A PyPSA-PH Case Study: Will Hydrogen ever have a role on Grid and Off-grid Island Electrification?

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PyPSA Users Meeting
01 July 2025 | Online

PyPSA-PH
GITHUB REPOSITORY

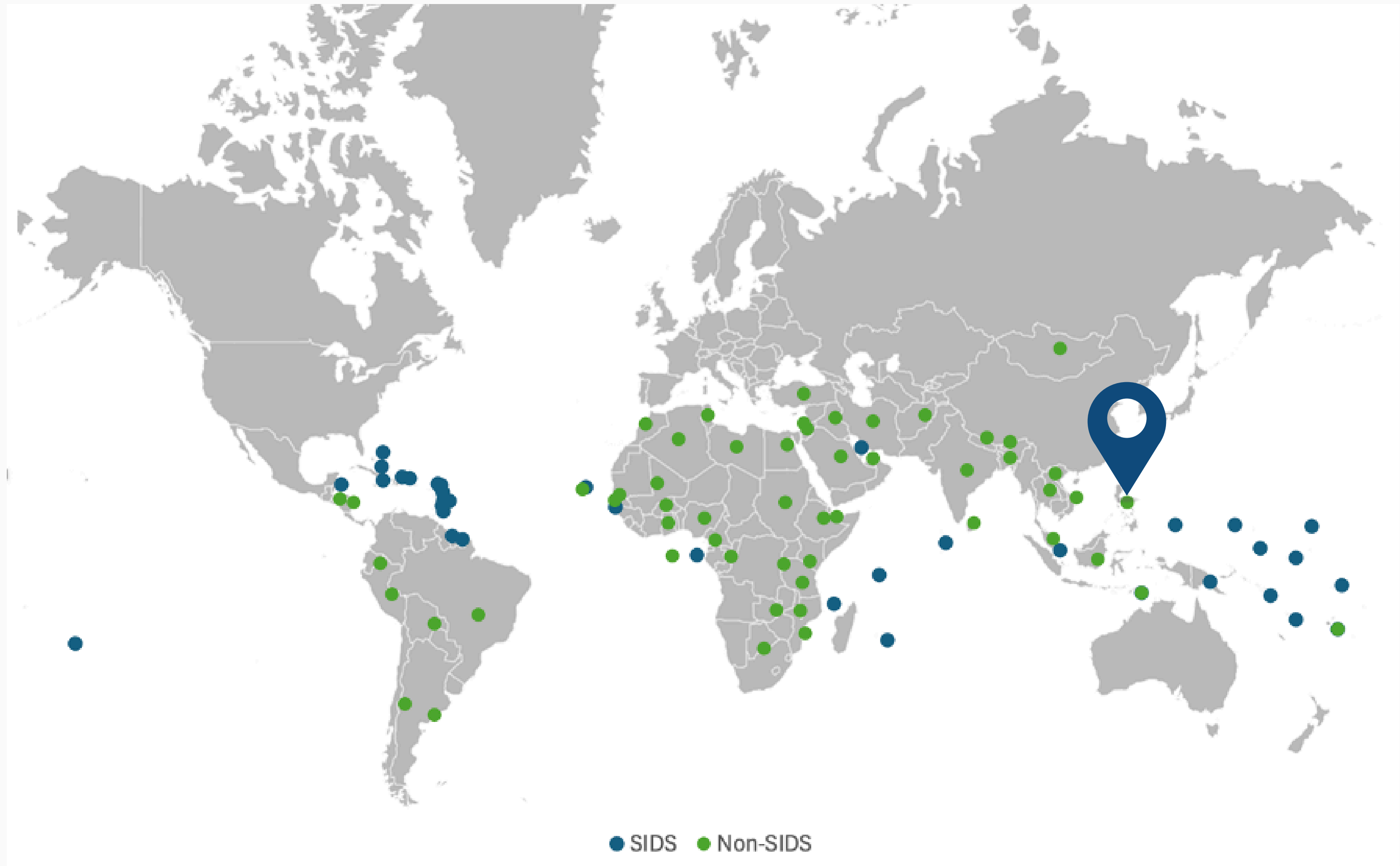
https://github.com/arizeosalac/PyPSA-PH.git

Outline

- *Challenges on Off-grid Electrification*
- *PyPSA-PH Baseline Model and Validation*
- *Future Hydrogen Scenarios ON Grid*
- *Future Hydrogen Scenarios OFF-Grid*
- *Recommendation*

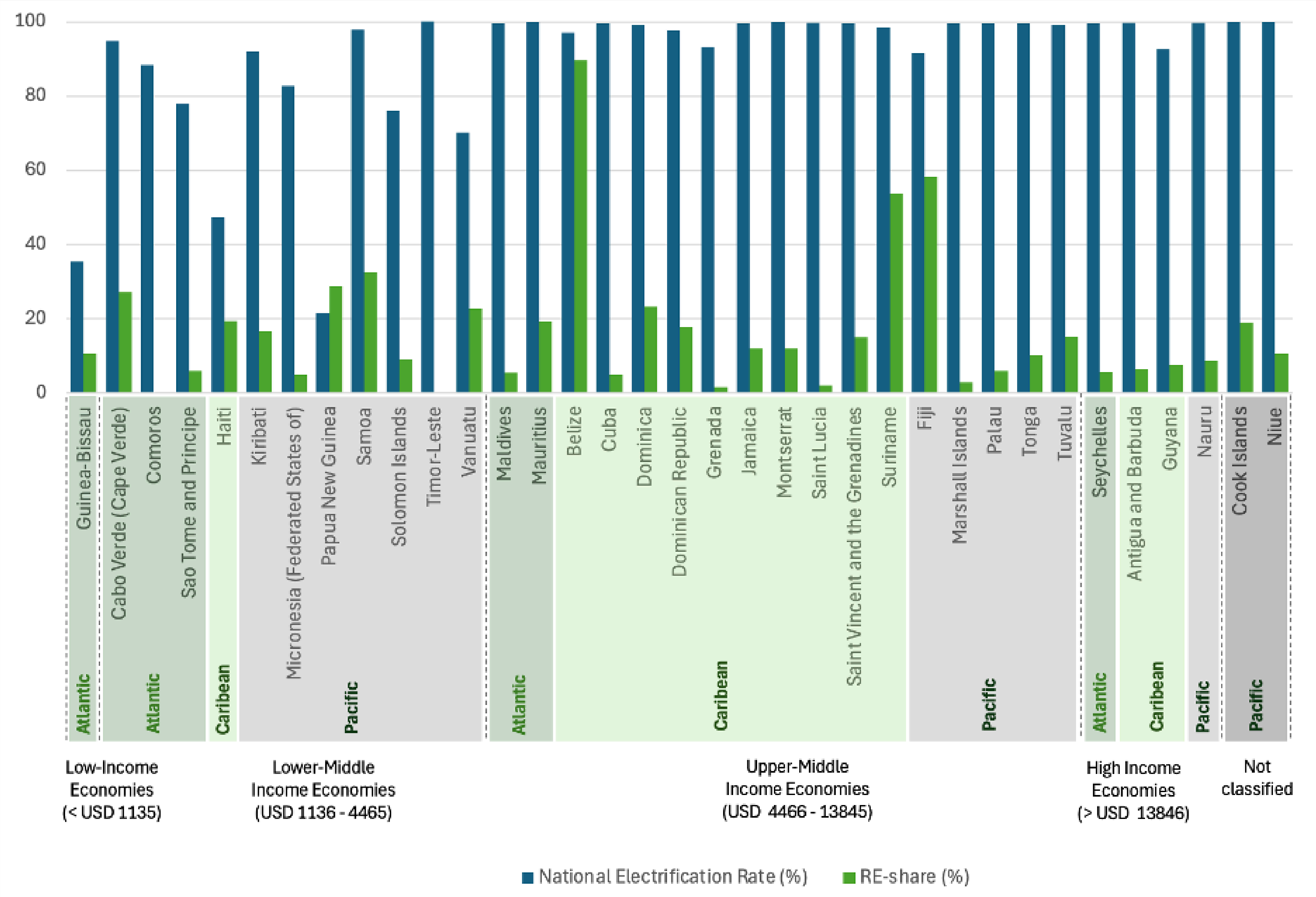
Challenges of Island Electrification

Lagging Electrification in Off-grid Communities



Most island countries could have achieved electrification, but have been prone to risk due to **high dependence to fossil fuel** [1]

Most energy and power system analysis have focused more on mainland countries and **lacks investigation on offgrid island communities.**

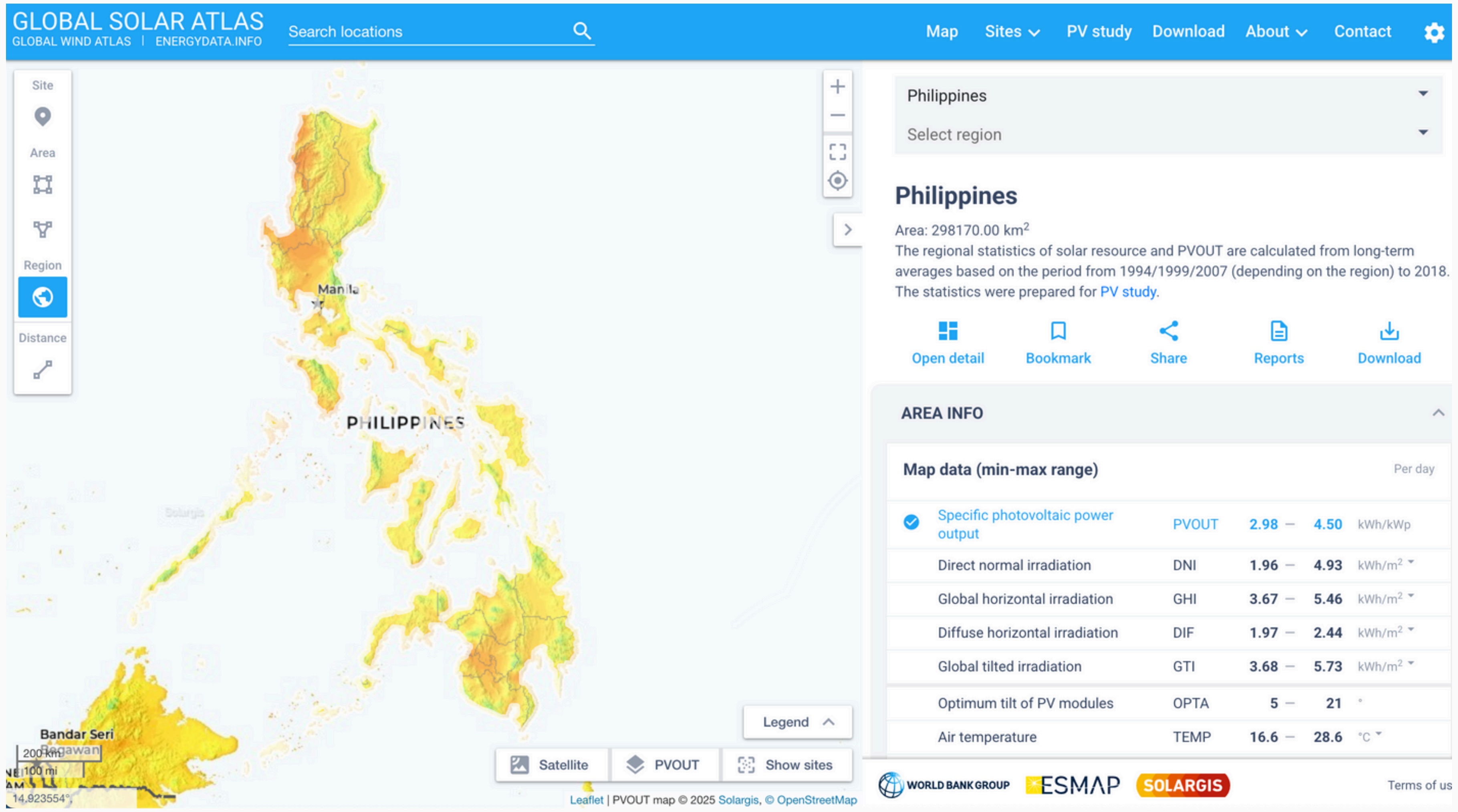


Electrification in the Philippines

Why is it hard to electrify islands?

The Philippines has fairly good solar resource potential [2] **BUT**:

- Geographical isolation of islands make it hard to connect to the grid [3]
- Small market demand for expensive RE leaving them diesel dependent in most cases [4],
- And more (lack of technical and management skills, lack of ability to pay, etc.)



[2] Global Solar Atlas
[3] Bertheau, P., & Cader, C. (2019). Electricity sector planning for the Philippine islands: Considering centralized and decentralized supply options. Applied Energy, 251, 113393.
[4] Castro, M. T., Pascasio, J. D. A., Delina, L. L., Balite, P. H. M., & Ocon, J. D. (2022). Techno-economic and financial analyses of hybrid renewable energy system microgrids in 634 Philippine off-grid islands: policy implications on public subsidies and private investments. Energy, 257, 124599.

Electrification in the Philippines

Can we still electrify Philippine islands green?

NPC-SPUG EFFECTIVE RATES
As of January 2024

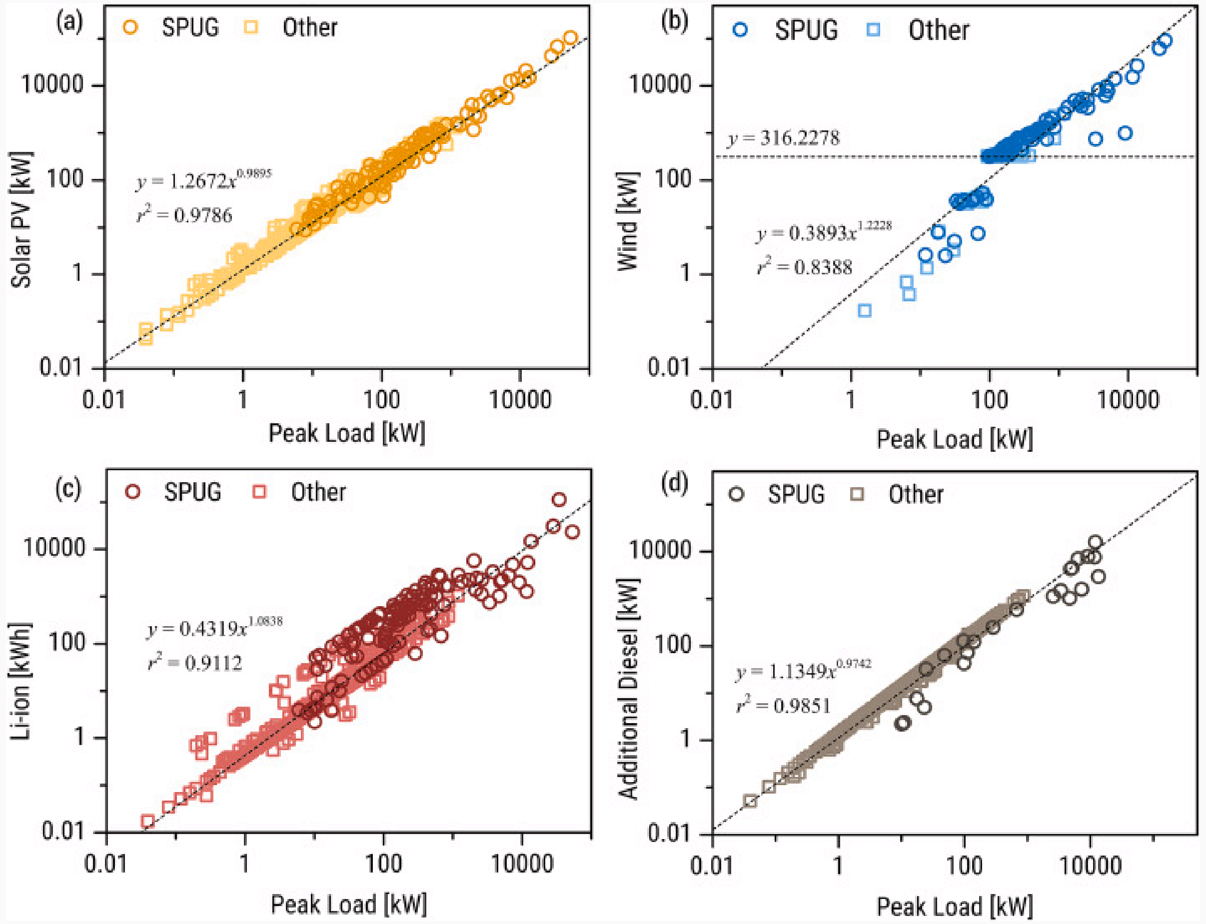
AREAS	EFFECTIVE RATES FOR ELEC. COOPS. AND LGU CUSTOMERS	ERC APPROVED UCME RATES					TOTAL EFFECTIVE RATES (SAGR + UCME) AS OF JAN. 2024
	New SAGR[1]	Universal Charge for Missionary Electrification (UCME)					
	CY 2024	BASIC UCME[2]	TRUE-UP[3]	TOTAL UCME for NPC	RED-CI[2]	TOTAL UCME	
	a	b	c	d = b+c	e	f = d+e	g = a+f
14 PSP Areas (ERC Case 2004-449RC)							
Mindoro	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Marinduque	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Mainland Palawan	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Puerto Princesa							
Coron/Busuanga							
Catanduanes	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Masbate	6.8663	0.1805	0.0672	0.2477	0.0017	0.2494	7.1157
Tablas	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Romblon	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Bantayan	8.2582	0.1805	0.0672	0.2477	0.0017	0.2494	8.5076
Camotes	8.2582	0.1805	0.0672	0.2477	0.0017	0.2494	8.5076
Siquijor	8.2582	0.1805	0.0672	0.2477	0.0017	0.2494	8.5076
Tawi-Tawi	7.0215	0.1805	0.0672	0.2477	0.0017	0.2494	7.2709
Basilan	7.0215	0.1805	0.0672	0.2477	0.0017	0.2494	7.2709
Sulu	7.0215	0.1805	0.0672	0.2477	0.0017	0.2494	7.2709
Other SPUG Areas (ERC Case 2006-020RC)							
Other Luzon							
Group 1	6.5520	0.1805	0.0672	0.2477	0.0017	0.2494	6.8014
Group 2	7.3900	0.1805	0.0672	0.2477	0.0017	0.2494	7.6394
Other Visayas	7.6433	0.1805	0.0672	0.2477	0.0017	0.2494	7.8927
Other Mindanao	6.7072	0.1805	0.0672	0.2477	0.0017	0.2494	6.9566

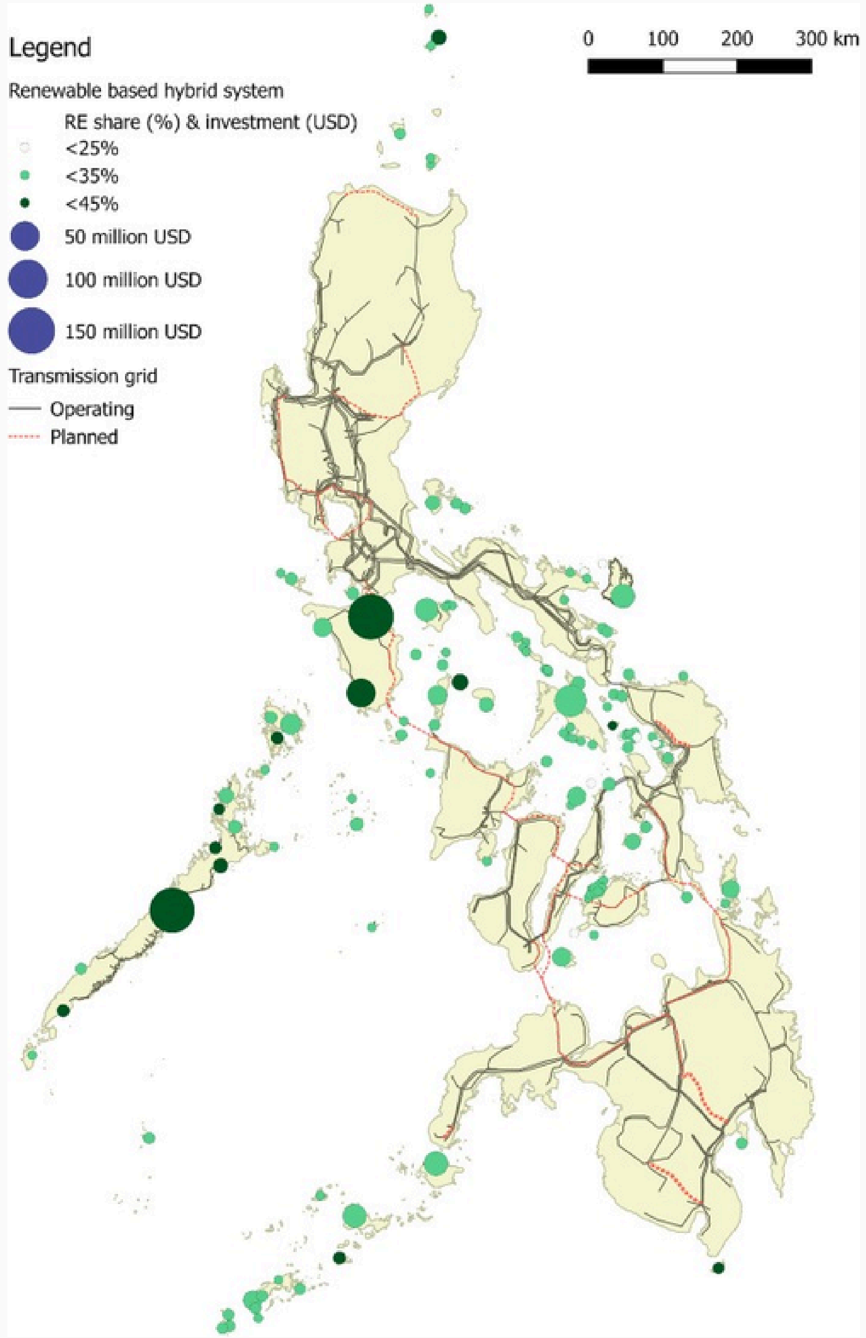
[1] ERC Decision on ERC Case No. 2018-048 RC dated 29 September 2021 and promulgated on 31 January 2022. Implemented on March 2022.

[2] ERC Order on ERC Case No. 2022-014 RC (CY 2023 UCME) promulgated on 05 September 2023 granting an Interim Relief of P0.1805/kWh Basic UCME and P0.0017 RE Developers Cash Incentive

[3] Per ERC Decision on ERC Case No. 2013-191 RC dated 04 August 2022. PSALM Remittance to NPC started October 2022 and ERC Decision on ERC Case Nos. 2014-089 RC and 2016-008 RC dated 22 March 2023 (CY 2013 & 2014 True-Up). PSALM Remittance to NPC started June 2023

Figure 25. Effective Selling Rate of NPC to its SPUG Customers as of January 2024





Through the **Universal Charge for Missionary Electrification (UCME)**, all consumers pay for the incurred additional cost of off-grid diesel reliance [5] when imported fuel prices become volatile.

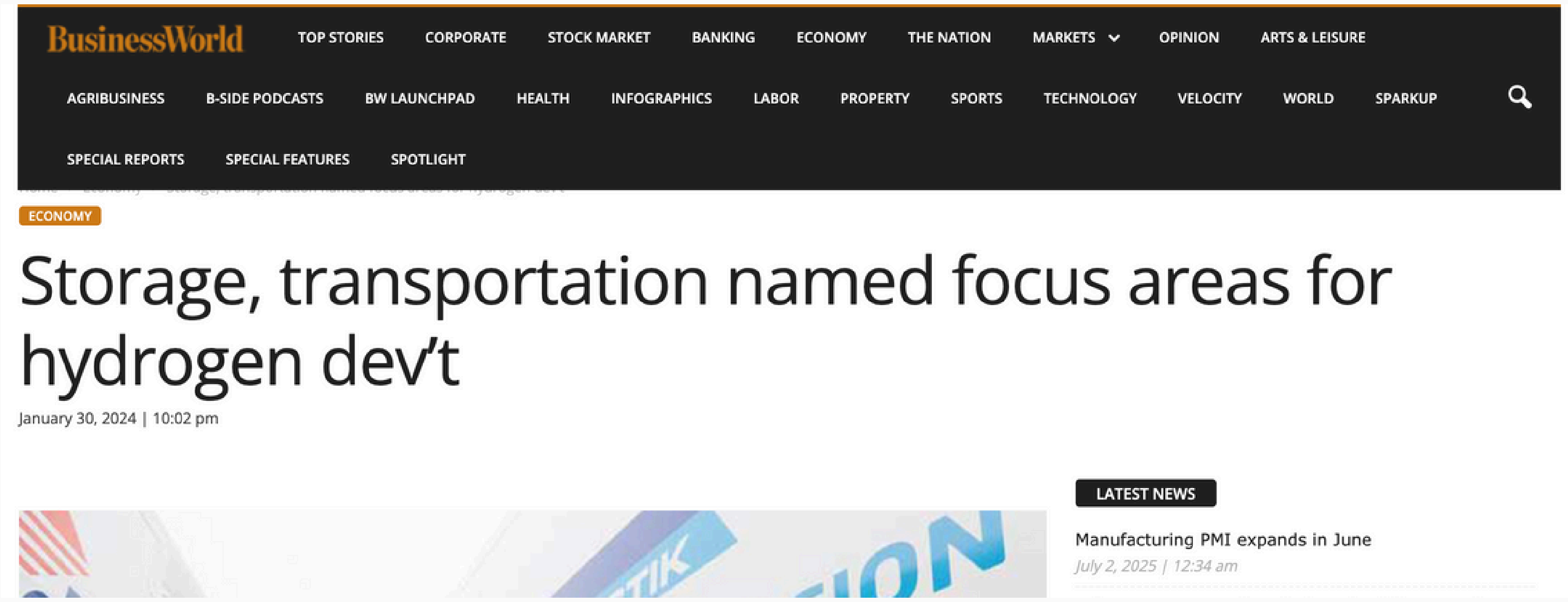
Isolated microgrid optimizations showed that smaller islands <100kW peak load will still be diesel dependent since wind turbines and batteries are too expensive for such scale. [4]

Optimal grid extension using bathymetric vs decentralized approach connected larger islands to grid and but still leaves smaller islands to highly depend on diesel. [3]

[3] Bertheau, P., & Cader, C. (2019). Electricity sector planning for the Philippine islands: Considering centralized and decentralized supply options. Applied Energy, 251, 113393.
[4] Castro, M. T., Pascasio, J. D. A., Delina, L. L., Balite, P. H. M., & Ocon, J. D. (2022). Techno-economic and financial analyses of hybrid renewable energy system microgrids in 634 Philippine off-grid islands: policy implications on public subsidies and private investments. Energy, 257, 124599.
[5] DOE Philippines, 2024-2028 Missionary Electrification Development Plan

Electrification in the Philippines

Hydrogen in the Philippines?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ECONOMY

Storage, transportation named focus areas for hydrogen dev't

January 30, 2024 | 10:02 pm

LATEST NEWS

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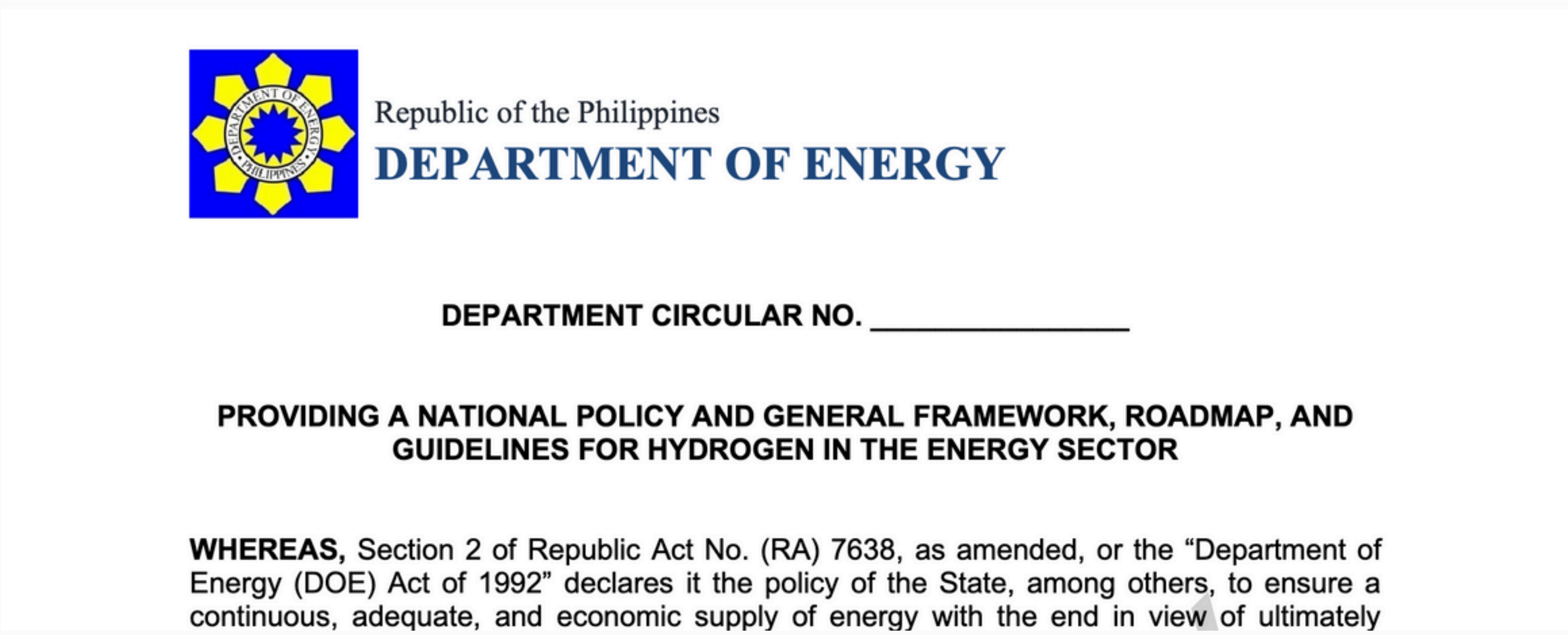

Republic of the Philippines

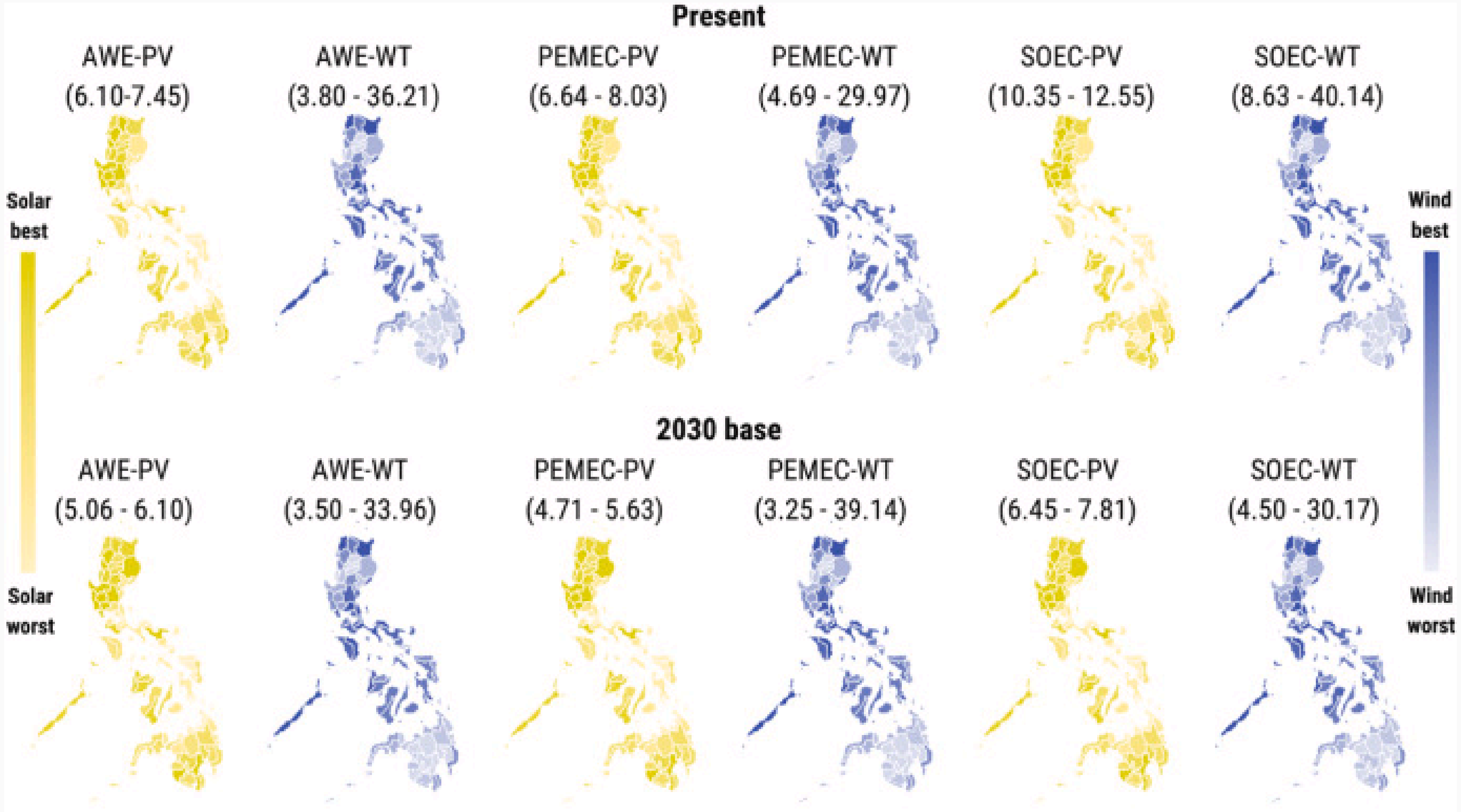
DEPARTMENT OF ENERGY

DEPARTMENT CIRCULAR NO. ______________

PROVIDING A NATIONAL POLICY AND GENERAL FRAMEWORK, ROADMAP, AND GUIDELINES FOR HYDROGEN IN THE ENERGY SECTOR

WHEREAS, Section 2 of Republic Act No. (RA) 7638, as amended, or the "Department of Energy (DOE) Act of 1992" declares it the policy of the State, among others, to ensure a continuous, adequate, and economic supply of energy with the end in view of ultimately

The Philippine DOE published a **circular on a hydrogen framework in the energy sector** early in 2024



Production of green hydrogen (from solar or wind) showed sites with fair potential for local production, however **prices vary too much** across the country due to the **islanded (non-grid) calculation approach** [7].

[6] https://www.bworldonline.com/economy/2024/01/30/572203/storage-transportation-named-focus-areas-for-hydrogen-devt/
[7] Tubalinal, H. O. S., Castro, M. T., Alcanzare, M. T., Matienzo, D. D. C., Paraggua, J. A. D., Chuang, P. Y. A., & Ocon, J. D. (2024). Prospects of green hydrogen production in the Philippines from solar photovoltaic and wind resources: A techno-economic analysis for the present and 2030. Renewable Energy, 235, 121286.

Hydrogen Fuel as a replacement for Diesel Fuel

in this case study, we ask...

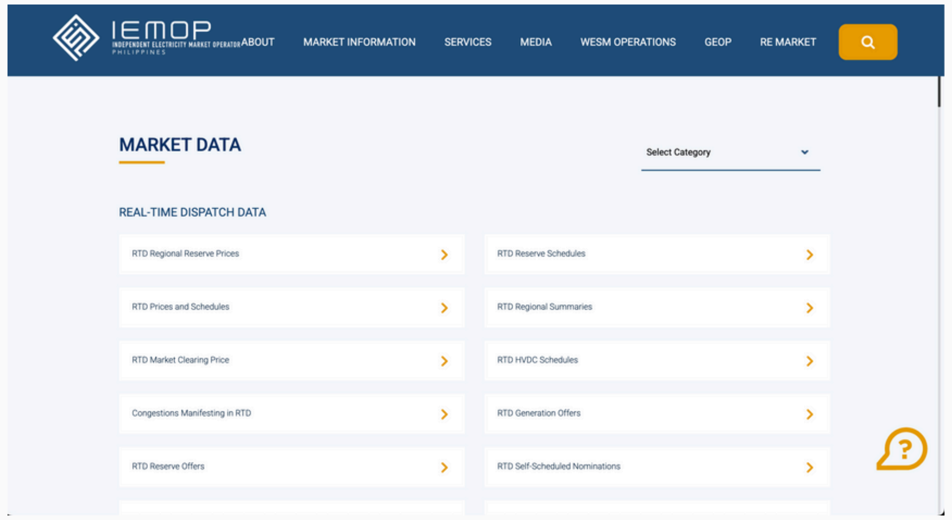
Could a local grid-produced hydrogen market be a solution for a less imported diesel-dependent off-grid island renewable electrification?

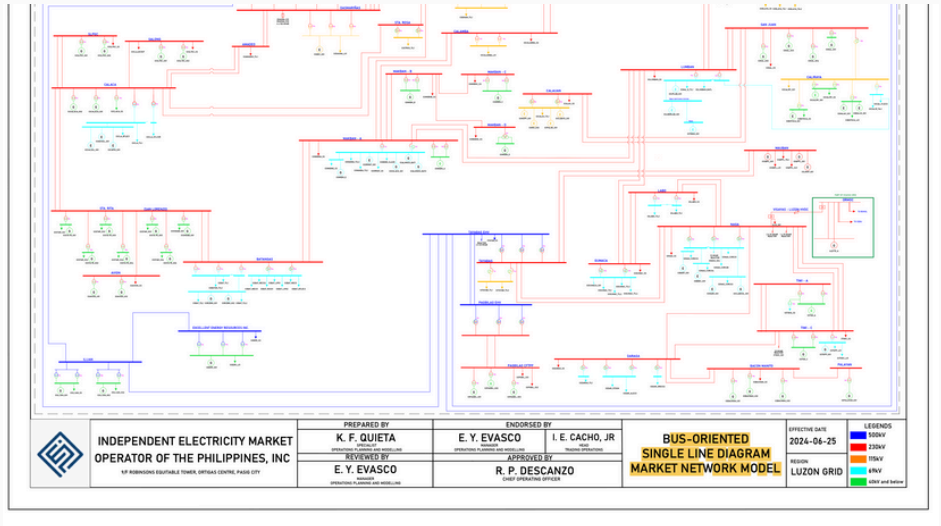
PyPSA-PH Baseline Model

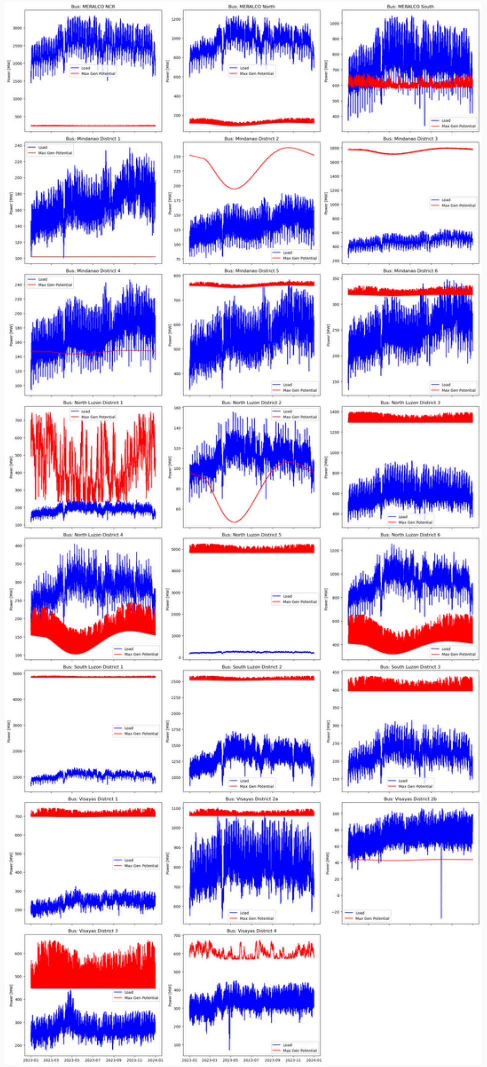
Data Resources

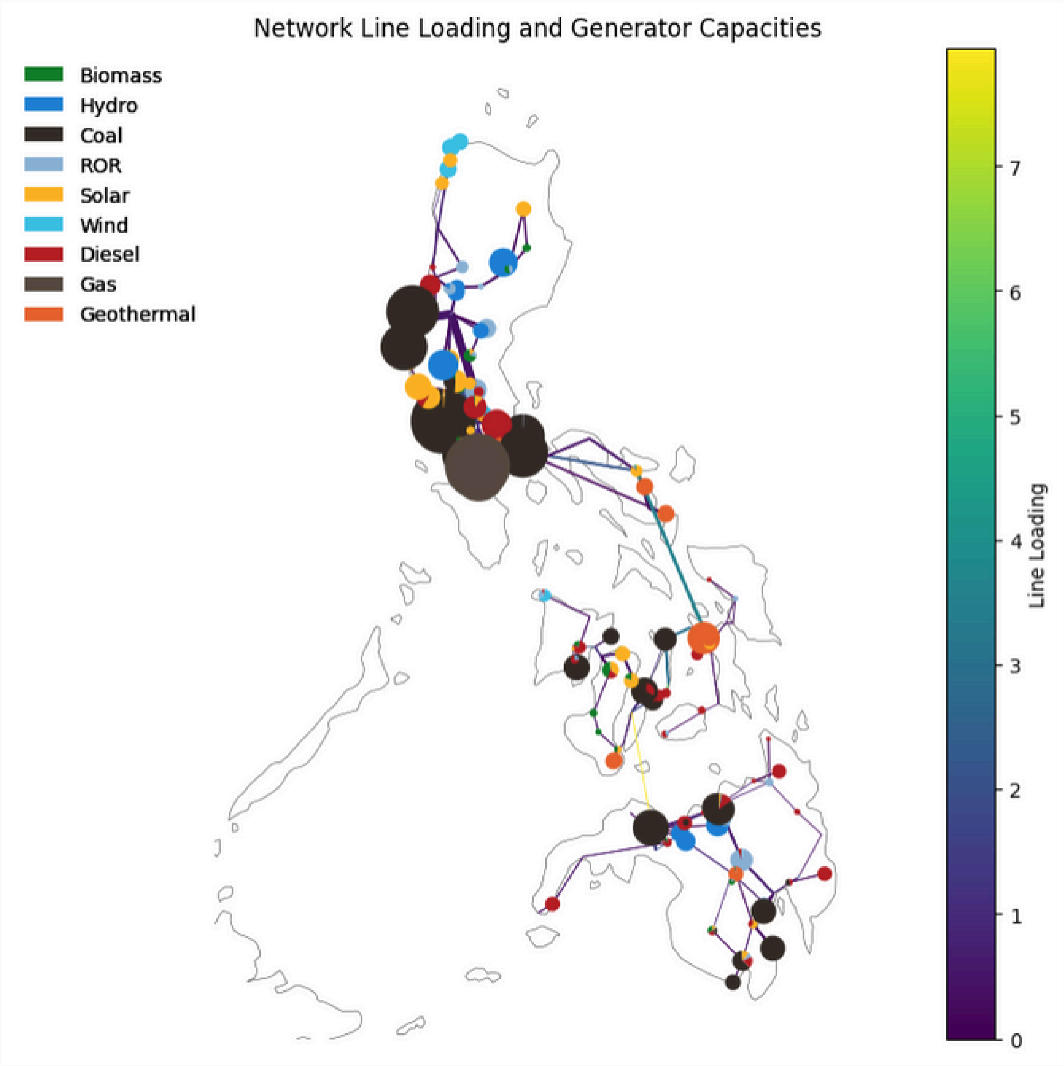
In this analysis, we took **actual market demand data from trading nodes** published by the country's market operator and built the **power network following their updated simple line diagram** of the grid [8]. Offgrid data from [9]

Given these data, we built the model using **PyPSA in Jupyter Notebooks.** We aggregated trading buses to the power districts identified by the transmisison service provider to match it with the available data for future demand projection.









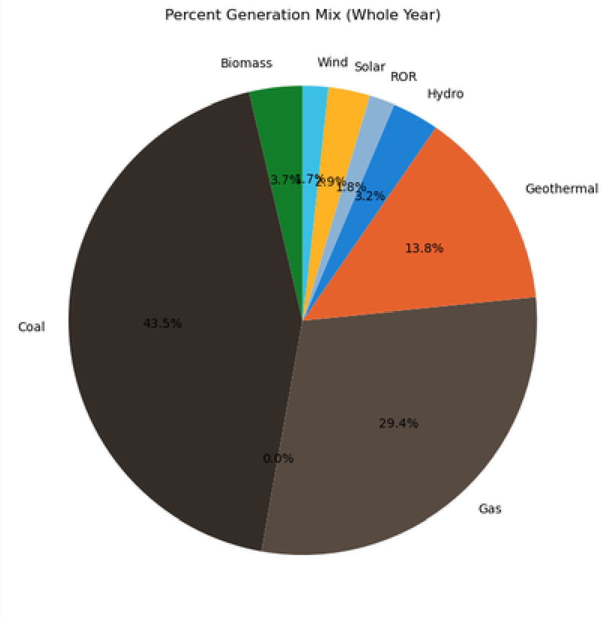
PyPSA-PH GITHUB REPOSITORY

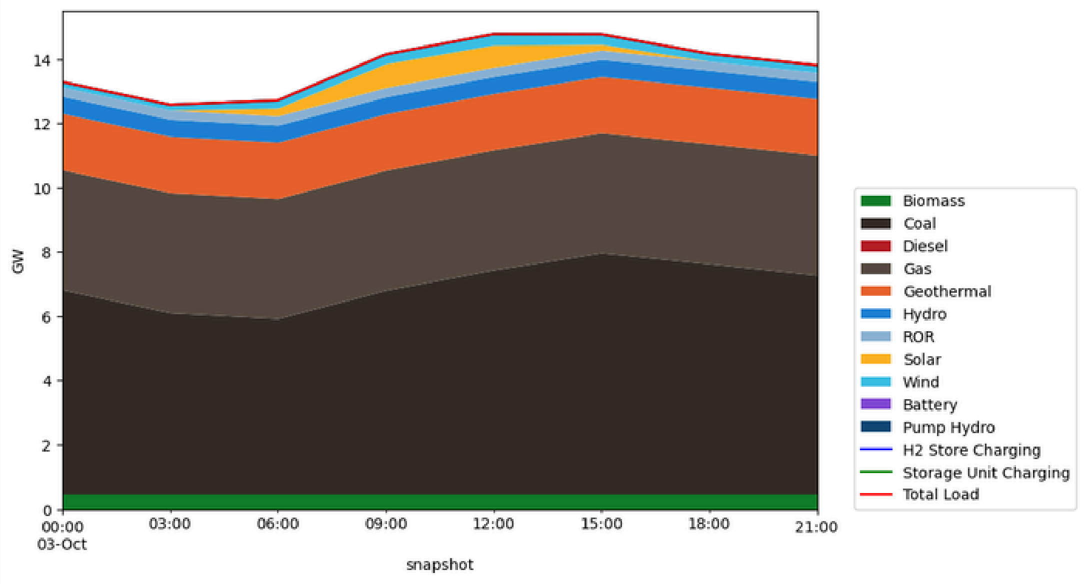
https://github.com/arizeosalac/PyPSA-PH.git

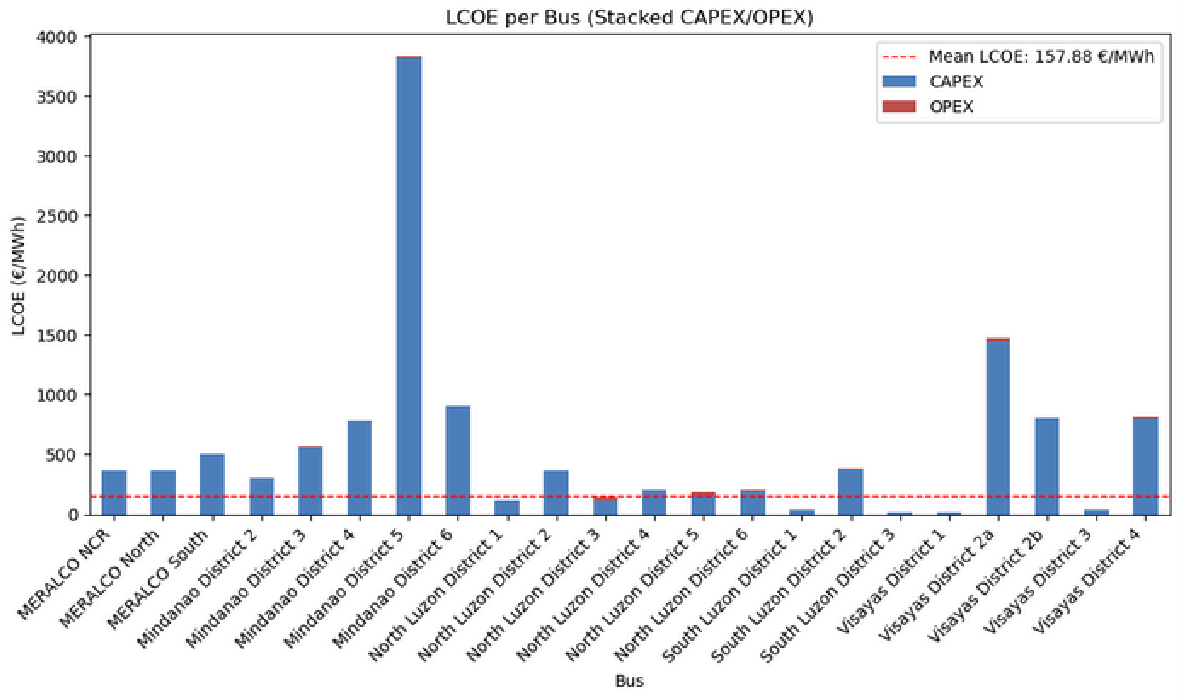
[8] https://www.iemop.ph/the-market/market-data/
[9] Castro, M. T., Pascasio, J. D. A., & Ocon, J. D. (2022). Data on the techno-economic and financial analyses of hybrid renewable energy systems in 634 Philippine off-grid islands. Data in Brief, 44, 108485.

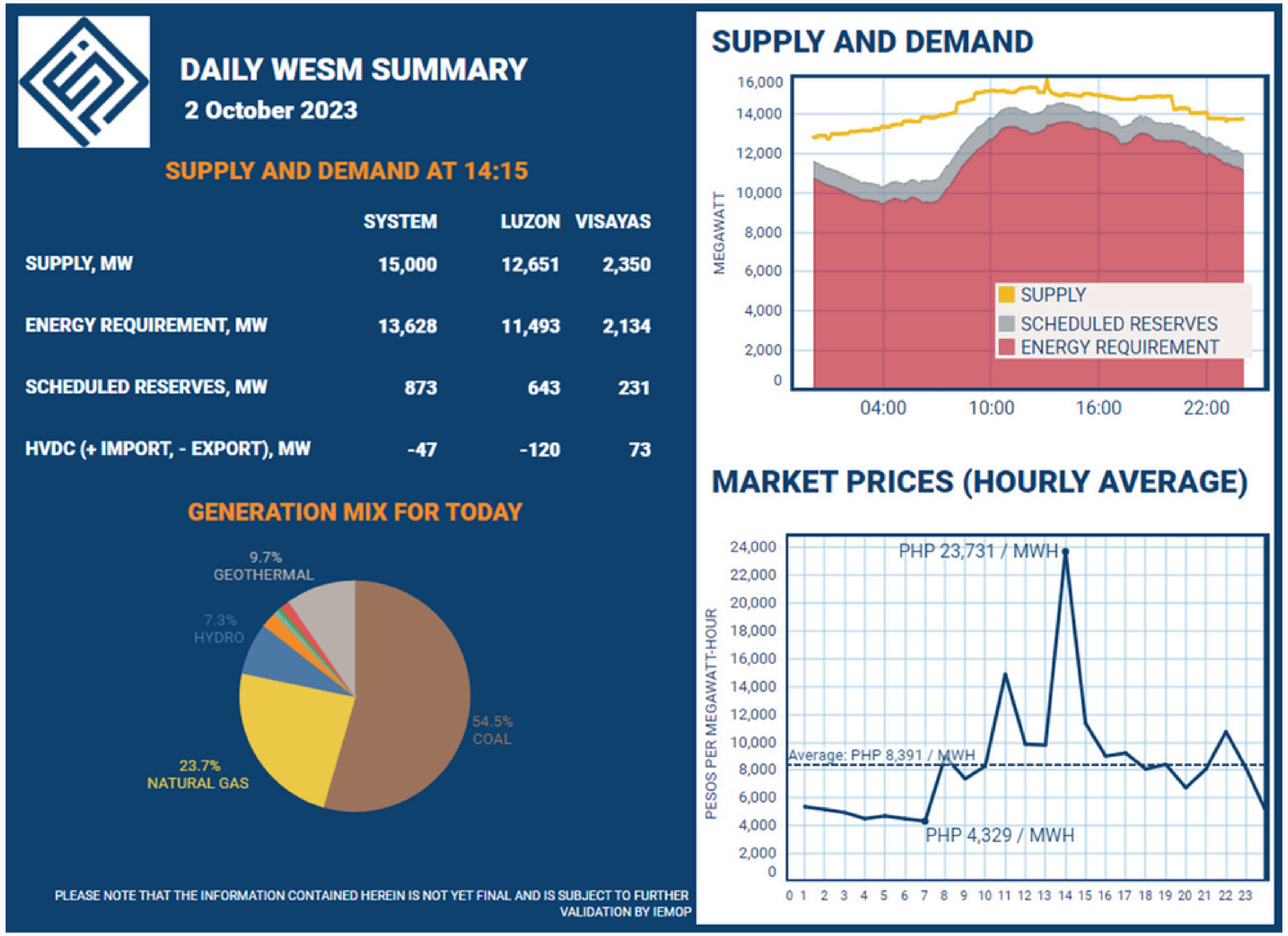
PyPSA-PH Baseline Model

Model Output Validation









After solving the baseline PyPSA-PH model, we compare the **generation mix and average LCOE** with the actual generation mix and average market price published by the market operator, respectively.

The generation fraction of coal is the largest though quite underestimated by ~10% which was taken by gas (overestimated by ~6%) and geothermal (overestimated by ~4%). Electricity market **price difference is about 10Eur/MWh**. [10]

[10] https://www.facebook.com/photo.php?fbid=762558975885876&set=pb.100063953410708.-2207520000&type=3

Future H2 Scenarios ON GRID

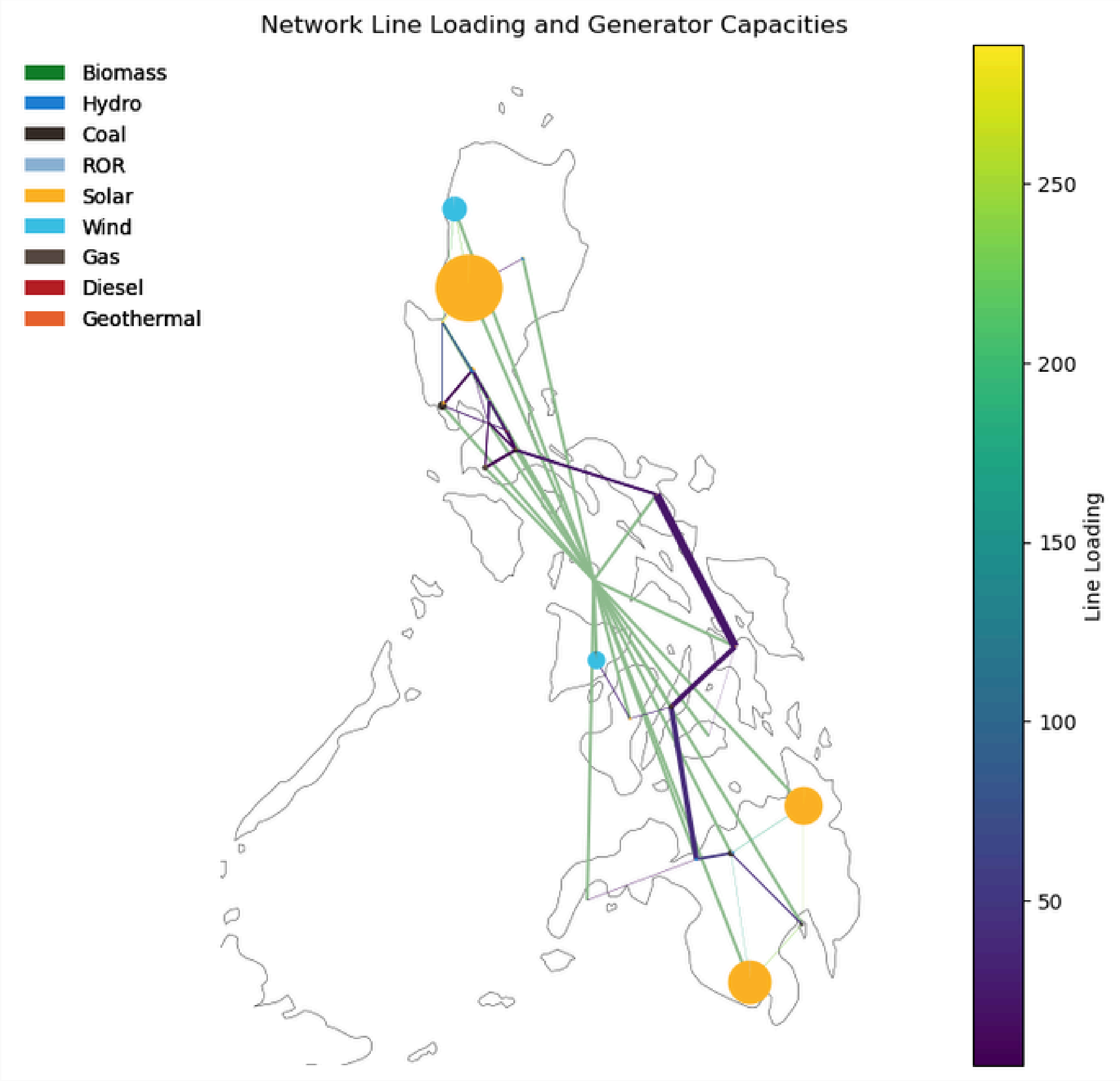
Scenario building

```python
H2_load_projection = [1, 250, 500, 1000] # np.linspace(1, 1000, 5)  #
scenario_name = "2040CO2red0"

output_dir = f"results/{scenario_name}"
os.makedirs(output_dir, exist_ok=True)

# configure scenario parameters here:
for key in range(len(H2_load_projection)):
    n_custom = project_network(
        n=n.copy(),
        y=2040,
        re_percent=None,
        co2_red=0,
        add_gen_tech=["Solar", "Wind", "Coal"],
        add_store_tech=["Battery"],
        H2_SU=True,
        H2_S=True,
        H2_p_set=H2_load_projection[key],
        load_growth_factor=None)
    solup_net(n_custom)
    n_custom.export_to_netcdf(f"{output_dir}/PyPSA-PH_{scenario_name}
```

Using the baseline model, we project it to the future by updating it with the **projected load, retire old generation units, and add new extendable generators and hydrogen assemblies**



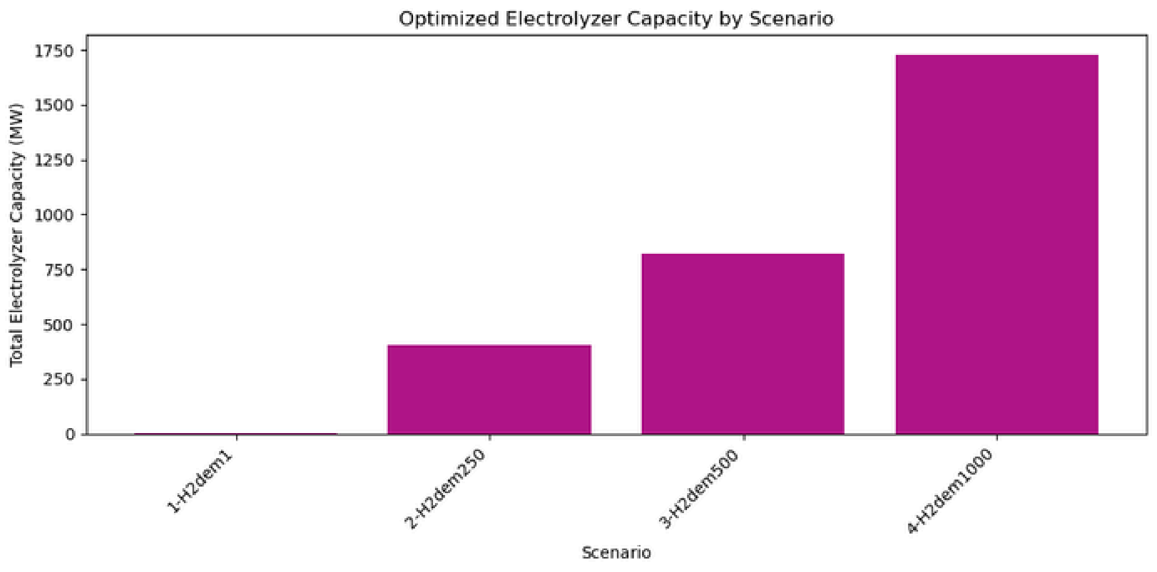
Each **AC bus has been paired with a corresponding H2 bus** which holds the H2 assemblies. They are all connected to a "**main_H2" bus that holds the H2 load** / H2 production to suffice off-grid Hydrogen demand.

Future H2 Scenarios ON GRID

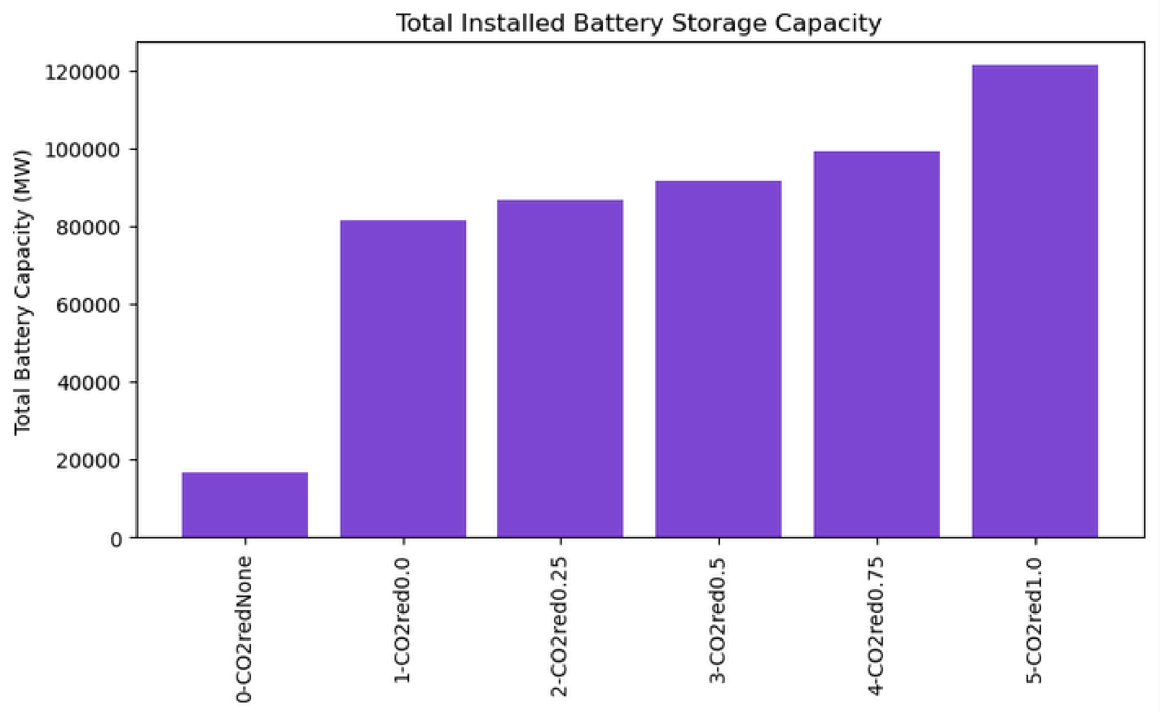
Q1: Will H2 have an energy storage / P2X2P role on the grid?

Based on the model, NO.

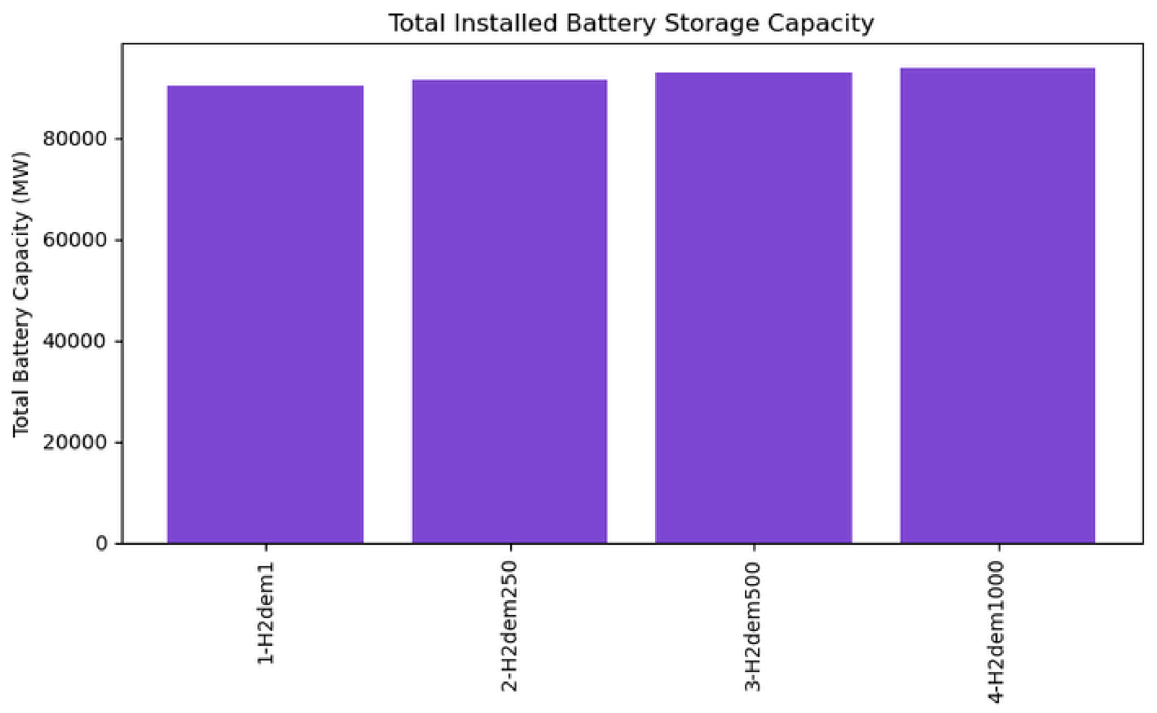
Since the capital **cost requirement for a battery energy storage system is much less compared to a hydrogen energy storage system assembly** (fuel cell, H2 store, electrolyzer), the grid favored BESS optimal capacity increases strongly with CO2red and weakly with H2demand. Only electrolyzers and H2 storages were sized to fulfill the set H2 demand.



	marginal_cost	capital_cost
gas boiler steam	1.007000	5740.377982
solar	0.010600	42964.843777
onwind	1.314300	95631.951255
oil	157.523871	39582.339405
coal	32.213321	337208.027448
hydro	0.000000	182698.734592
geothermal	0.000000	26412.028127
solid biomass boiler steam	2.867900	83748.123319
ror	0.000000	308170.371903
battery storage	0.000000	70568.716996
Pumped-Storage-Hydro-store	0.000000	684825.980933
electrolysis	0.000000	150972.620665
fuel cell	0.000000	193399.123456
hydrogen storage tank type 1 including compressor	0.000000	2835.920022



constant H2dem0 for all scenarios



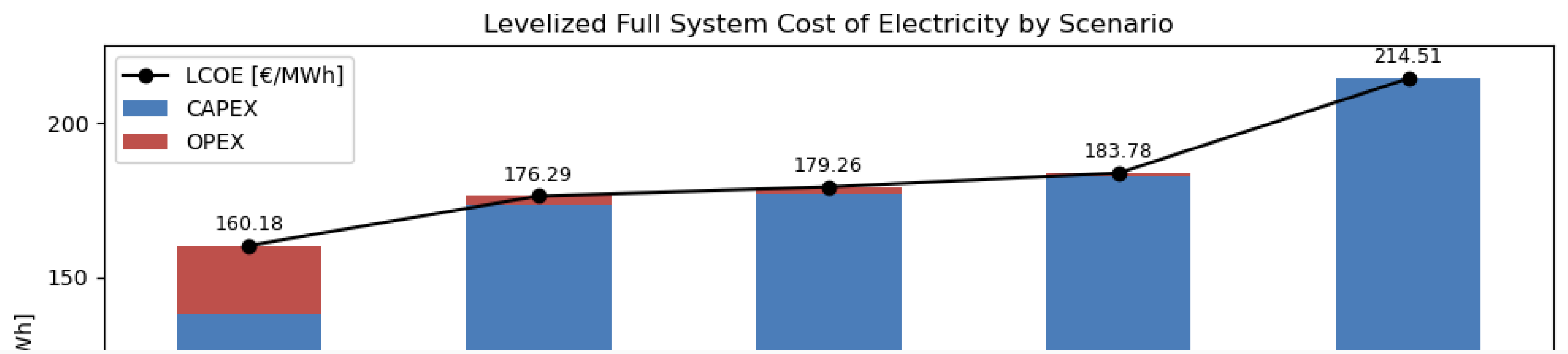
constant CO2red50 for all scenarios

Future H2 Scenarios ON GRID

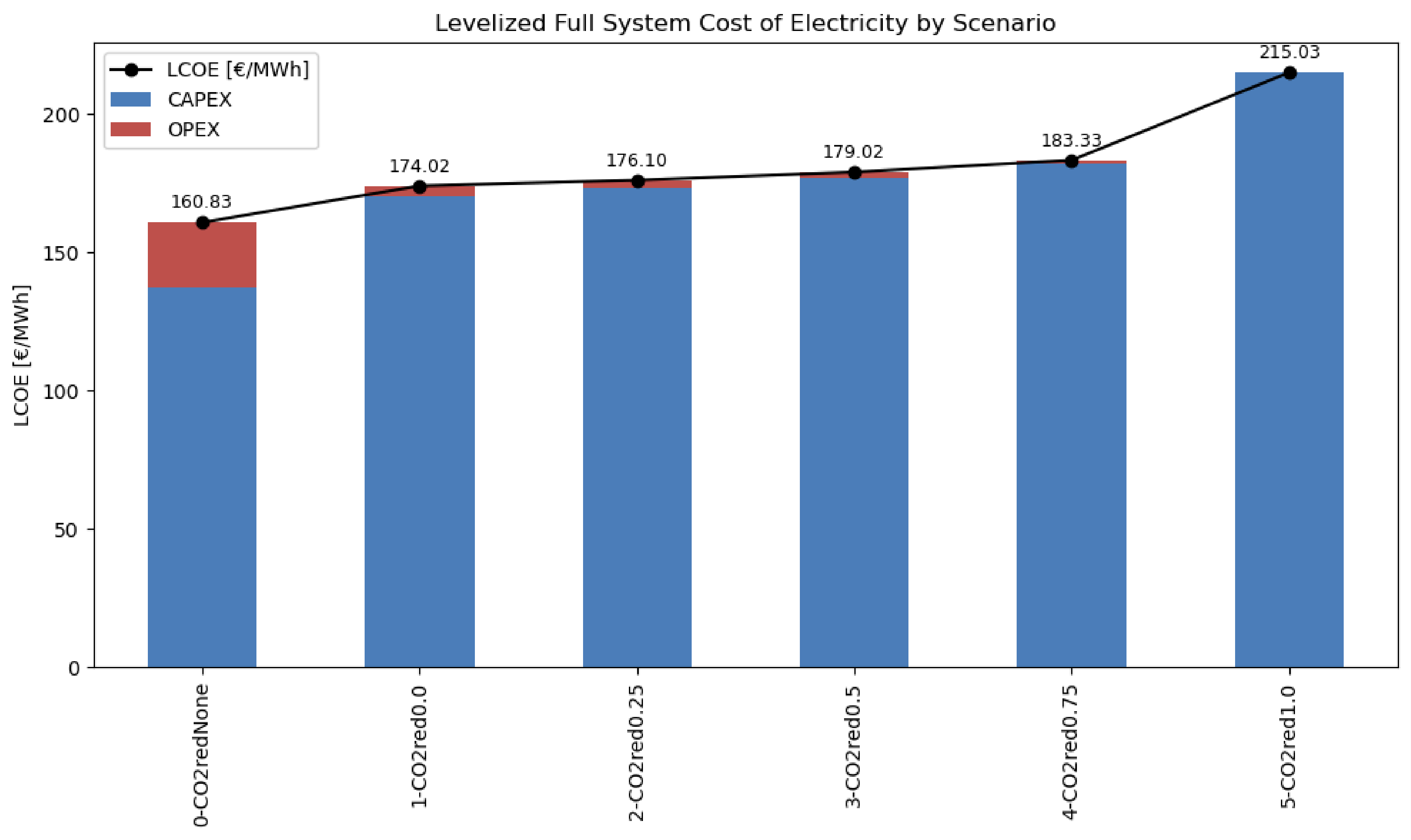
Q2: Will it be favorable for the grid to produce H2 for offgrid or not, in terms of LCOE?

CO2red increases LFSCOE, H2dem may slightly decrease it

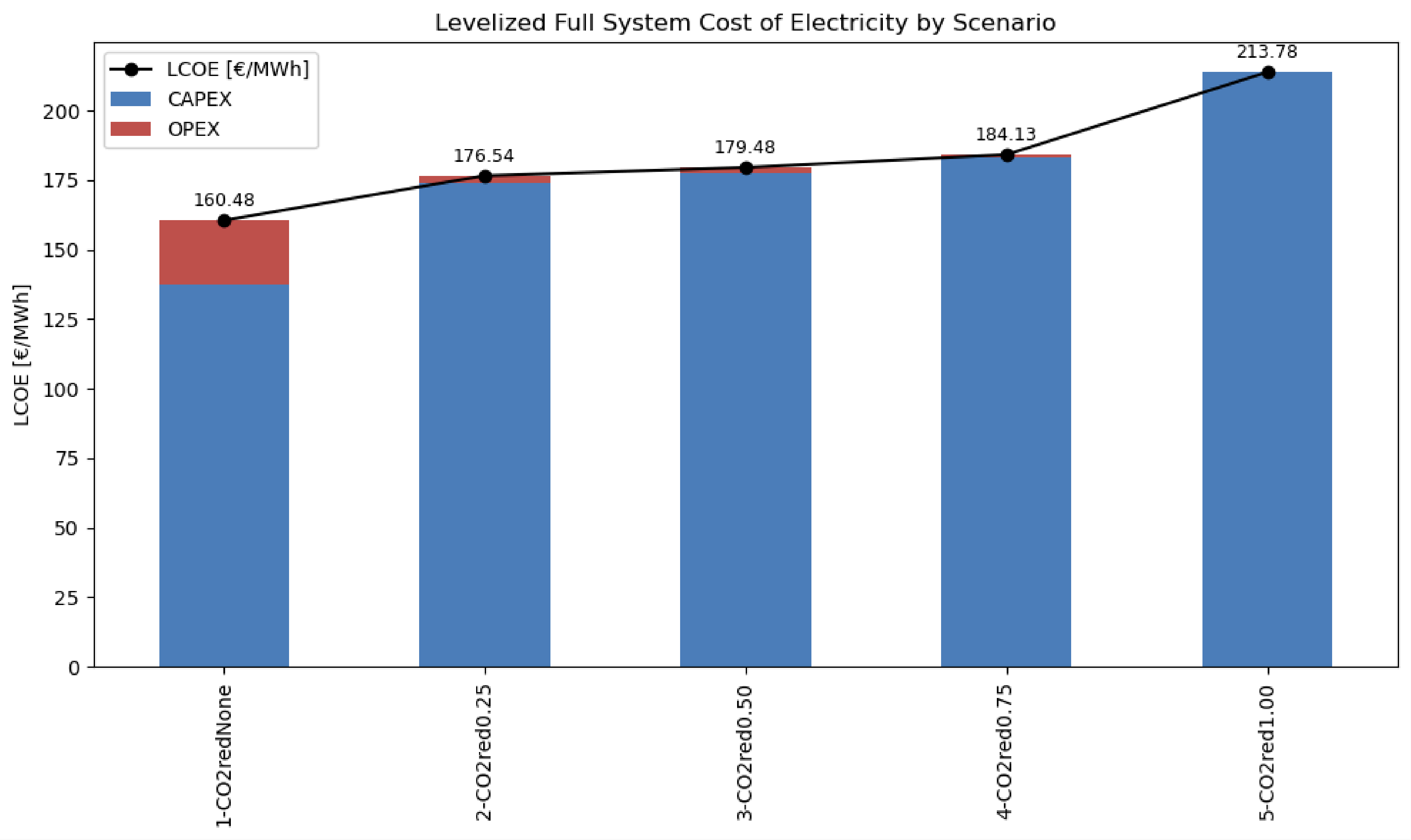
Since the **off-grid H2 demand is significantly smaller than the grid power demand**, negative effects on LCOE is usually minimal. At higher CO2red, H2 production uses cheap curtailable VRE power which increases capacity factor of VREs lowering the LFSCOE.



constant H2dem250 for all scenarios



constant H2dem0 for all scenarios



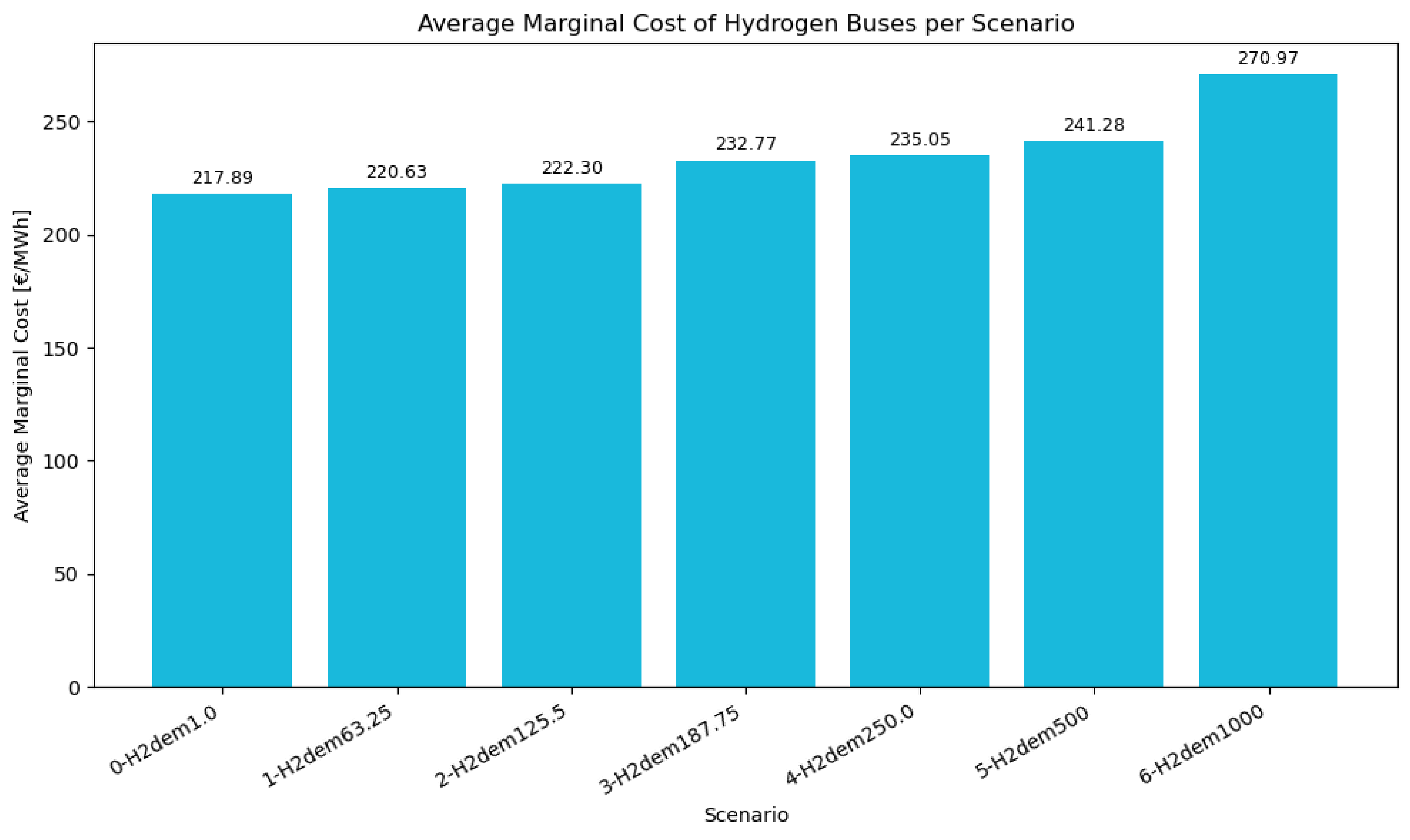
constant H2dem1000 for all scenarios

Future H2 Scenarios ON GRID

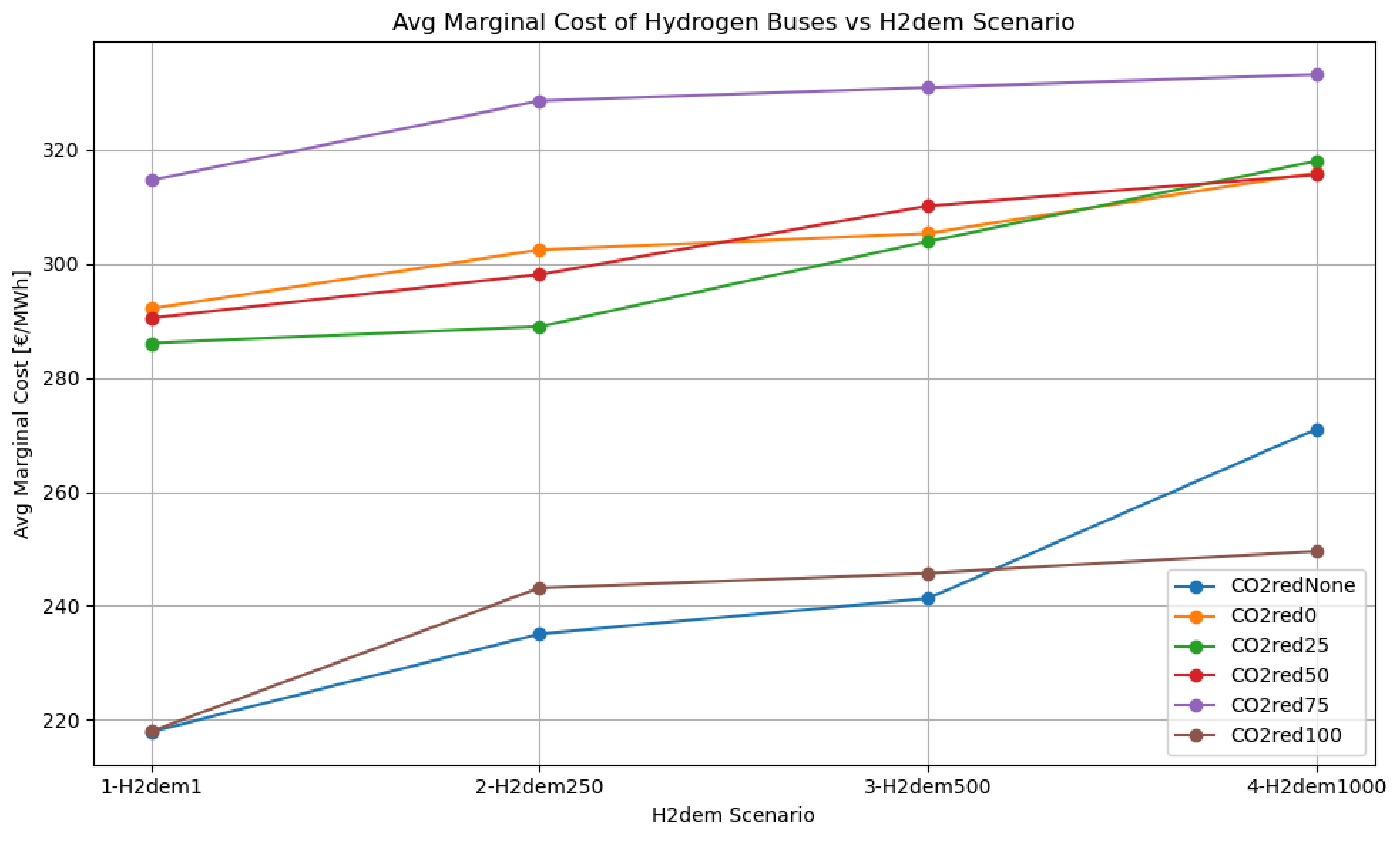
Q3: How will the H2 supply-side market from the grid will look like?

H2 Cost increases with demand for all CO2red cases

This is expected. However, CO2redNone give lesser prices since coal is unrestrained and could give more flexibility for VREs and avoid oversizing them. Thus, gives lower electrcity and H2 prices.



constant CO2redNone for all scenarios

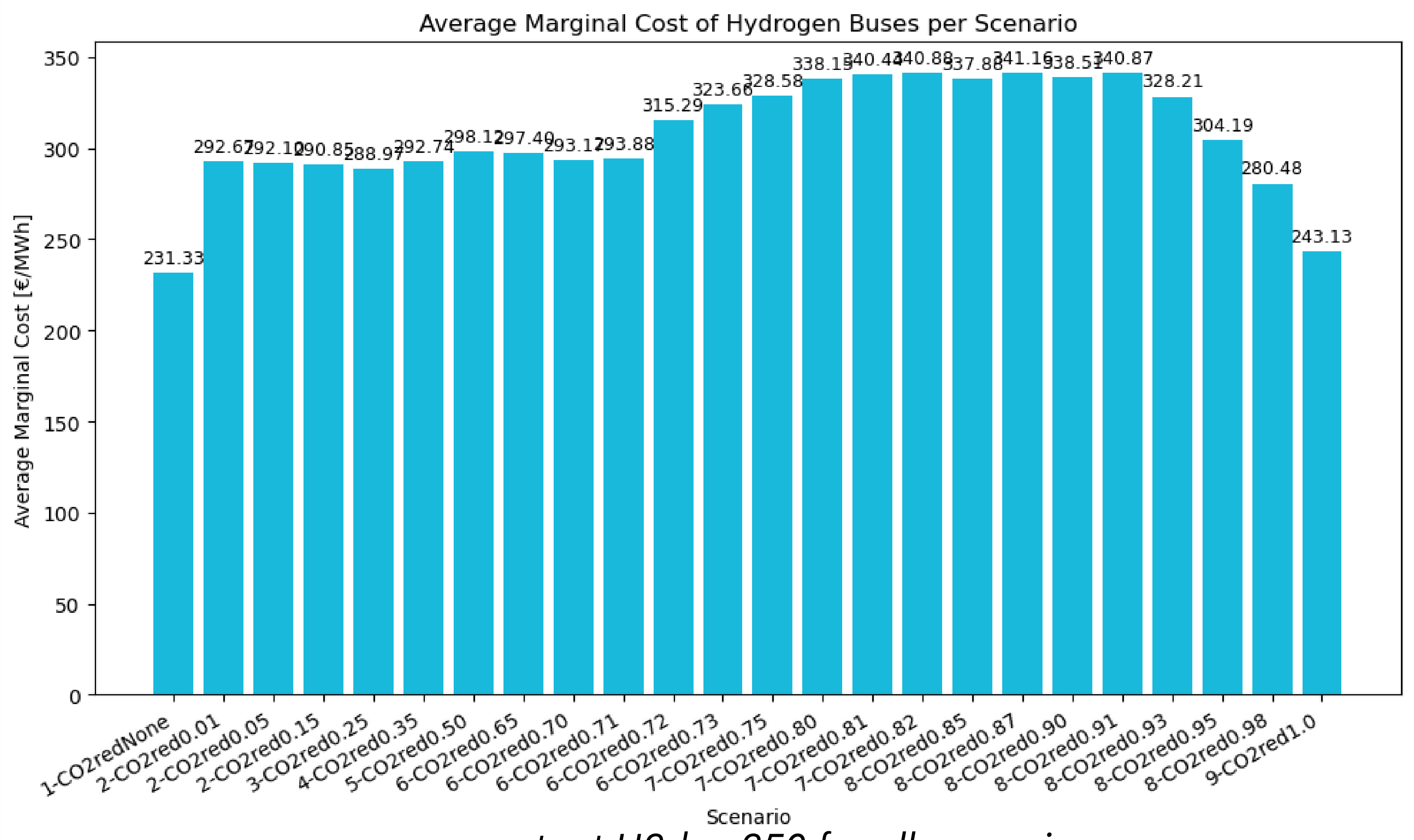


Future H2 Scenarios ON GRID

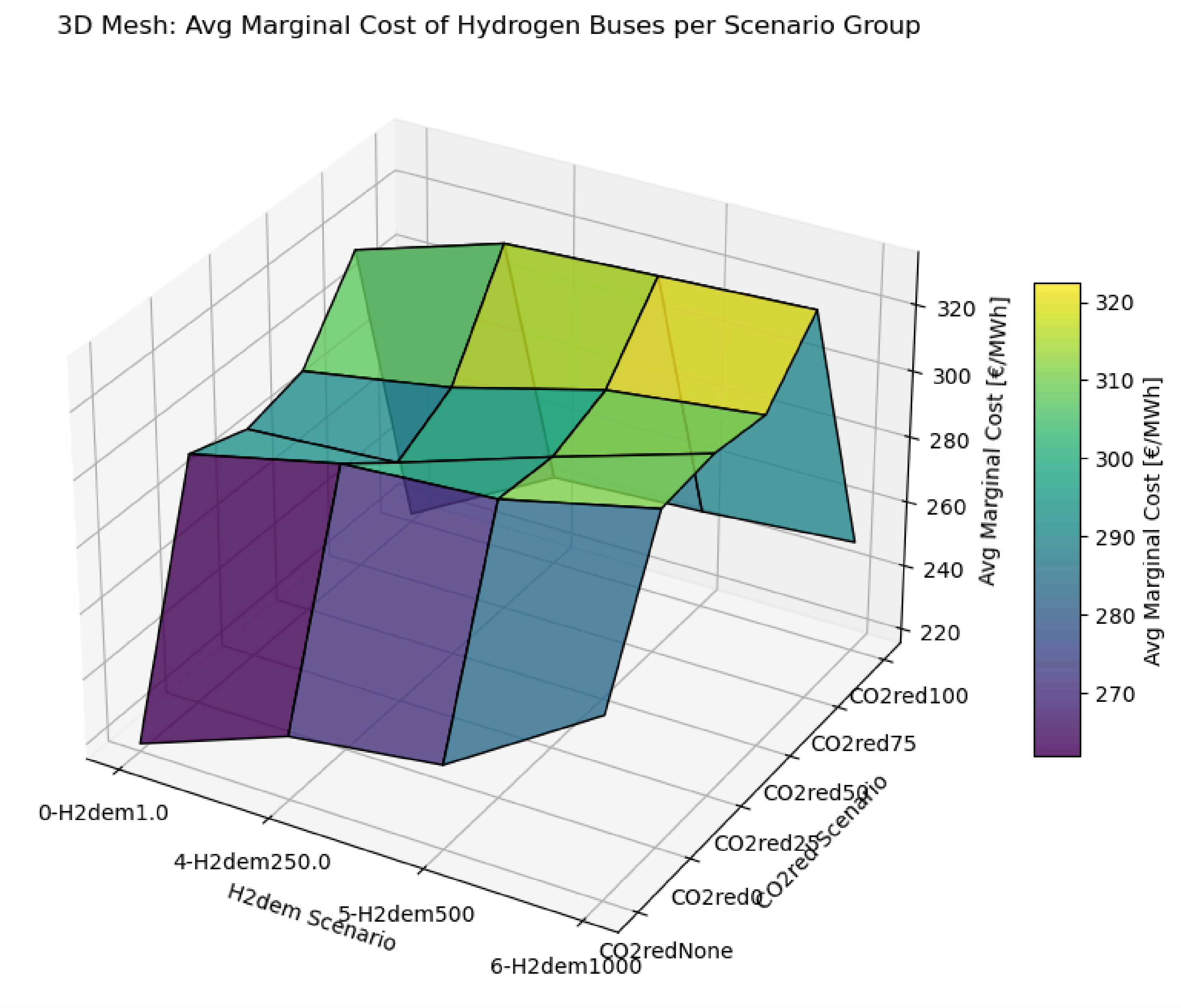
Q3: How will the H2 supply-side market from the grid will look like?

H2 cost could increase from CO2red0.72 before it drops at CO2red0.91

At H2dem250, it was observed that till CO2red0.72, the optimal price could settle between 292 to 298 Eur/MWh since coal capacity is less restricted. However in any H2dem, **when coal starts to reduce in size, flexibility lessens** and the burden to easily dispatch falls on battery and H2 storage capacities, **increasing H2 cost.**



constant H2dem250 for all scenarios

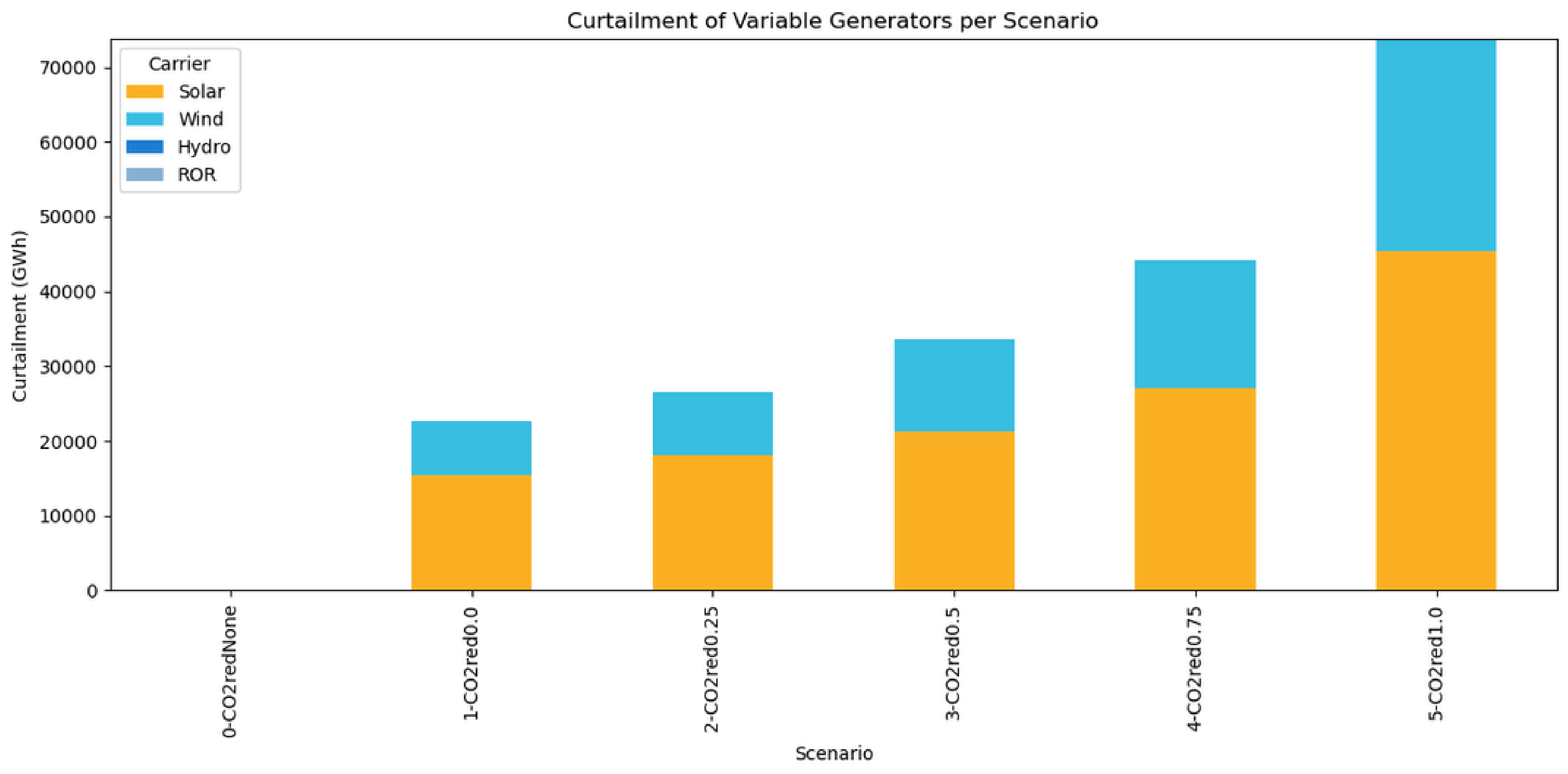


Future H2 Scenarios ON GRID

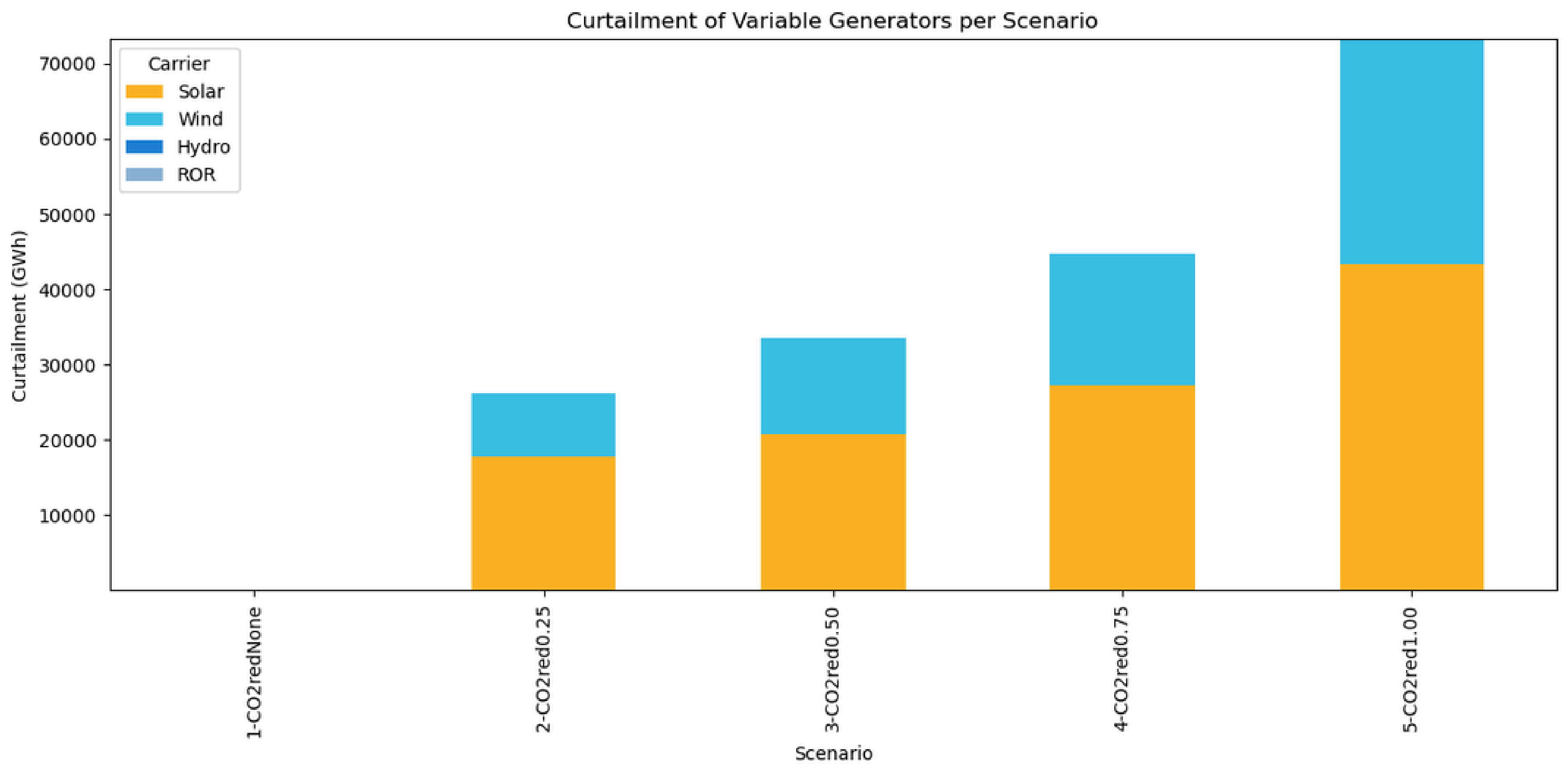
Q4: Will H2 lower curtailment of VREs on higher CO2red?

May happen at higher CO2red, but not that significant

Again, H2 demand considering already all islands is still insignificant compared to total overall grid demand.



constant H2demNone for all scenarios



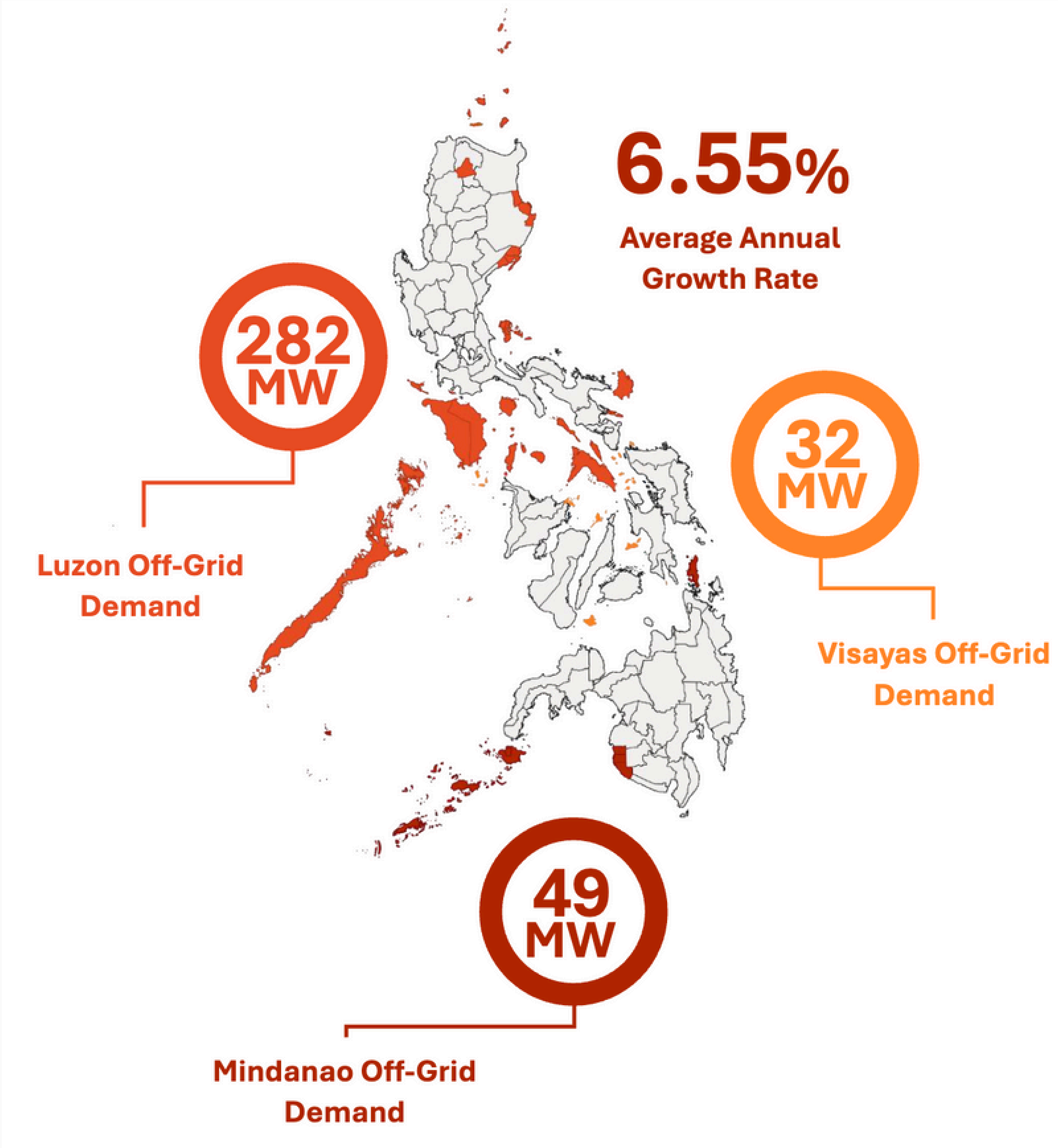
constant H2dem1000 for all scenarios

Future H2 Scenarios OFF-GRID

Microgrid Scenario Modelling

```
microgrid_id=273
microgrid = build_microgrid_network(
    microgrid_id,
    islands_df,
    microgrids_df,
    peak_load_df,
    norm_loadprof_df_1MWmore,
    norm_loadprof_df_100kW,
    norm_loadprof_df_100kWless,
    p_max_pu_normprof_df,
    solar_GHI_df,
    wind_speed_df,
    existing_diesel_capacity_df,
    year=2040,
    multload=1.0,
    diesel_cost=(0.94*1.142/(0.010756)), # from Castro, et al.'s data
    H2_cost=250)  # If set to None, assumed free, else 243 Euro/MWh f
    #for real assumption CO2red50 is targeted by PH by 2040, and give
microgrid.optimize(solver_name="gurobi")
```

Each microgrid was modelled and optimized using the **616 Philippine Microgrid data** from [9] for 2040. Since these are smaller islands, no load growth was assumed at the moment with total market size of 254MW in 2018. **Diesel cost was also assumed to be higher** due to compounded transport cost.



For reference, the current total energy market for Philippine off-grid islands is about **360 MW with 6.55% annual growth rate**. [5]

[9] Castro, M. T., Pascasio, J. D. A., & Ocon, J. D. (2022). Data on the techno-economic and financial analyses of hybrid renewable energy systems in 634 Philippine off-grid islands. Data in Brief, 44, 108485.
[5] DOE Philippines, 2024-2028 Missionary Electrification Development Plan

Future H2 Scenarios OFF-GRID

Q1: How will the H2 demand-side market on off-grid will look like?

Maximum H2 buying price could range between 250 to 260 EUR/MWh

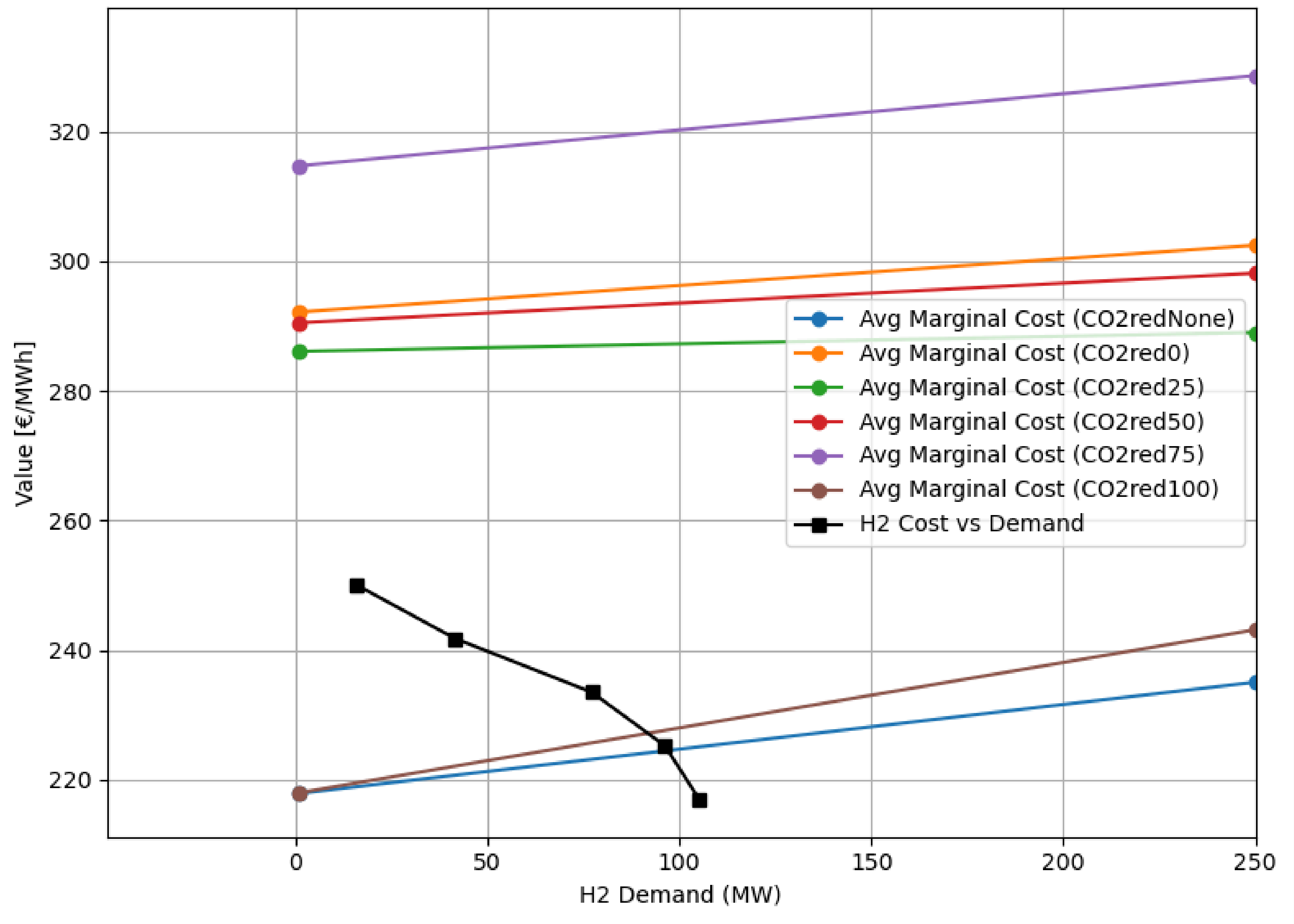
After running all microgrids with varying H2 cost, the optimal H2 demand for the fuel cell component was obtained and plotted. T

The demand curve intersected with the CO2red100 curve at **227.15782 EUR/MWh satisfying an H2dem of 91.81837 MW**.

he second intersection is with the CO2redNone curve at **224.50489 EUR/MWh satisfying an H2dem of 97.0304 MW**.

This can provide for more than **a third of the market for offgrid H2 demand**.

H2 Demand vs Suppy Curves



Future H2 Scenarios OFF-GRID

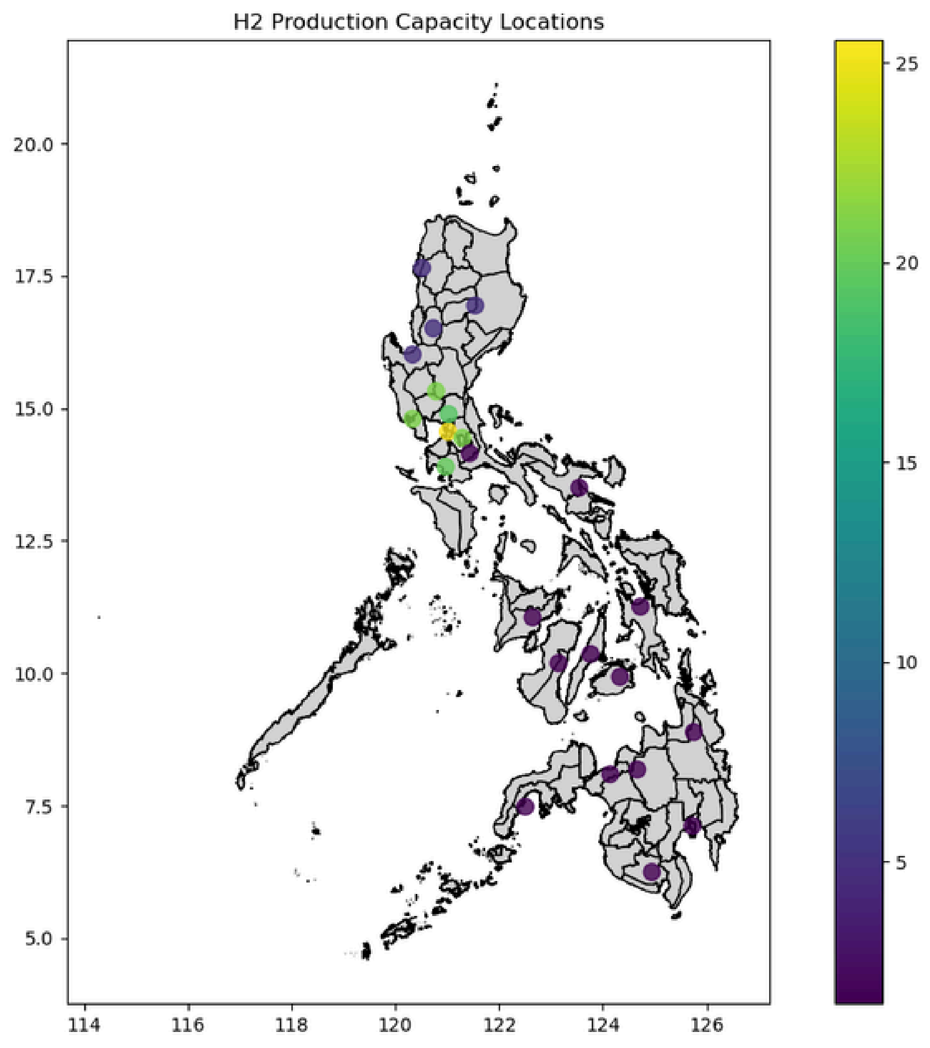
Q2: Where will Hydrogen be produced and by how much?

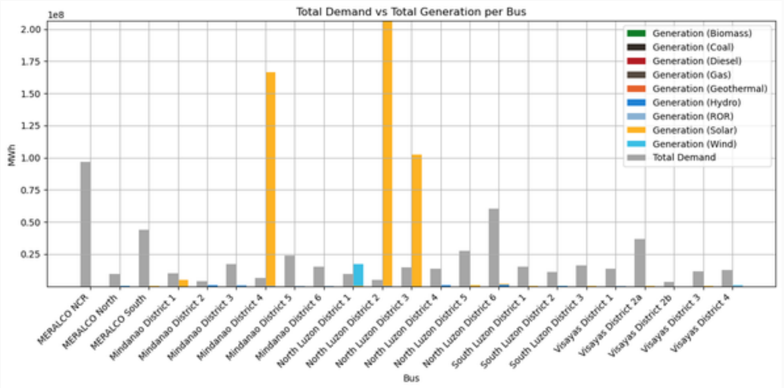
Considering these two optimal scenarios:

Green H2 from the CO2red100 scenario is highly generated at **Central Luzon and Batangas area** where **huge shipping ports** were also located. This location is also optimal as big off-grid islands like Palawan and Mindoro are located.

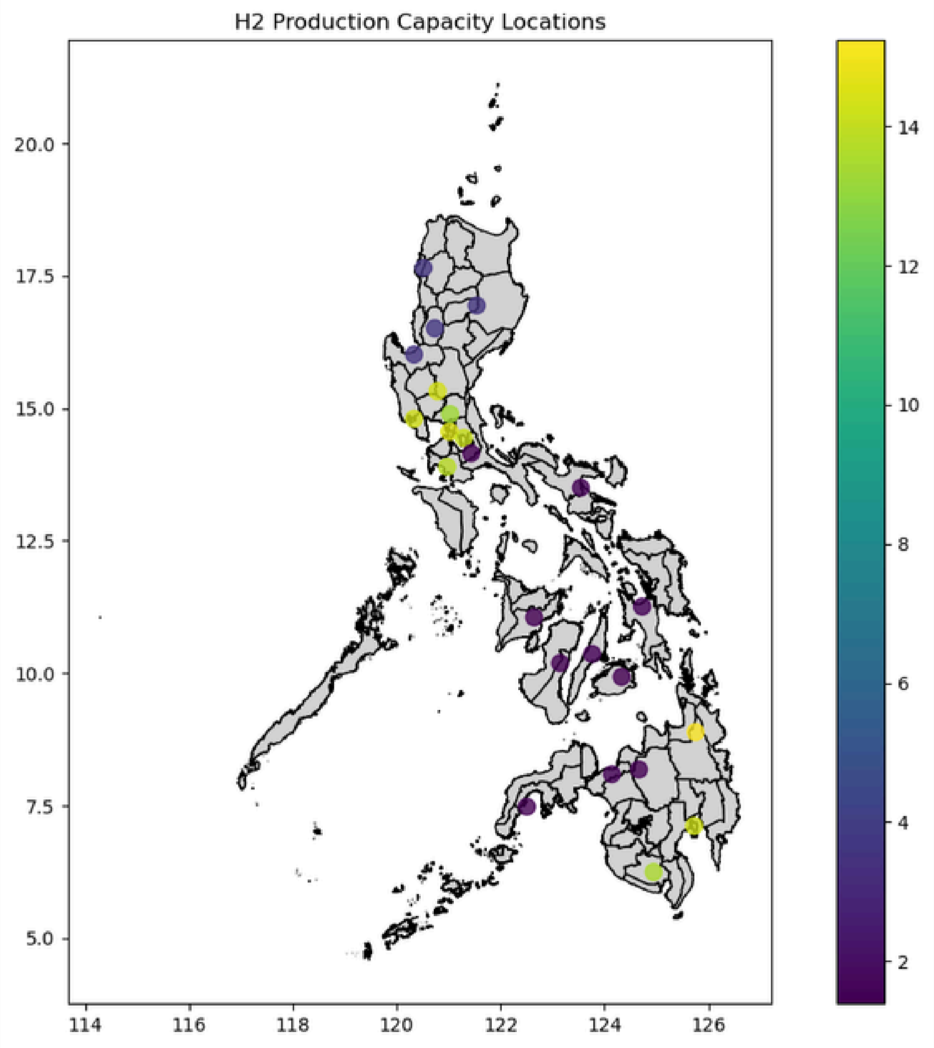
The CO2redNone scenario **allows H2 generation in the Southern Mindanao area** which could serve southernmost off-grid islands of Tawi-tawi and Sulu better.

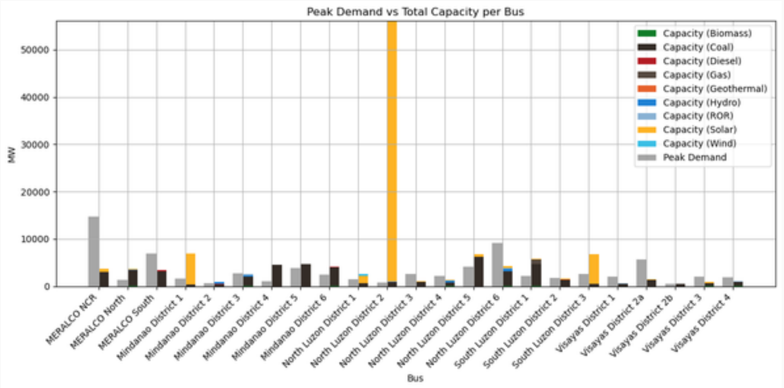
CO2red100, H2dem91.82





CO2redNone, H2dem97.03



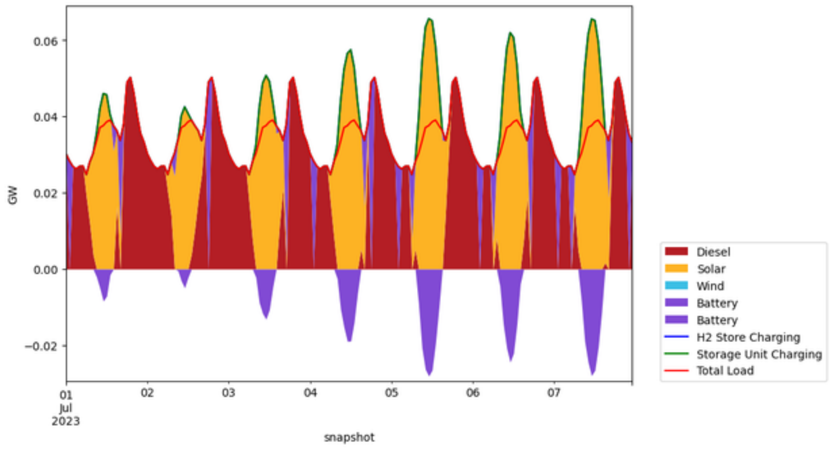


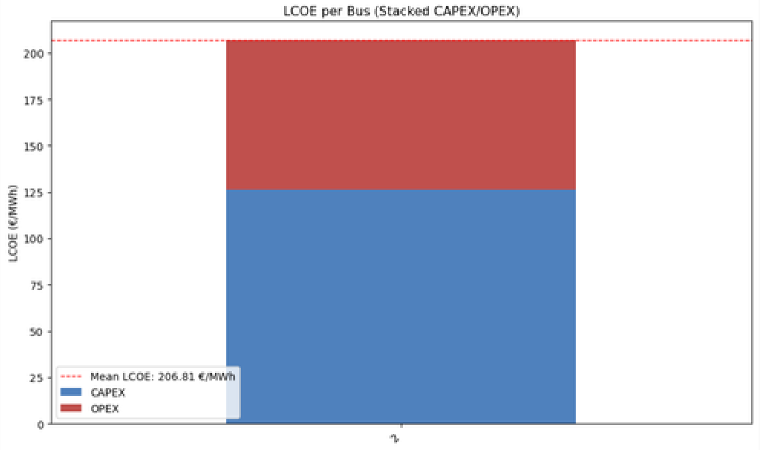
Future H2 Scenarios OFF-GRID

Q3: What is the LCOE and CO2red at off-grid as H2 transitions it?

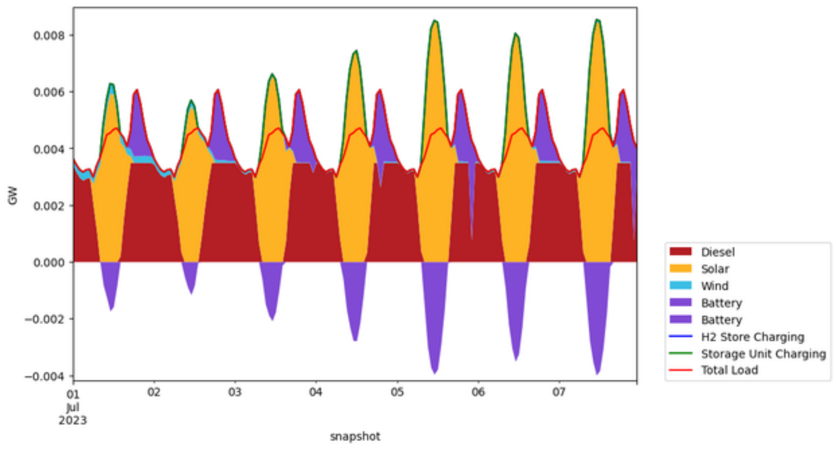
Assuming the cost of H2 from the CO2red100 scenarion of 227.15782 EUR/MWh

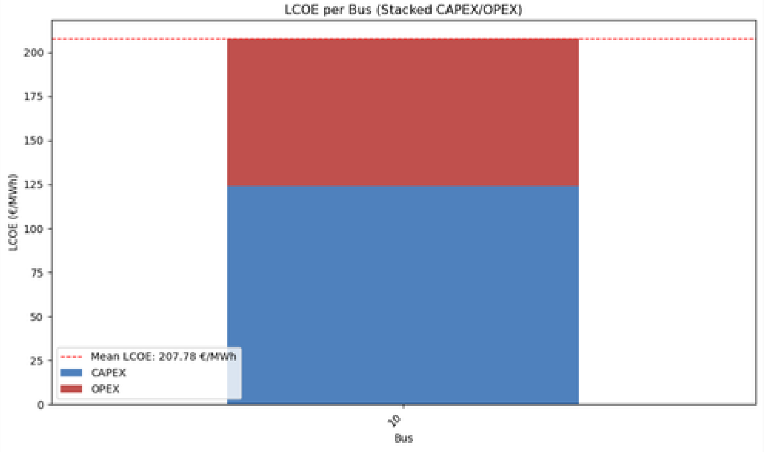
Without Hydrogen Fuel Cells



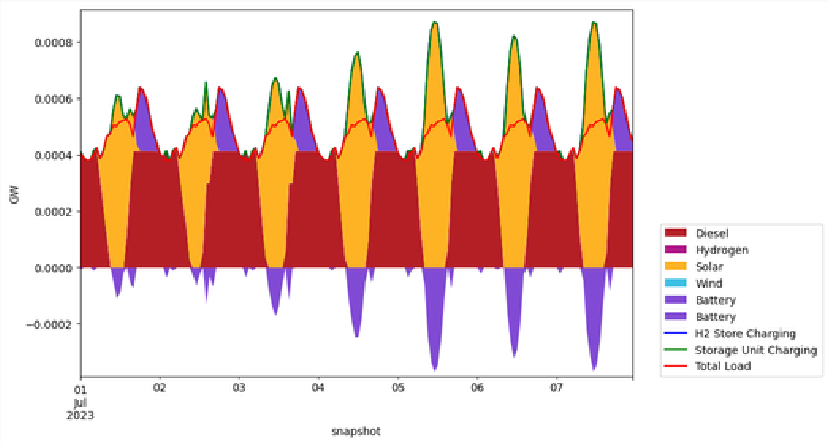


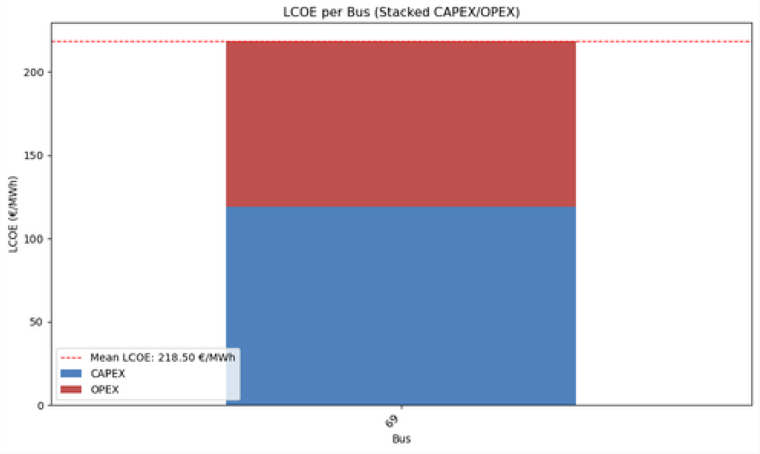
Island Name [MG ID]: Mindoro [2]
Peak Load, kW: 52704.78
Emission_tCO2/MWh_th: 0.065985





Island Name [MG ID]: Tablas [2]
Peak Load, kW: 6414.30
Emission_tCO2/MWh_th: 0.008191





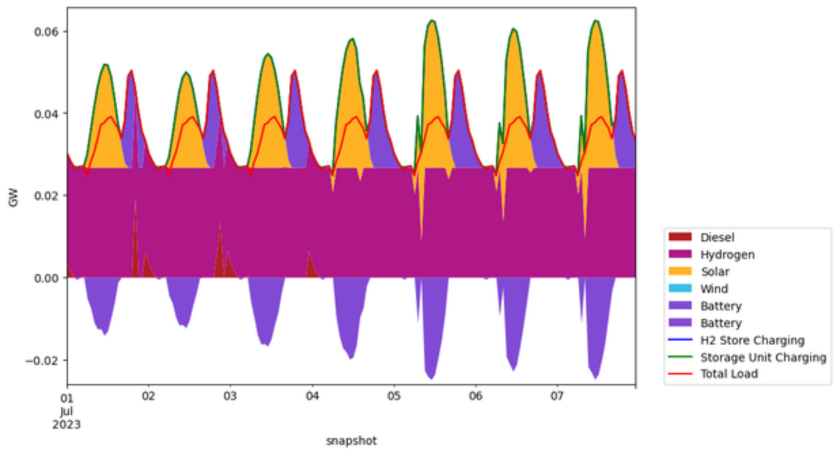
Island Name [MG ID]: Cuyo [56]
Peak Load, kW: 676.04
Emission_tCO2/MWh_th: 0.00111

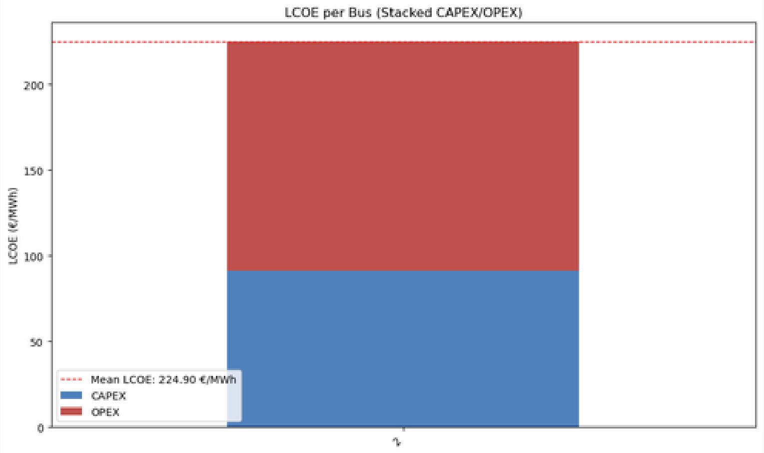
Future H2 Scenarios OFF-GRID

Q3: What is the LCOE and CO2red at off-grid as H2 transitions it?

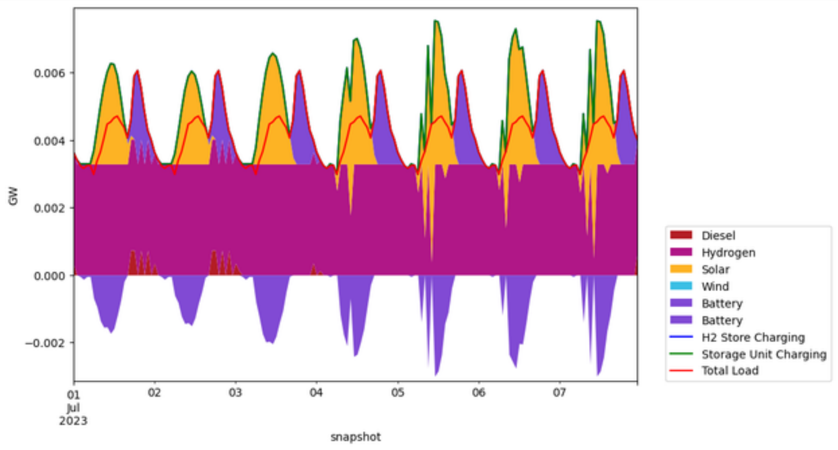
Assuming the cost of H2 from the CO2red100 scenarion of 227.15782 EUR/MWh

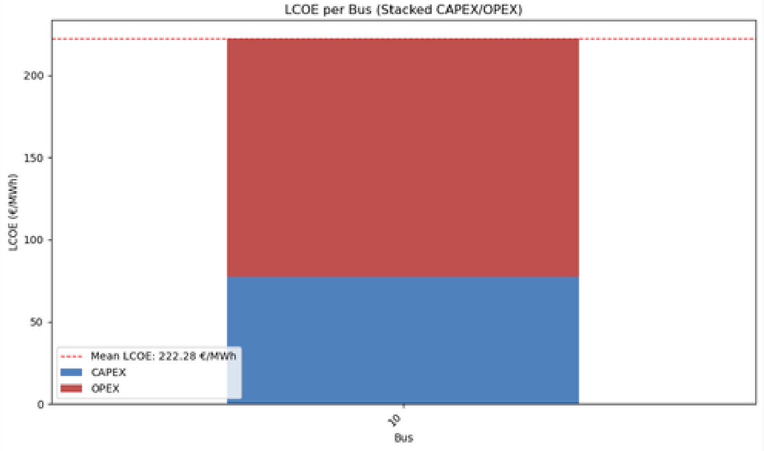
With Hydrogen Fuel Cells



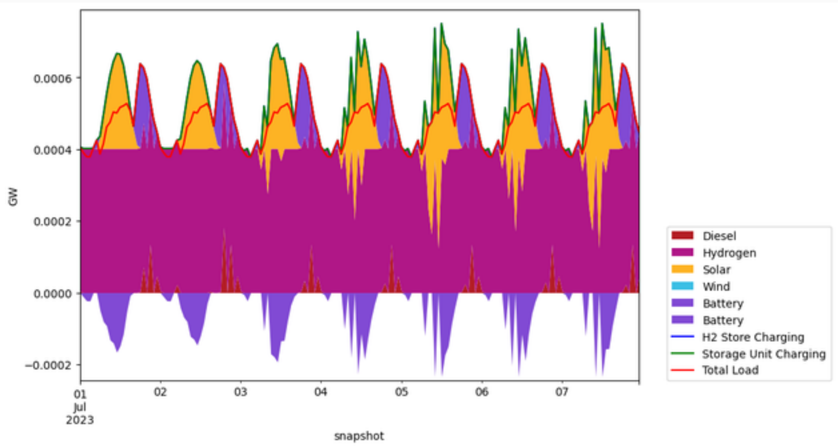


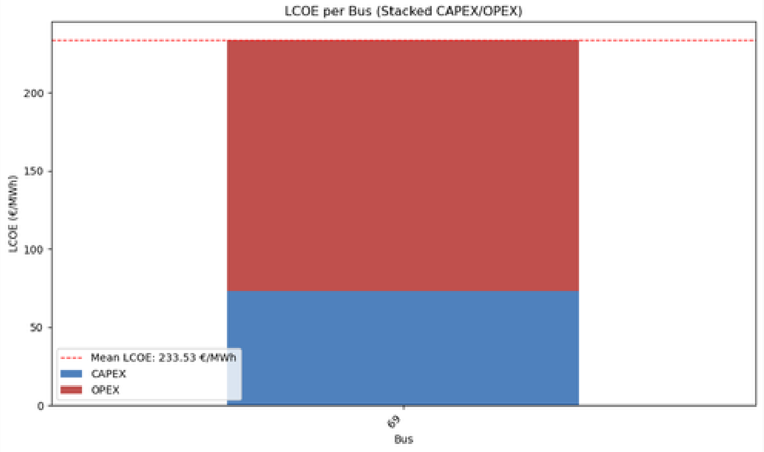
Island Name [MG ID]: Mindoro [2]
Peak Load, kW: 52704.78
Emission_tCO2/MWh_th: 0.00074 (-91%)





Island Name [MG ID]: Tablas [2]
Peak Load, kW: 6414.30
Emission_tCO2/MWh_th: 0.000304 (-97%)





Island Name [MG ID]: Cuyo [56]
Peak Load, kW: 676.04
Emission_tCO2/MWh_th: 0.000071 (-94%)

Takeaways

- Local hydrogen production can reduce diesel reliance and enable cleaner energy for both grid and off-grid Philippine islands.

- Hydrogen is not competitive for grid storage compared to batteries and has limited benefits even under high CO_2 reduction goals.

- Hydrogen becomes viable for larger islands with high diesel use, but remains cost-sensitive and needs supportive policy to scale.

Recommended further analyses

Sensitivity analyses on capital and marginal fuel costs effects

Cost of transportation of Hydrogen

Shipping schedule

Conversion to other hydrogen-derived carriers (ammonia)

Considering Off-grid Demand growth

A PyPSA-PH Case Study: Will Hydrogen ever have a role on Grid and Off-grid Island Electrification?

Arizeo Salac*, Davide Fioriti
Dottorando - Dipartimento di Ingegneria dell'Energia, dei Sistemi, del Territorio e delle Costruzioni (DESTEC)

PyPSA-PH
GITHUB REPOSITORY

https://github.com/arizeosalac/PyPSA-PH.git

PyPSA Users Meeting
01 July 2025 | Online

Supplementary Figures

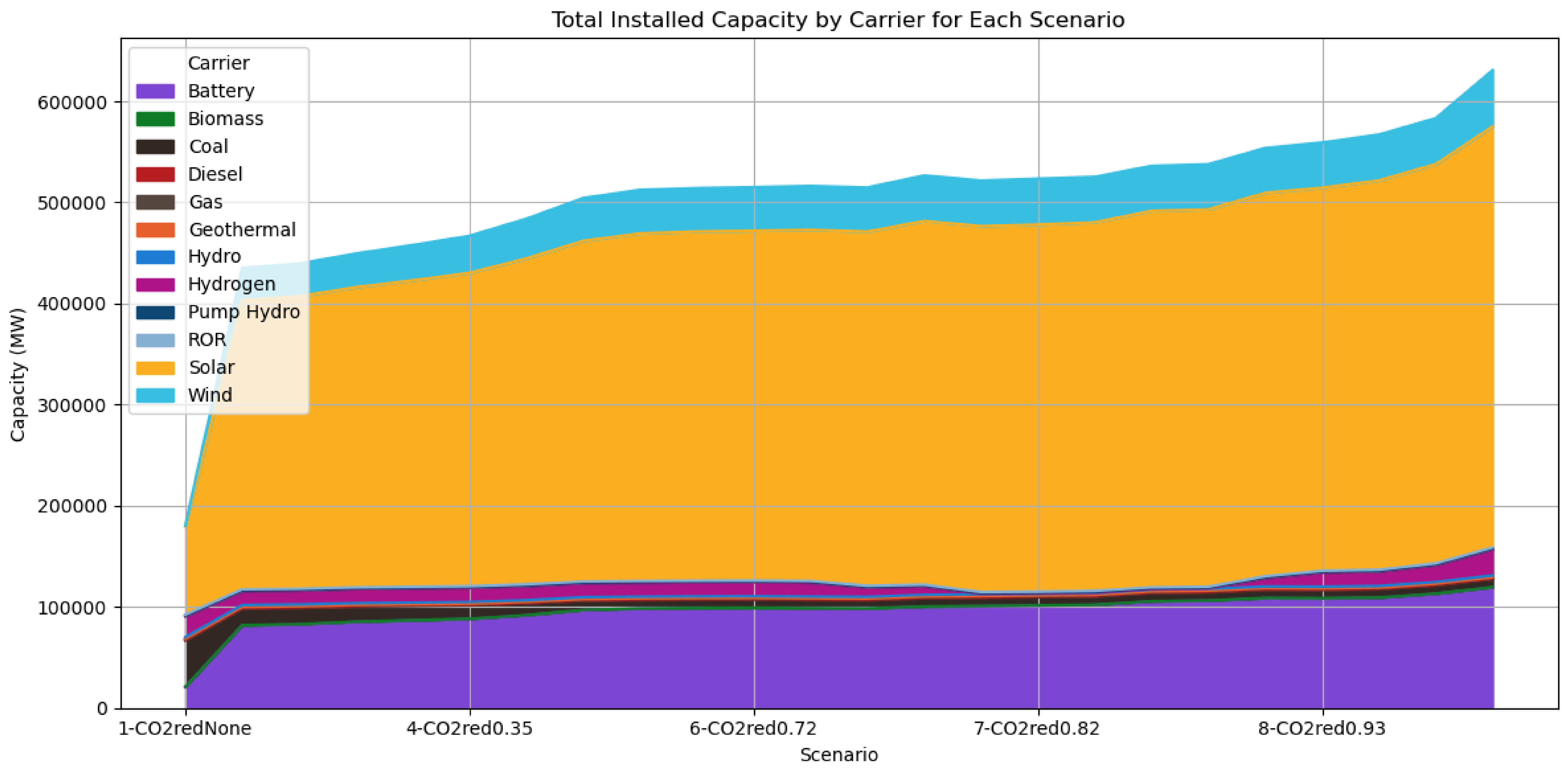
Supplementary Materials

Plots of Electrolyser and H2 Store SOC and Dispatch 1

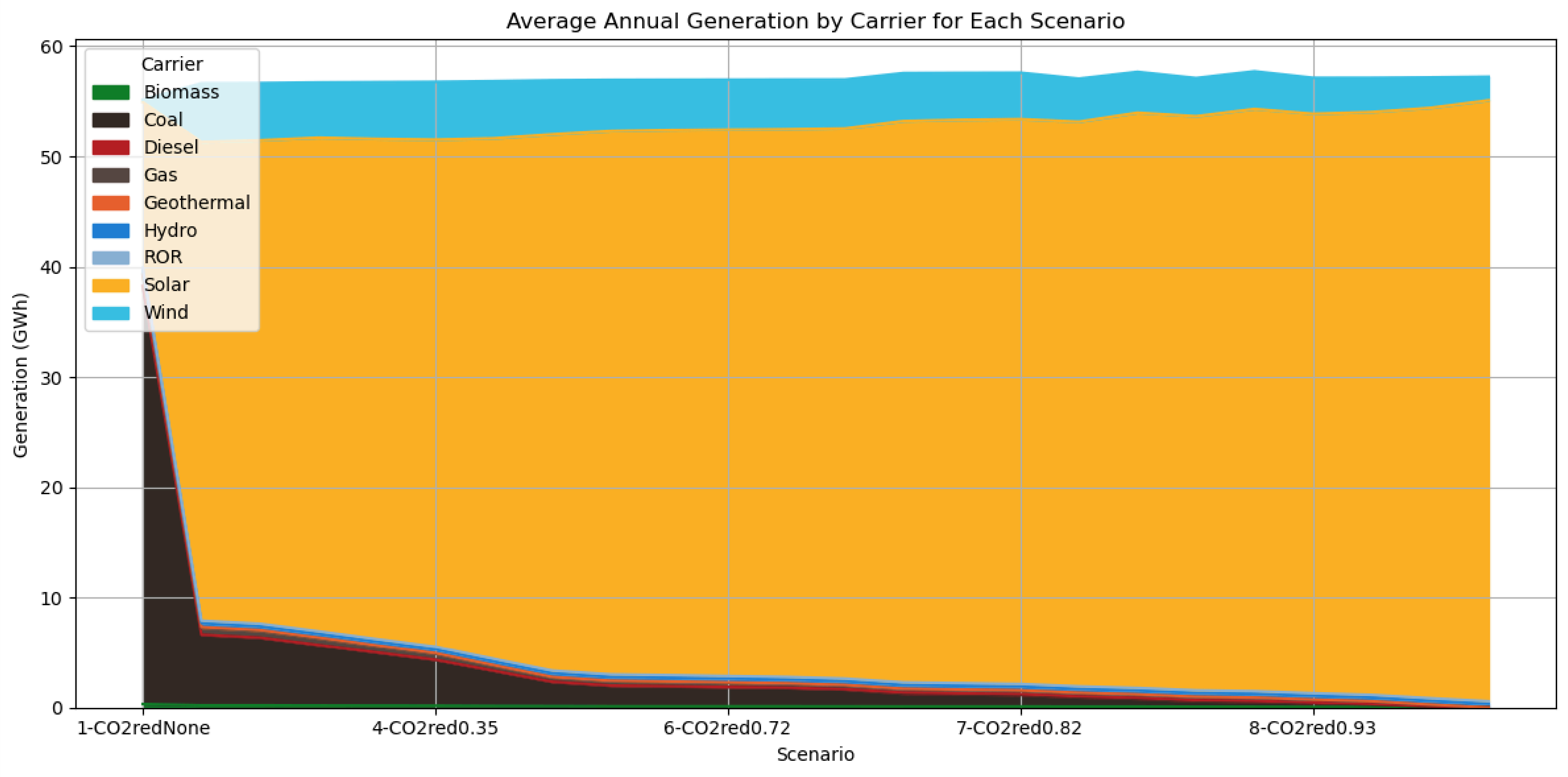
Supplementary Materials

Plots of Electrolyser and H2 Store SOC and Dispatch 2

Supplementary Materials



Supplementary Materials



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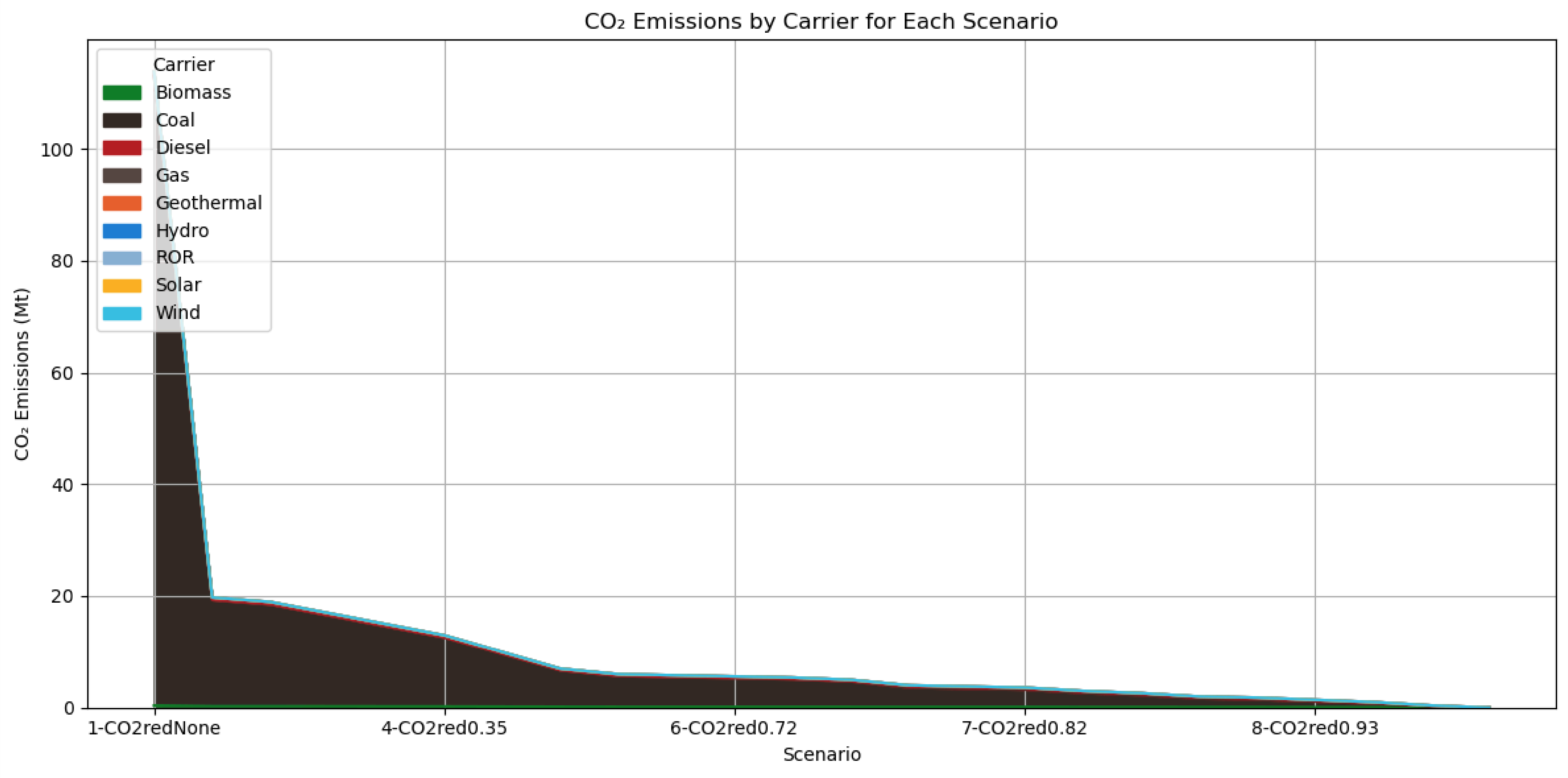

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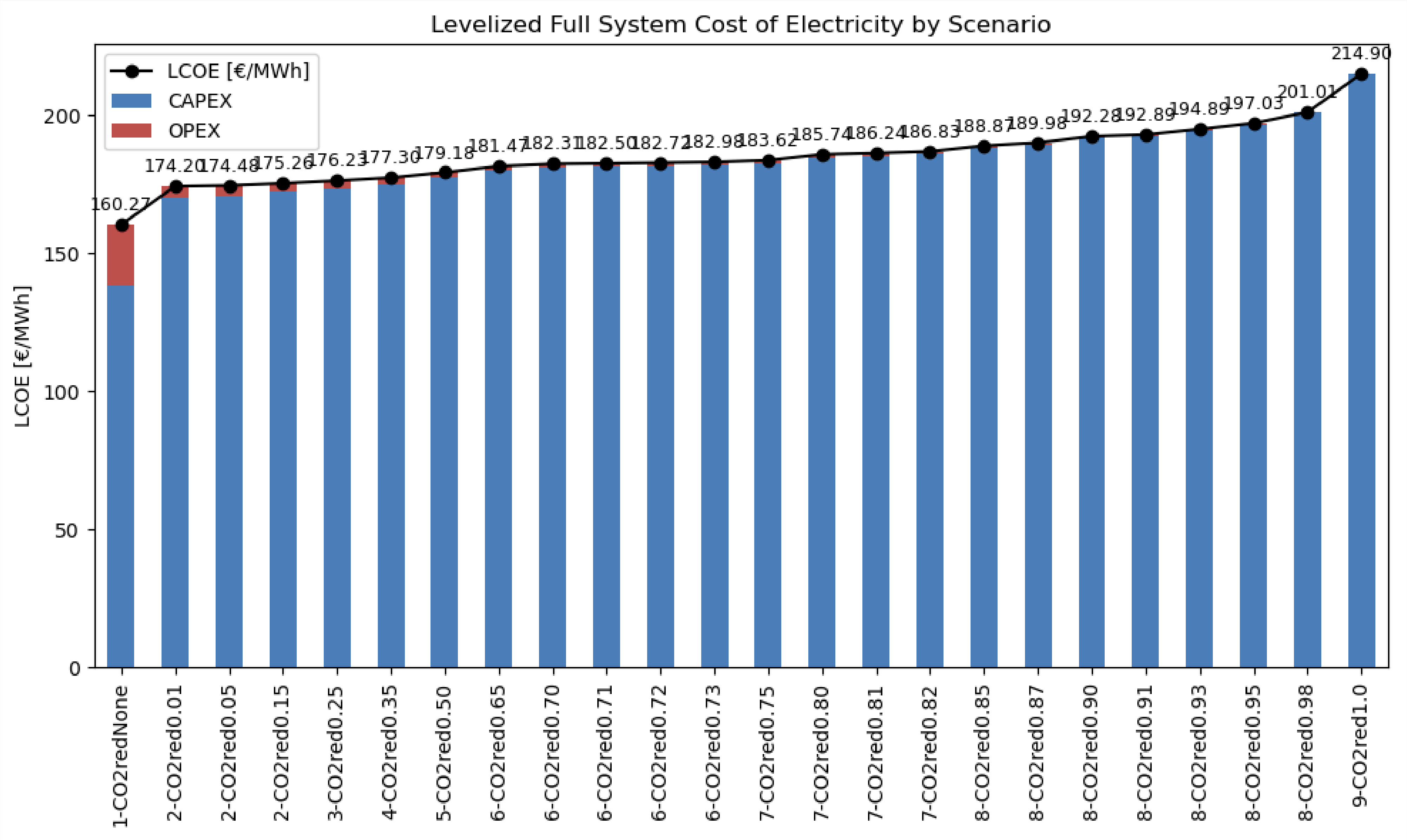

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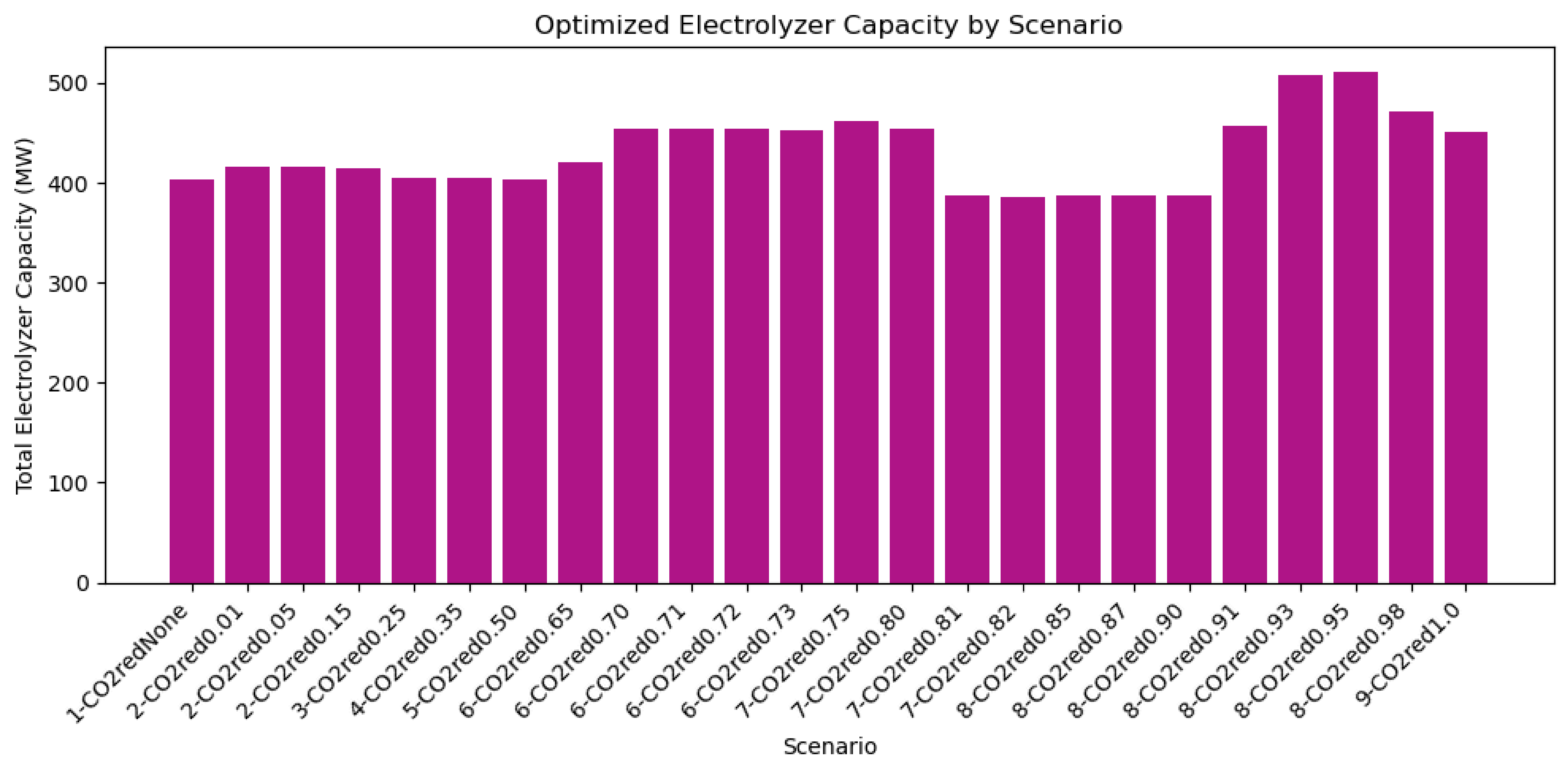

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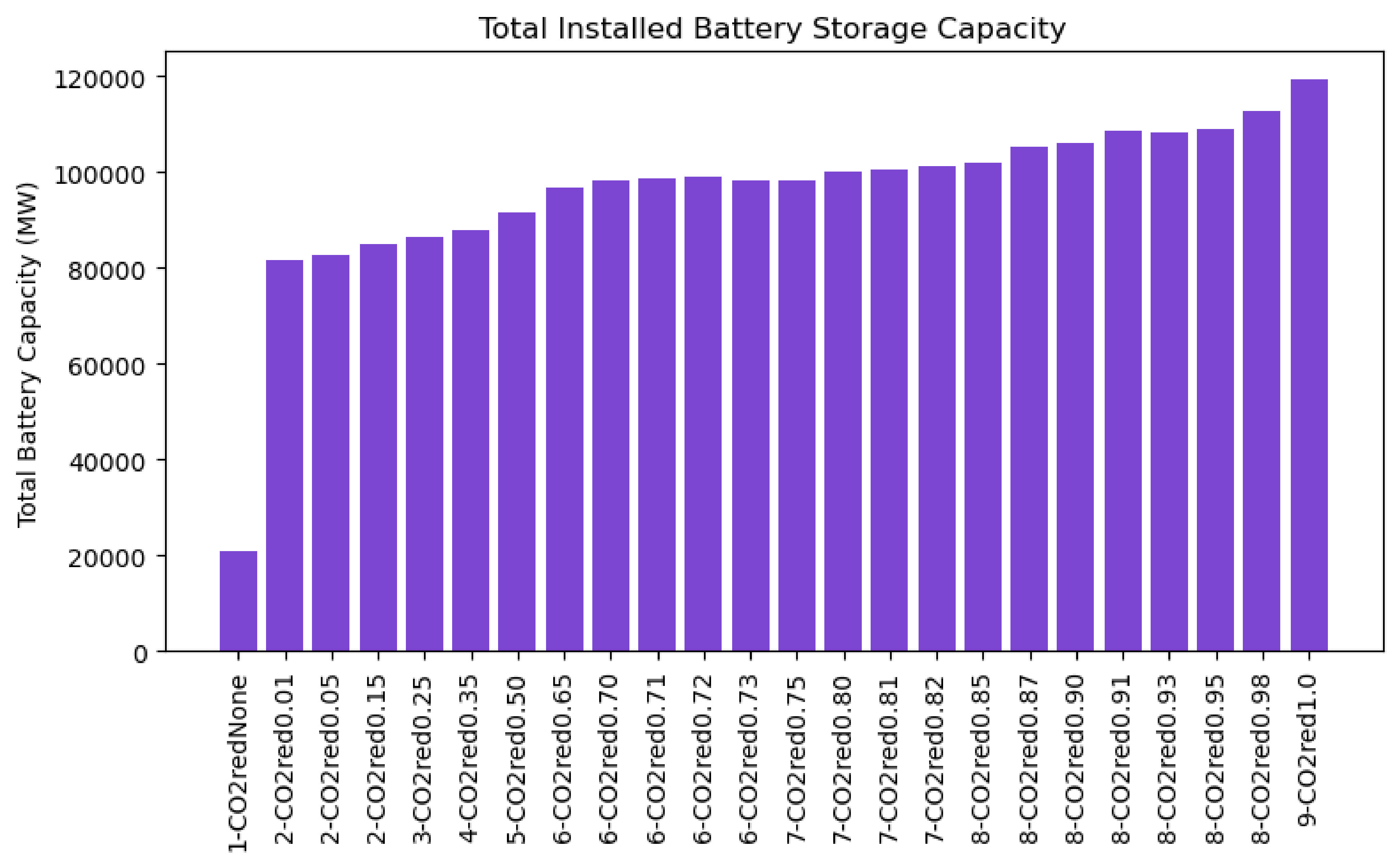

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Text

Things I want to show

Will Hydrogen ever have a role on Grid and Off-grid Island Electrification?

Philippine Island Realities
Q1: Why is it hard to electrify islands? Good solar resource potential but Geographical challenges and hard to connect to grid, small market demand for expensive RE leaving them diesel dependent in most cases, and more (lack of technical and management skills, lack of ability to pay, etc.)
Q2: Can we electrify Philippine islands green? Microgrids via ISLA diesel still plays huge part (Castro) Microgrids vs Grid-connection (Bertheau and Cader), PH MEDP plans for 2050 and UCME offgrid is still tied to grid by sharing the burden of high cost fossil fuel! we pay for price volatility of imported diesel fuel

Problem statement: Could we develop a local market for hydrogen to power grid and off-grid islands and reduce their diesel fuel dependency?

PyPSA-PH Model structure and validation:
Q1: How was the model built? Sources of Data (baseline from 2023 IEMOP),
Q2: How does the model validated? Capacity Mix, Generation cost

Future H2 scenarios at varying CO2red levels ON GRID
Q1: Will H2 have a role on the grid in time shifting/storage? NO market on grid since bateries are more cheaper in static storage! Show scenarios CO2red levels and H2 production for offgrid (None to 0 to 1000MW peak), only production, does not favor fuel cell building on grid, instead higher batteries (confirm) as coal decreases in increasing CO2red
Q2: Will it be favorable for the grid to produce H2 for offgrid or not, in terms of LCOE? Run H2demNone at all CO2red levels for comparison and compare LFSCOE average for all scenarios, for extreme cases it will increase LMP for AC at buses a little by i think 10Eur/MWh as it approaches CO2red1.0 (that will be the cost of coal that they need to pay to use coal - LMP)
Q3: How will the H2 supply side market on grid will look like? Show the curves of prices vs production as shown on 3d plot but make it 2d superimposed
Q4: Will H2 lower curtailment of VREs on higher CO2red? Show plot of curtailment vs without demand

Future scenario of H2 in Off-grid
Q1: How will the H2 demand side market on off-grid will look like? show total peak demand total market size, Show prices vs demand for H2 from run, put cost assumptions for fuel alone and disclaimers
Q2: Which island peak load size will benefit and which will not? Calculate percentage MW demand wrt to peakload island or with diesel average MW capacity.
Q3: What is the LCOE and CO2red at off-grid as H2 transitions it? Calculate for representative islands (case studies due to lack of time)
Q4: Sensitivity analysis on capital and marginal fuel costs effects? What could be the effec? only predict especially wrt to status quo and CO2red

For development and recommendation: