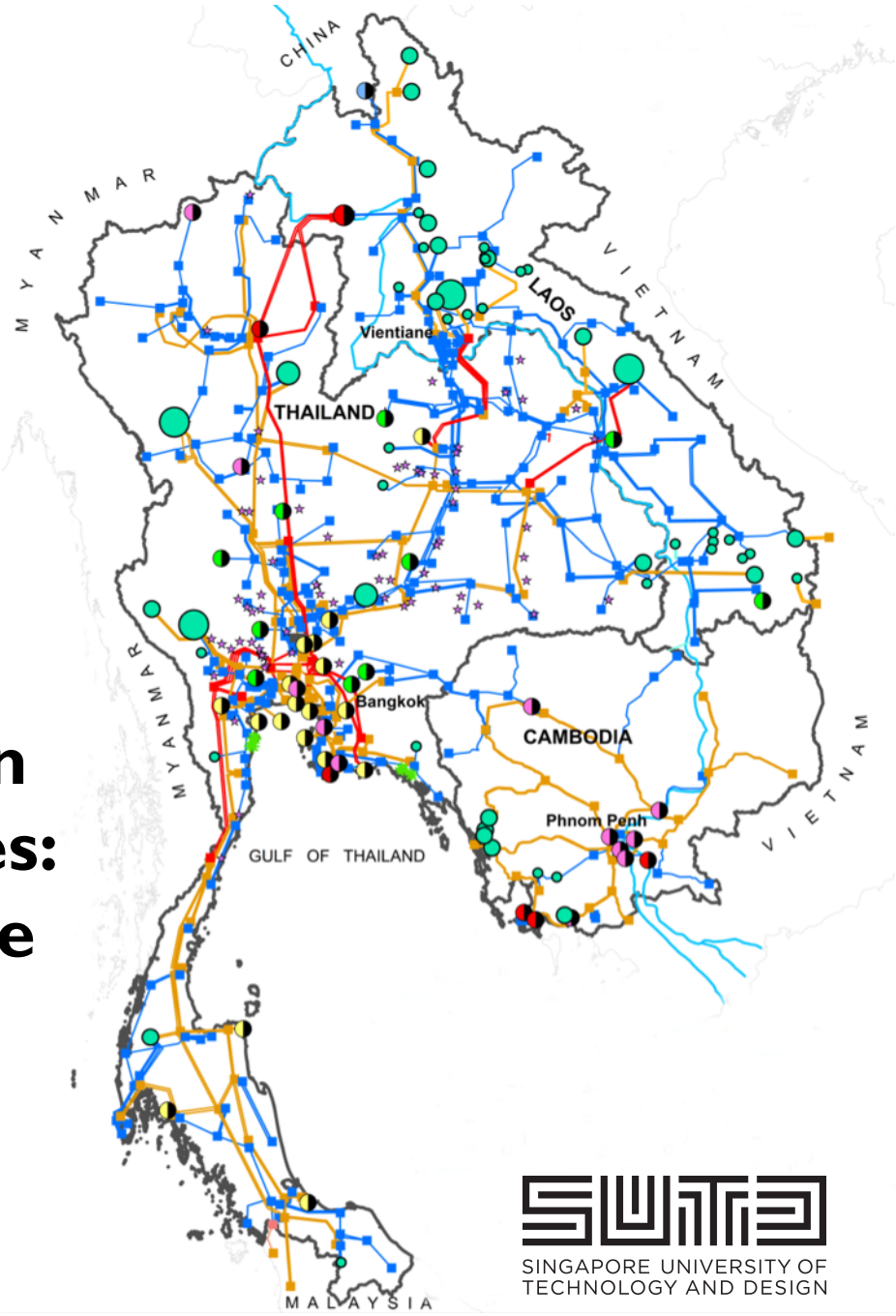
@ EGU General Assembly 2020
HS5.3.2/ERE2.5
EGU2020-12347

Challenges, trade-offs, and opportunities in the design of power transmission lines: a water-energy perspective



S. Galelli, K. Chowdhury, T. Dang

Pillar of Engineering Systems and Design,
Singapore University of Technology and Design

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Motivation

- High-voltage transmission lines connect power plants to demand centers
- They have a critical role in power systems relying on renewable resources, whose production is not constant over time
- A common problem is **line congestion**

  → Curbs the benefits of renewables

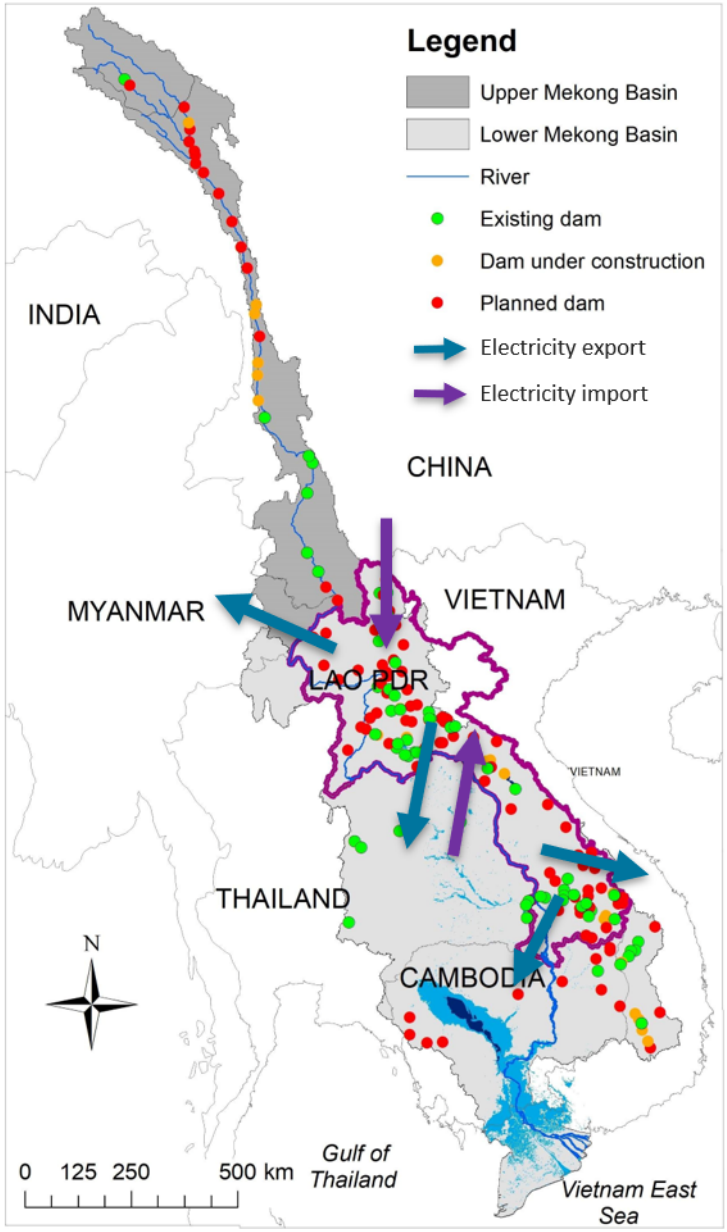
  → Requires large investments to improve transmission capacity

A case in point: Mekong and Laos

Mekong River basin

Hydropower development in the Mekong river basin. Key facts

- Hydropower potential of roughly 200 GW
- More than 100 dams in the basin, with an installed capacity of ~70 GW
- Laos plays a pivotal role …



Data retrieved from https://wle-mekong.cgiar.org/maps/

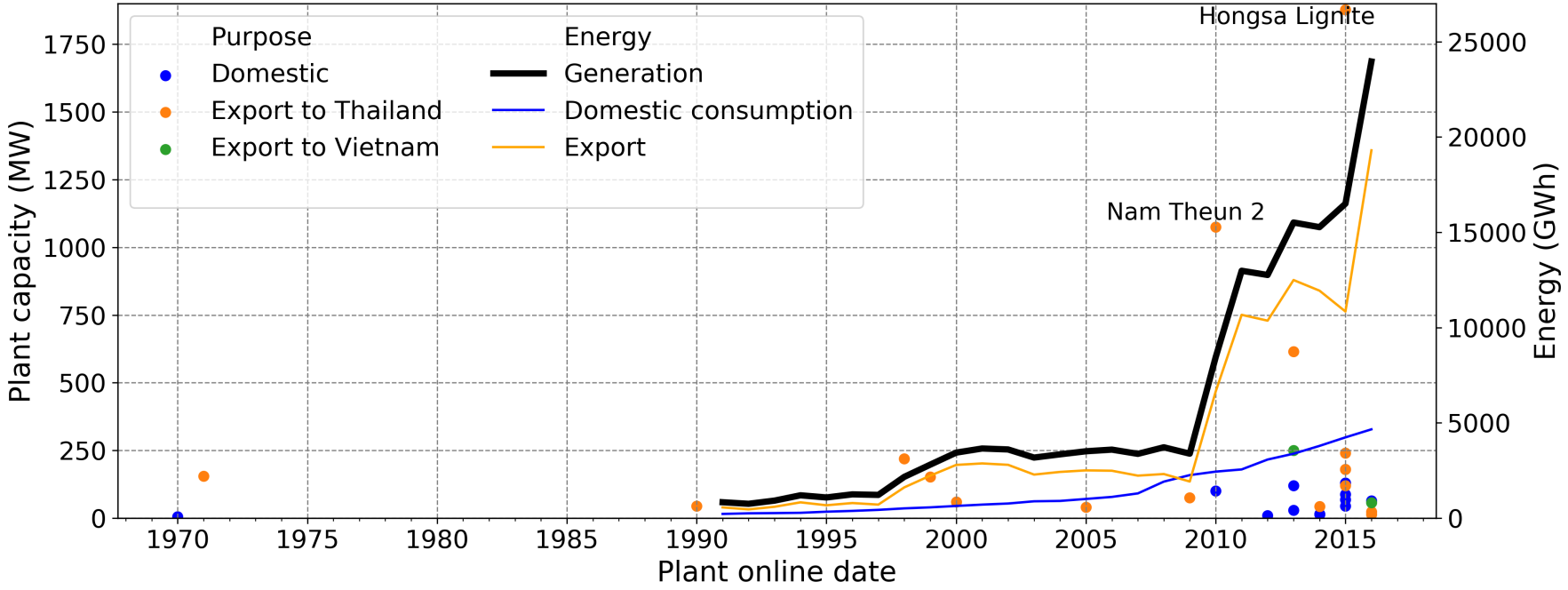
Expansion of the Laotian power system

Nam Theun 2 (1,075 MW)

Source: https://asia.edf.com/en/

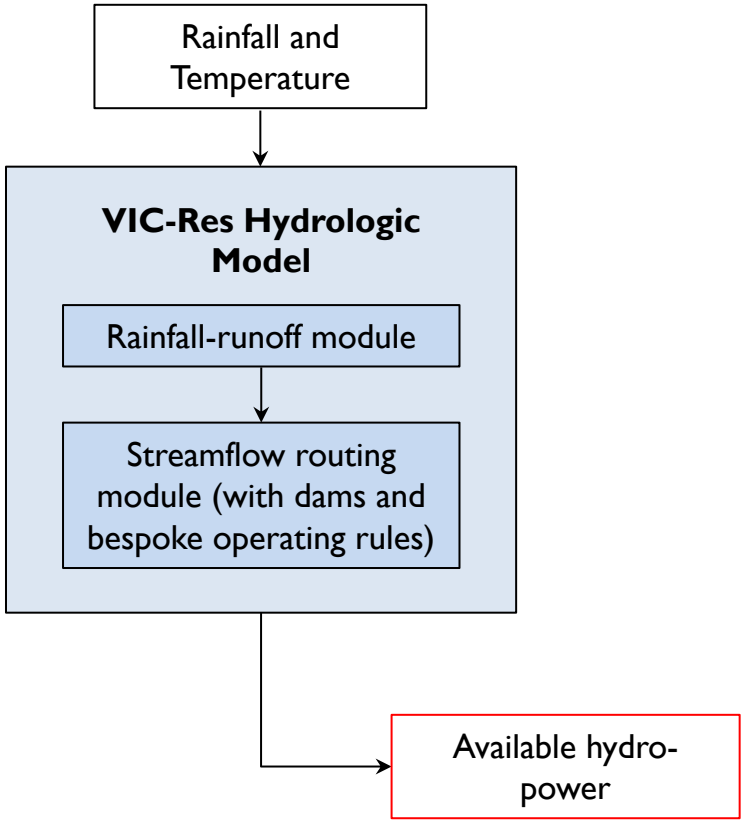
Hongsa Lignite (1,878 MW)

Source: http://www.hongsapower.com



Water-Energy model

VIC-Res



DOI: 10.1016/j.envsoft.2020.104673

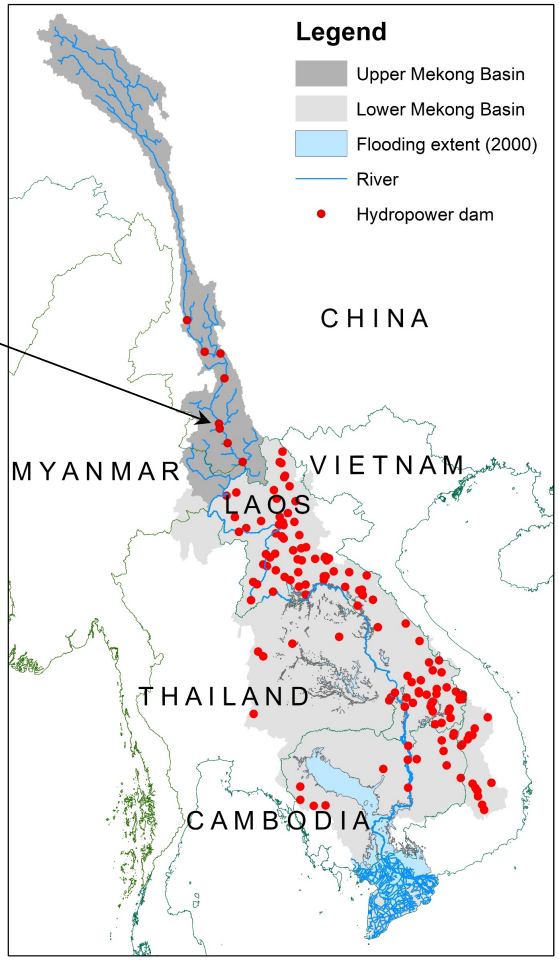
VIC-Res – setup

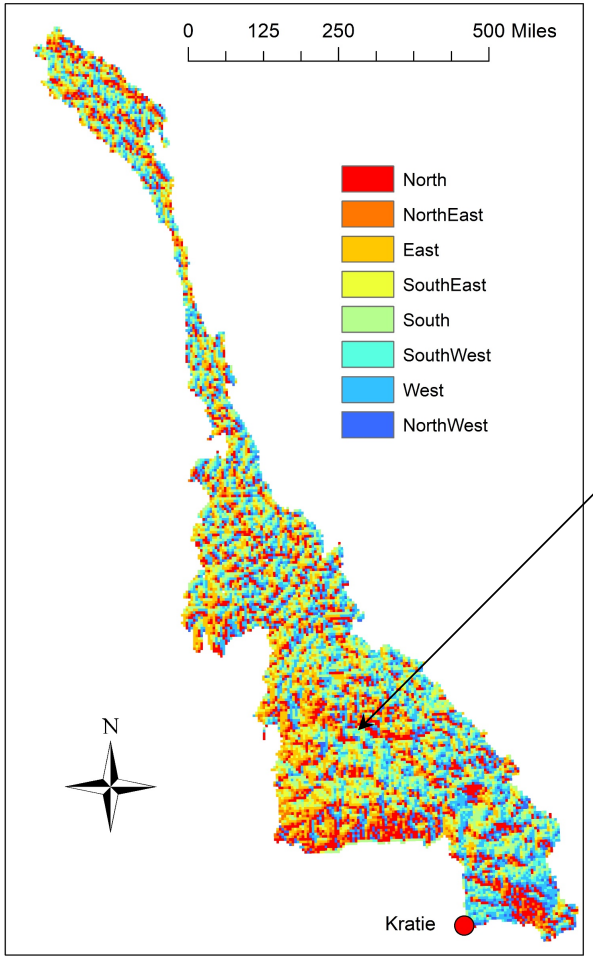
Spatial domain

Flow direction

Bespoke reservoir rule curves

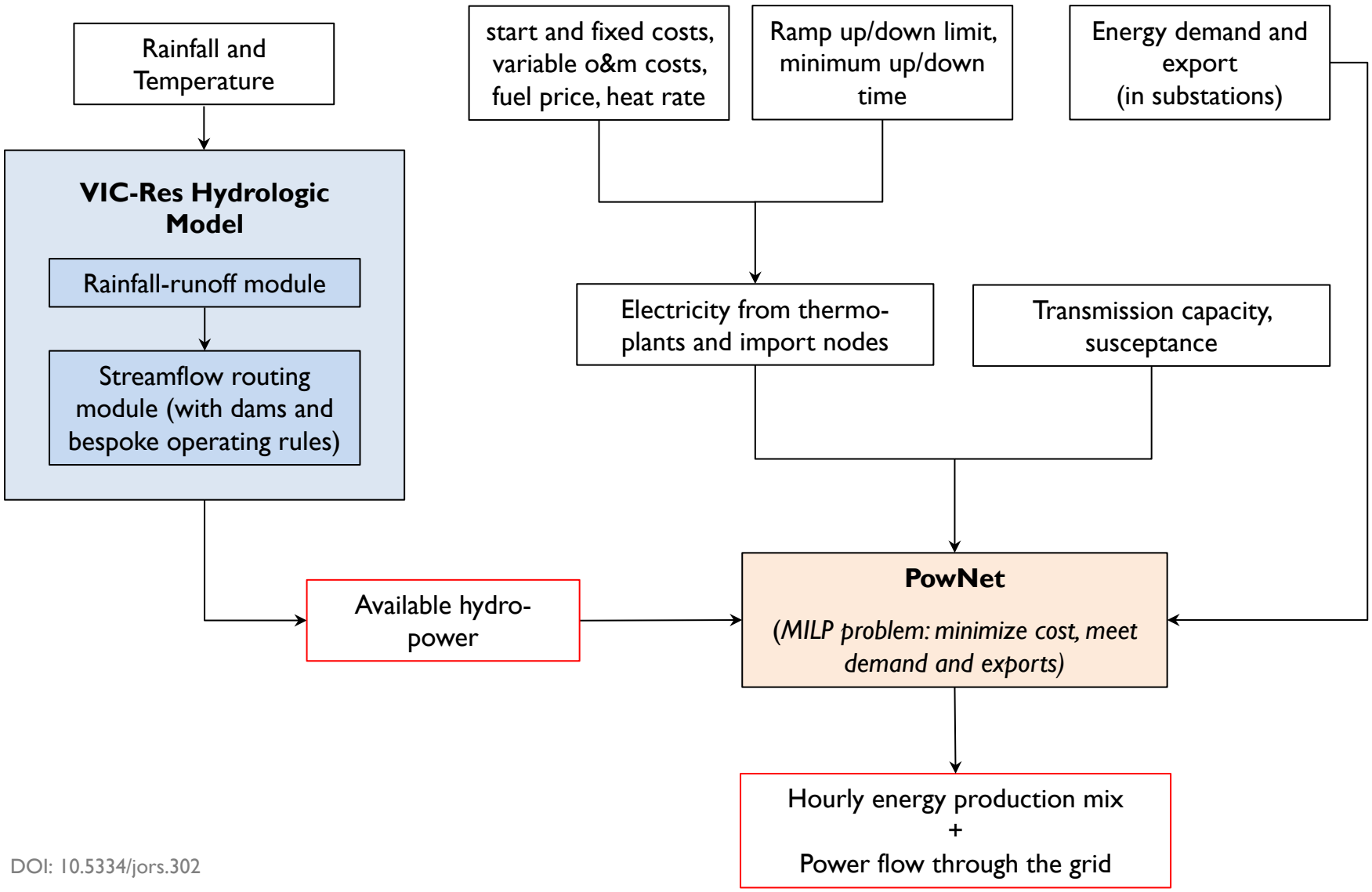
Spatial resolution of 0.0625 degrees (~6.9 km)





DOI: 10.5194/hess-2019-334

PowNet

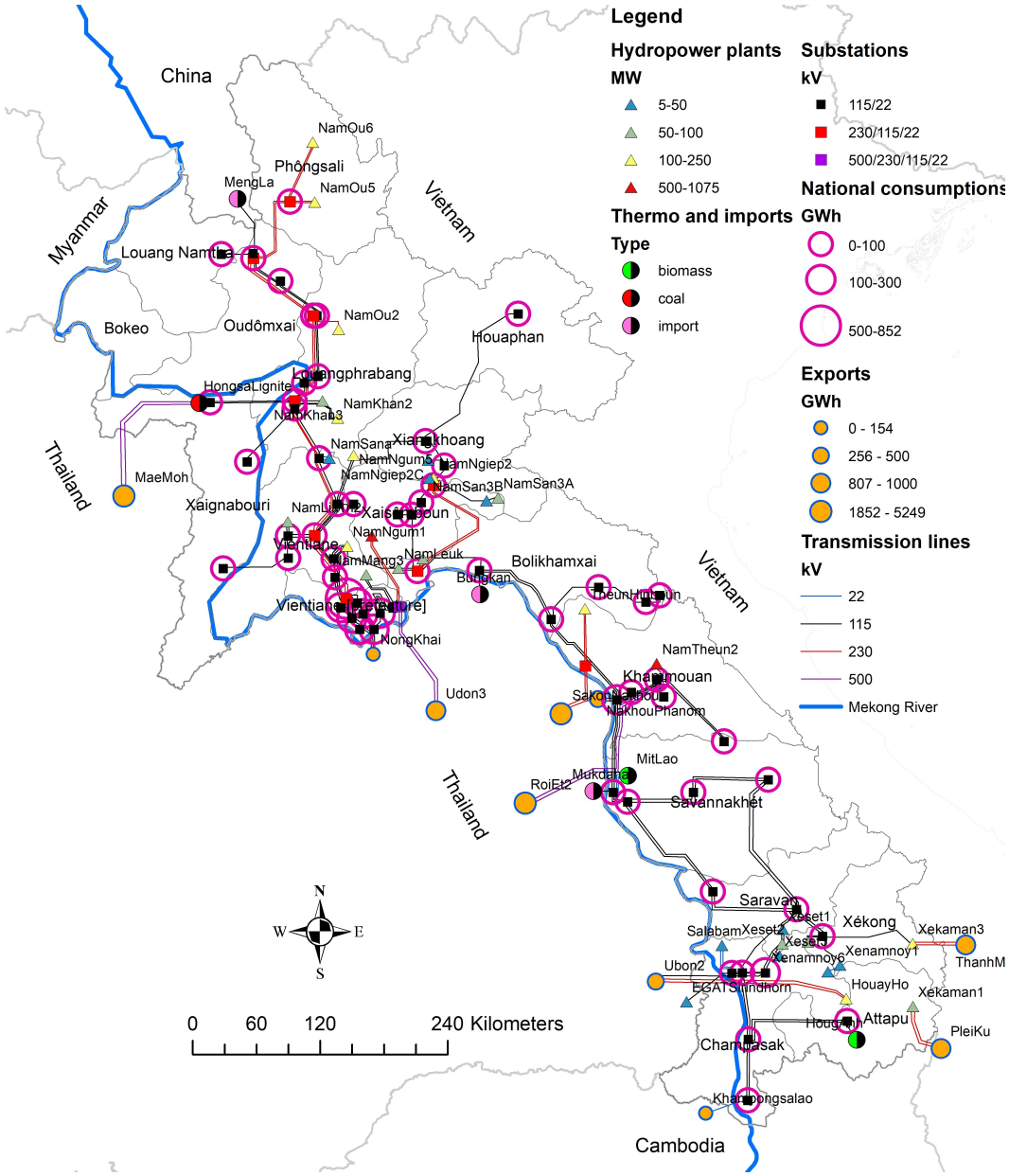


DOI: 10.5334/jors.302

PowNet – setup

110 nodes (2016 data):

- **Generators:** 30 hydro (4,734 MW), 1 coal (1,878 MW), 2 biomass (40 MW)
- **Import nodes:** 3 from Thailand, 1 from China
- **Substations:** 64 transformers
- **Export nodes:** 7 to Thailand, 2 to Vietnam, 1 to Cambodia

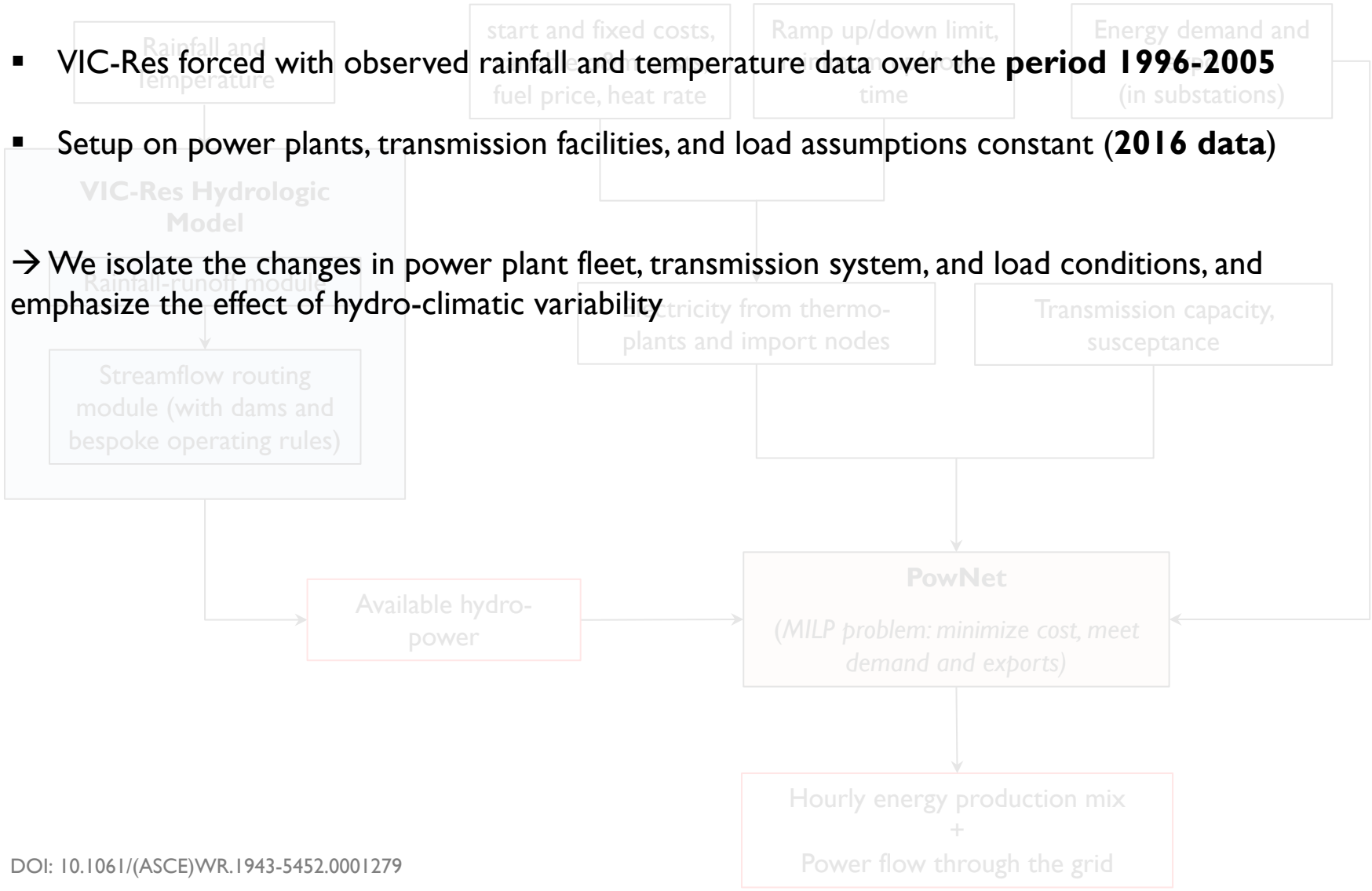


DOI: 10.1061/(ASCE)WR.1943-5452.0001279

Input data

- VIC-Res forced with observed rainfall and temperature data over the **period 1996-2005**
- Setup on power plants, transmission facilities, and load assumptions constant (**2016 data**)

→ We isolate the changes in power plant fleet, transmission system, and load conditions, and emphasize the effect of hydro-climatic variability



DOI: 10.1061/(ASCE)WR.1943-5452.0001279

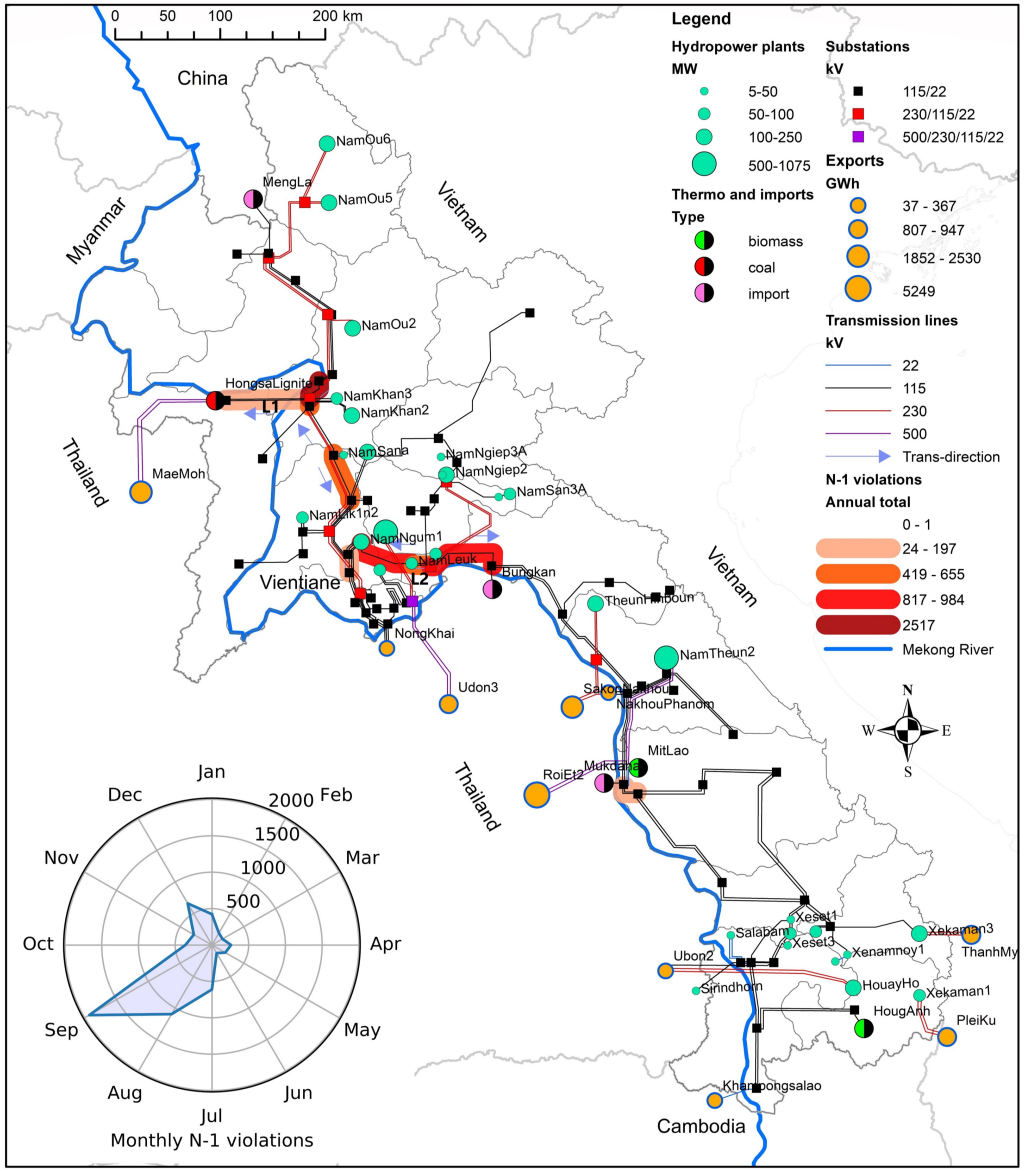
Challenges

Effect of transmission facilities

N-1 violations indicate stress conditions in the grid

→ inability to dispatch the available power

→ Most of the violations occur during the monsoon season, when hydropower production is at its peak

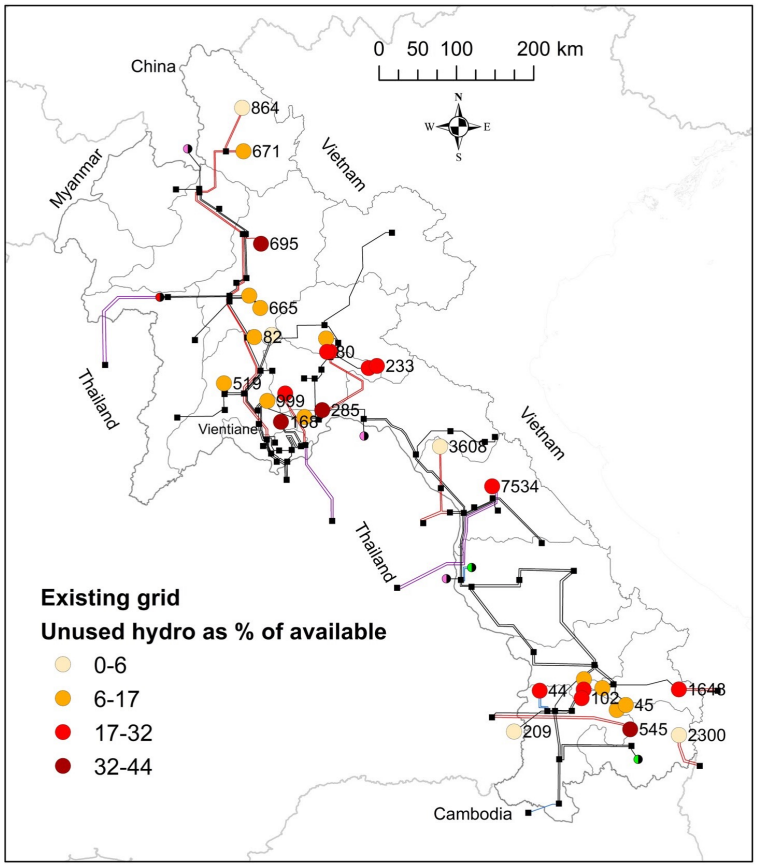


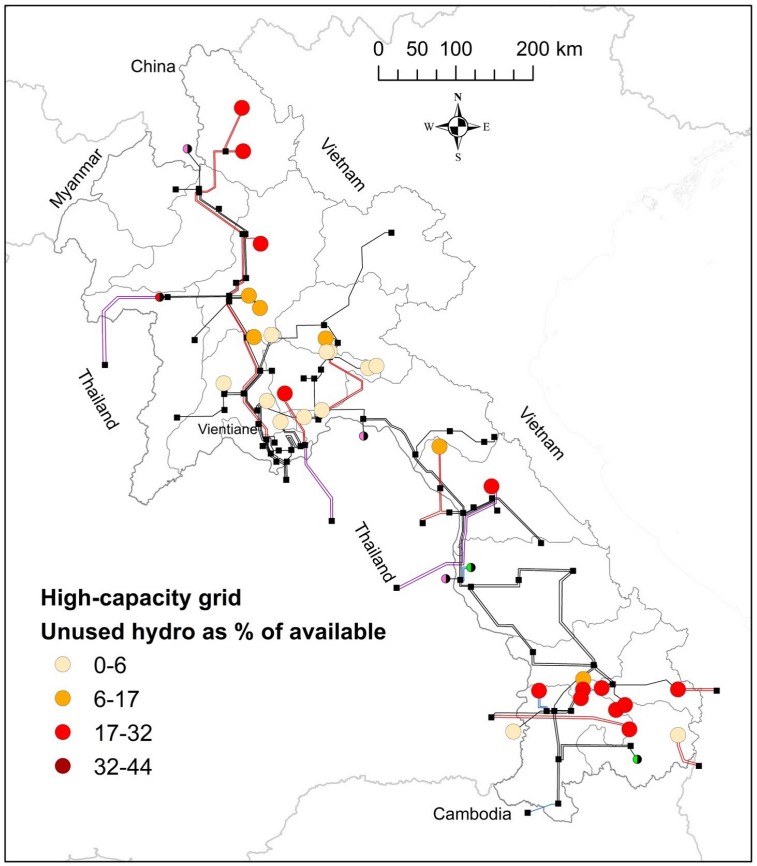
DOI: 10.1061/(ASCE)WR.1943-5452.0001279

Effect of transmission facilities

What would happen if we reduced the N-1 violations (by increasing the transmission capacity)?

→ Unused hydro-electricity decreases from 21 to 16% (from 2,350 to 1,800 GWh/year)
→ Power production costs and CO_2 emissions decrease by 6 and 15% (11.2 million USD/year and 0.39 Mtonnes/year)

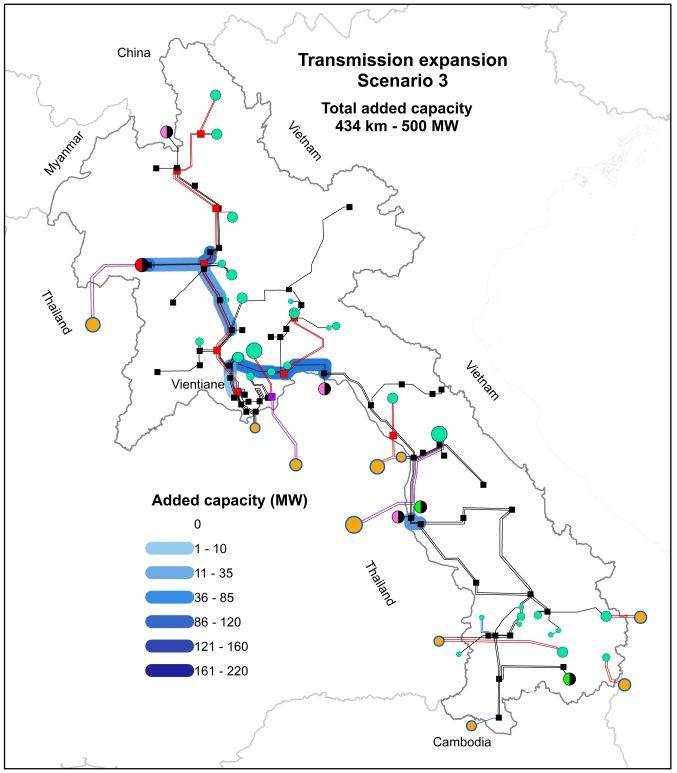


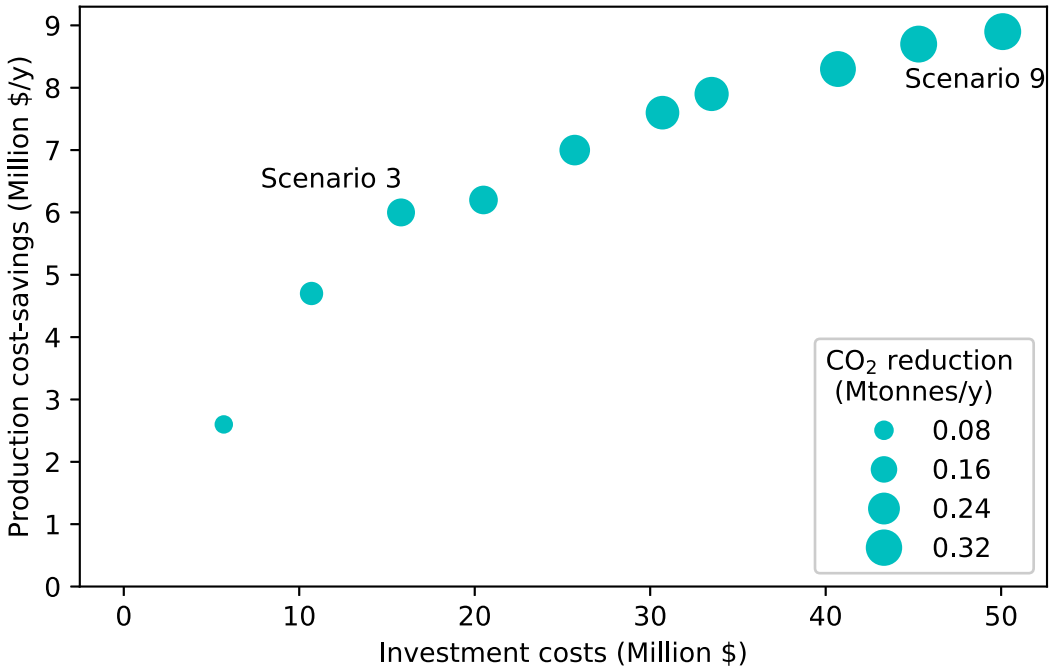


Opportunities and Trade-offs

Capacity expansion of selected lines

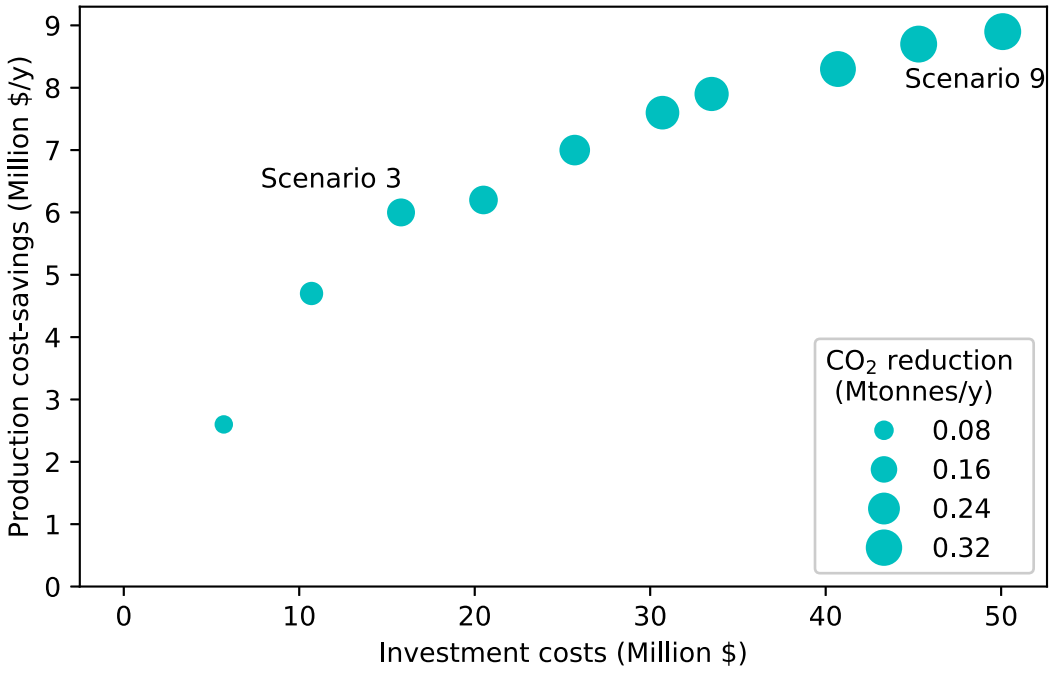
- We focus on just 12 lines, for which we evaluate expansions ranging from 185 to 1,665 MW
- We evaluate performance in terms of average annual reduction of power production costs and CO_2 emissions
- Analysis carried with VIC-Res and PowNet

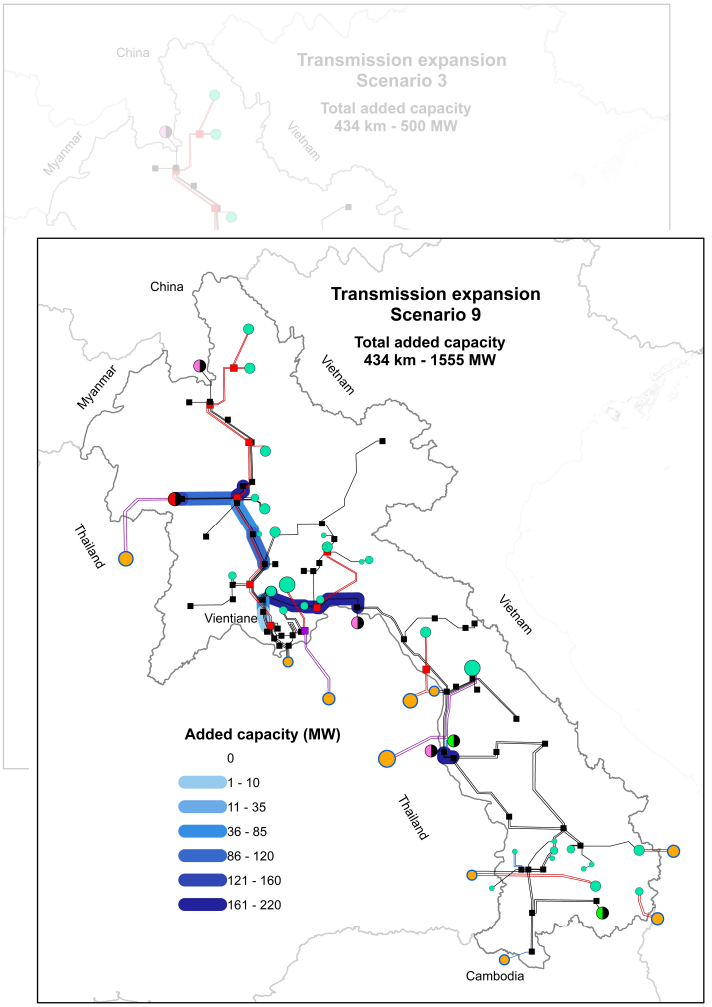




Capacity expansion of selected lines

- We focus on just 12 lines, for which we evaluate expansions ranging from 185 to 1,665 MW
- We evaluate performance in terms of average annual reduction of power production costs and CO_2 emissions
- Analysis carried with VIC-Res and PowNet





Integration with the Thai power system

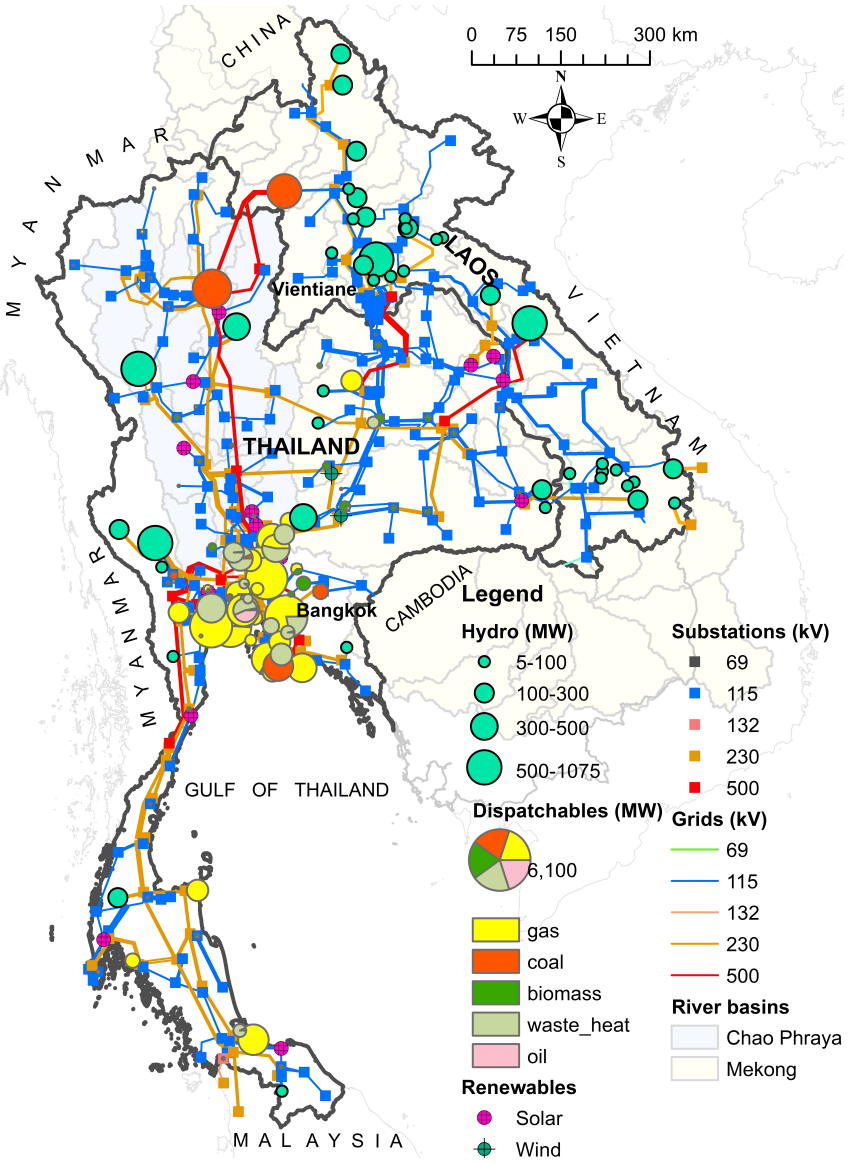
Laotian energy system

- Installed capacity of 6.6 GW
- Annual generation of ~24,000 GWh:
  - 87% hydro
  - 9% coal

~19,000 GWh

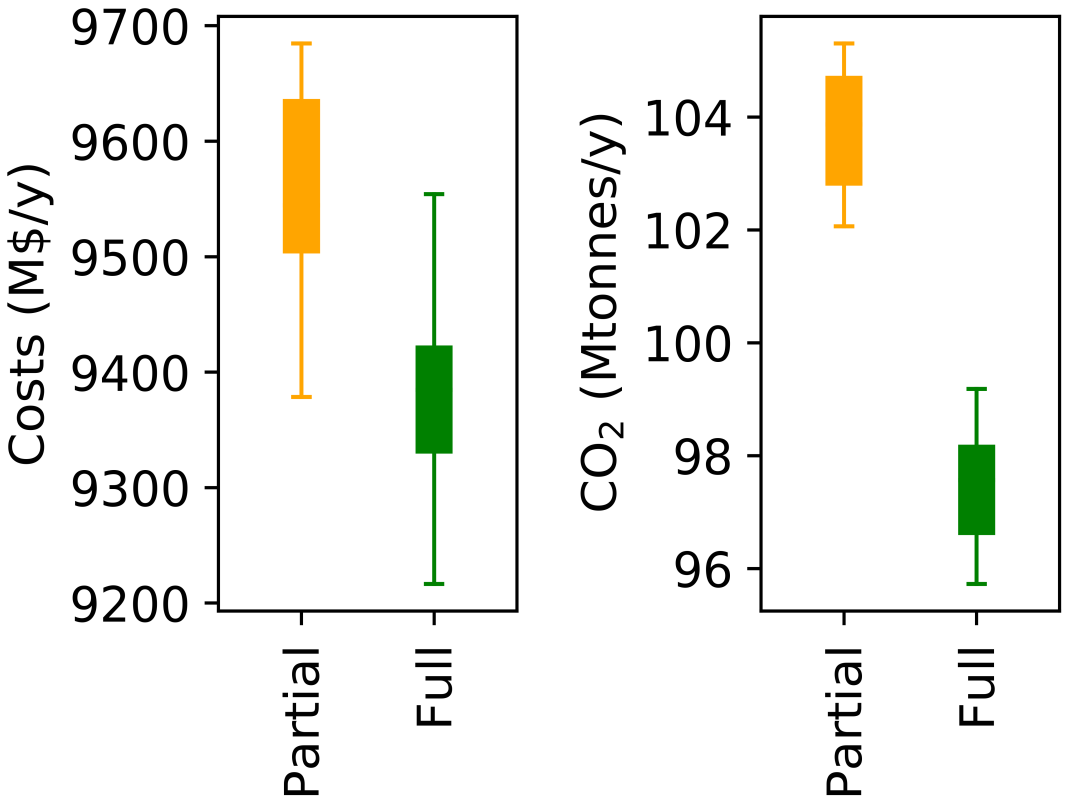
Thai energy system

- Installed capacity of 43 GW
- Annual generation of ~200,000 GWh:
  - 63% gas
  - 19% coal
  - 10% import (from Laos)
  - 6% biomass
  - 2% domestic hydro



Integration with the Thai power system

The adoption of a wide area synchronous grid (between Thailand and Laos) would reduce power production costs and CO_2 emissions of both countries



Conclusions

- Rapid development of hydropower systems can lead to **line congestion** problems—if such development is not combined with adequate investments in transmission capacity
- Congestion problems in Laos appear to curb the benefits of hydropower development, resulting in suboptimal power production costs and CO_2 emissions
- There are multiple opportunities for improving system performance
  - Capacity expansion of a few selected lines
  - Deeper integration with the Thai power system, which already imports hydropower from Laos
- **Detailed water-energy models** are necessary to describe physical processes and inform decision-makers

Acknowledgements:

- Singapore's Ministry of Education (grant no. MOE2017-T2-1-143)

Thanks!

Stefano Galelli
stefano_galelli@sutd.edu.sg

Resilient Water Systems Group
http://people.sutd.edu.sg/~stefano_galelli/

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

References

Chowdhury, A. K., Kern, J., Dang, T. D., & Galelli, S. (2020). PowNet: A Network-Constrained Unit Commitment/Economic Dispatch Model for Large-Scale Power Systems Analysis. *Journal of Open Research Software,* 8(1).

Chowdhury, A. K., Dang, T. D., Bagchi, A. & Galelli, S. Expected benefits of Laos' hydropower development curbed by hydro-climatic variability and limited transmission capacity—opportunities to reform. *Journal of Water Resources Planning and Management*, in press, doi: 10.1061/(ASCE)WR.1943-5452.0001279

Dang, T. D., Vu, D. T., Chowdhury, A. K., & Galelli, S. (2020). A software package for the representation and optimization of water reservoir operations in the VIC hydrologic model. *Environmental Modelling & Software,* 126, 104673.

Dang, T. D., Chowdhury, A. F. M., & Galelli, S. (2020). On the representation of water reservoir storage and operations in large-scale hydrological models: implications on model parameterization and climate change impact assessments. *Hydrology and Earth System Sciences*, 24, 397–416.