# Improved Representations of Water-Power System Interactions to Inform Clean Energy Transition for Mainland Southeast Asia


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PREP-NEXT

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## MOTIVATION

**Existing energy planning models** → **Couple long-term investments with short-term operations using representative period method** / **Over-simplify or overlook river dynamics** → **Potentially yielding power system plans that lack resilience or viability**

To address the above, we introduce **an integrated model for water and power systems with a refined decomposition algorithm**.

### OUR STUDY

- ✓ Captures **river dynamics** in power system operation and planning;
- ✓ **Individual plant level**;
- ✓ Hour-scale **continuous annual planning** for power systems.

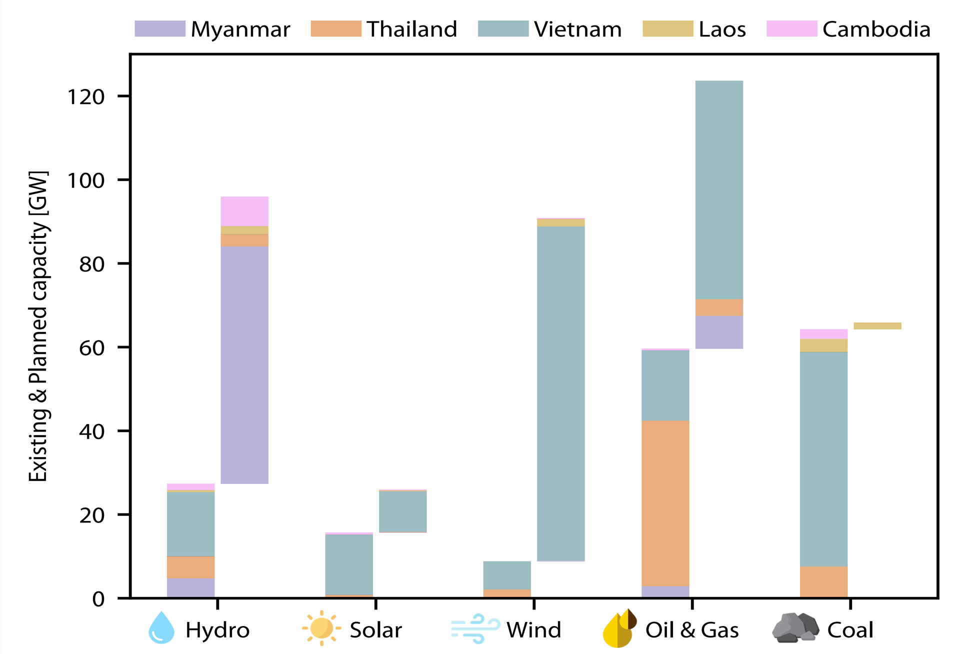



Fig | 1. Existing and planned power plant capacity in Southeast Asia.

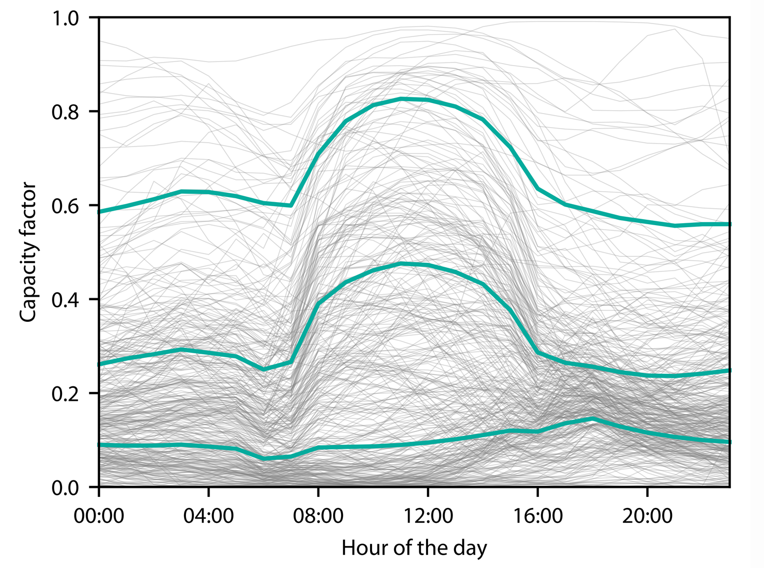



Fig | 2. Representative periods (teal lines) fail to capture the variability of wind power within the day.

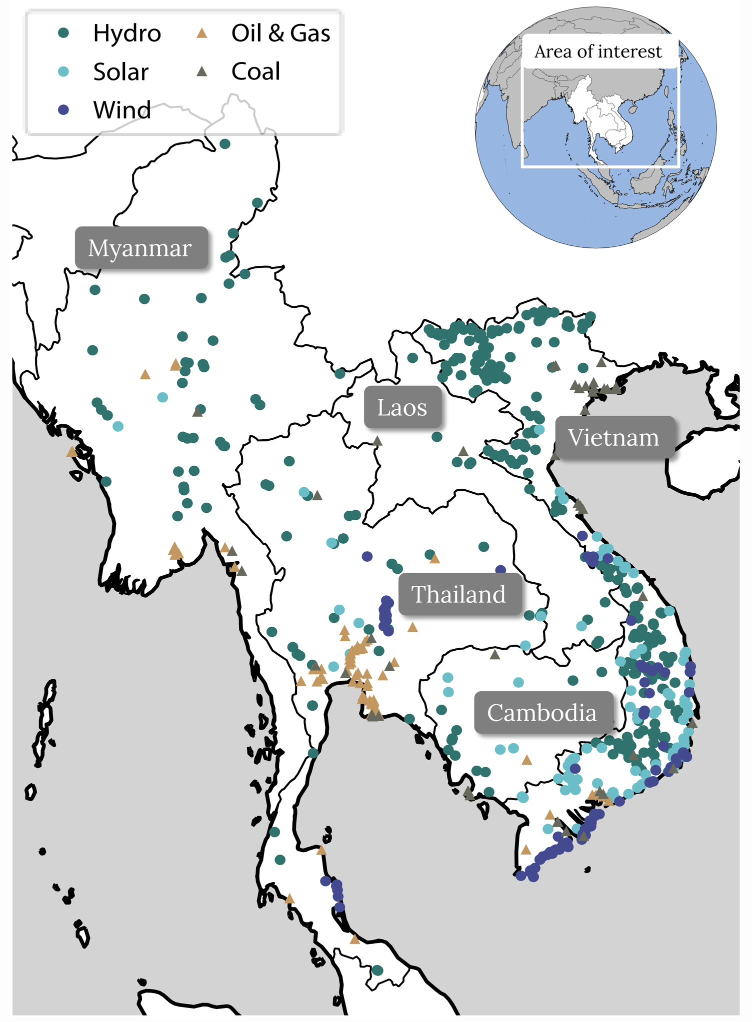
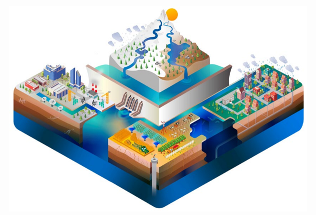



Fig | 3. Operational power plants in Southeast Asia. (Global Energy Monitor, 2023)

## METHODOLOGY

**1** Run Community Water Model (CWatM) to simulate daily natural streamflow and reservoir operation



**2** Run River Basin Model (RBM) to simulate daily water temperature based on simulated daily streamflow

Reverse particle tracking from each node

$T(x_0, t_0)$ $T(x, t)$ $\xi = x - x_0 - \int_{t_0}^{t} u dt$

Integrate heat fluxes along path from $t_0$ to $t$

$$\Delta T = \Delta t [\frac{H_{air-water}(t, x_{j'})}{\rho C_p D(t, x_{j'})} + \Phi(t, x_{j'})]$$

Update water temperature at next time step

**3** Build statistical modelling to estimate water-related efficiency loss of thermal power plants

Estimate unit-level curtailment according to available stream discharge and temperature for each thermal power plant.

**4** Use PREP-SHOT (***P****athways for* ***R****enewable* ***E****nergy* ***P****lanning coupling* ***S****hort-term* ***H****ydropower* ***O****pera****T****ion*) for energy expansion optimization

### I. Prepare Inputs

**Hydropower**

- Cascade topology
- Water travel time
- Initial water head
- Initial & Terminal storage
- Natural inflow
- Storage bounds
- Ramping rate
- Outflow bounds
- Output bounds
- Output efficiency
- Stage-Storage curve
- Tailwater rating curve
- Water head loss coefficient

**Storage Technology**

- Initial & Terminal energy storage level
- Discharging & Charging efficiency
- Power to energy ratio
- Discharging & Charging output bounds

**Non-dispatchable Technology (Solar & Wind)**

- Capacity factor
- Installed upper bound

**Dispatchable Technology (Coal & Nuclear)**

- Ramping rate
- Power output bounds
- Carbon dioxide emission per unit of electricity
- Fuel cost per unit of electricity

**Transmission Line**

- Transmission topology
- Transmission efficiency

**Cost-related Parameters**

- Discount rate
- Unit investment cost,
- Unit fixed Operation and Maintenance (O&M) cost
- Unit variable O&M cost
- Lifetime of technologies and transmission lines
- Capacity-Age relationship

**Non-cost Parameters**

- Electricity demand
- Planning horizon
- Representative periods
- Time step
- Others (see details in See details in Liu & He, 2023 )

### II. Build Model

PREP-SHOT Pathways for Renewable Energy Planning coupling Short-term Hydropower OperaTion

***Objective function***

- Minimize the cost of the whole energy system

***Constraints***

- Lifetime constraints
- Carbon emission constraints
- Power balance constraints
- Transmission constraints
- Power output constraints
- Power output variation constraints
- Energy storage constraints
- Water balance constraints
- Reservoir outflow constraints
- Reservoir storage constraints

### III. Solve Model

***Software***

- GUROBI

***Algorithms***

- Simplex method
- Interior point method
- Benders decomposition method

### IV. Analyze Results

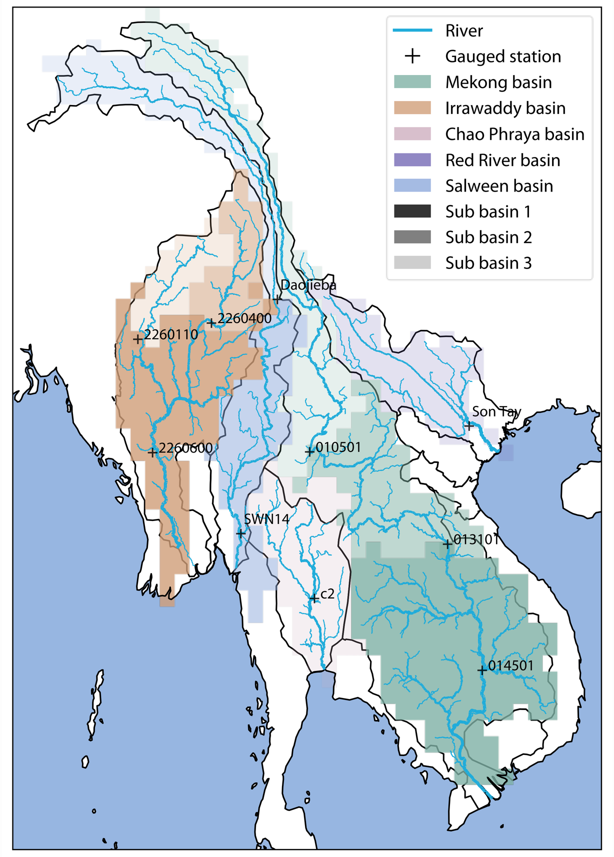
***Model output***

- Capacity of newly built technology per modelled year per zone
- Capacity of newly built transmission lines per modelled year per zone
- Transmitted power per year between zones
- Generation of each technology and discharging and charging of each storage per modelled year per zone
- Generation flow, withdrawal water flow and spillage flow of each hydropower station per modelled year

## PRELIMINARY RESULTS

**CALIBRATION & VALIDATION RESULTS**

| *Catchment* | *Station* | *Calibration (validation) period* | *Kling-Gupta efficiency* | | *Nash-Sutcliffe efficiency* | | *Pearson correlation* | | *Root mean square error* | |
|---|---|---|---|---|---|---|---|---|---|---|
| Chao Phraya | c2 | 1975-1990 (1991-2002) | 0.59 | 0.53 | 0.44 | 0.27 | 0.81 | 0.77 | 427 | 550 |
| Irrawaddy | 2260110 | 1996-2005 (2006-2010) | 0.85 | 0.81 | 0.77 | 0.8 | 0.88 | 0.9 | 2435 | 2071 |
| | 2260400 | 1996-2005 (2006-2010) | 0.61 | 0.56 | 0.54 | 0.59 | 0.89 | 0.87 | 3121 | 2760 |
| | 2260120 | 1996-2005 (2006-2010) | 0.73 | 0.77 | 0.6 | 0.68 | 0.92 | 0.92 | 3255 | 2722 |
| | 2260600 | 1996-2005 (2006-2010) | 0.5 | 0.48 | 0.76 | 0.73 | 0.93 | 0.92 | 5246 | 5385 |
| Mekong | 10501 | 1960-1980 (1981-2000) | 0.75 | 0.6 | 0.67 | 0.54 | 0.87 | 0.87 | 1402 | 1383 |
| | 11201 | 1960-1980 (1981-2000) | 0.75 | 0.7 | 0.77 | 0.72 | 0.91 | 0.9 | 1738 | 1737 |
| | 11903 | 1967-1980 (1981-2000) | 0.79 | 0.71 | 0.74 | 0.65 | 0.9 | 0.85 | 1972 | 2157 |
| | 13101 | 1960-1980 (1981-2000) | 0.91 | 0.92 | 0.83 | 0.85 | 0.92 | 0.93 | 3007 | 2624 |
| | 13402 | 1960-1980 (1981-2000) | 0.92 | 0.93 | 0.84 | 0.88 | 0.92 | 0.94 | 3091 | 2521 |
| | 13801 | 1966-1980 (1981-2000) | 0.89 | 0.88 | 0.86 | 0.86 | 0.93 | 0.93 | 3525 | 3309 |
| | 13901 | 1960-1980 (1981-2000) | 0.92 | 0.92 | 0.86 | 0.86 | 0.93 | 0.93 | 3859 | 3562 |
| | 14501 | 1960-1980 (1981-2000) | 0.92 | 0.93 | 0.87 | 0.9 | 0.93 | 0.95 | 5031 | 4274 |
| Red | Son Tay | 2010-2015 (2016-2019) | 0.42 | 0.32 | 0.21 | 0.23 | 0.82 | 0.83 | 1718 | 1836 |
| Salween | Daojieba | 1982-1983 (1984-1985) | 0.86 | 0.81 | 0.75 | 0.77 | 0.87 | 0.9 | 636 | 735 |
| | SWN14 | 1998-1999 (2004-2005) | 0.73 | 0.47 | 0.72 | -0.23 | 0.88 | 0.93 | 2724 | 3407 |




**NSGA-III + Regional parameterization + ISIMIP3a inputs**

| Parameter | Min | Max | Initial |
|---|---|---|---|
| Snowmelt coefficient | 0.001 | 0.007 | 0.003 |
| Crop factor | 0.8 | 3 | 1.11 |
| Soil depth factor | 0.8 | 1.8 | 1.28 |
| Preferential bypass flow | 0.5 | 8 | 4.5 |
| Infiltration capacity parameter | 0.01 | 1 | 0.19 |
| Interflow factor | 0.33 | 3 | 2.8 |
| Recession coefficient factor | 0.1 | 10 | 5.28 |
| Runoff concentration factor | 0.1 | 5 | 0.1 |
| Channel Manning's n factor | 0.1 | 10 | 1.86 |
| Normal storage limit | 0.15 | 0.85 | 0.44 |
| Lake "A" factor | 0.33 | 3 | 0.33 |
| Lake and river evaporation factor | 0.5 | 3 | 1.52 |

## FUTURE WORK

Enhance reservoir operation rules to improve streamflow simulations affected by reservoir activities.

Perform energy expansion optimization using the PREP-SHOT model with simulated stream temperature and efficiency loss.

Identify the investment priority of power plants for the climate-adaptation planning.

SCAN ME!

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