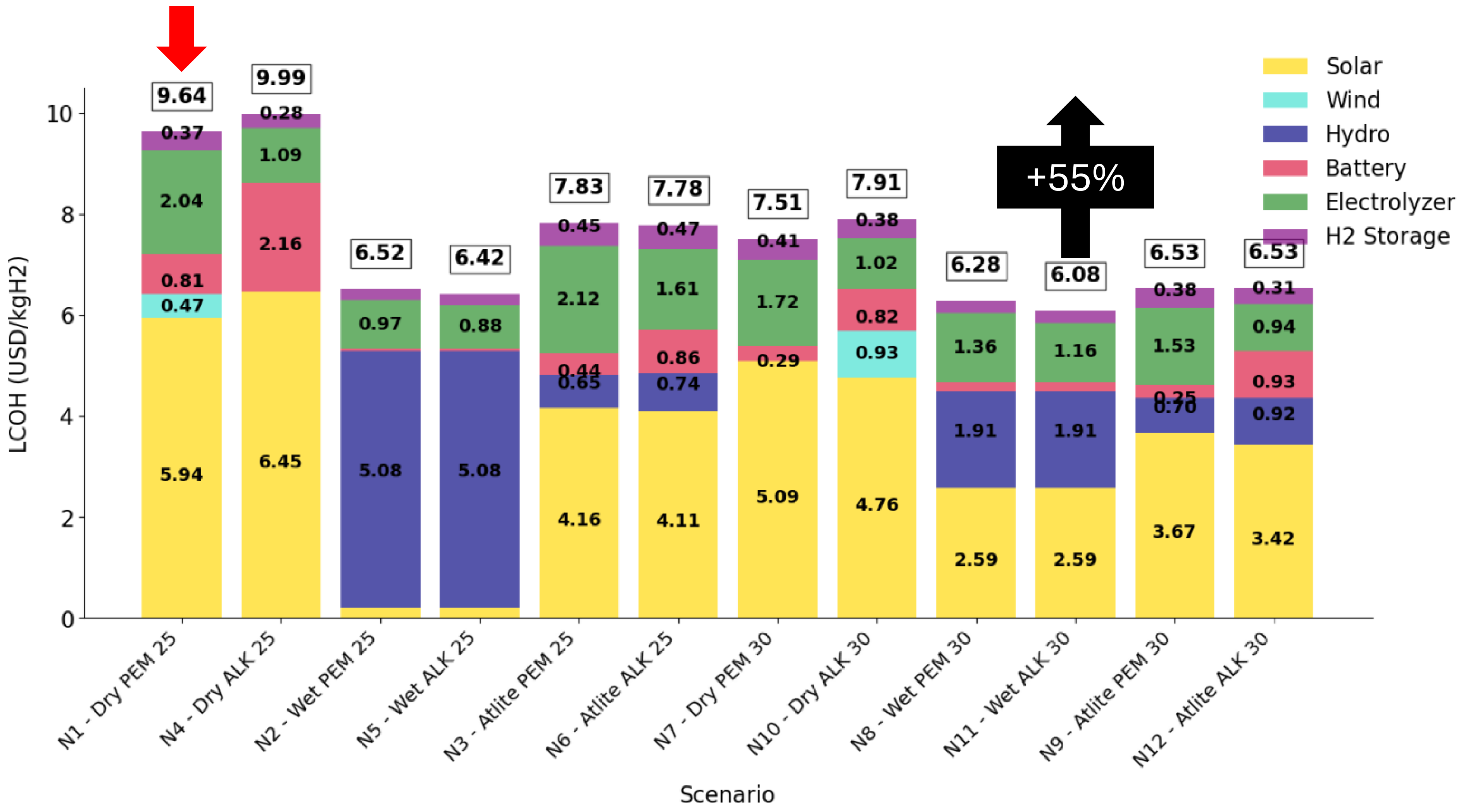


(b) Detailed view on cheapest hexagons

Results for Total Generation



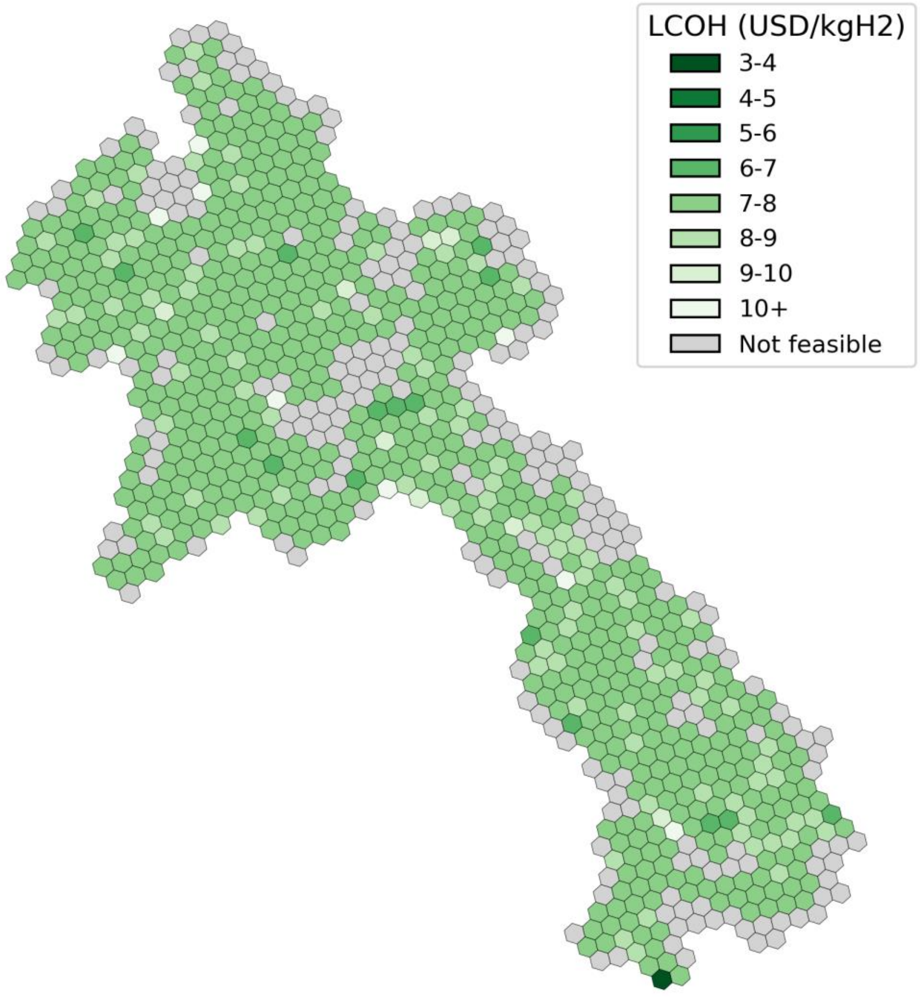
Results for Net Generation



Runoff variability is the main uncertainty for LCOH

Laos can produce hydrogen in 2030 with an LCOH of

3.90 $/kg **during a wet year.**



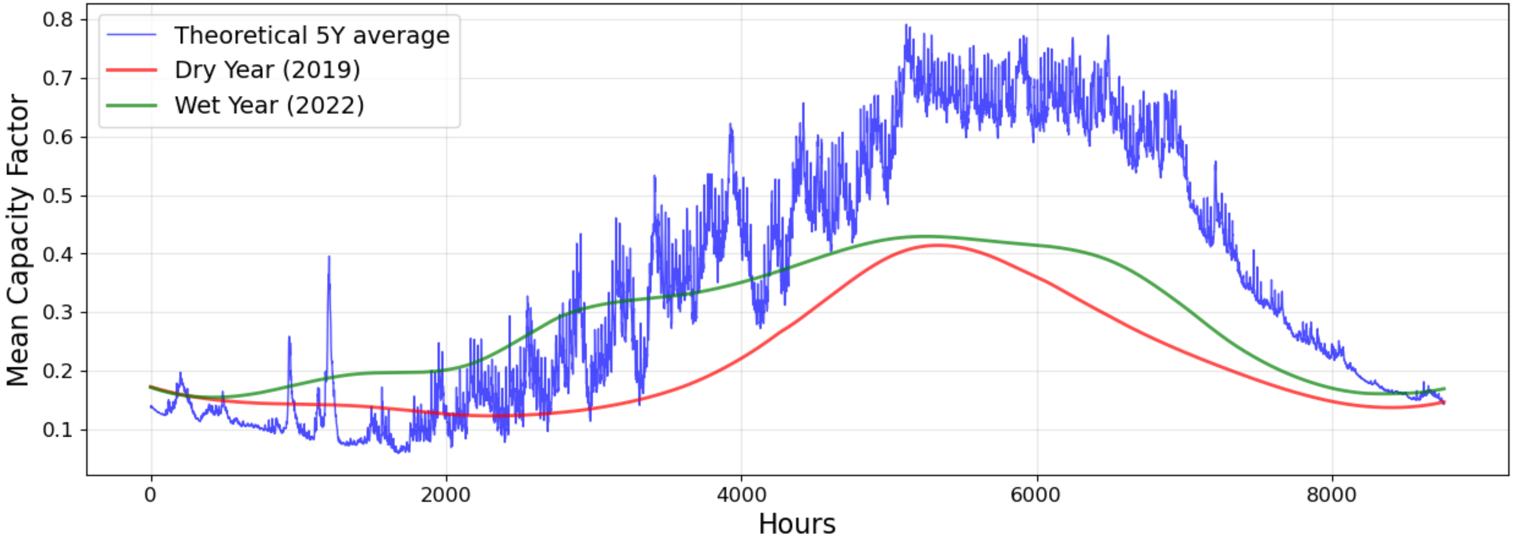
IMPERIAL

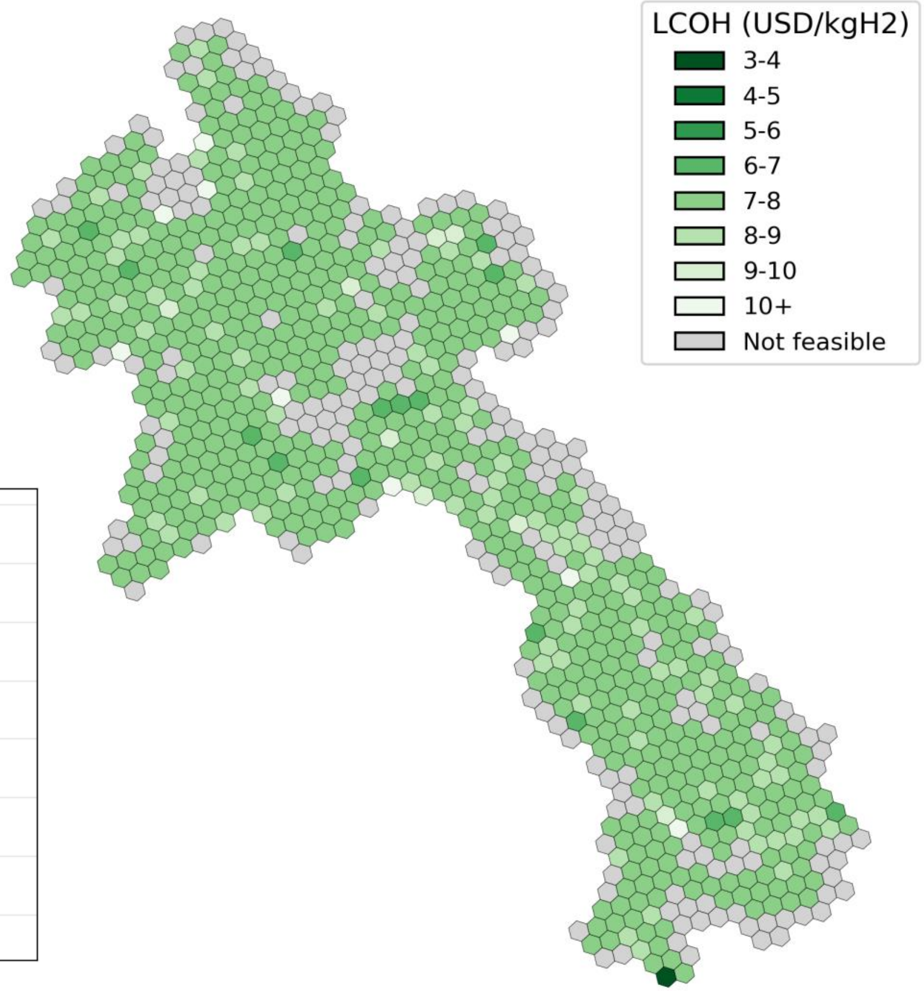
Runoff variability is the main uncertainty for LCOH

Laos can produce hydrogen in 2030 with an LCOH of

3.90 $/kg during a **wet** year.

6.49 $/kg during a **dry** year.





Summary

Limitations

- Uniform hydrogen demand distribution
- Lack of grid capacity
- Hexagon division impact
- Underutilised potential through fixed demand

Novelty

- Slope-exclusion
- Algorithm to estimate the hydraulic head of existing hydropower
- Integration of hydropower in GeoH2
- Evaluating hydrogen potential in Lao PDR

Research Highlights:

- Optimisation of least-cost hydrogen production with integrated hydropower
- Hydropower potential is modelled using ERA5 runoff and empirical generation data.
- Hydrogen production costs are lowest (US$3.9/kg) in wet years with alkaline electrolyser.
- Runoff variability in Laos can double hydrogen production costs in dry years.
- Accounting for electricity demand increases hydrogen costs, favouring southern Laos.

IMPERIAL

Thank you