Optimisation of green hydrogen supply chains in Chile

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

Francisca Jalil Vega, Research Fellow in Hydrogen Systems, UCL

Co-investigators: Tito Homem-de-Mello, Nicolás Allendes, UAI

Pedro Vargas, Enzo Sauma, David Pozo, MIGA

f.jalil-vega@ucl.ac.uk

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Agenda

1. Introduction
2. Methodology: Off-grid model
3. Results
4. Costs discussion
5. Methodology: On-grid model
6. Results comparison
7. Conclusion

Introduction

- Chile’s NDC:
  - Commitment to reach net-zero carbon emissions by 2050, with intermediate carbon budgets
  - Reduction of black carbon emissions by 25% with respect to 2016 levels over the next decade
- Hydrogen, when produced from low-carbon supply chains, has been recognised as a potential alternative for decarbonising “hard-to-abate” sectors (heavy duty transport, shipping, aviation, industry, heating)
- Chile has the potential to produce low-cost green hydrogen production
- How would such hydrogen supply chains (HSC) look like, and what are their environmental and economic implications?

Questions

- Where to build generation and transport infrastructure to make optimal use of existing resources?
    - Where to install solar/wind plants and what is their optimal capacity
    - Where to install electrolysis technologies, which technologies and what capacity
    - What do we transport? From/to where? (water, electricity, hydrogen)
- How to configure and operate the supply chains considering variable energy supply?
- How to produce hydrogen with limited water resources?
    - Location and capacity of water desalination and transport

Methodology – Off-grid model

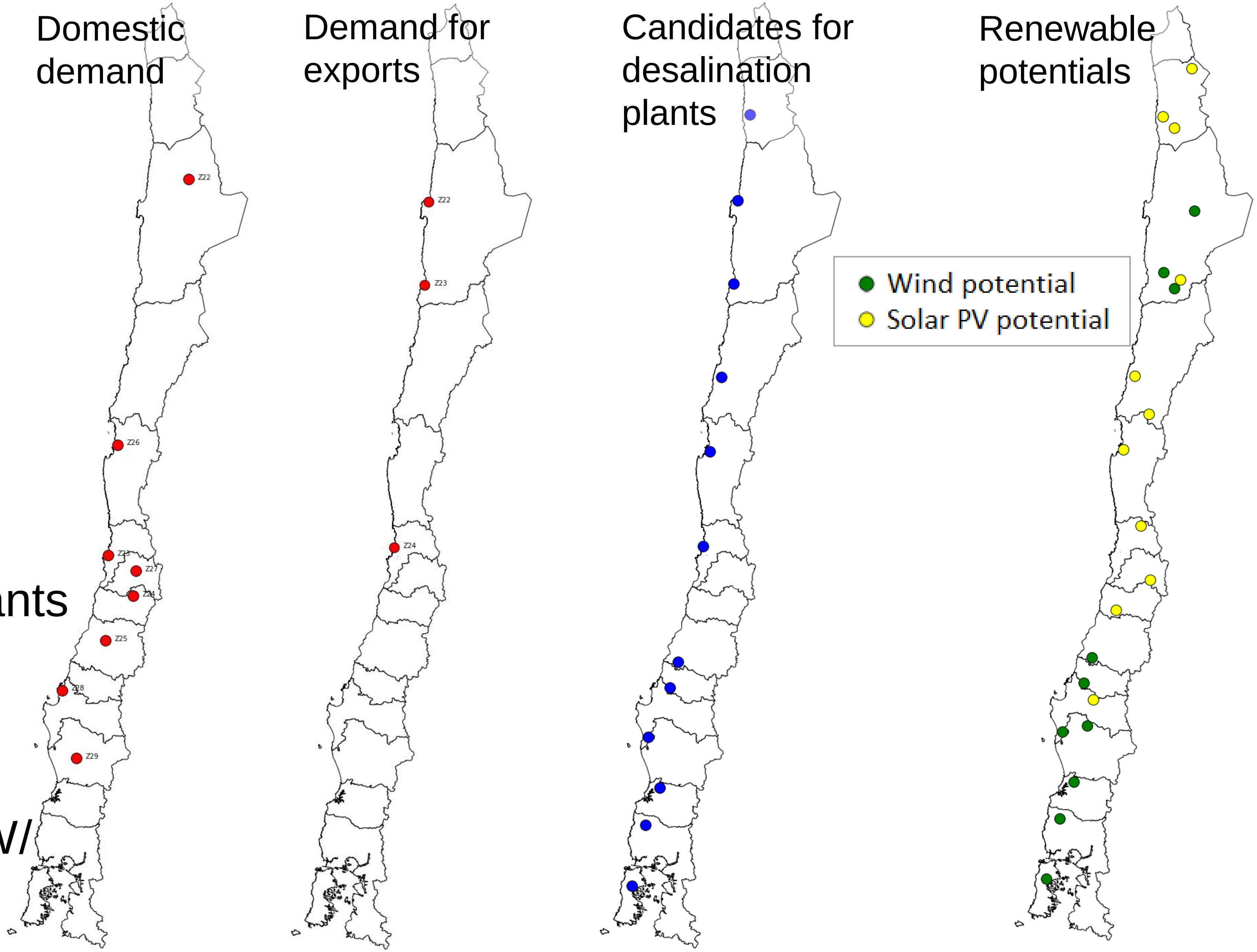
- We propose a **geographically explicit** linear optimisation model for green hydrogen supply chain (HSC).
- The model **minimises** the **levelised cost of hydrogen** (LCOH) for a planning horizon between **2025-2050**, using typical days and **hourly** resolution.
- Investment decisions every 5 years
- **6 demand scenarios**: E1 (demand for exports), and E2 (domestic demand)
- Model decides:
    - Locations and capacities of wind and solar generation technologies
    - Locations, capacities, and types of electrolysers
    - Locations and capacities of desalination plants
    - Capacities and layouts of electricity lines, water pipelines, and hydrogen transport (trucks and pipelines)
    - Hourly operation of technologies

Annual hydrogen demand (Mt).
E1: Demand for exports
E2: Domestic demand

Year	E1.3	E1.5	E1.10	E1.15	E1.20	E2
2025	0	0	0	0	0	0.011
2030	0.11	0.19	0.38	0.57	0.77	0.023
3035	0.27	0.45	0.91	1.37	1.82	0.035
2040	0.43	0.72	1.44	2.16	2.88	0.046
2045	0.59	0.98	1.97	2.95	3.94	0.046
2050	0.75	1.25	2.5	3.75	5	0.046

Methodology

- Modelled area: SEN
- 2 scenarios
  - Domestic demand
  - Demand for exports
- Candidate zones for installing desalination plants
- Renewable potential clusters – candidates for installing wind/PV generation plants (50 GW/ 650 GW)



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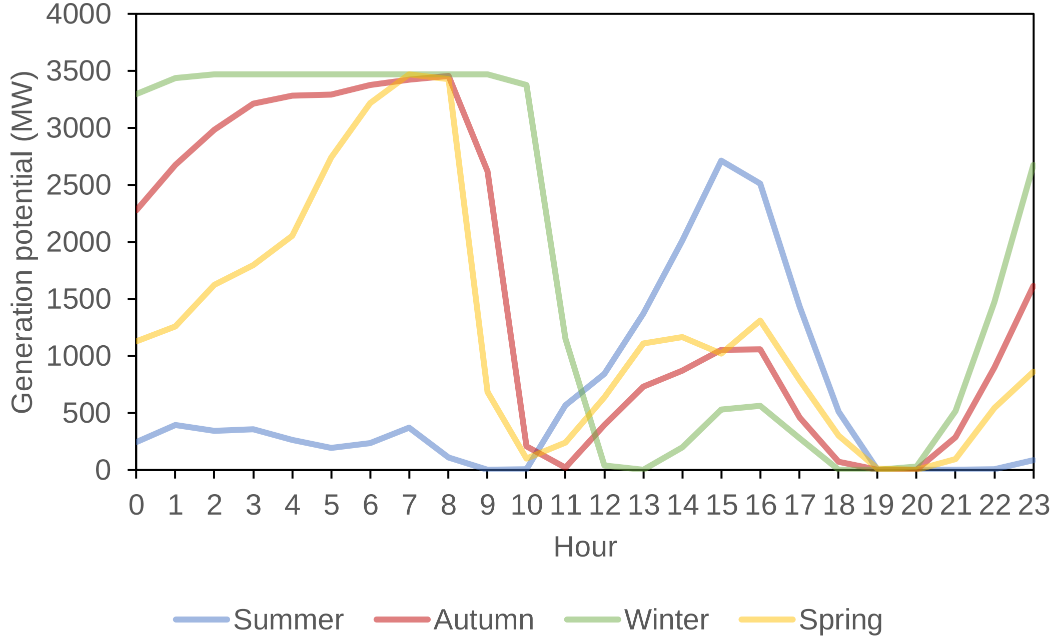
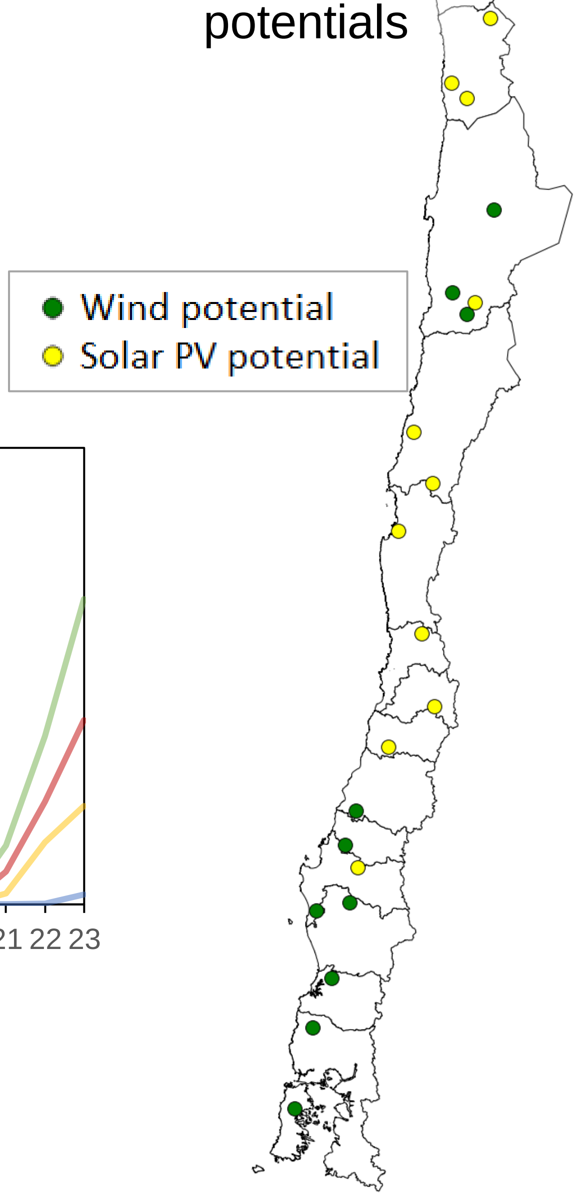
Example: Zone 1, wind profiles



Renewable potentials



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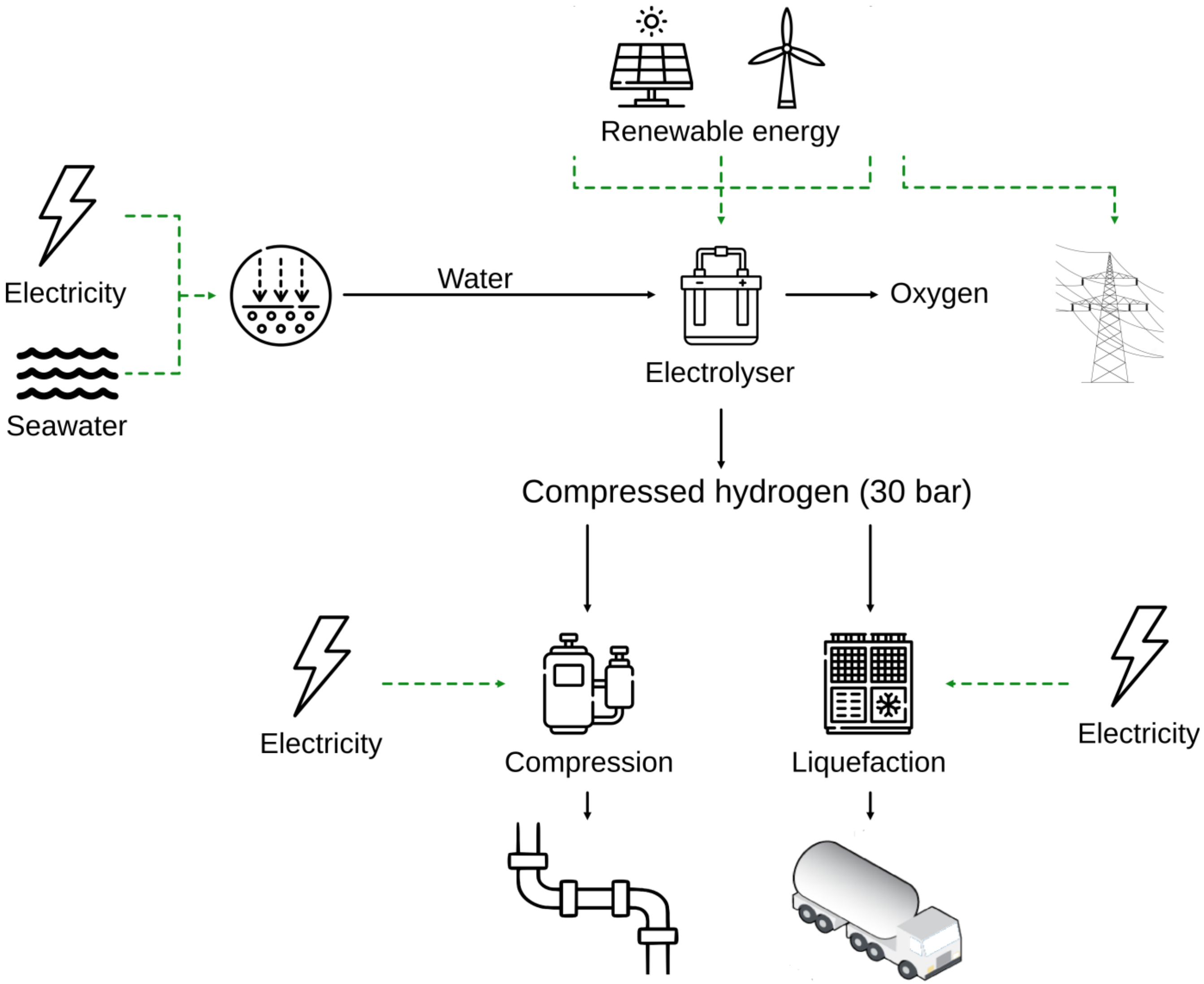


Methodology

- **Model**
  - Flows
    - Electricity
    - Hydrogen
    - Water
  - Transport modes
    - Electricity: Transmission lines
    - Hydrogen: Pipelines, liquid hydrogen trucks
    - Water: Pipelines
  - Conversion technologies
    - Electricity generation: PV, wind turbines
    - Electrolysis: PEM
    - Desalination: Reverse osmosis

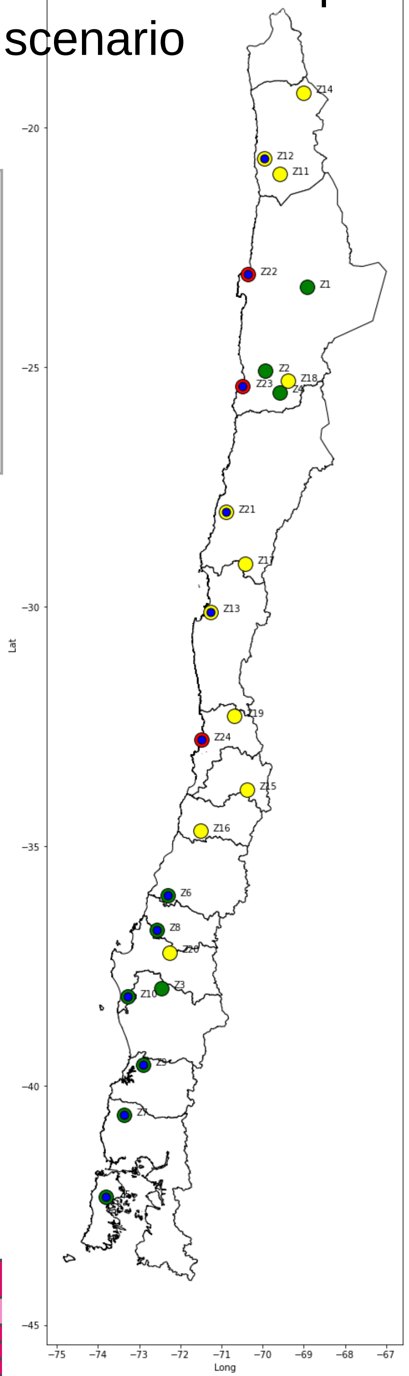
Wind potential

PV potential

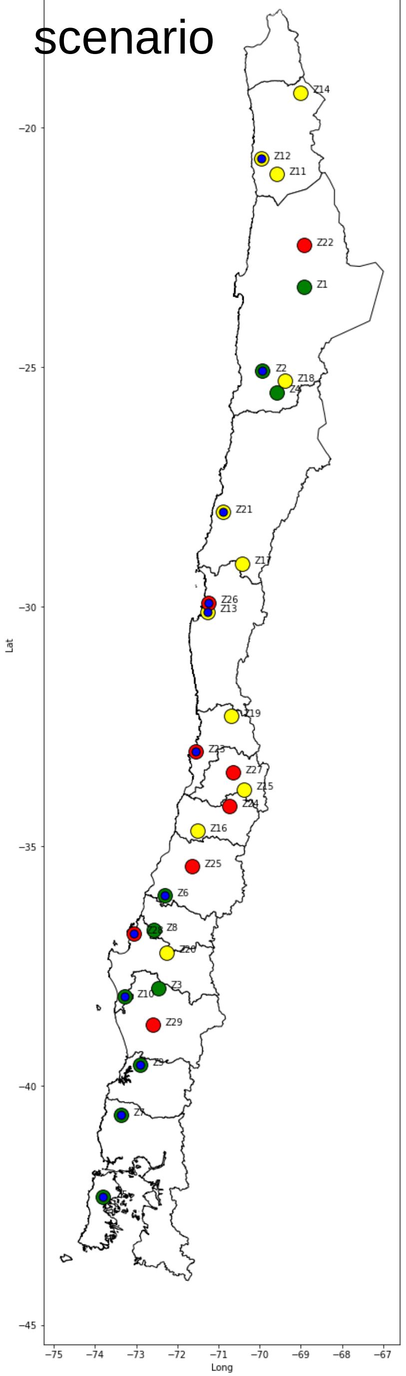
Demands

Desalination candidates

Demand for exports scenario



Domestic demand scenario



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Methodology – Model formulation

Constraints and objective function

$$LCOH = \frac{\sum_{t=2025}^{2050} \frac{I_t + O\&M_t - RV_{2050}}{(1+r)^{t-2020}}}{\sum_{t=2025}^{2050} \frac{H_2\ Demand_t}{(1+r)^{t-2020}}}$$

Flow constraints

- Flow balance in each zone for all vectors

Technology capacities

- Operative capacities constrained by installed capacities
- Decommission technologies when meeting lifetime

Operation constraints

- Electricity generation constrained by renewable potentials and profiles
- Flow conversion considering conversion efficiency of technologies

Transport modes

- Transport capacity can only be installed between neighbour zones
- Flows constrained by transport modes capacities

Objective function

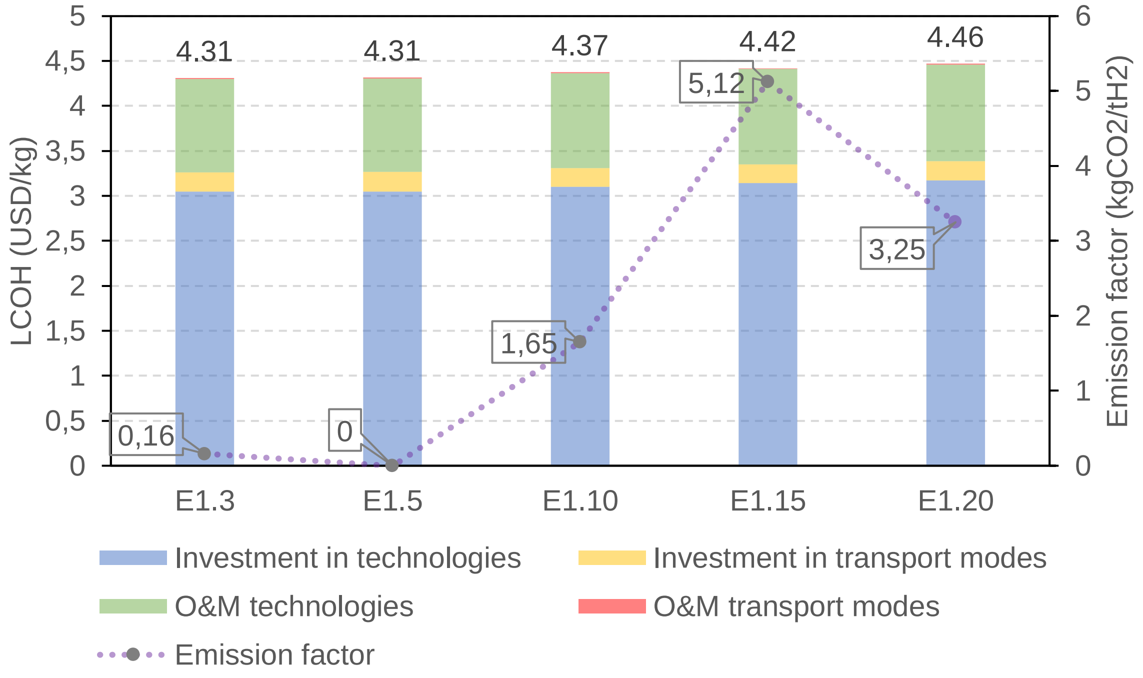
- Minimise levelised cost of hydrogen (LCOH)
- CAPEX, OPEX, residual values at the end of the planning horizon

Results

Total hydrogen demand for planning horizon (Mt)

E1.3	E1.5	E1.10	E1.15	E1.20	E2
7.81	13.03	26.06	39.06	52.08	0.86

LCOH decomposition and emission factors for export scenarios



- Main results for domestic and exports scenarios:
  - Export scenarios:
    - LCOH: 4.31 – 4.46 USD/kg
    - Emission factors: 0 – 5.12 kgCO2/tonH2
    - Water consumption: 70 – 469 Mt
  - Domestic demand scenarios:
    - LCOH: 6.26 USD/kg
    - Emission factor: 1.09 $kgCO_2/tonH_2$
    - Water consumption: 7.76 Mt
  - Different demands lead to different HSC configurations

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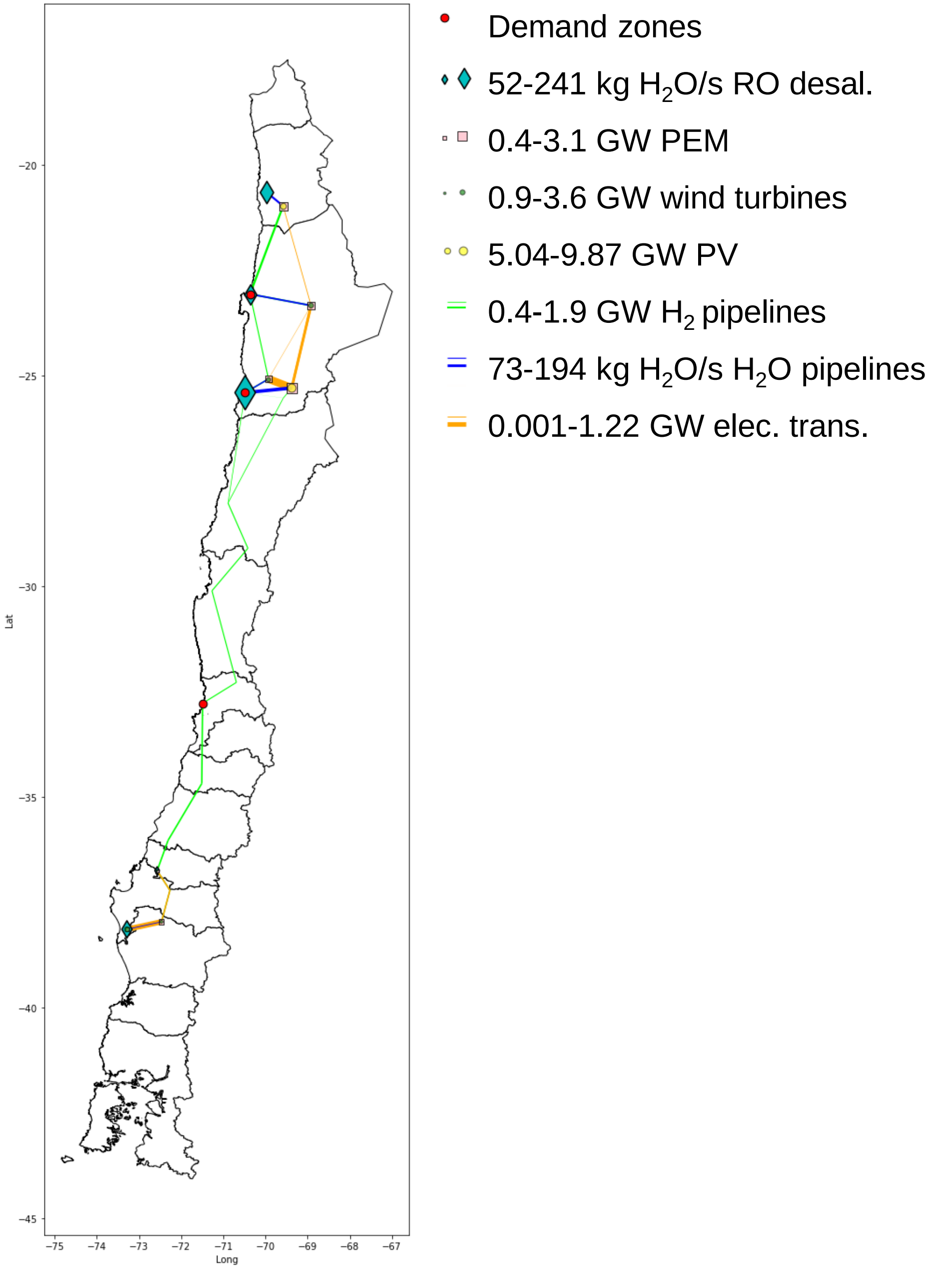
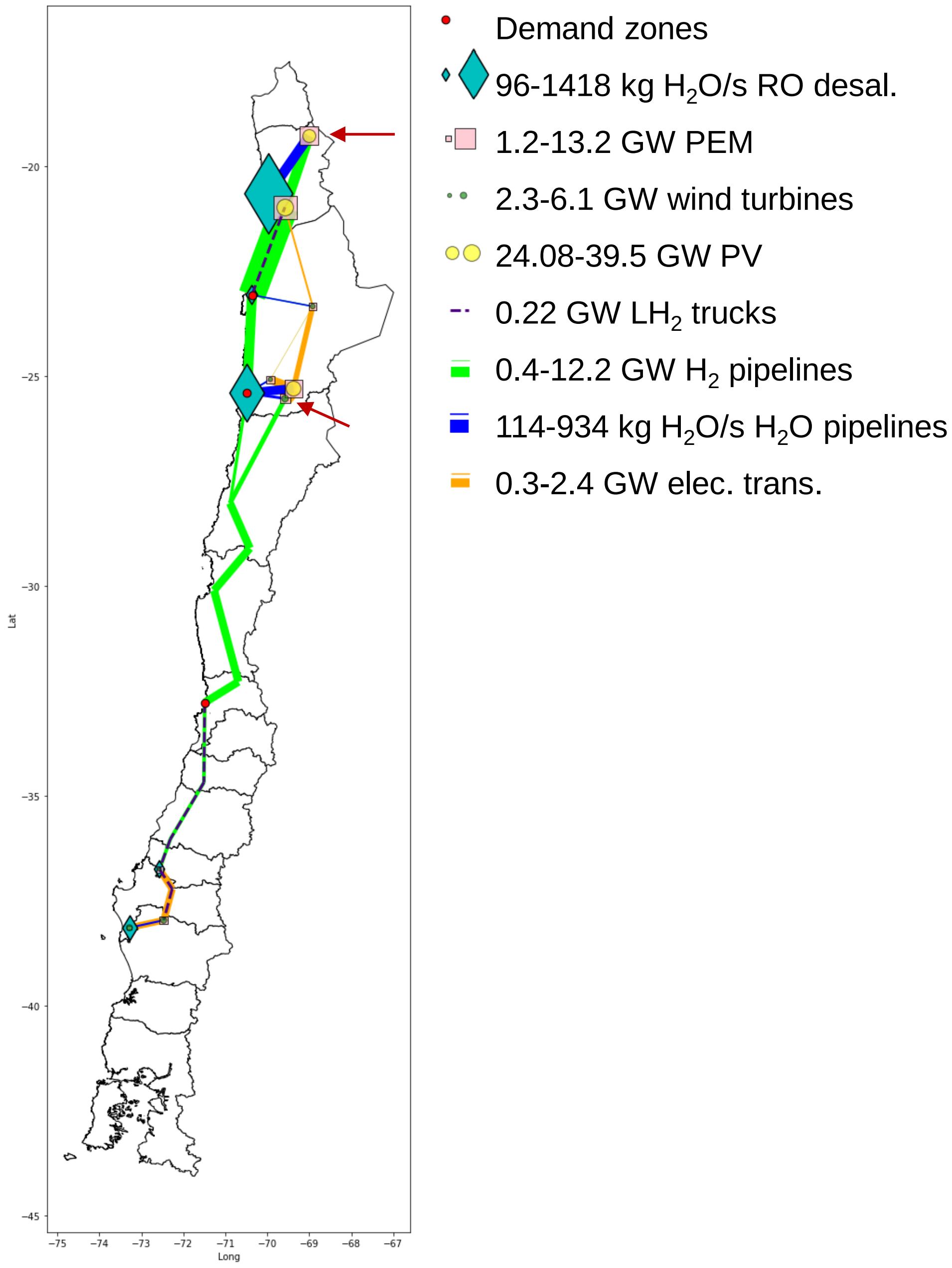
Results

- Exports scenario E1.5 – 2050
  - Infrastructure concentrated in northern regions
  - Hydrogen production in interior zones
  - Both renewable sources used for electricity generation (PV, wind)
  - Water distributed to interior zones
  - No use of H_2 trucks



Results

- Exports scenario E1.20 – 2050
  - Higher installed capacities of technologies and transport infrastructure
  - Increase of LCOH
  - Hydrogen production in interior zones: PV and wind, mostly PV
  - Incorporates the use of H_2 trucks for H_2 transport
  - New zones of H_2 production



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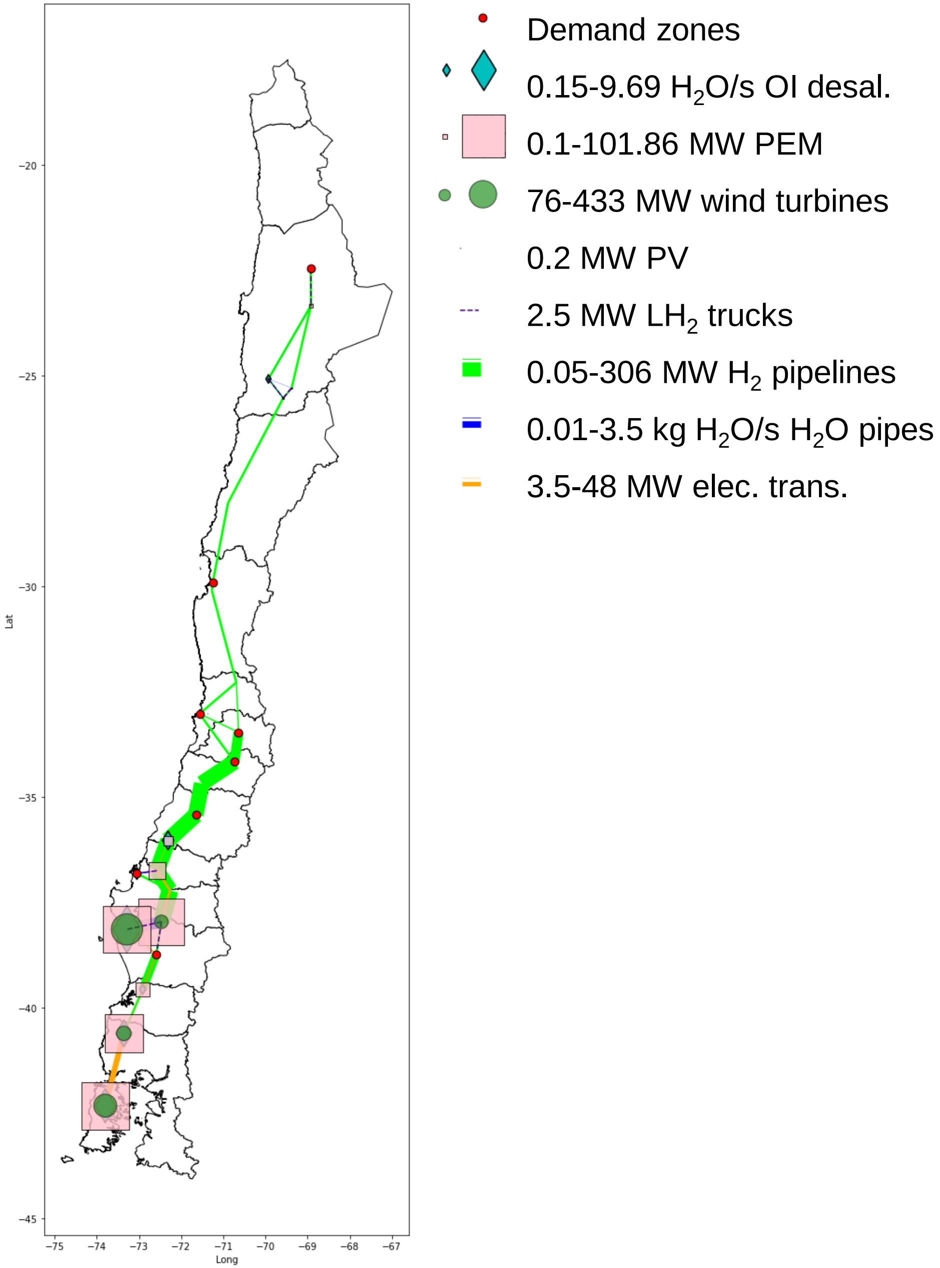
Results

- Domestic demand scenario E2 – 2050
  - Smaller capacities
  - Infrastructure concentrated in southern regions
  - Mainly wind turbines for electricity generation
  - Hydrogen produced in coastal and demand zones



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Costs discussion

- Hydrogen for exports cost comparison

Destination	Distance (km)	Final calculated LCOH[1] (USD/kg)	Local green H_2 LCOH[2] (USD/kg)	Local blue/grey H_2 LCOH[2] (USD/kg)	Competitiveness against local green H_2 production	Competitiveness against local blue/grey H_2 production
Osaka, Japan	17500	6.86-7.01	6.89-7.31	3	X	X
LA, USA	8500	6.33-6.48	8.01-9.13	2-2.78	✓	X
Busan, South Korea	17500	6.86-7.01	8.11-12.6	6.17	✓	X
Hamburg, Germany	14500	6.69-6.84	6.96-19.14	2.73	✓	X
Shanghai, China	18500	6.91-7.06	8.3-15.8	1.2-3.46	✓	X

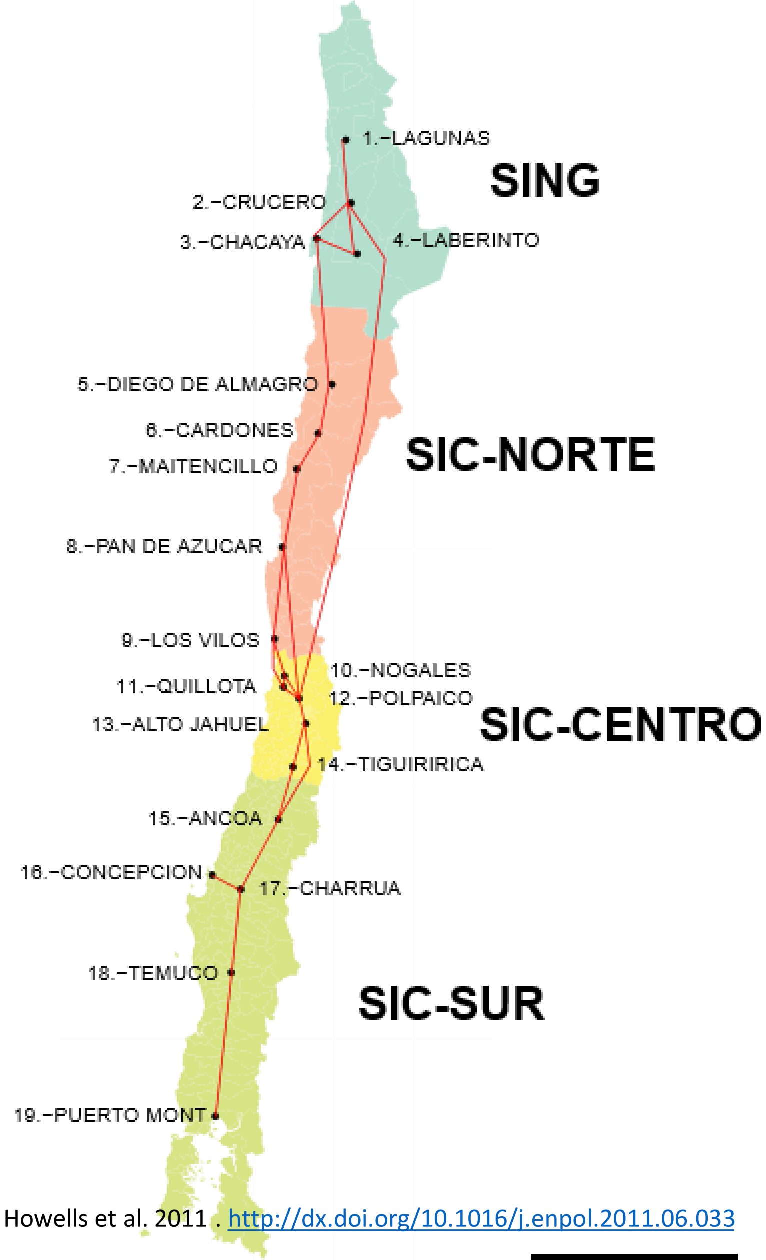
[1]Assumptions:
- Levelised cost of liquefaction 1.5 USD/kg
- Levelised cost of shipping: Distance dependent

[2]Costs from literature survey

On-grid model

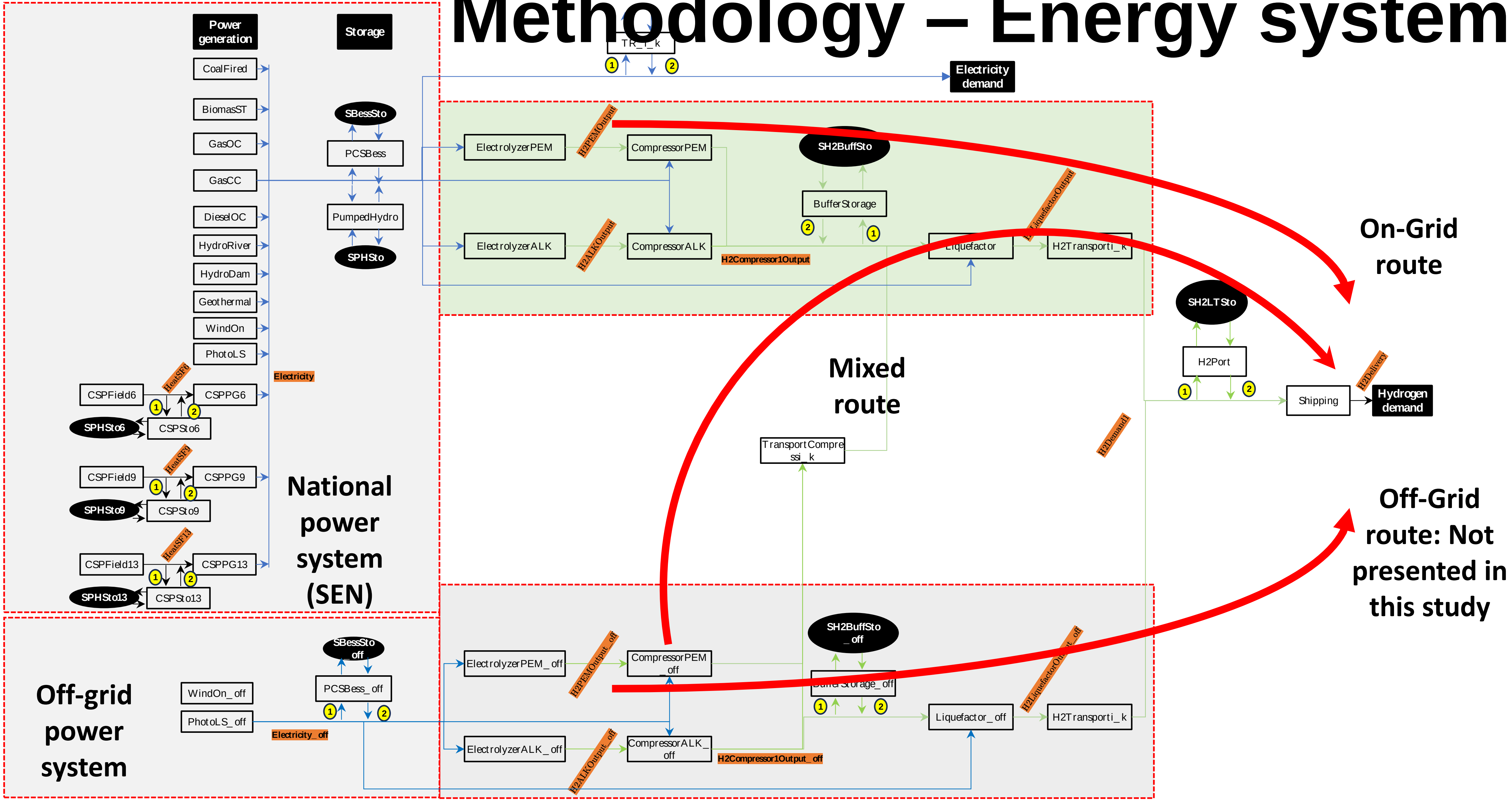
Methodology – On-grid model

- Energy systems model OSeMOSYS [1].
- Minimum cost optimisation considering whole system's growth and operation
- 19 nodes and 23 transmission lines
- Investment periods every 5 years (2025 to 2060).
- 4 typical days, hourly resolution
- Hydrogen demand from *Accelerated Transition* scenario PELP.
- Generation potentials, installed capacities, projects under construction, fuel costs, hourly availability of variable renewables, CAPEX, OPEX
- **Additional constraints:** Emissions limit for the whole period of H_2 production of 28.2 gCO_2/MJ (EU)
- **H2-Ref and H2-Limit scenarios:** On-grid production **without** and **with** emissions limit

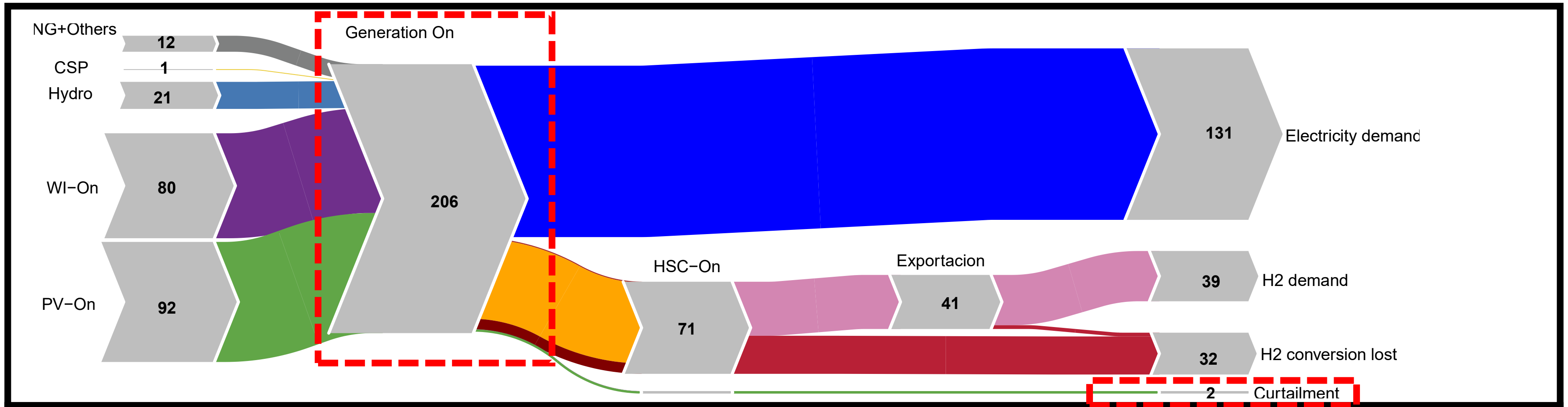


[1] Howells et al. 2011 . http://dx.doi.org/10.1016/j.enpol.2011.06.033

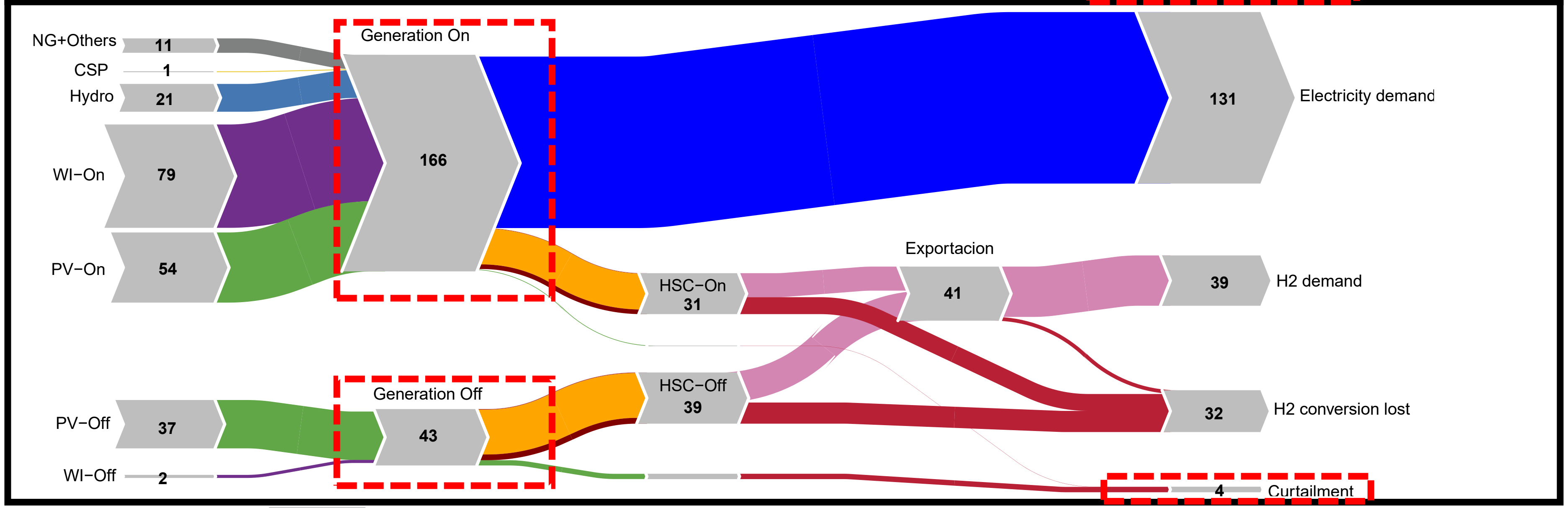
Methodology – Energy system



Results



Energy balance 2040
H2-Ref scenario (TWh)



Energy balance 2040
H2-Lim scenario (TWh)

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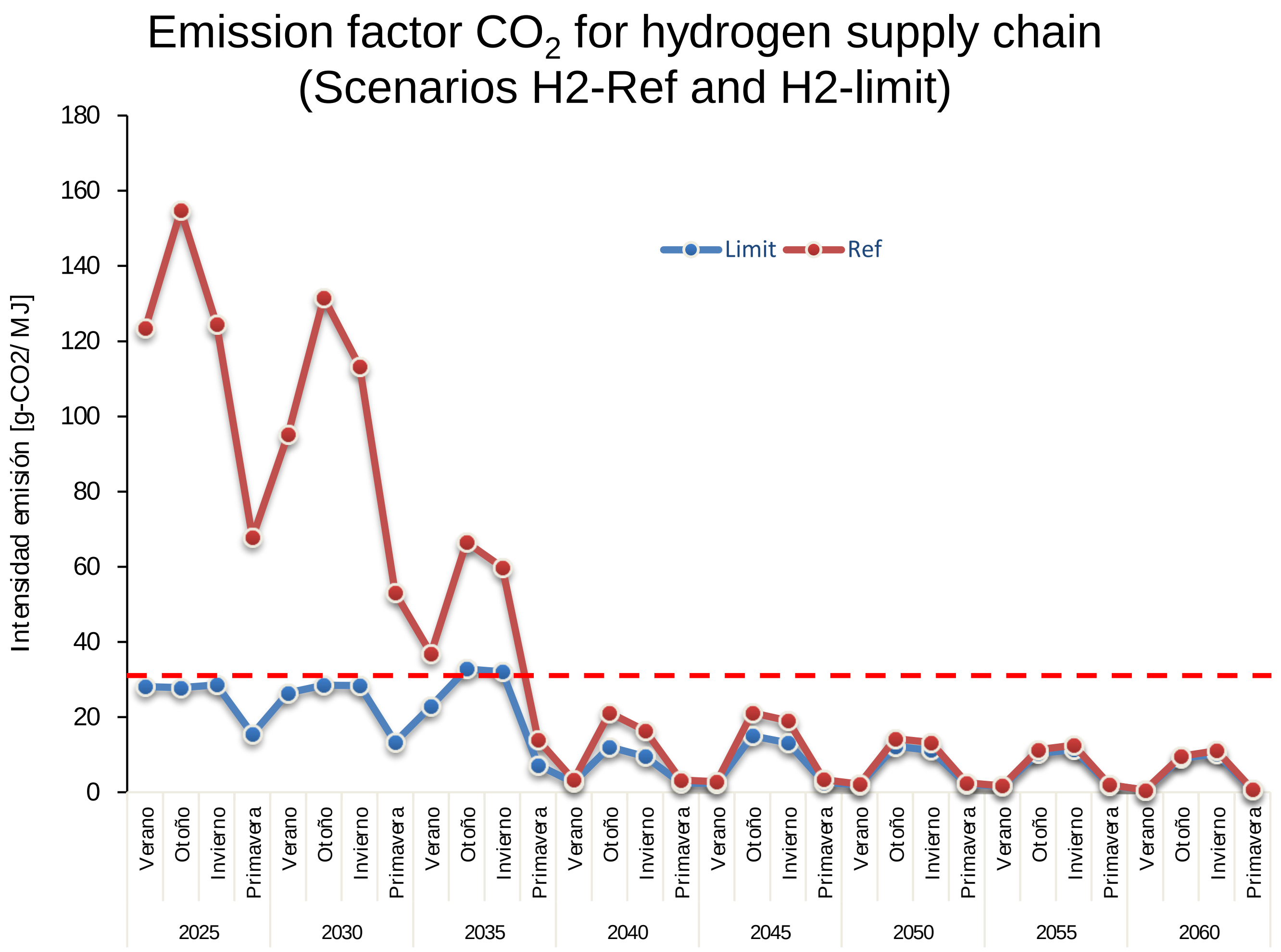
Results

- LCOH:
  - H2-Ref: 3 USD/kg
  - H2-Limit: 3.14 USD/kg
  - (Previous: 4.31 – 4.46 USD/kg)
  - H2_Limit: Emission factor does not exceed 28.2 gCO_2/MJ



Conclusion

- Different assumptions (spatial resolution, location and magnitude of demands)
- LCOH:
  - Off-grid exports: 4.31 – 4.46 USD/kg
  - Off-grid domestic demand: 6.26 USD/kg
  - On-grid green: 3.14 USD/kg
- Optimal HSC configuration:
  - Off-grid exports:
    - Concentrated in the north: **PV**, wind
    - Hydrogen production in interior areas
  - Off-grid domestic demand:
    - Concentrated in the south: **wind**
    - Production near demand and coast
  - On-grid green:
    - Concentrated in the north: **PV**

- Competitiveness for exports
  - Sensitive to technoeconomic assumptions
  - Potentially competitive compared to local green hydrogen production
  - Not competitive against blue/grey hydrogen
- Current/future work
  - Hourly operation for whole year, include hydrogen and electricity storage, and operational constraints for alkaline electrolysers
  - Environmental impacts of brine production, and H_2 leakage GWP
  - Off grid versus on-grid production scenarios

Thank you for listening

Francisca Jalil-Vega, Research Fellow in Hydrogen Systems,
f.jalil-vega@ucl.ac.uk
ucl.ac.uk/bartlett/energy @UCL_Energy

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