Data and Policy Analytics Seminar Series

Mapping ASEAN's Clean Power

What 218 Projects Say About Cost Competitiveness

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Overview

1. **Why it is necessary to evaluate clean power generation costs in ASEAN countries?**
   – Huang Yijia
2. **How expensive is clean energy production in ASEAN? A comparison by country and technology**
   – Parag Dass
3. **What influences clean energy production costs? An index capturing clean energy competitiveness**
   – Yan Bowen
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Why it is necessary to evaluate clean power generation costs in ASEAN countries?

Huang Yijia

RE adoption: fulfilling sustainability commitments while ensuring energy security

- To enhance energy security, resilience, and accelerate energy transition, ASEAN needs to expand their adoption of renewable energy.
  - **45%** share of Renewable Energy (RE) in total installed power capacity by 2030 (APAEC 2026-2030)
- ASEAN member countries also outline their plans on increasing renewable power adoption.

Country	Goals on RE adoption	Target year
Singapore	3 gigawatt-peak of solar energy	2030
Cambodia	72% of RE in installed capacity	2035
Indonesia	61% of RE in installed capacity	2034
Malaysia	40% of RE in installed capacity	2035
Vietnam	About 47% of RE in installed capacity	2030

Note: APAEC stands for ASEAN Plan of Action for Energy Cooperation

Source: ACE, 2025a, b, 2026; Cambodia's Third Nationally Determined Contribution, 2025; PLN, 2024; Ministry of Economy, Malaysia, 2023; Ministry of Finance, Singapore, 2026

RE adoption: complying green regulations and capitalising opportunities in green economy

- **Green regulations incentivise to reduce carbon emissions**
  - Carbon tax in the ASEAN region: Singapore, Indonesia, Malaysia (upcoming)
  - EU's Carbon Border Adjustment Mechanism (CBAM): impose a "fair price" on carbon emission during the production of carbon-intensive goods → extra cost for ASEAN manufacturers (EU: ASEAN's 4th largest export destination)

- **Businesses, especially leading MNCs are greening their supply chains by using RE power**
  - Drivers: national and supra-national sustainability goals and regulations; consumers' demand for eco-friendly products
  - Example: RE 100 Initiative (e.g. AstraZeneca, Apple, Google and First Solar) -- 100% renewable electricity usage in operations

- **Strong growth momentum in green investment led by power sector**
  - Private green investments in the ASEAN region: ~ USD 8 billion in 2024, 43% up from 2023
  - Power sector: ~ 2/3 of the investments (solar industry as a key driver)

Source: European Commission (n.d.), Chepeliev et al. (2025) and Bain & Company, GenZero, Google, Standard Chartered, and Temasek (2025), RE 100 (n.d.), EY (2025)

RE adoption has expanded domestically in ASEAN countries

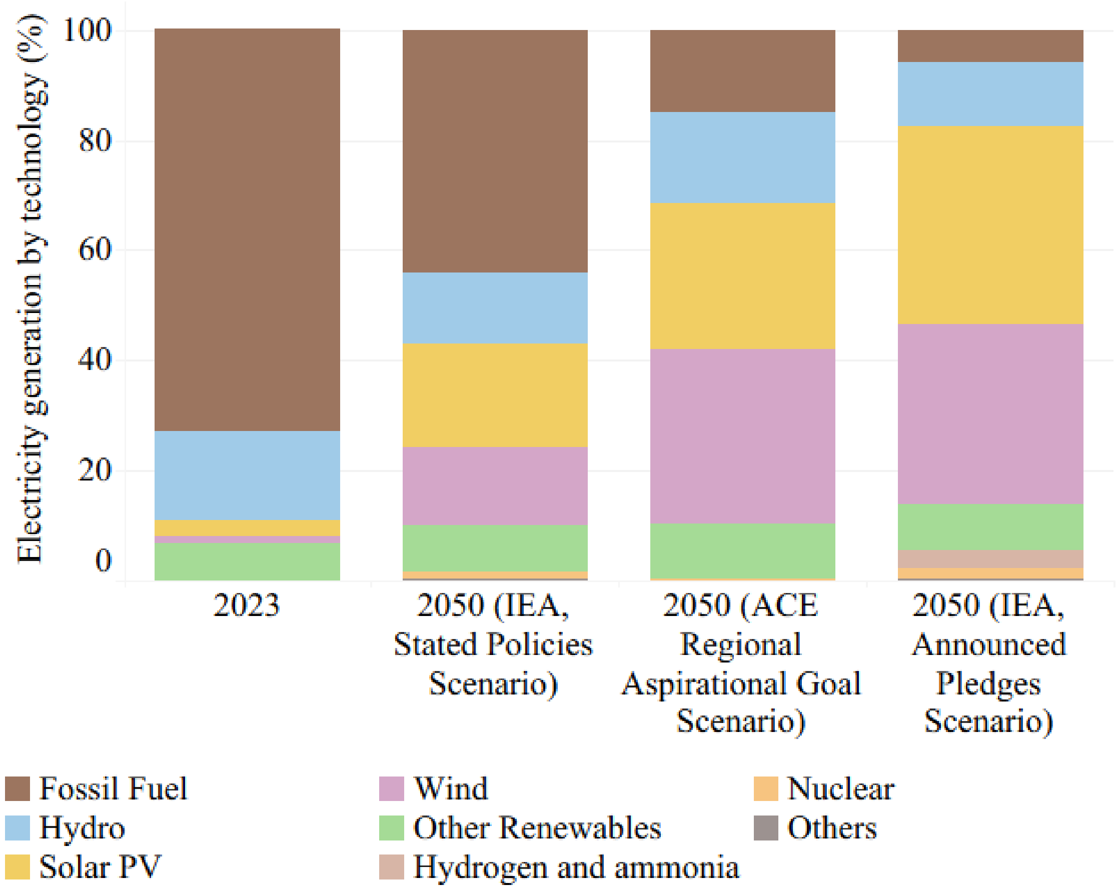
- **ASEAN countries have incorporated more RE in installed power capacity**
  - RE's share in regional installed capacity: 25.8% (2018) VS 31.9% (2024)
  - Notable rise of RE's share in Laos, Singapore and Vietnam

Country	RE's share %	
	2018	2024
Laos	77.0	86.3
Vietnam	41.1	57.9
Singapore	2.43	13.4

Source: ACE, 2021, 2025 and IRENA

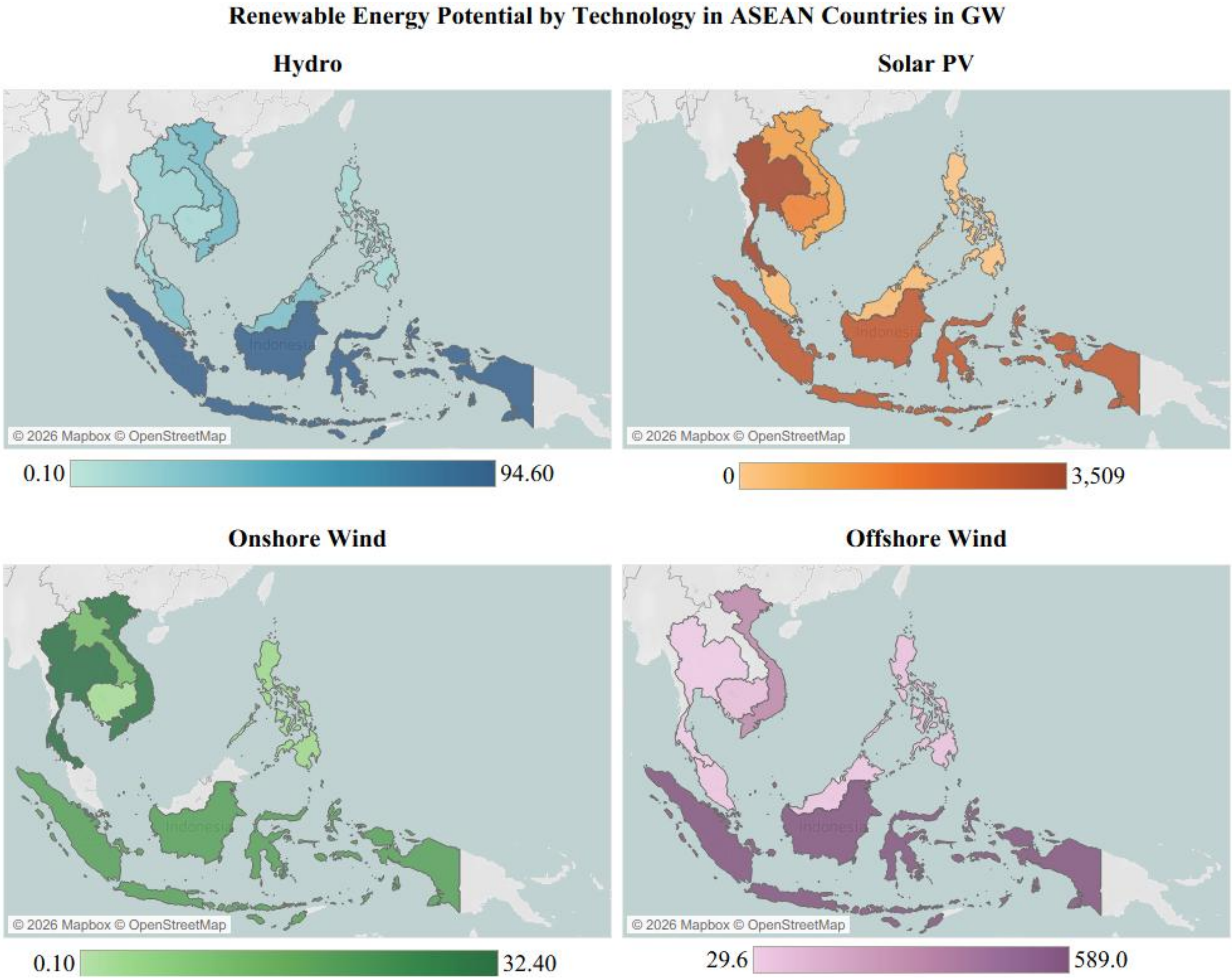
- **ASEAN countries could incorporate more RE in power generation in the future**
  - RE's share in power generation: 27.3% (2023) VS 54.3% (2050)
  - Led by solar and wind expansion

ASEAN's Power Generation by Technology (%) in 2023 and 2050 (Forecasted under Scenarios)



Source: IRENA and IEA (2024)

Significant RE potential distributed unevenly and remained untapped in ASEAN

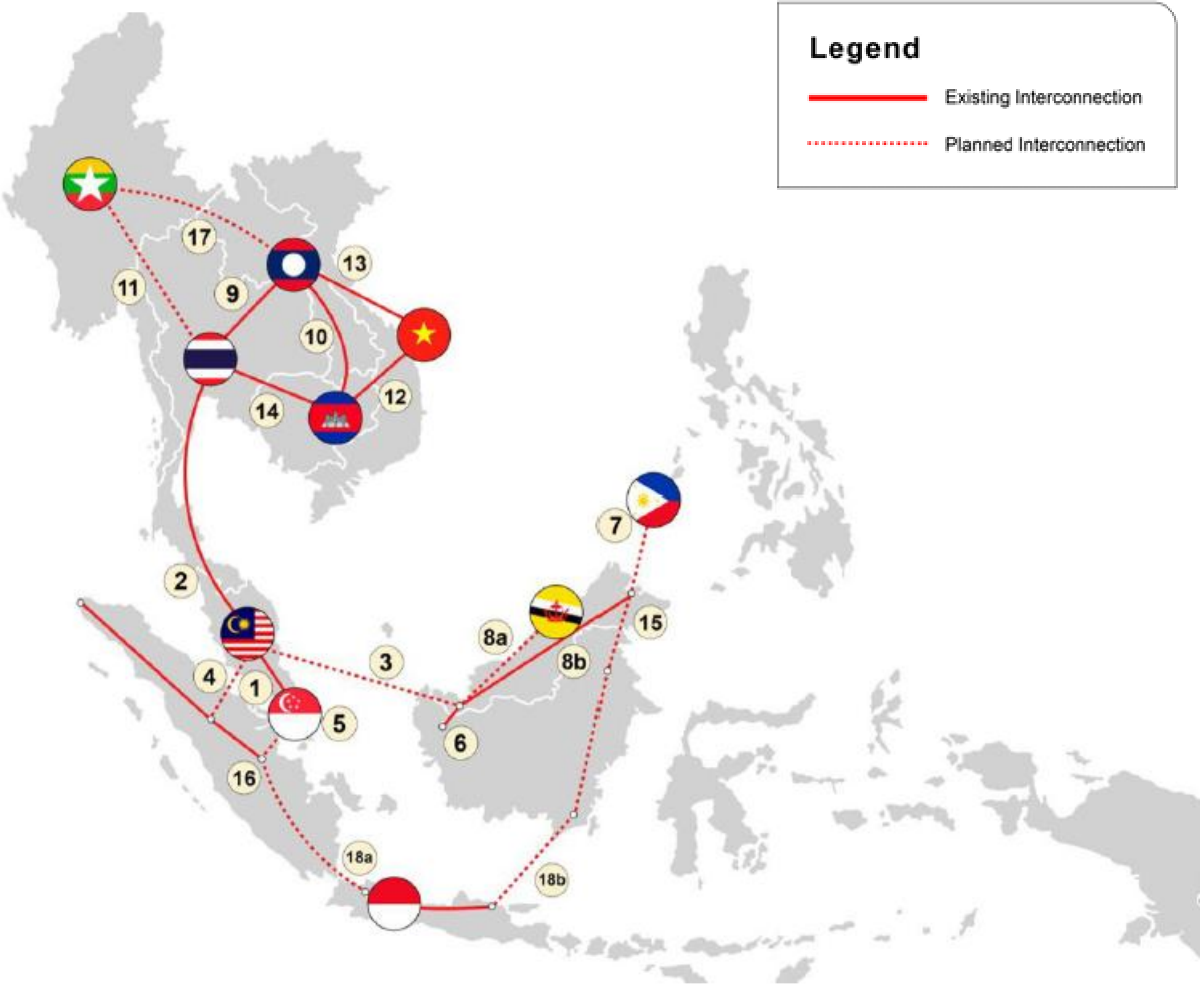


Source: JICA (2025)

Note: Data for Myanmar is not available

Regional power trade allows ASEAN to better utilise its significant RE potential

- **Policy goal of ASEAN Power Grid**
  - Meet rising electricity demand, improving access to reliable and affordable energy, and strengthening regional energy cooperation
  - Accelerate the region's renewable energy transition by tapping into ASEAN's renewable potential
- **Significant progress on ASEAN Power Grid**
  - Operational capacity: 7.65 GW (2020) VS 10.3 GW (2024);
  - Total amount of electricity traded under LTMS-PIP: 30.2 GWh (as of 2020) VS 266 GWh (as of 2024)
  - Looking ahead: 6 future submarine interconnections



Note: LTMS-PIP refers to Lao PDR-Thailand-Malaysia-Singapore Power Integration Project
Source: ACE, 2021 and 2025

Research questions

Expand the adoption of RE domestically and via regional power trade → **Which RE** to adopt in different countries?

- What are the **cost structures** of clean energy production in ASEAN countries?
- What are the **underlying factors** driving differences in the cost structures?

This study outlines the most cost-effective low carbon electricity, by country and technology, in the ASEAN region

Data sources

- **Global Energy Monitor & BMI: Track RE project level information and calculate the LCOE**

Information	BMI	Global Energy Monitor (GEM)
Location	City, State, Country	Local Area, City, State, Region, Country, **Latitude, Longitude**
CAPEX (Overnight Construction Cost)	**In USD**	
Technology	Solar PV, Onshore Wind, Offshore Wind, Hydropower	
Project Size	Capacity (MW)	
Date	Start, Complete	Start, Retire
Status	Announced, Pre-Construction, Construction, Operating, Retired, Cancelled, Shelved, Mothballed	Feasibility stage, Announced, Planning Stage, Approved, Tender stage, Contract awarded, Project finance closure, Under construction, Completed

- **Climate Policy Database: Track policy support for clean power development**
  - Basic information: policy title & description, location (country, state, city), status, start year, sector
  - Policy type: renewables, energy efficiency
  - Policy instrument: feed-in-tariff, fiscal or financial incentives, CO2 taxes, RD&D funding, building codes and standards

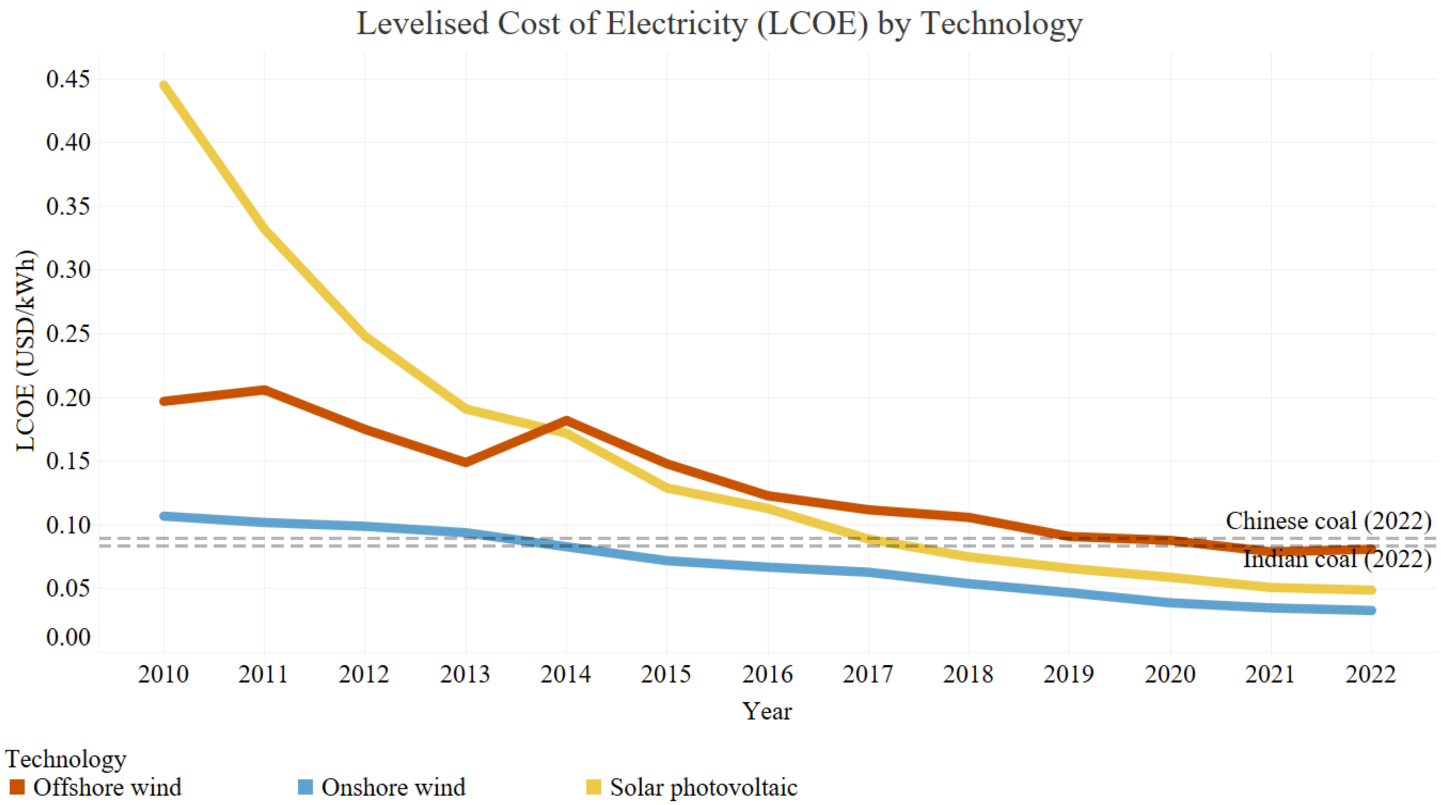
How expensive is clean energy production in ASEAN?

- A comparison by country and technology

Parag Dass

Methodology: LCOE calculation

- A common metric used in literature for comparing the cost structure of electricity production is the Levelised Cost of Electricity (LCOE) (Hansen, 2019; Supriyanto et al., 2022; Timilsina, 2021).
- LCOE calculates the average cost to generate one unit of electricity over a power plant's entire lifetime (USD/kWh).
- Existing LCOE estimations exist for many countries across the globe, but ASEAN countries are missing in global LCOE databases.



Source: Authors based on data from IRENA (2022).

Cost components within LCOE

LCOE (USD/kWh) calculation (Timilsina, 2020)

$$LCOE = ACC + FOMC + VOMC + FC$$

Annualised Construction Cost

$$ACC = \frac{OC*CRF*1000}{CAF*24*365}$$

Overnight construction cost (OC)

Capital Expenditure (CAPEX) per unit of capacity

Capital Recovery Factor (CRF)

$$CRF = \frac{r(1+r)^n}{(1+r)^n - 1}$$

Capacity Availability Factor (CAF)

Actual output over theoretical maximum output

Operations & Maintenance (O&M) Costs: Fixed and Variable

VOMC ≈ 0 for clean energy technologies for LCOE estimation (Lee et al., 2020; Tran & Smith, 2018).

Annualised FOMC

$$FOMC = \frac{FXC*1000}{CAF*24*365}$$

Fuel Costs

Fuel costs are not relevant for clean energy technologies

Note: This method do not include the subsidies, taxes and any other financial incentives offered by governments when calculating LCOE

Sourcing data for LCOE

$$LCOE = ACC + FOMC$$

CAPEX accounts for most variation in LCOE

Overnight construction cost (OCC)
BMI CAPEX data

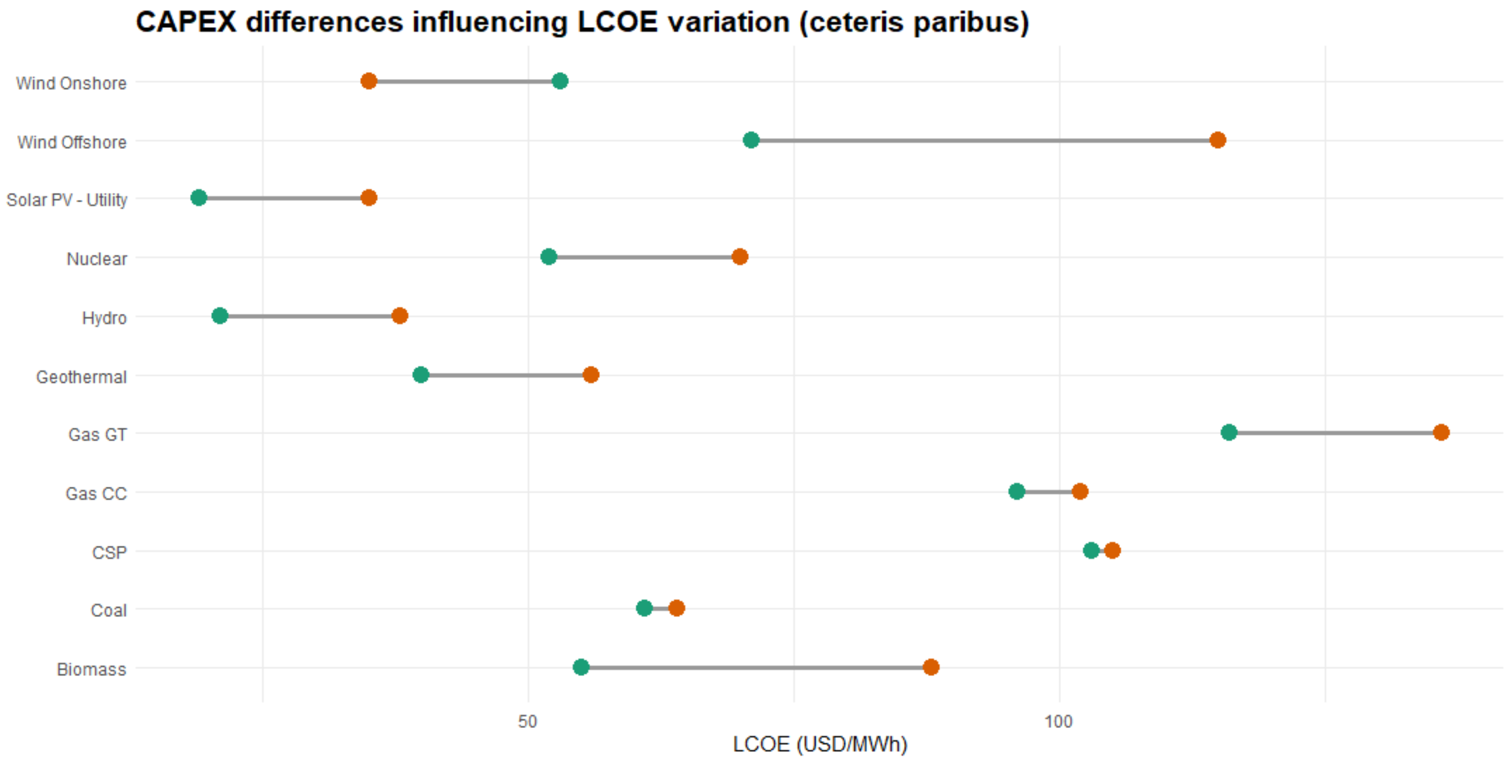
Discount rate (for CRF)
IRENA
IEA Cost of Capital Observatory

Capacity Availability Factor (CAF)
ASEAN Centre for Energy (ACE)
IRENA

Fixed O&M Costs (FOMC)
ASEAN Centre for Energy
USAID
IESR Indonesia
IRENA

Largest component of LCOE: CAPEX and determinants of variation

- What causes variations in CAPEX?
  - **Technological configurations**:
    - Solar panel: amorphous vs crystalline silicon
    - Hydropower: reservoir type vs run-of-river
  - **Design and quality** of various components
    - turbine, generator, boiler, and other accessories.
  - **Size** of power plants (economies of scale).
  - **Geographic** location



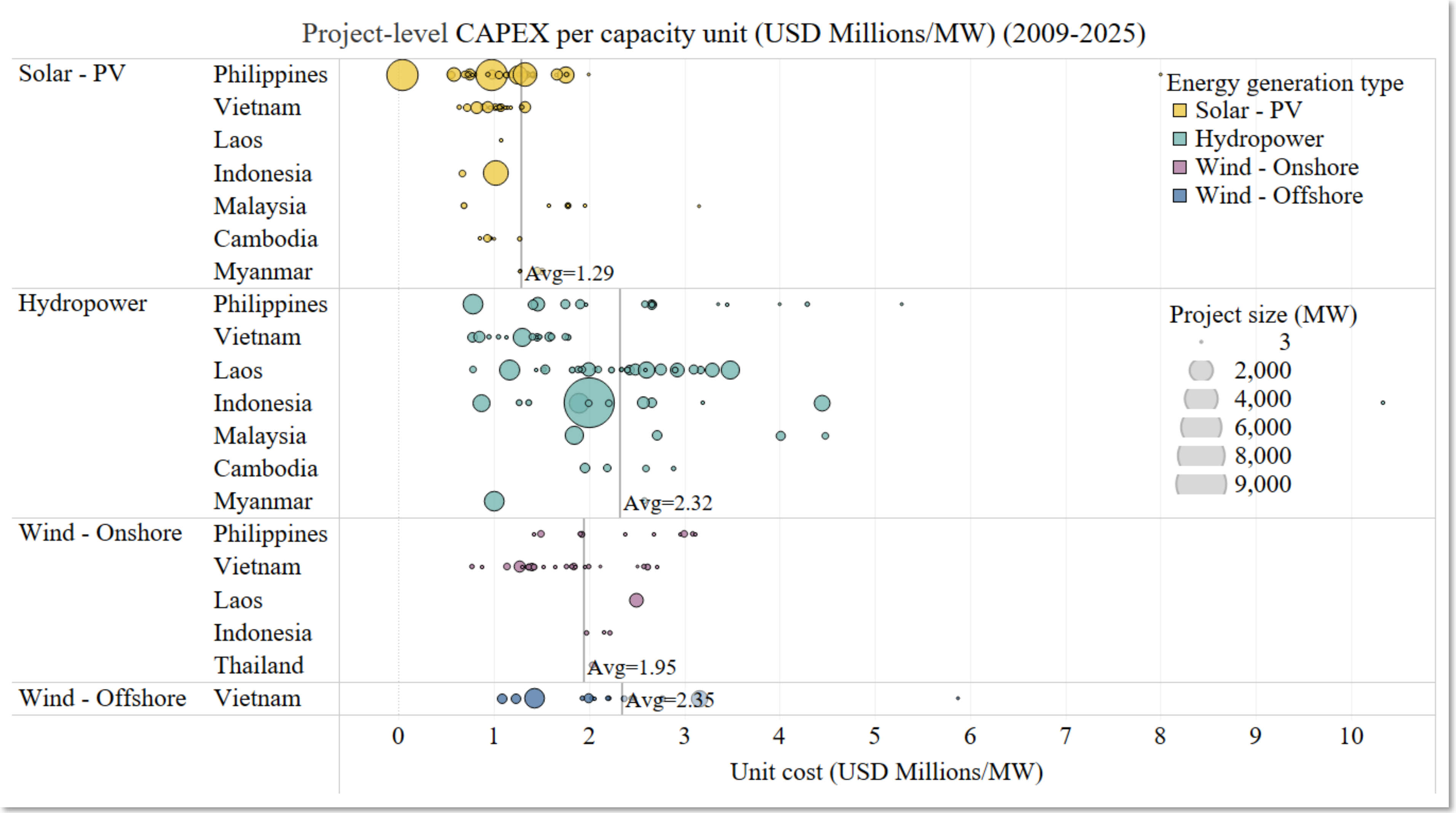
Source: Timilsina (2020)

BMI Data: project-level CAPEX

Data Coverage (number of projects)

Country coverage: **PHI (72), VNM (70),** LAO (29), IDN (17), MLY (11), KHM (10), MYR (7), THA (2)

Technology coverage: **Solar PV (85), Hydropower (79)**, Wind (Offshore)(39), Wind (Onshore) (15)



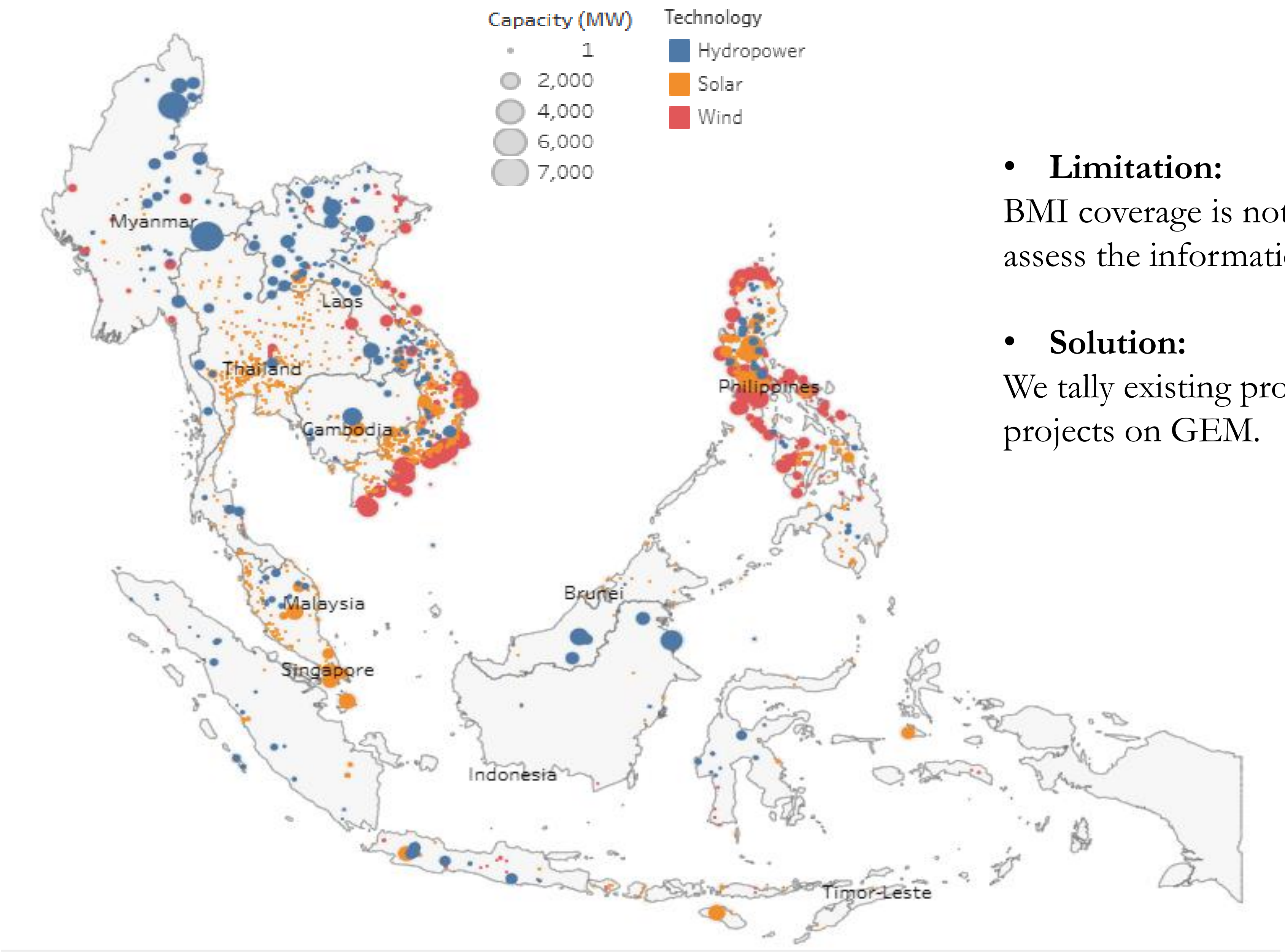
Source: Authors based on BMI data.

BMI Data: ASEAN countries' CAPEX over time across technologies

- ASEAN countries' CAPEX on clean power projects has significantly reduced over time across technologies. This suggests increasing cost-competitiveness.

Source: Authors based on BMI data.

GEM Data: comprehensive coverage of existing projects



- **Limitation:**

BMI coverage is not comprehensive; how can we assess the information gaps?

- **Solution:**

We tally existing projects on BMI with the total projects on GEM.

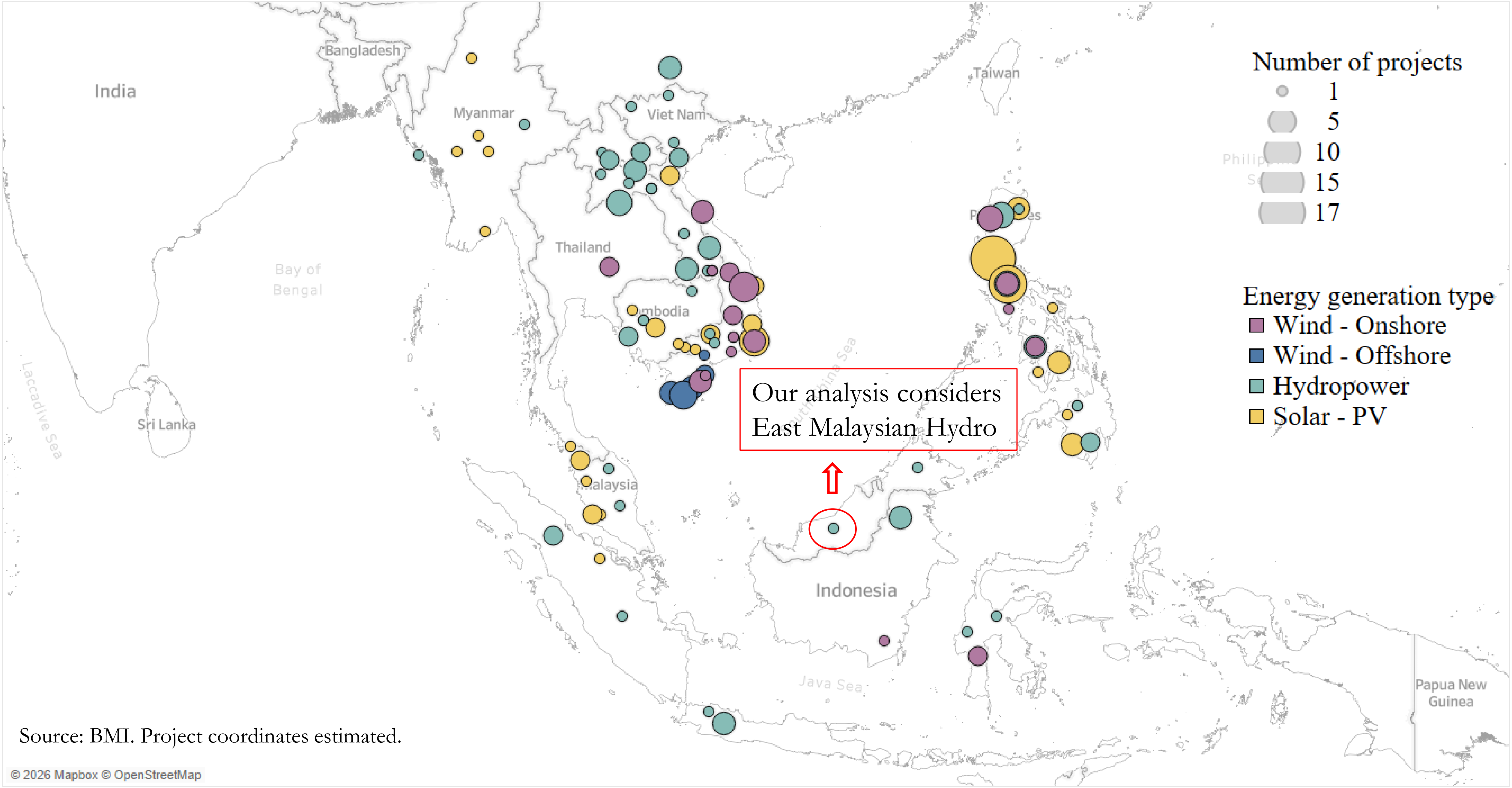
Source: Authors based on GEM data.

LCOE by country-technology pair

- Considering **LCOE**, **Hydropower** is more cost-effective than other clean technologies → **Solar PV** → **Onshore wind** → **Offshore wind**.

Country	Technology	LCOE in $/kWh
MYS	Hydropower	0.0442
IDN	Hydropower	0.0480
VNM	Hydropower	0.0485
MMR	Hydropower	0.0526
KHM	Hydropower	0.0572
LAO	Hydropower	0.0639
IDN	Solar PV	0.0670
PHL	Hydropower	0.0771
LAO	Solar PV	0.0800
IDN	Onshore wind	0.0825
KHM	Solar PV	0.0852
VNM	Solar PV	0.0891
PHL	Solar PV	0.0955
VNM	Onshore wind	0.1141
MYS	Solar PV	0.1148
THA	Onshore wind	0.1306
PHL	Onshore wind	0.1426
LAO	Onshore wind	0.1546
MMR	Solar PV	0.1657
VNM	Offshore wind	0.1804

Cost-competitive LCOE: A sub-national perspective



Source: BMI. Project coordinates estimated.

Towards LCOE-intelligent regional power trade (I)

ASEAN Countries	MYS (Hydropower)	IDN (Hydropower, Solar PV, Onshore Wind)
MYS	• Sarawak-Peninsular Malaysia Interconnection (pre-feasibility study completed 2025) • Sarawak-Sabah Power Interconnection (completed 2024-25)	• BIMP-PIP conceptualised 2023 • Sarawak-West Kalimantan Interconnection (since 2016)
IDN	• BIMP-PIP conceptualised 2023 • Sarawak-West Kalimantan Interconnection (since 2016)	• Expanding renewables transmission in the Java-Bali grid (2022) • Expanding Sumatra-Java HVDC Interconnection (2025)
VNM	• Vietnam-Malaysia-Singapore Offshore Wind Interconnection Project (agreed 2025)	NA
MMR	NA	NA
BRN	• BIMP-PIP conceptualised 2023 • Expanding Sarawak-Sabah Power Interconnection (2025)	• BIMP-PIP conceptualised 2023
KHM	NA	NA
LAO	• LTMS-PIP commenced 2022	NA
THA	• LTMS-PIP commenced 2022 • Expanding Thailand-Malaysia Interconnections (2025)	NA
PHL	• BIMP-PIP conceptualised 2023	• BIMP-PIP conceptualised 2023
SGP	• LTMS-PIP commenced 2022 • Expanding Singapore-Malaysia Interconnectors (2025) • Sarawak-Singapore Interconnection conditionally approved (2025) • Vietnam-Malaysia-Singapore Offshore Wind Interconnection Project (agreed 2025)	• Conditional approval for Riau solar PV import projects (2023) • Agreement on expanding cross-border electricity trade (2025)

Towards LCOE-intelligent regional power trade (II)

ASEAN Countries	VNM (Hydropower, Solar PV, Onshore Wind, Offshore Wind)	KHM (Solar PV)	THA (Onshore Wind)
MYS	• **Vietnam-Malaysia-Singapore Offshore Wind Interconnection Project (agreed 2025)**	NA	• **LTMS-PIP commenced 2022** • **Expanding Thailand-Malaysia Interconnections (2025)**
IDN	NA	NA	NA
VNM	• Well-developed domestic grid integration	• **Expanding VTN electricity exports to KHM in PDP VIII (2025)** • **ASEAN Power Grid North Sub-system Expansion** • **Greater Mekong Subregion Electricity Interconnection**	• **ASEAN Power Grid North Sub-system Expansion** • **Greater Mekong Subregion Electricity Interconnection**
MMR	• ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection	• ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection	• ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection
BRN	NA	NA	NA
KHM	• **Expanding VTN electricity exports to KHM in PDP VIII (2025)** • **ASEAN Power Grid North Sub-system Expansion** • **Greater Mekong Subregion Electricity Interconnection**	• Well-integrated domestic grid systems	• **Existing Thailand-Cambodia Power Interconnection for Thai electricity exports** • ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection
LAO	• Multiple transmission lines since 1998 • Expanding hydropower imports along existing infrastructure • ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection	• Champasak-Stung Treng transmission line (2016) • ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection	• Existing Laos-Thailand Power Interconnection for Lao hydropower exports • LTMS-PIP commenced 2022 • ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection
THA	• ASEAN Power Grid North Sub-system Expansion • Greater Mekong Subregion Electricity Interconnection	• **Existing Thailand-Cambodia Power Interconnection for Thai electricity exports** • **ASEAN Power Grid North Sub-system Expansion** • **Greater Mekong Subregion Electricity Interconnection**	• Well-developed domestic grid integration
PHL	NA	NA	NA
SGP	• **Conditional approval for offshore wind import projects (2023)** • Vietnam-Malaysia-Singapore Offshore Wind Interconnection Project (agreed 2025)	• **Conditional approval for solar PV import projects (2023)**	• LTMS-PIP commenced 2022

What influences clean energy production costs?

- An index capturing clean energy competitiveness

Yan Bowen

Beyond LCOE: determinants of clean energy cost competitiveness

Economic Policy Instrument
- Revenue-providing (subsidies, tax relief, etc.)
- Cost-imposing (carbon tax, green certificates, etc.)

Learning-by-doing
- Installed power capacity

Input Costs
- Tariff rate

Geographic Factors
- Solar irradiance
- Wind speed
- Precipitation

Other Economic Factors
- Economic development level
- Financing costs
- Labour costs
- R&D expenditure

Methodology:
(II) Constructing the clean energy production competitiveness index

Step 1: Regression using global data

"How much does each factor contribute to LCOE?"

$$LCOE^{tech}_{country,year} = \alpha^{tech} + \boldsymbol{\beta X}^{tech}_{country,year} + \varepsilon^{tech}_{country,year}$$

Step 2: Prediction using ASEAN data

"For ASEAN countries, given their underlying factors, what could be their LCOE?"

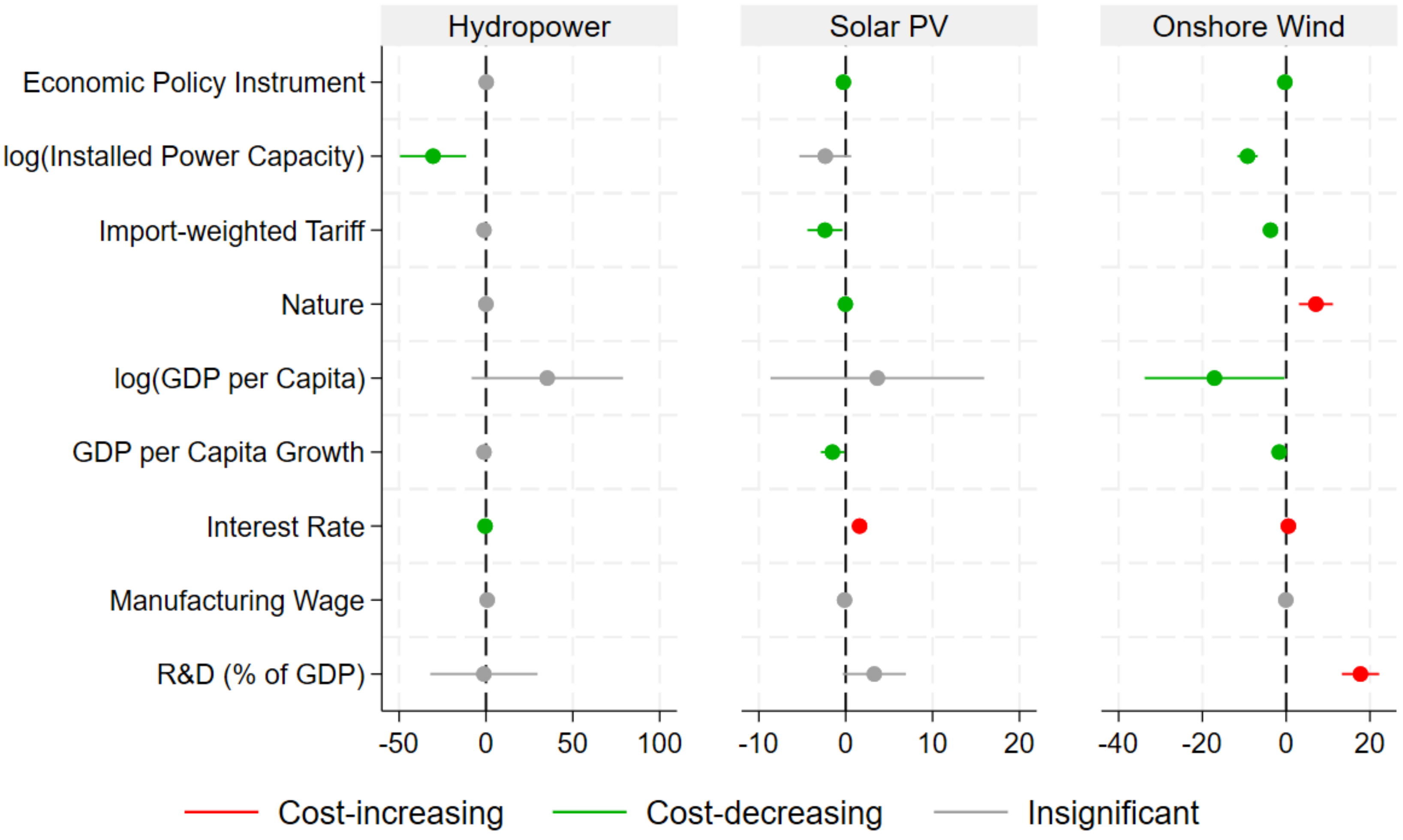
$$\widehat{\mathrm{LCOE}}^{tech}_{\mathrm{ASEAN}\ country,year} = \hat{\alpha}^{tech} + \widehat{\boldsymbol{\beta}}\boldsymbol{X}^{tech}_{\mathrm{ASEAN}\ country,year}$$

Step 3: Constructing the cost competitiveness index

$$Index = \frac{1}{\widehat{\mathrm{LCOE}}^{tech}_{\mathrm{ASEAN}\ country,year}}$$

Global regression: quantify the impact of secondary determinants on LCOE

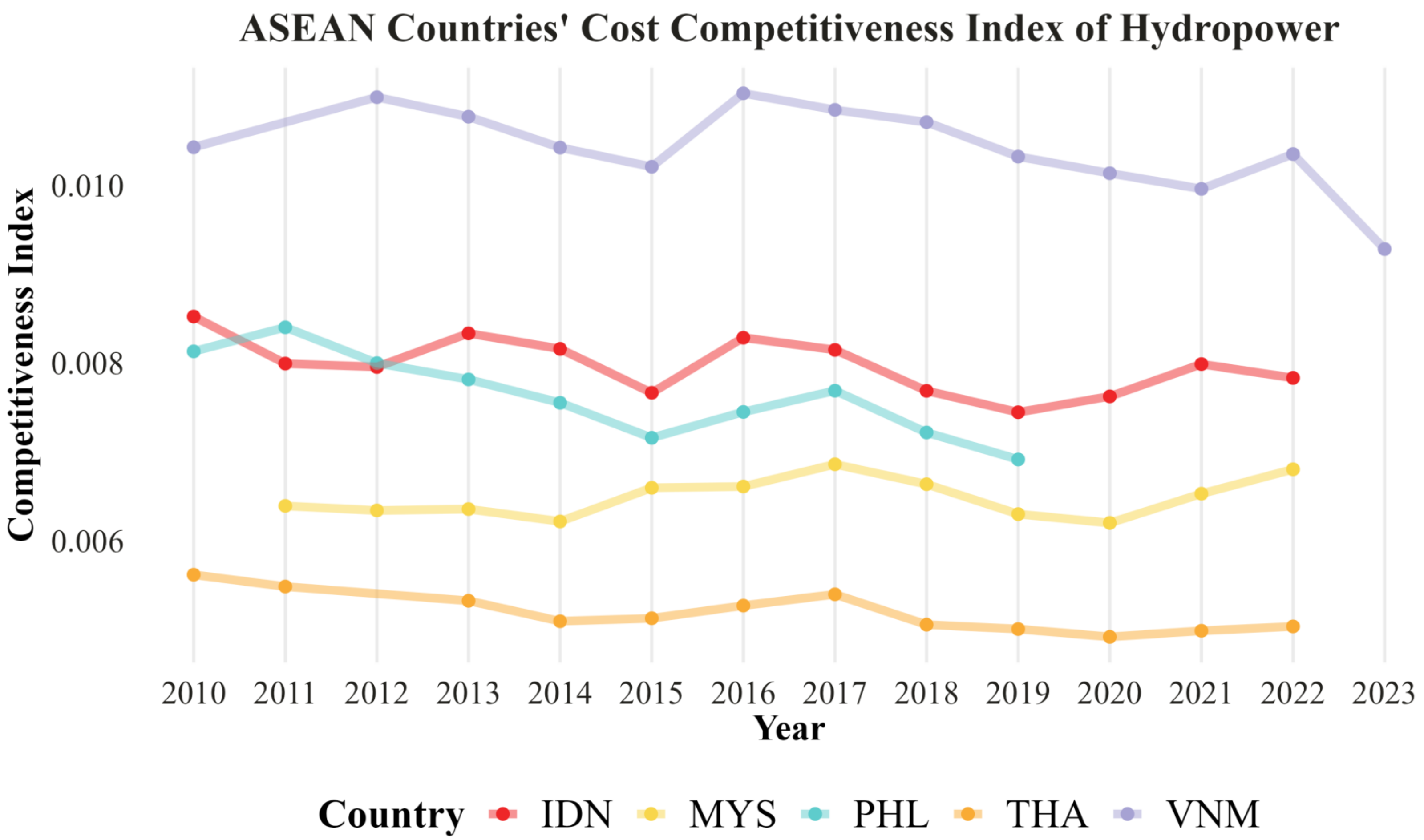
- Economic policy instruments are cost-decreasing for solar PV and onshore wind, although the impact is marginal.
- Learning-by-doing effects are observed across all technologies.
- Higher import tariff correlates with lower costs for solar PV and onshore wind, driven by advanced economies.



Note: The regressions have controlled for year fixed effects. There are 25, 90, and 193 observations for hydropower, solar PV, and onshore wind models, respectively. The spikes represent 90% confidence intervals.

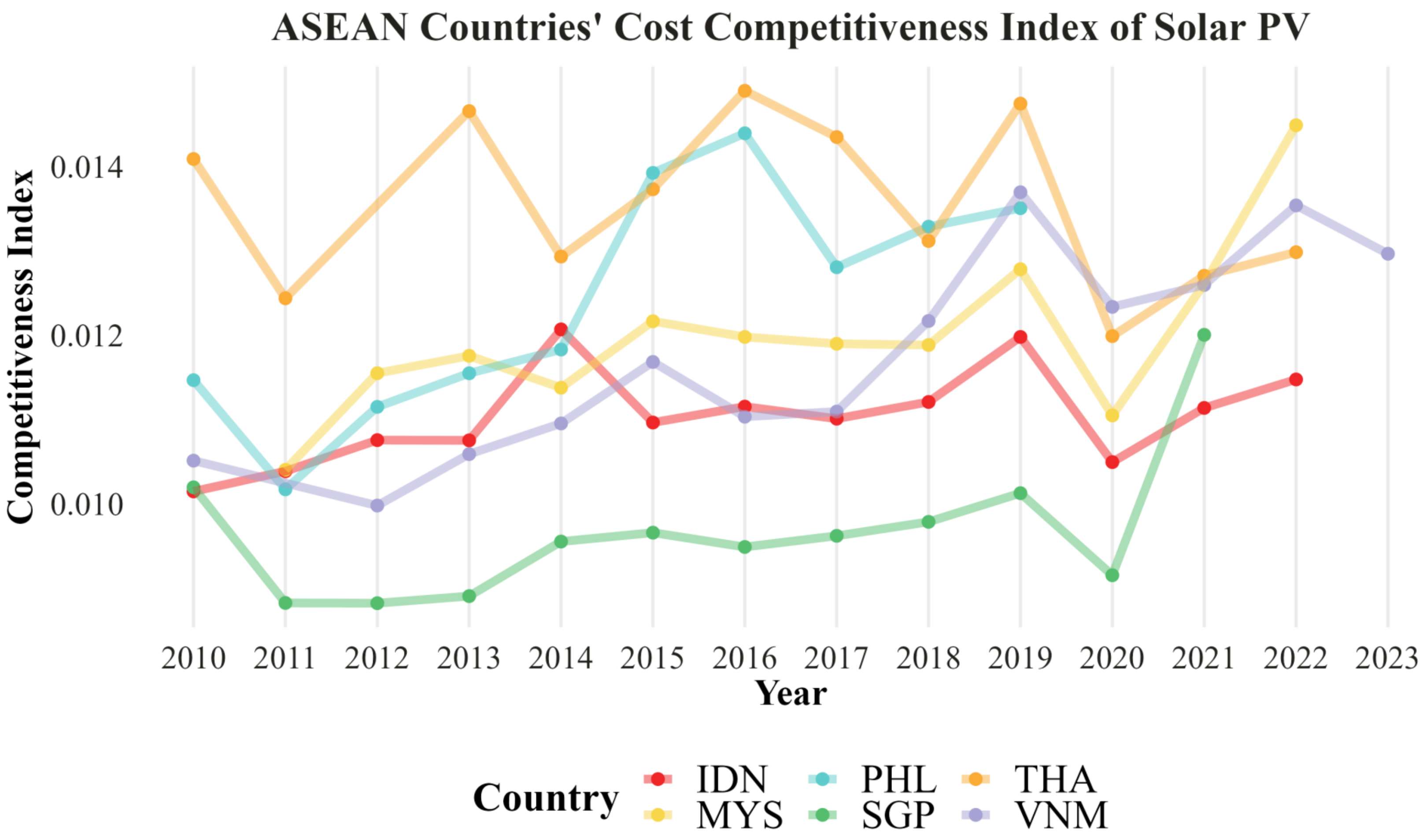
Hydropower: a mature technology with steady cost trajectory

- Minimal fluctuations across years.
- Vietnam remained the most cost-competitive; Thailand, the least.



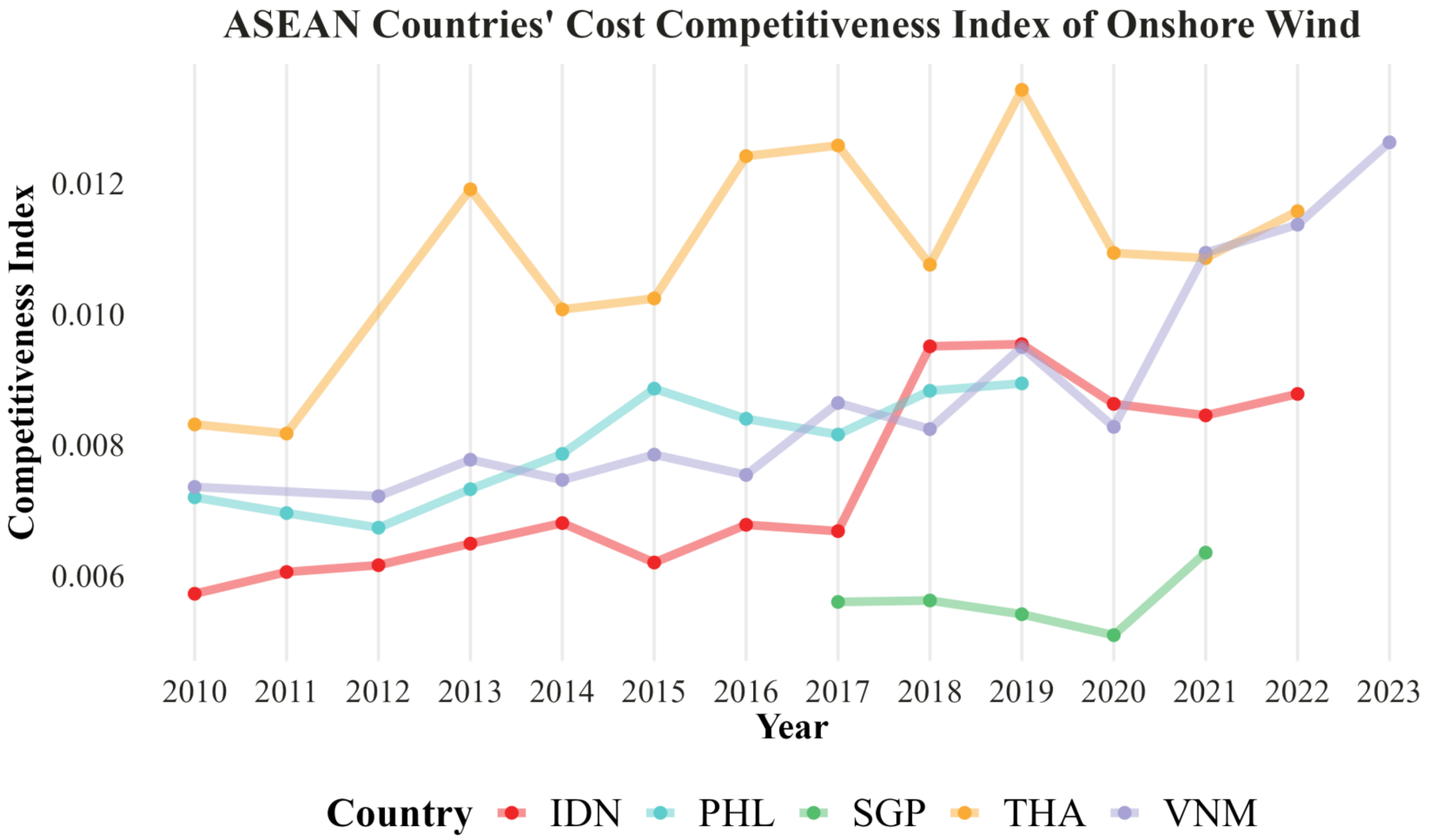
Solar PV: frequent fluctuations reflecting market dynamics

- A synchronised "V-shape" recovery in the index around the pandemic period.
- Vietnam's index has climbed significantly, closing the gap with Malaysia and Thailand.



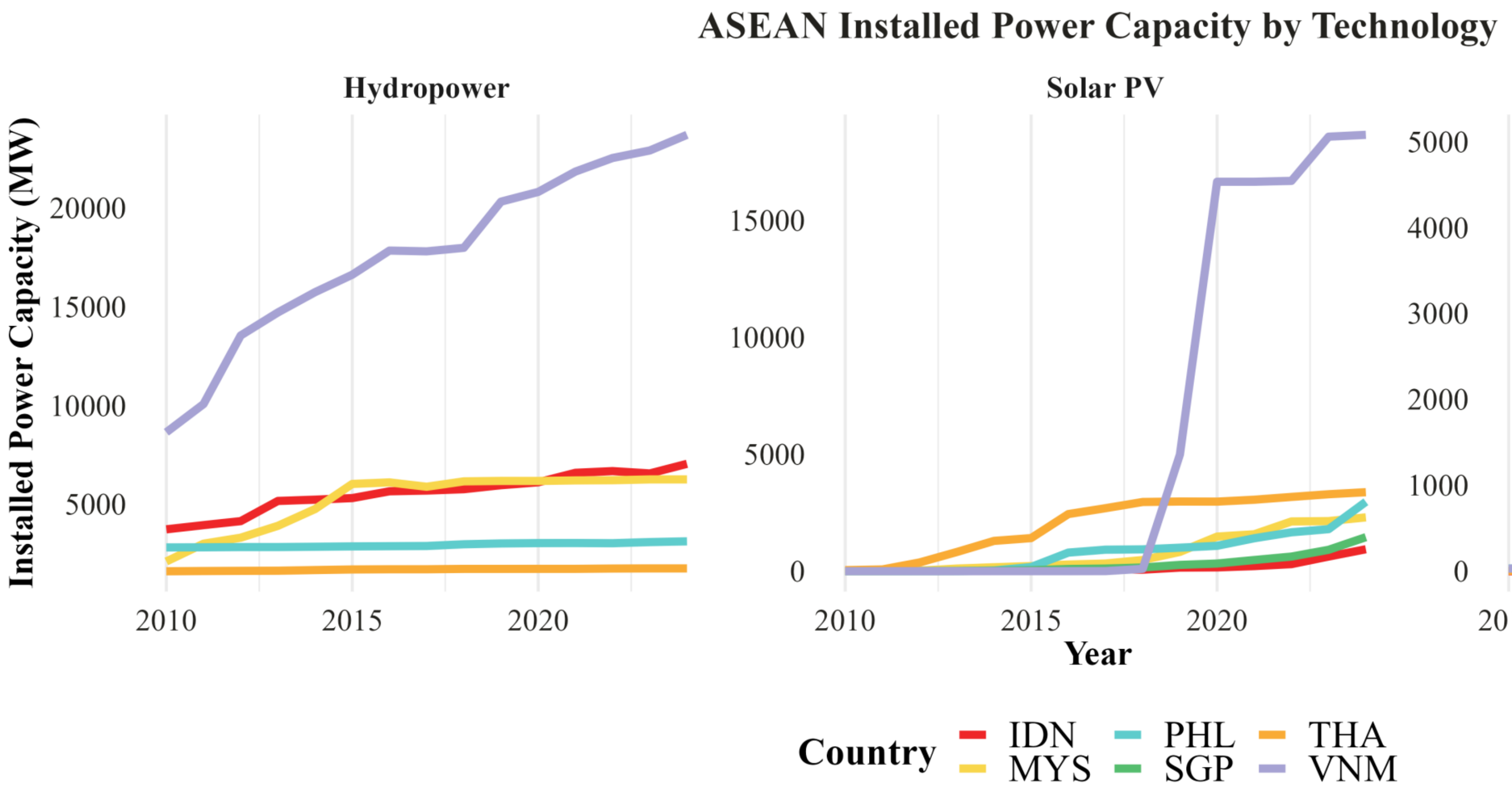
Onshore wind: increasingly cost-competitive over time

- Vietnam demonstrated a robust increase since 2020, nearly matching Thailand.
- Singapore is consistently the least cost-competitive, likely reflecting the country's geographic constraints.



Why do some countries perform better? The role of learning-by-doing

- Thailand's early and steady growth of solar PV and onshore wind.
- Vietnam experienced installed capacity expansion starting in 2018 for solar PV and in 2020 for onshore wind.
- Moderate capacity growth in Malaysia, the Philippines, Indonesia and Singapore.



Source: IRENA's Renewable Energy Statistics

Conclusion

- Expanding renewable energy (RE) adoption is key to enhancing energy security, resilience, and sustainability, as well as capitalising on the green economy.
- However, RE potential is distributed unevenly across the region, underscoring the importance of regional power trade.
- **Cost competitiveness by LCOE**
  - Among major RE technologies, LCOE competitiveness is as follows: **Hydropower (MLY, IDN, VNM)** → **Solar PV (IDN, KHM, VNM)** → **Onshore wind (IDN, VNM, THA)** → **Offshore wind (VNM)**.
  - Strengthening regional power trade infrastructure, centred around cost-competitive technologies in leading countries, will benefit ASEAN countries looking to decarbonise their grids.
- **Cost competitiveness by underlying factors**
  - Among ASEAN countries, Vietnam and Thailand are among the most cost-competitive for RE.
  - Higher installed capacity contributes to lower electricity generation cost, regardless of RE type.
- Upcoming projects that are currently under construction or in the planning pipeline are expected to drive LCOE down further and expand capacity across technologies and countries.

Q&A Segment

Please reach with further questions and inputs:

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