NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Renewable Energy Tools and Cross-Border Trade for South Asia

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SARI/EI 6th Project Steering Committee Meeting

8 March 2018

Agenda

- Sri Lanka – India Cross-Border Electricity Trade
- Nepal – India Market Factors Affecting Trade
- Renewable Energy Data Explorer
- Supply Curve Analysis
- Inter-Annual Variability

Renewable energy tools for South Asia

Sri Lanka – India Cross-Border Electricity Trade

Operational Analysis of a DC tie

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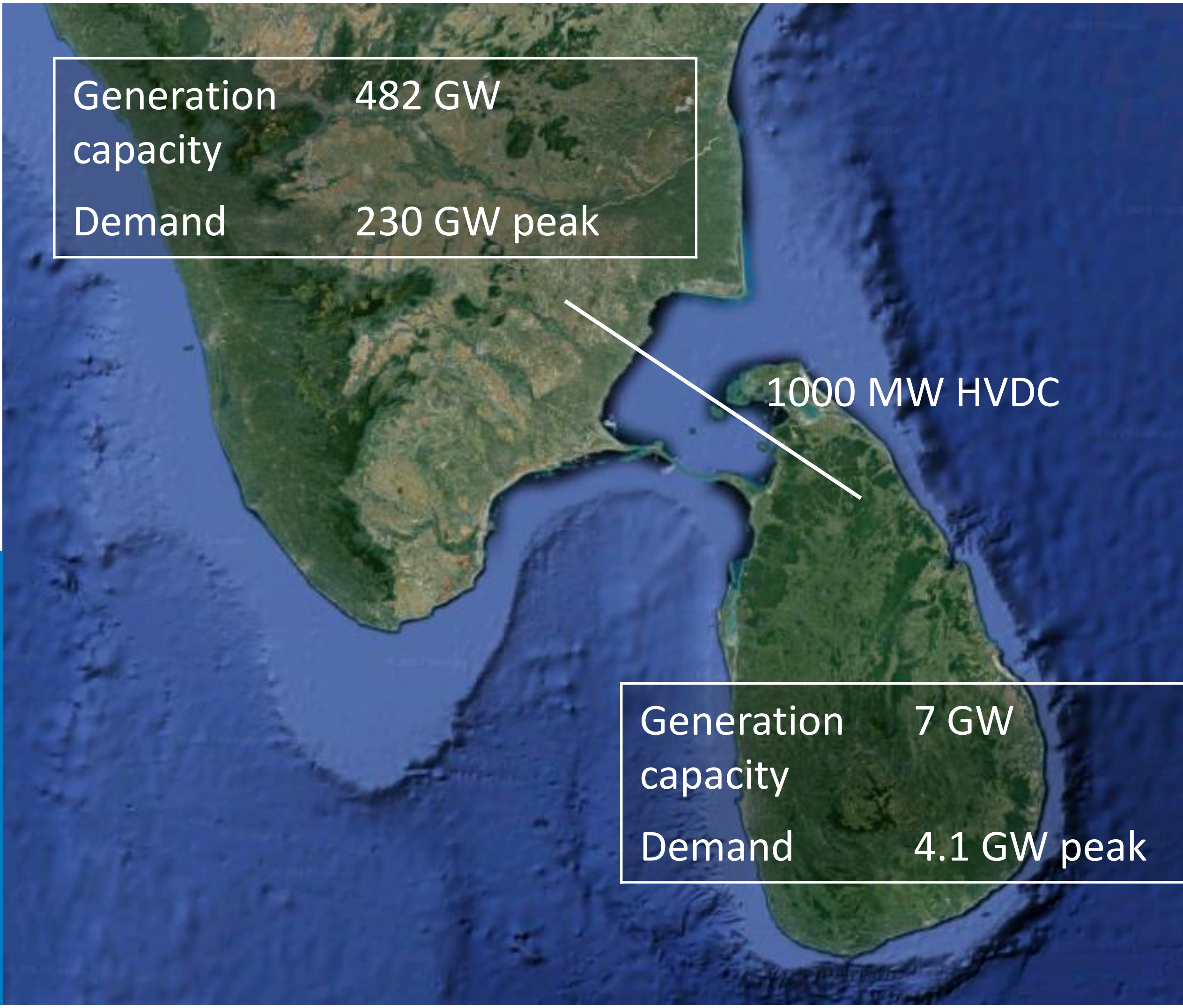
Objective

Analyze the operational impact of a DC tie between Sri Lanka and India in a future year

Main tool is a production cost model

- Time series analysis of future operations



Methodology Overview

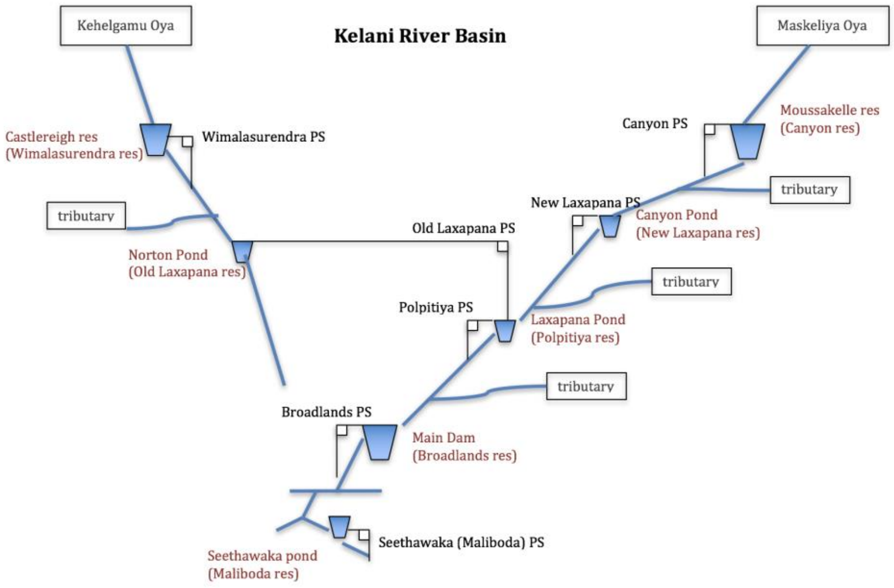
1. Build an operations model of today's power system
2. For future year, forecast load and necessary capacity to meet load
3. Simulate power system operations in the future year

We used the PLEXOS production cost model

Methods

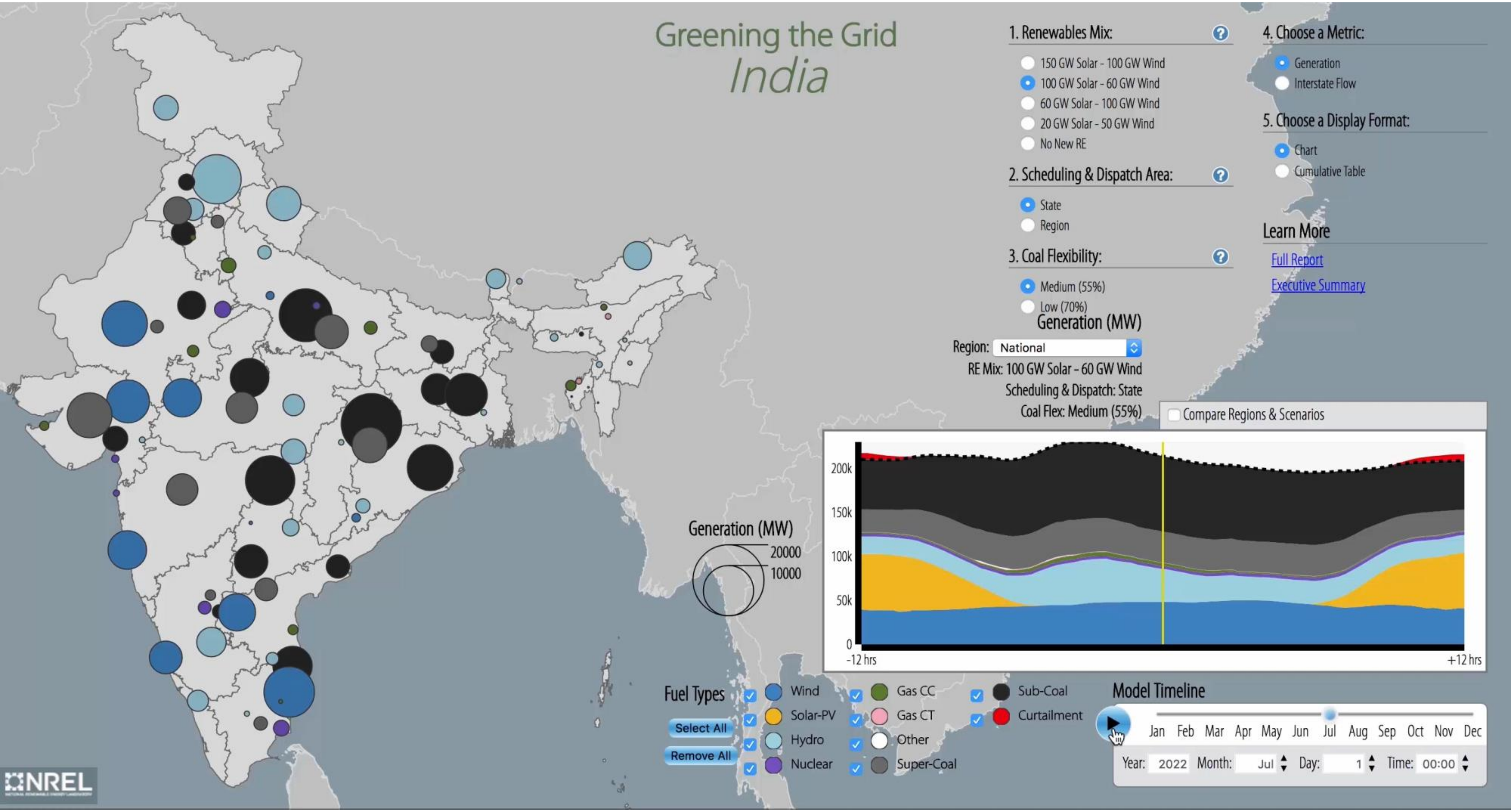
- This study builds on a model that was built of India for the Greening the Grid study*
- The Sri Lanka model was built and validated in close collaboration with CEB
- Detailed hydroelectric representation of Sri Lanka
- Wind and solar meet CEB 2025 targets

Compare operations between systems with and without DC tie



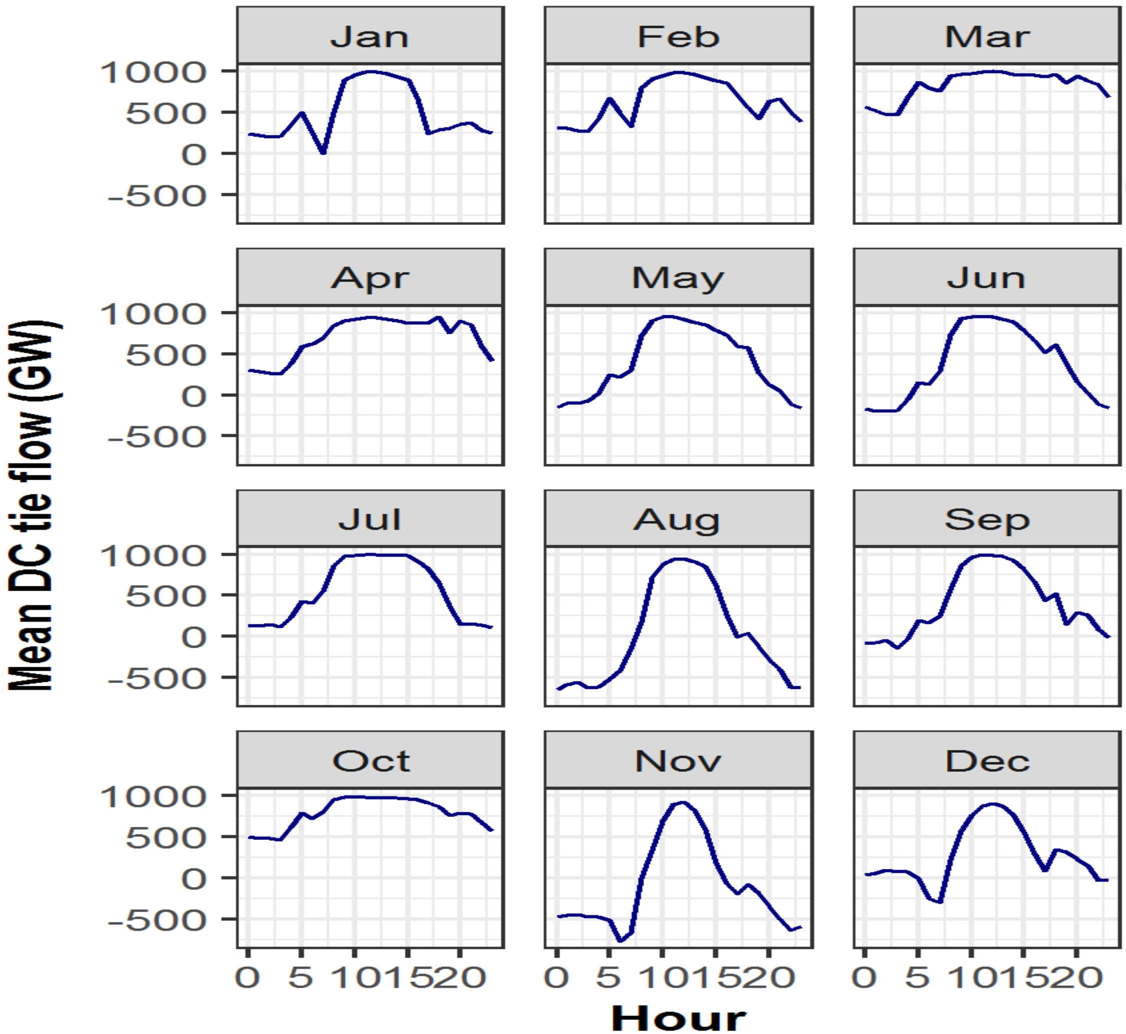
*www.nrel.gov/india-grid-integration

India's Power System in 2022—Achieving System Balance Every 15 Minutes

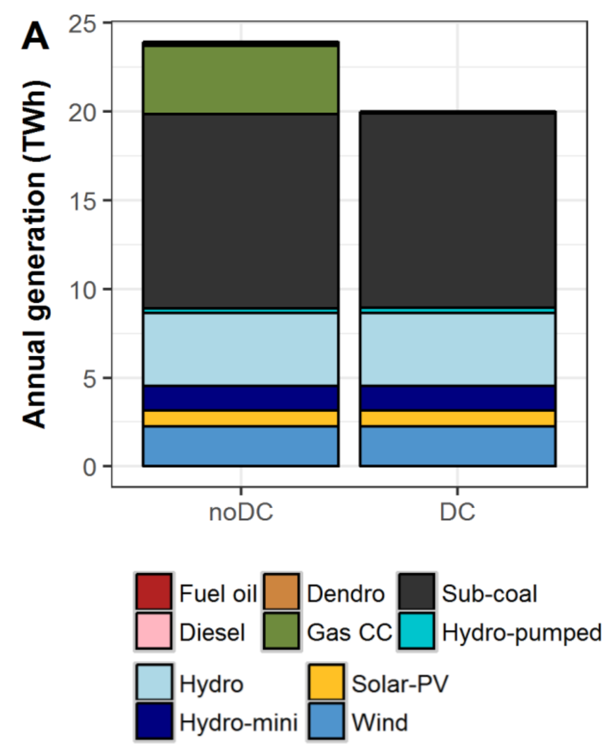


https://maps.nrel.gov/IndiaGTG/

4.5 TWh of energy flows toward Sri Lanka, resulting in a 50% reduction in production costs

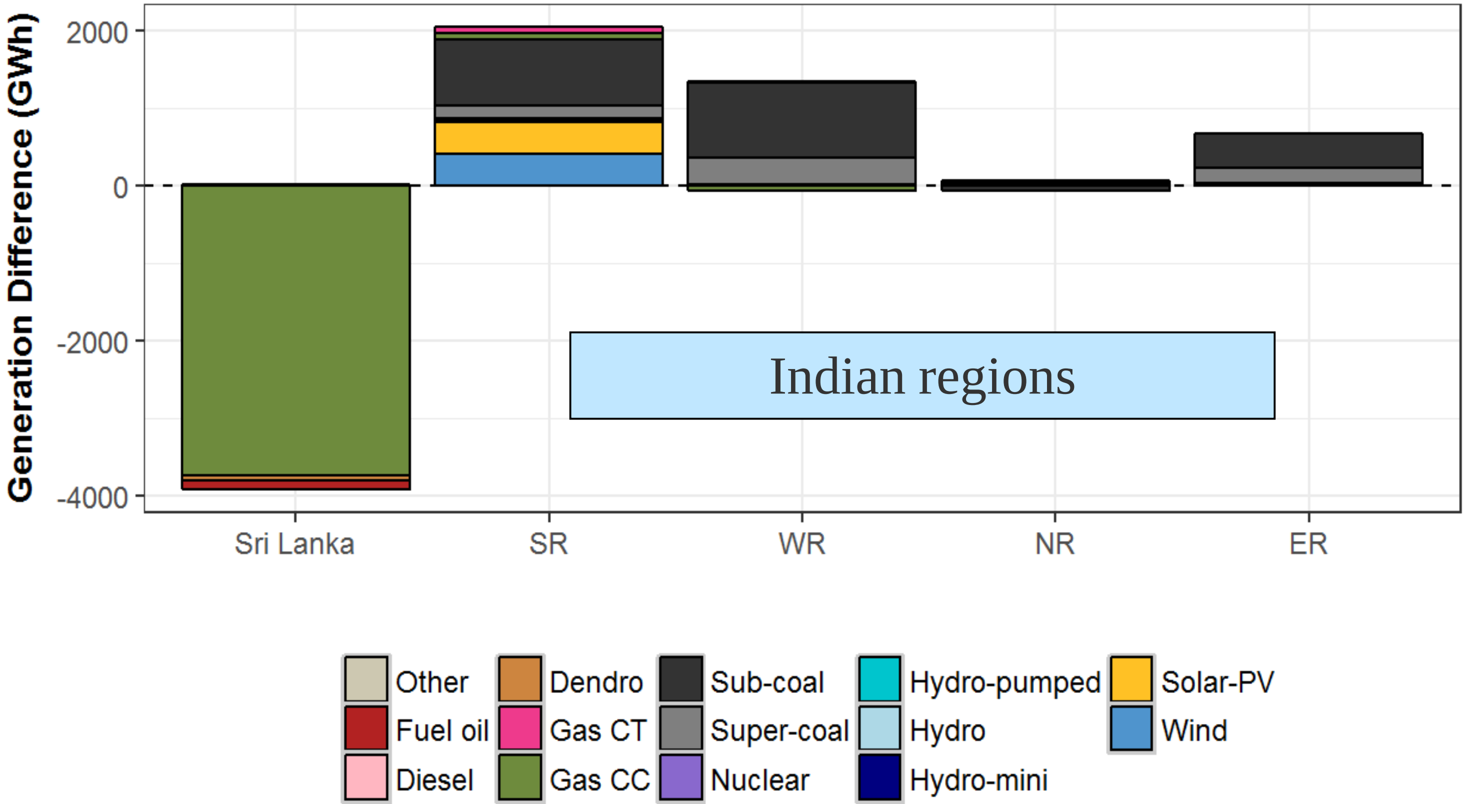


Most energy flows toward Sri Lanka, but during evenings in high hydro months Sri Lanka exports to India



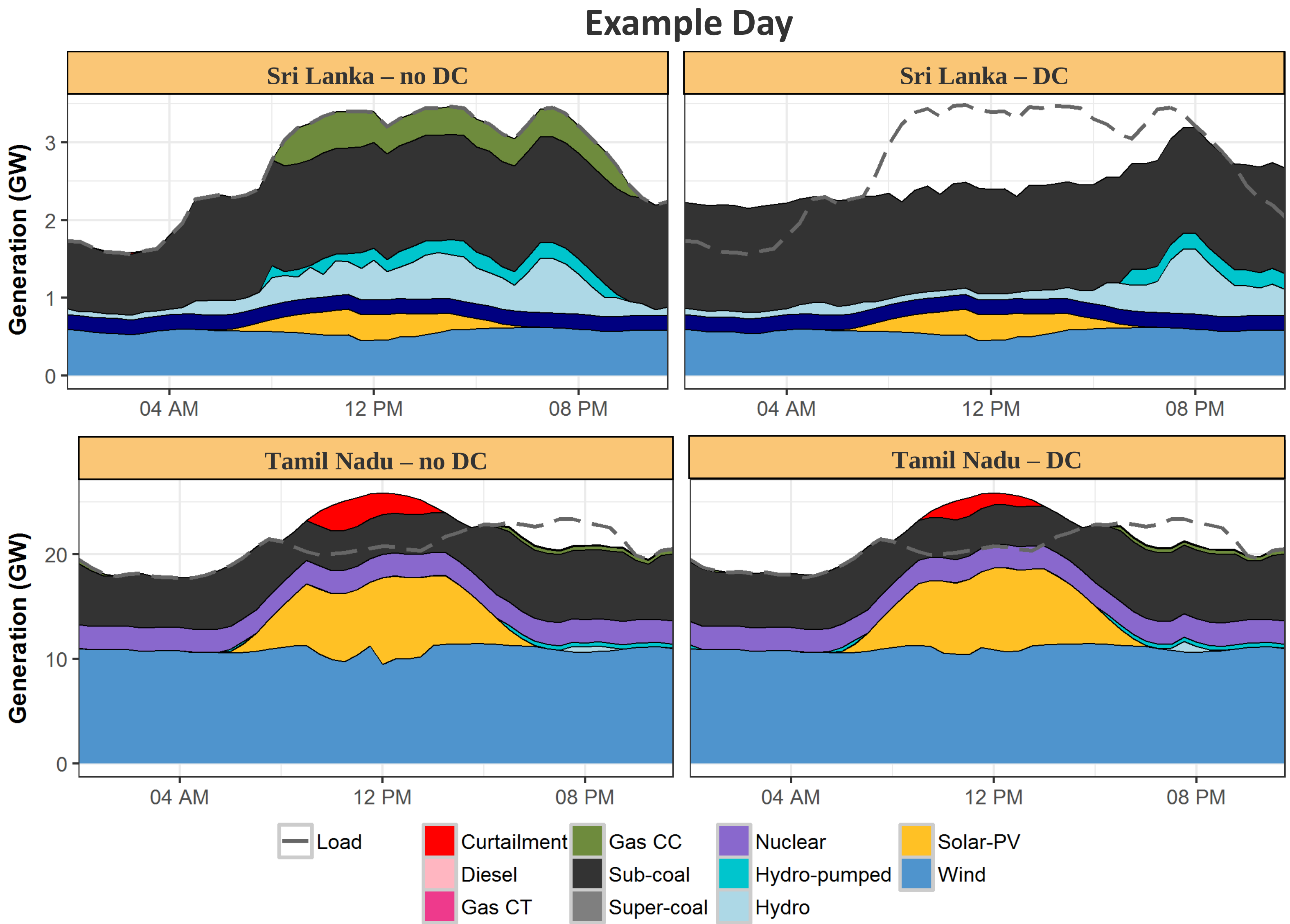
Positive indicates flow toward Sri Lanka, negative toward India

Sri Lankan gas generation falls 97%, while coal and RE increase in India

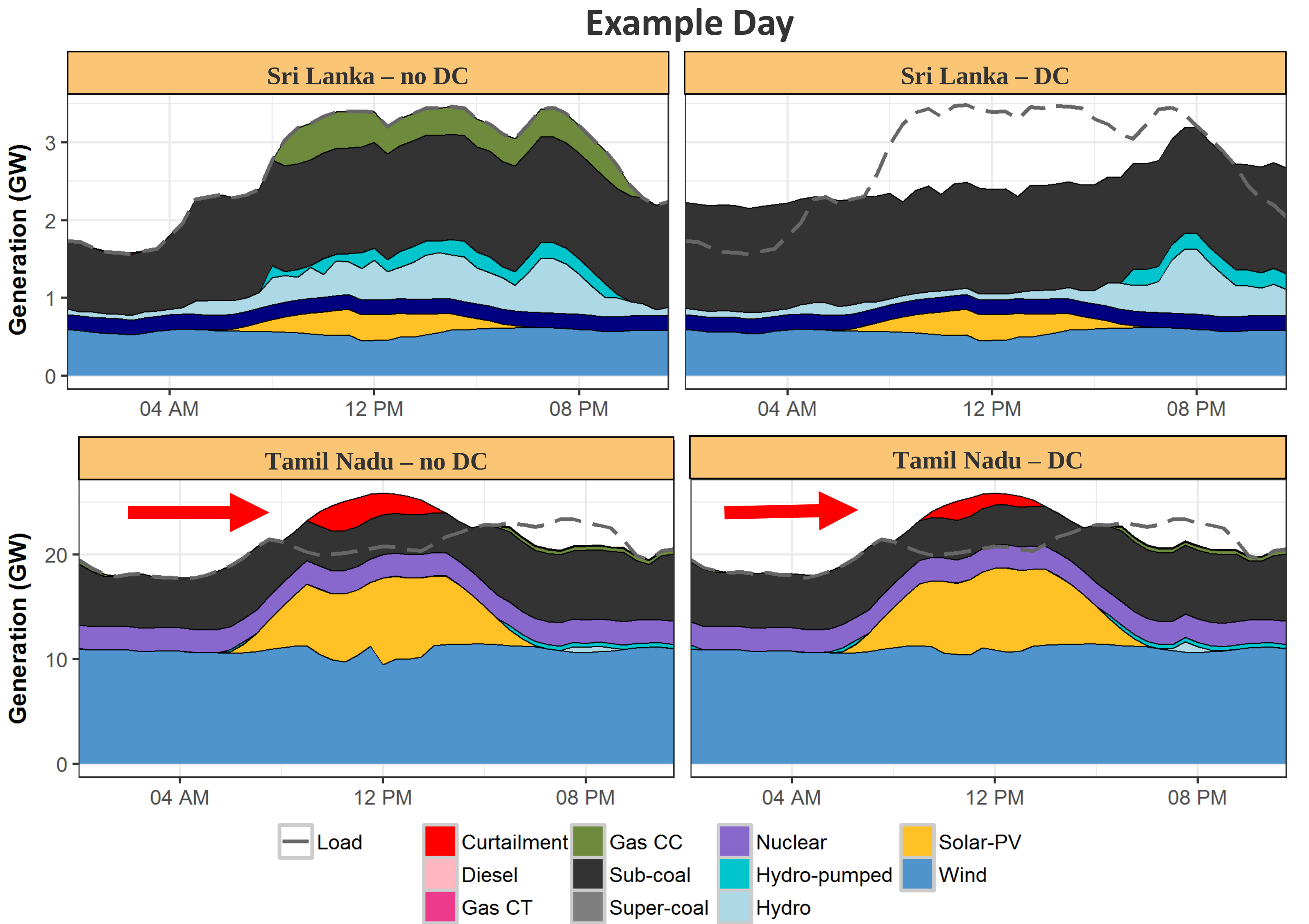


India increases both coal and renewable generation

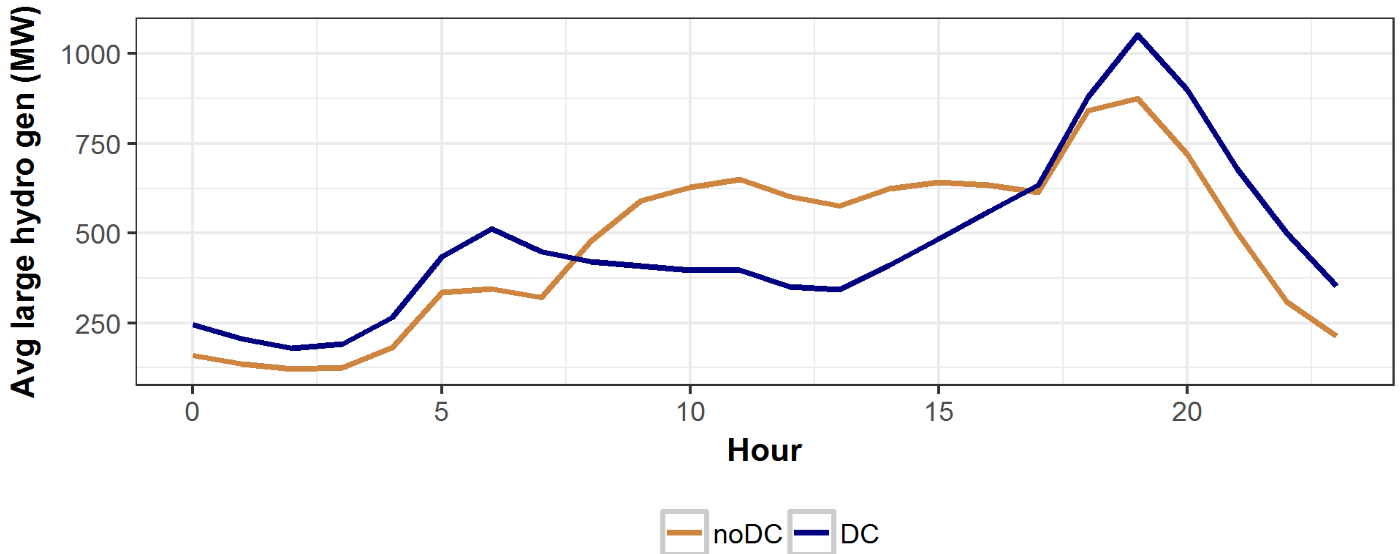
Sri Lanka operates its coal fleet more efficiently

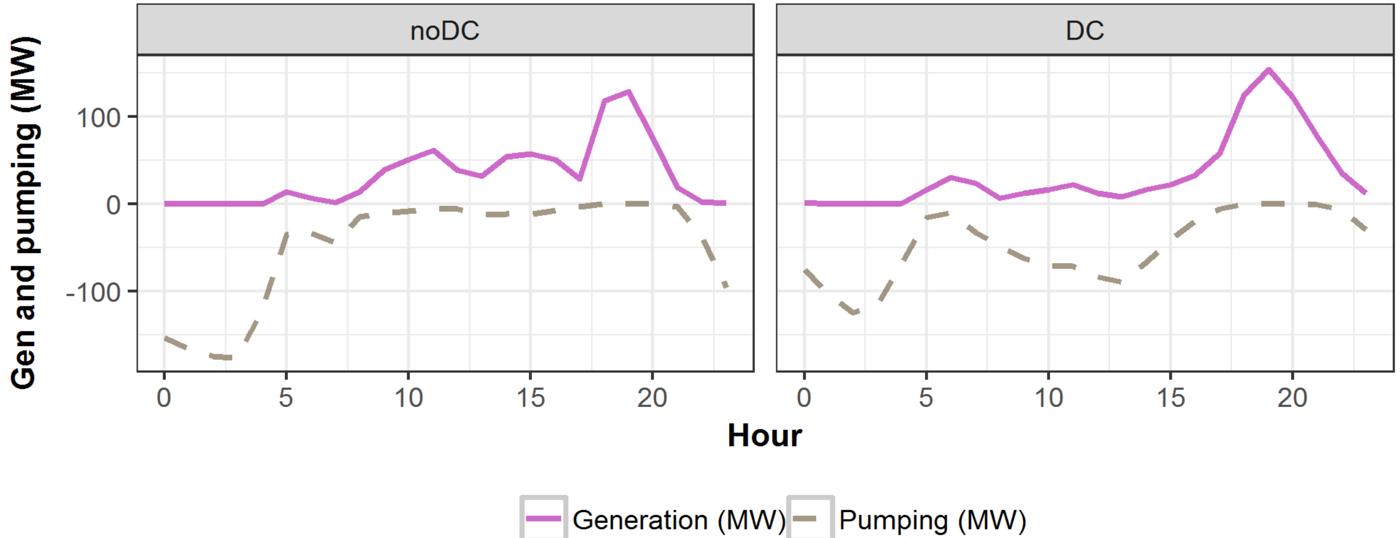


Curtailment of RE in India is reduced by 16% (816 GWh)



Hydro and pumped storage helps to meet peak generation in Sri Lanka, which has shifted to evening because of daytime import





Results

- The DC tie is congested for 32% of the year, implying that transfer capacity beyond 1000 MW could provide additional economic benefits
- Start costs go down by 4%, driven primarily by less expensive gas generators starting in Sri Lanka

Hydro Sensitivities (low and high hydro year for Sri Lanka)

- Compared to a medium hydro year, total production cost savings from cross-border trade are 12% higher in a dry year and 9% lower in a wet year

Key Takeaways

- **$266 million** annual savings with DC tie
- **97%** reduction in Sri Lankan gas generation
- **816 GWh** reduction in India's RE curtailment
- There may be thermal fleet efficiency improvements not fully captured

Nepal – India

Market Conditions Affecting Cross-Border Trade

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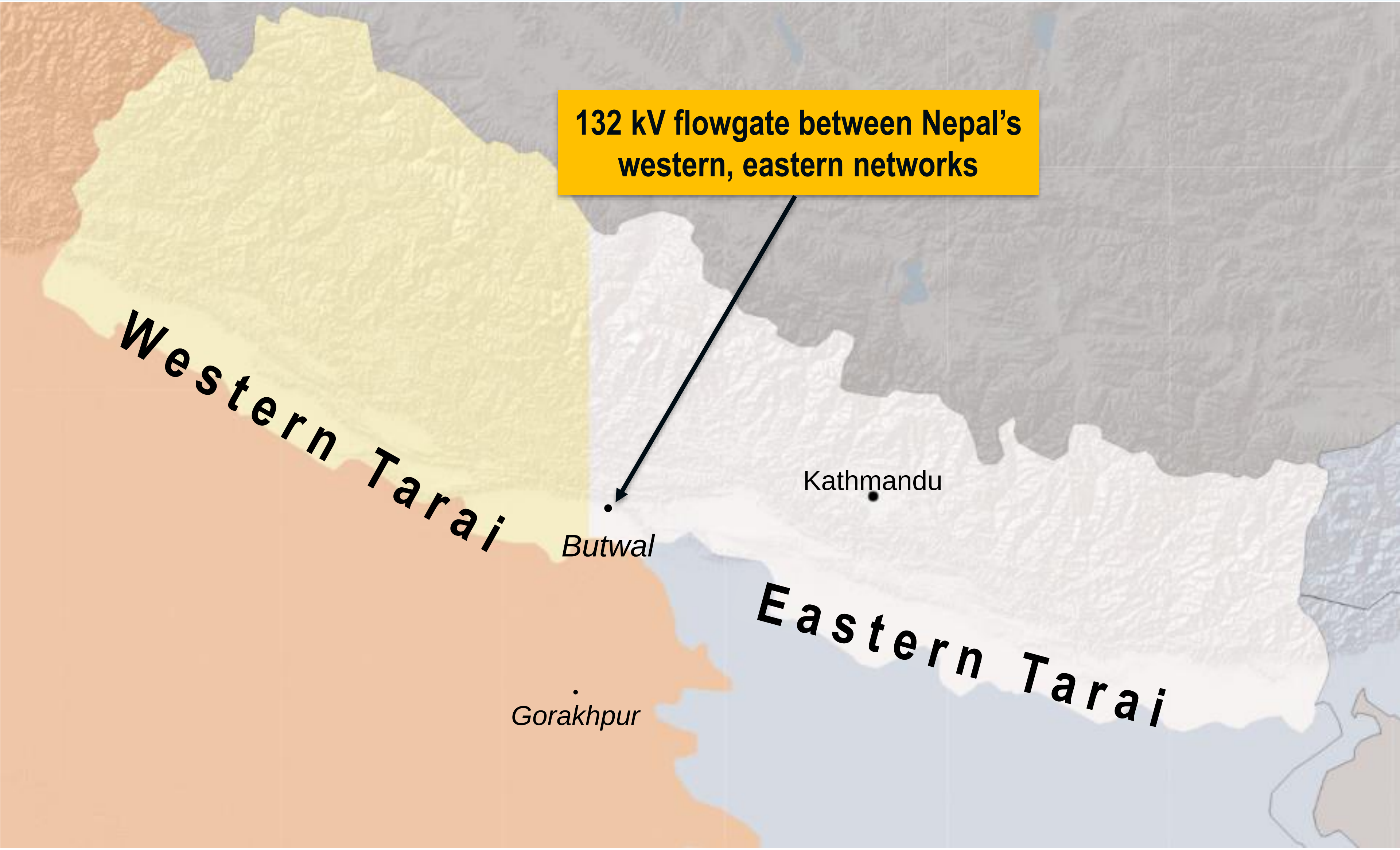
Current Nepal-India interconnection points

Butwal to Gorakhpur is a planned 400 kV connection.

Dhalkebar to Muzzafarpur is a 400 kV connection operating at 138 kV. Upgrade would not require additional right-of-way

Two distinct CBET areas



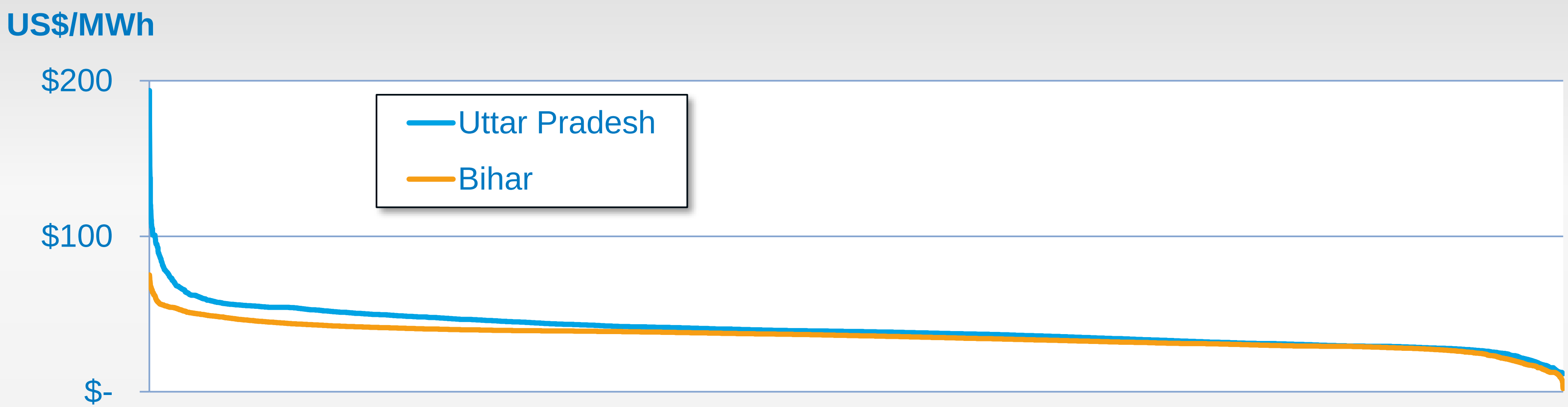
Northern Load Dispatch Center Region

Eastern Load Dispatch Center Region

Contrasts between CBET areas

	Western Tarai		Eastern Tarai
Nepal	10% of energy sales <1% of generating capacity	*One flowgate connecting east and west*	90% of energy sales 99% of generating capacity
India	*Uttar Pradesh* 345 TWh annual energy served Energy importer Mixed generation with connection to Rajasthan RE	*20 TWh annually to Uttar Pradesh from Bihar*	*Bihar* 134 TWh annual energy served Energy exporter Primarily coal, some hydro

Price duration curves for day-ahead energy (Indian Energy Exchange)



All hours, April 13, 2016 to April 12, 2017

Current issue affecting CBET: load shedding

- Insufficient domestic supply, partly met by importing electricity from Bihar
- Impact on CBET value
  - Nepal's implicit value of lost load (VOLL) is higher than tariff rates governing purchases from India
  - Above-market prices are therefore economically rational, for now
- Without load shedding, market prices—not VOLL—determine CBET value (and direction)
  - Amount of power purchased from India will likely fall

Further Evaluation with Production Cost Modeling

Questions to be further explored:

- Which CBET points along the Indo-Nepalese border have the best economic potential for additional flows, and how much would the flows tend to be?
- Which corridor (Eastern Tarai or the Western Tarai) exhibits the most line congestion?
- Do peaking run-of-river resources provide enough flexibility to manage evening ramping requirements?
- Is there any apparent seasonality to the above questions?

Further investigation with production cost modeling

- Market liberalization scenario
  - How would CBET flows and LMPs change if existing tariffs were replaced with liberalized trading at market prices?
- Renewable energy integration scenario
  - Will higher penetrations of wind and solar in India affect the value of CBET flows between Nepal and India?
  - Will market liberalization have a measurable effect on India's cost of integrating higher penetrations of wind and solar?

Further investigation with production cost modeling

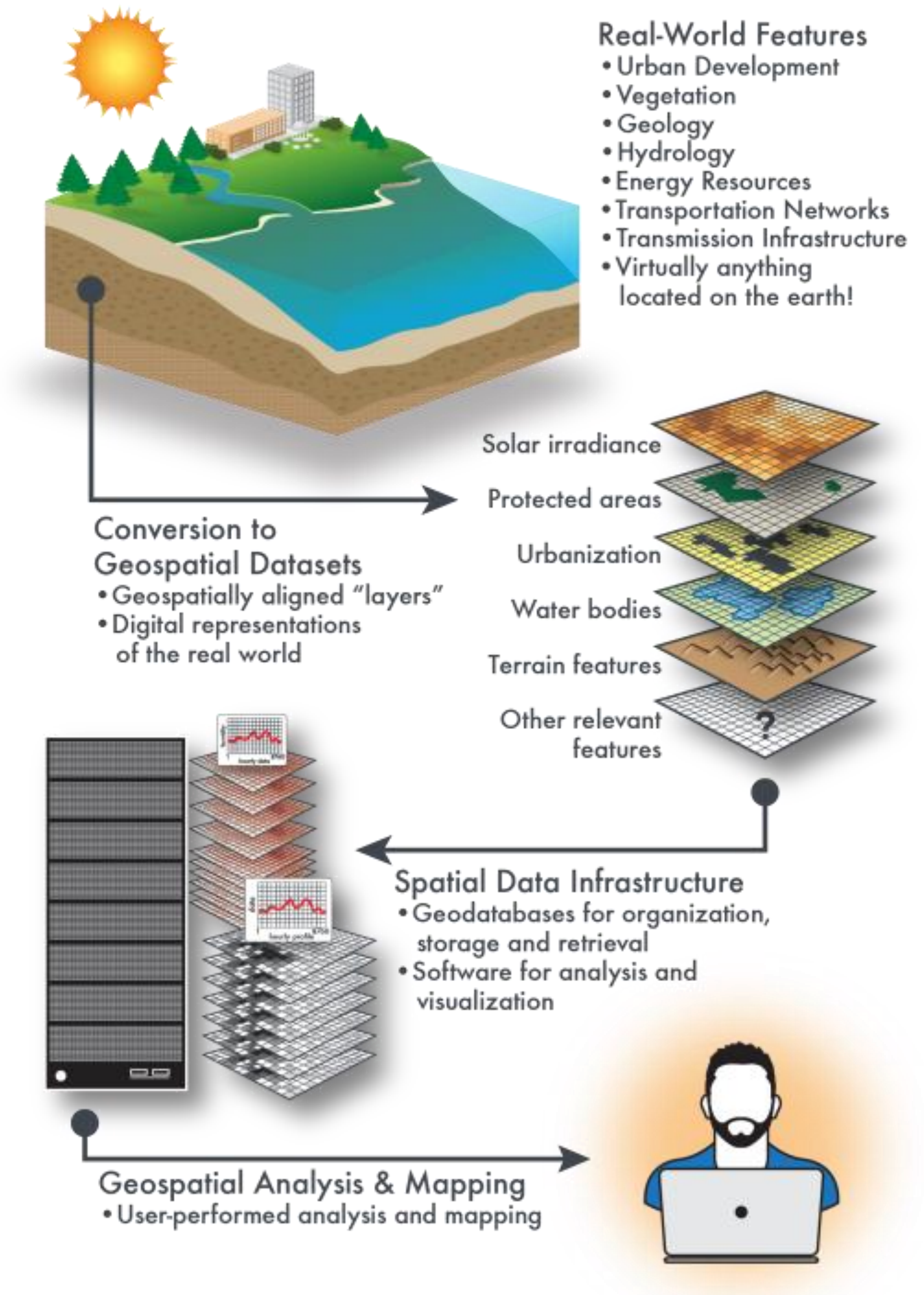
- Bangladesh bulk purchase scenario
  - If Bangladesh were to take 1 GW of hydropower from Nepal (by way of an expanded DC tie with West Bengal), how would power tend to flow from Nepal to West Bengal?

Renewable Energy Tools for South Asia

Geospatial Data Analysis

Geospatial Critical Questions in RE Development

- Optimal Resource?
- Optimal Transmission?
- Barriers to Development?
- Renewable Goals?
- Economic Competitiveness?

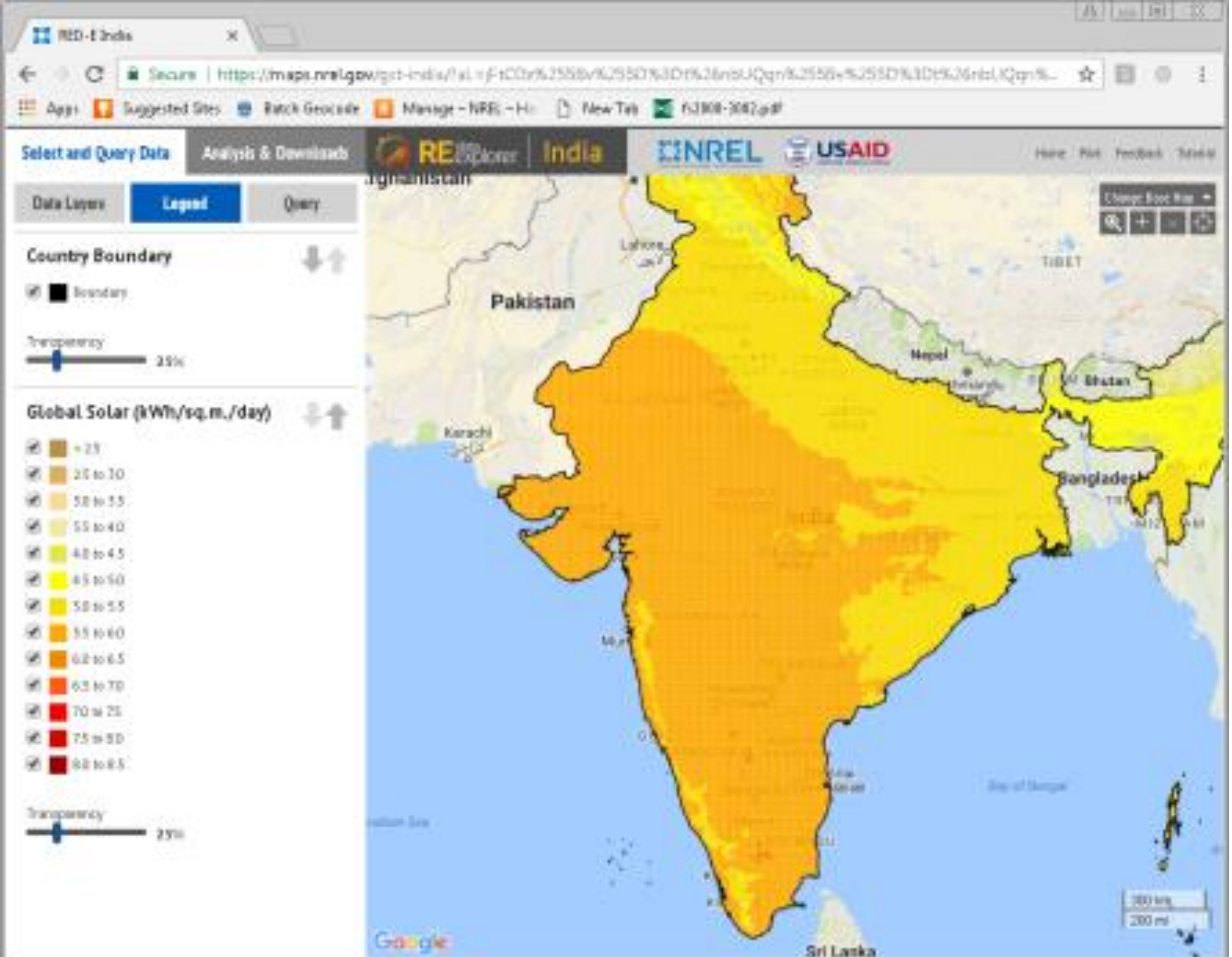


Renewable Energy Data Explorer (RED-E)

- Innovative web-based toolkit for renewable energy decision-making
- Wraps complex spatial analysis in easy-to-use interface targeted at non-specialists
- Platform for distributing data and metadata

re-explorer.org

The development of this tool has been supported primarily by USAID


RED-E India
Select and Query Data
Analysis & Downloads
RE Explorer
India
NREL
USAID
Data Layers
Legend
Query
Country Boundary
Boundary
Transparency
25%
Global Solar (kWh/sq.m./day)
< 2.5
2.5 to 3.0
3.0 to 3.5
3.5 to 4.0
4.0 to 4.5
4.5 to 5.0
5.0 to 5.5
5.5 to 6.0
6.0 to 6.5
6.5 to 7.0
7.0 to 7.5
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Transparency
25%
Pakistan
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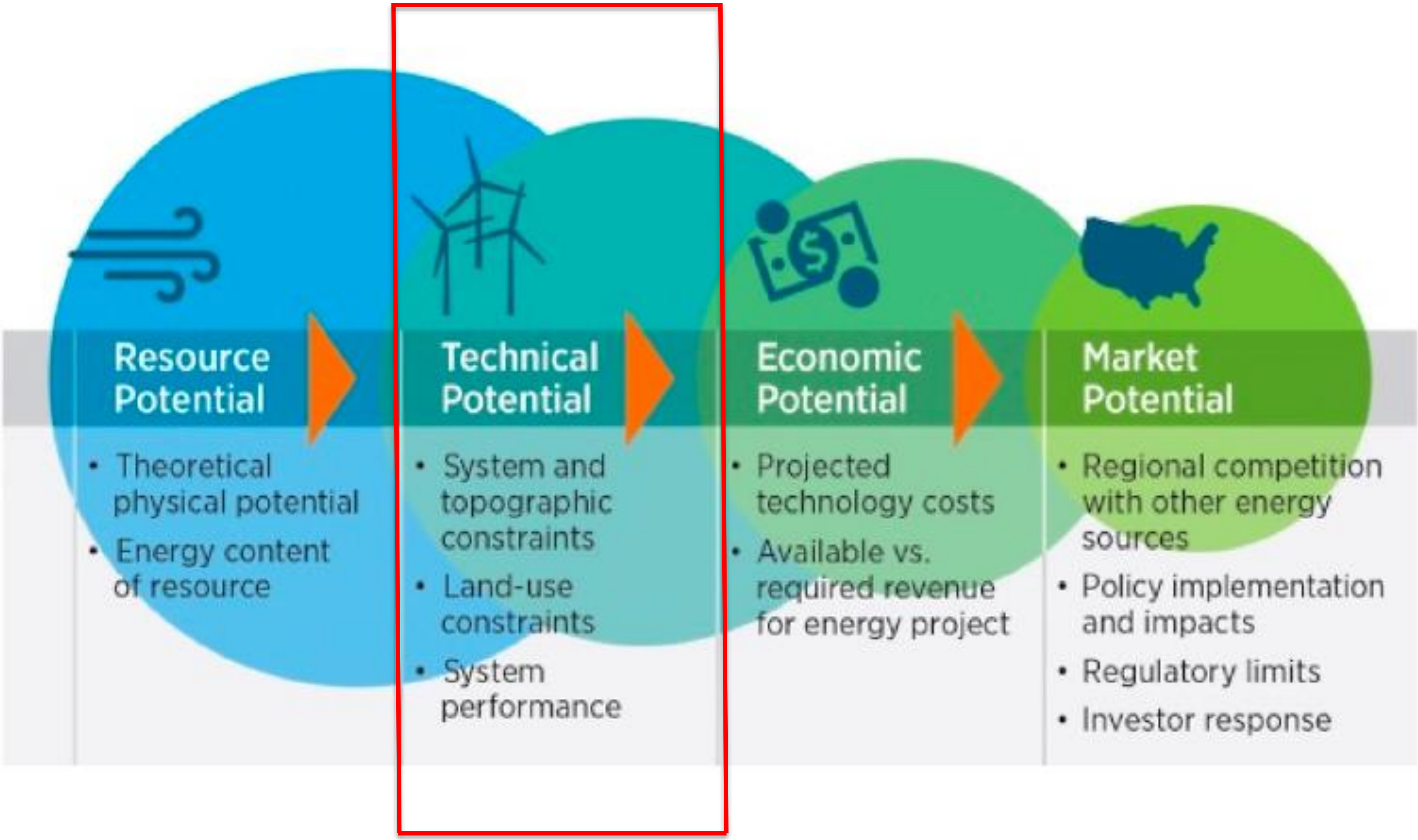
TIBET
Nepal
Bhutan
Karachi
India
Sri Lanka
Google

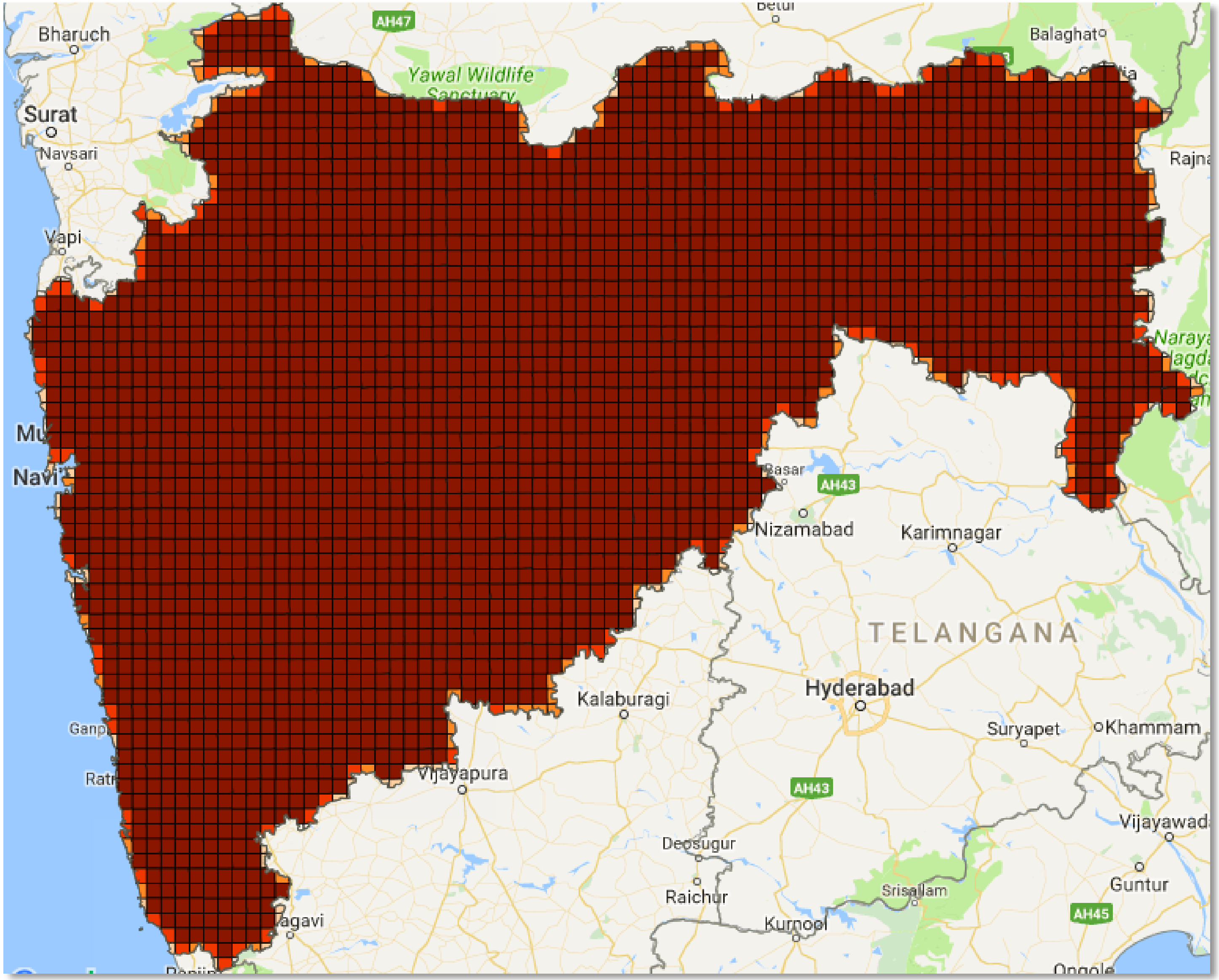
Supporting Policymaking



Evaluating Renewable Targets

~11 million MW of utility scale solar potential in the state of Maharashtra

Example target is 7,000 MW by 2022

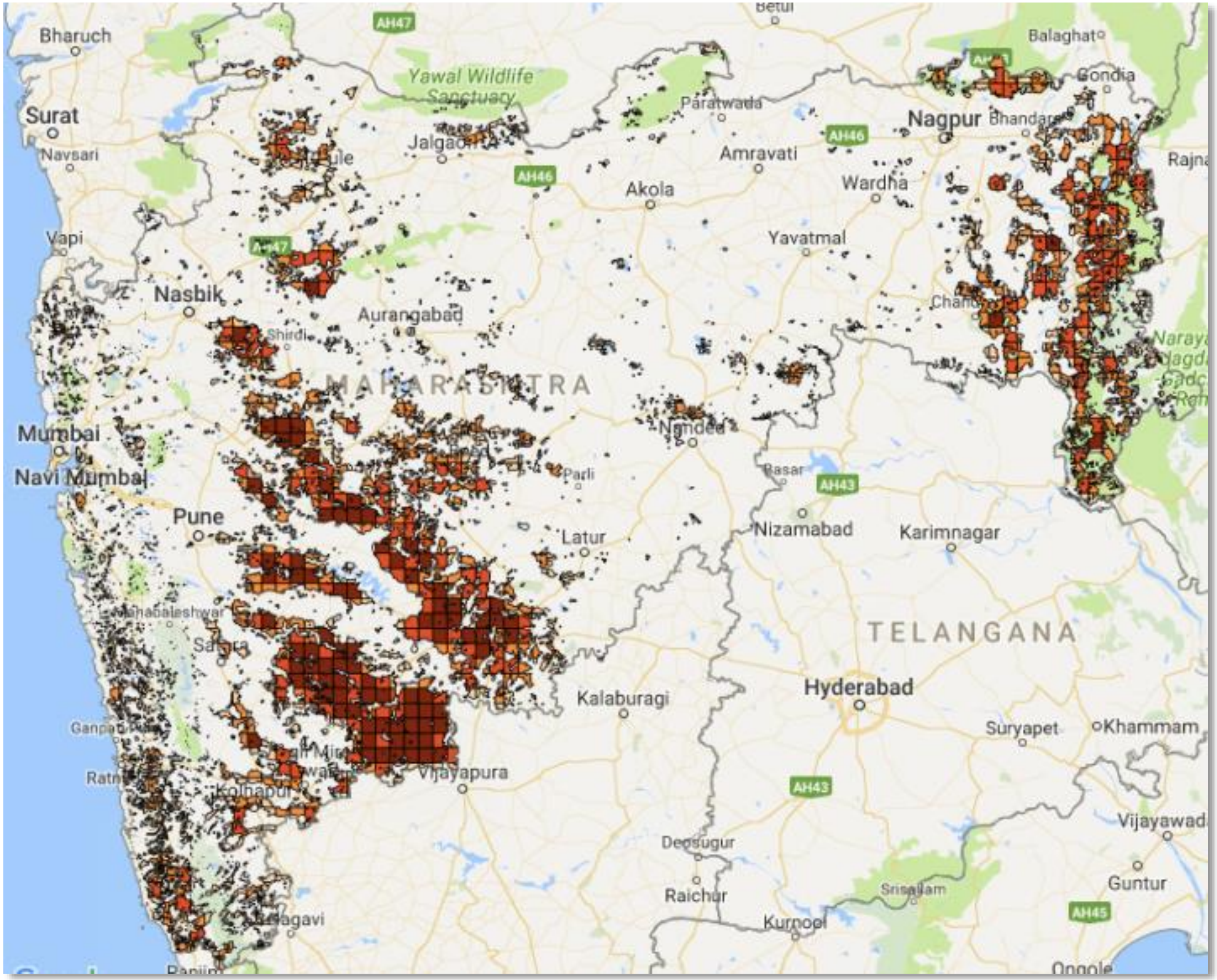


Evaluating Renewable Targets

RED-E allows evaluation of individual and combined factors impact on development potential.

Result of eliminating protected areas and limit development to non-farm lands:

~1 million MW



Evaluating Renewable Targets

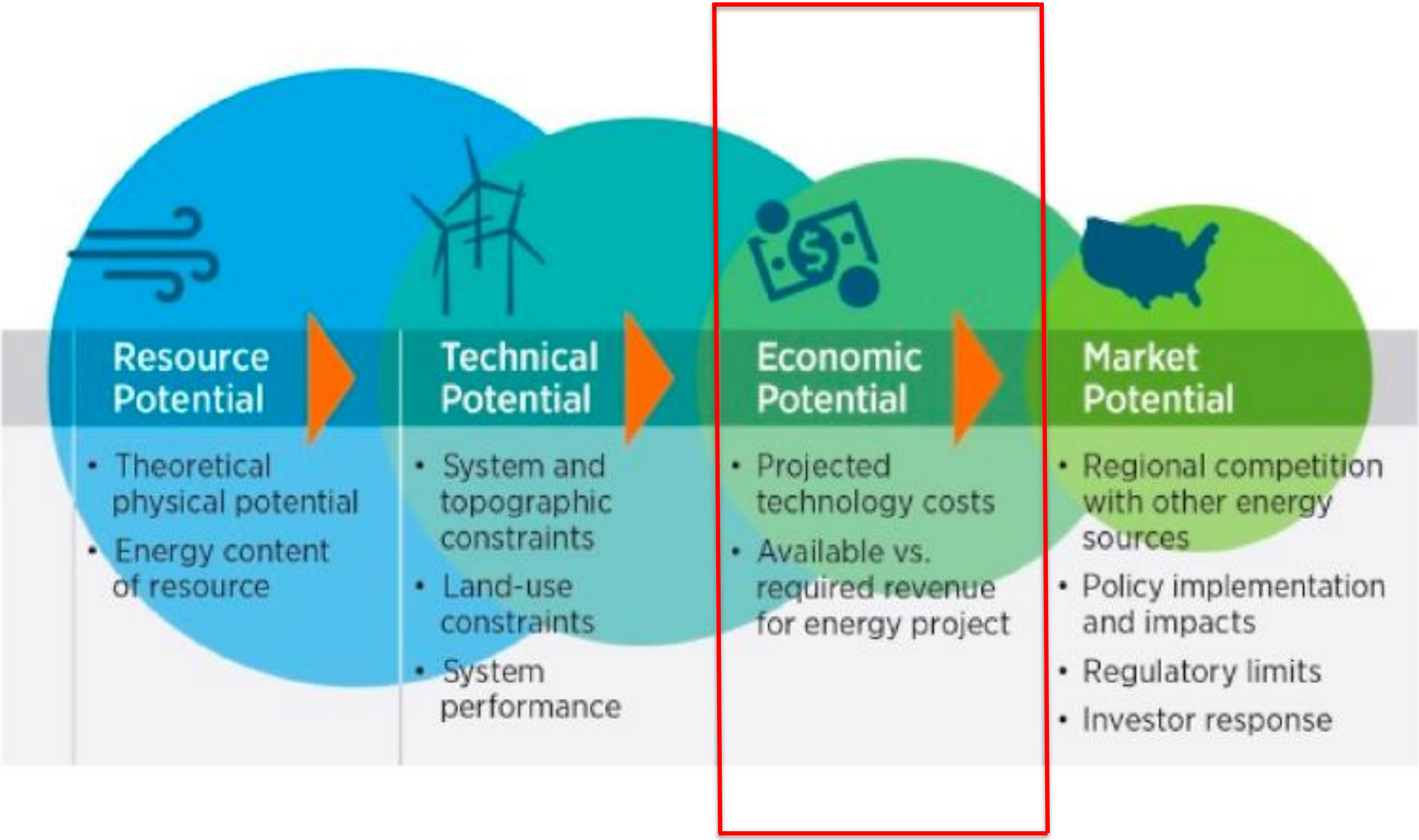
Tighten proximity to infrastructure still yields more than the initial target:

~50,000 MW remaining

RED-E provides high level screening of development opportunities

South Asia RE Supply Curve Analysis

Renewable Energy Analysis



Supply Curve Analysis

Potential Uses for Supply Curve Analysis

- Understanding regional renewable energy supplies, and their cost relative to other generation options
- Insight into policy initiatives that could impact the economic viability
- Cost factors that impact renewable energy supply regionally

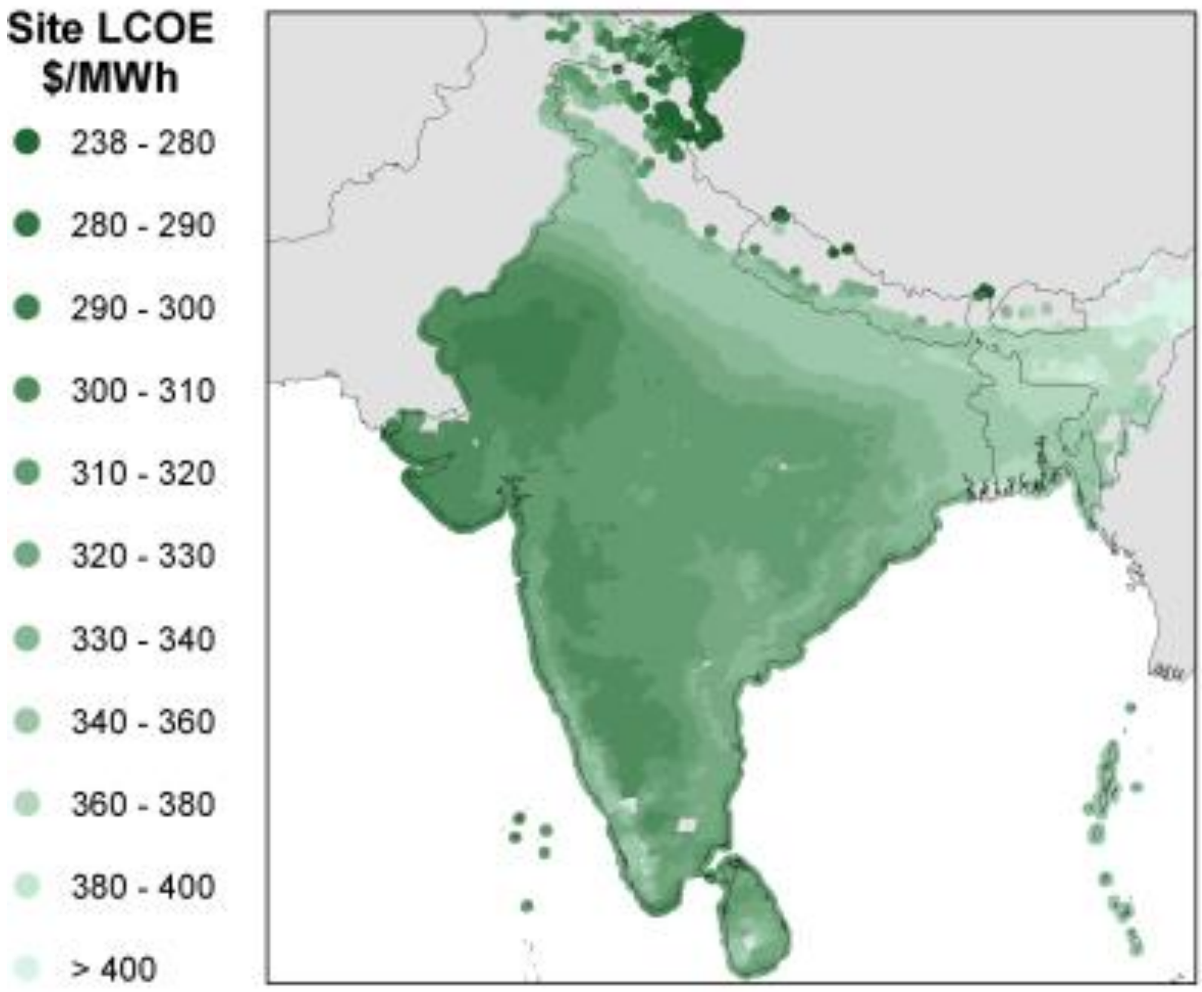
Supply Curve Analysis

- Supply curves give information on amount of potential capacity at specific potential cost intervals
- Sensitivity of results to changes in system cost and performance can readily be evaluated
- Aggregate results by national, state, or sub-state level

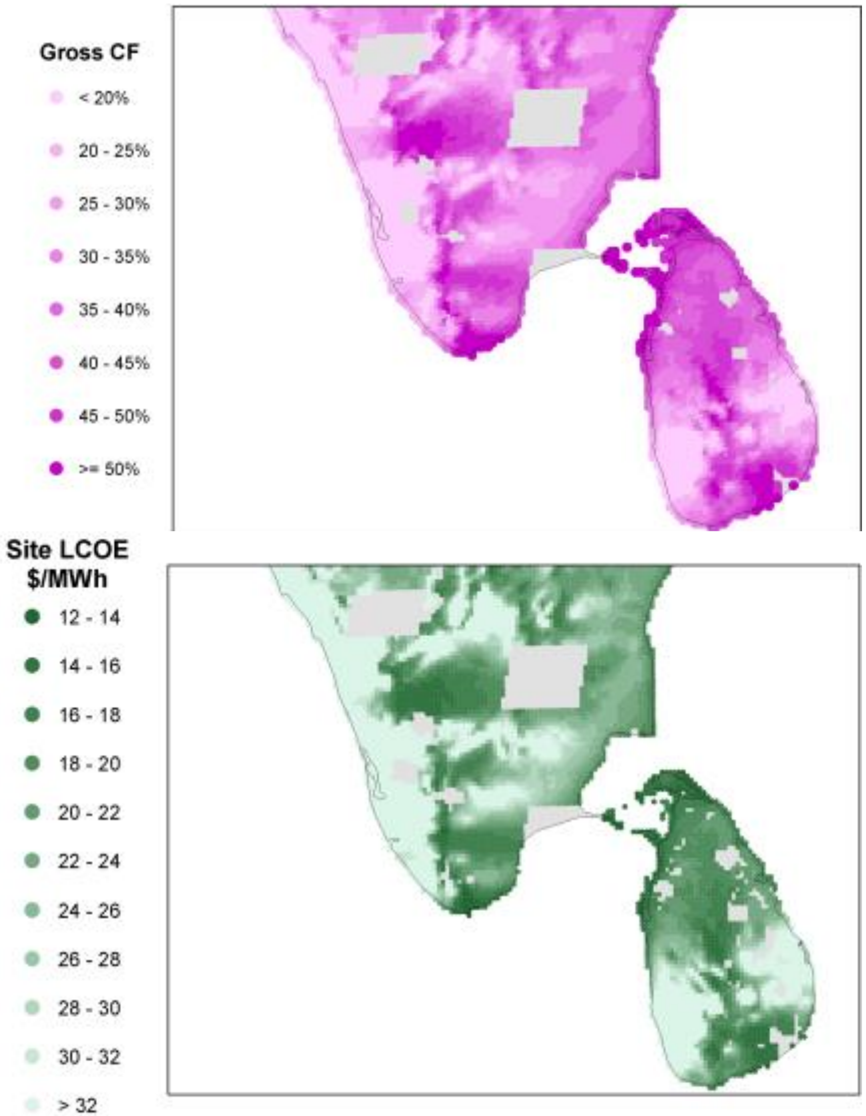
$$\text{Levelized Cost of Energy (LCOE)} = \frac{\text{FCR * CAPEX + Fixed O\&M}}{\text{Capacity Factor (CF) * 8760 hrs/year}} = \text{\$/MWh}$$

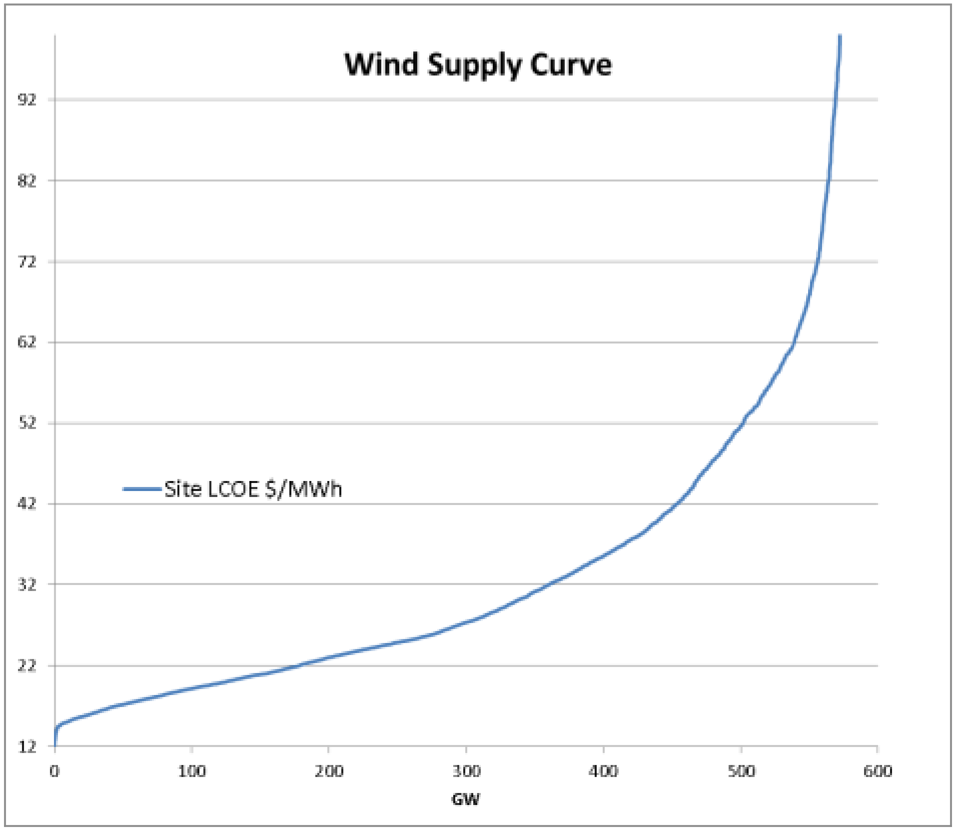
Utility Solar Supply Curve Results

- LCOE determined solely by resource capacity factor
- Lowest cost resource areas in western India, where resource is highest



Regional Example – S India/Sri Lanka, Wind





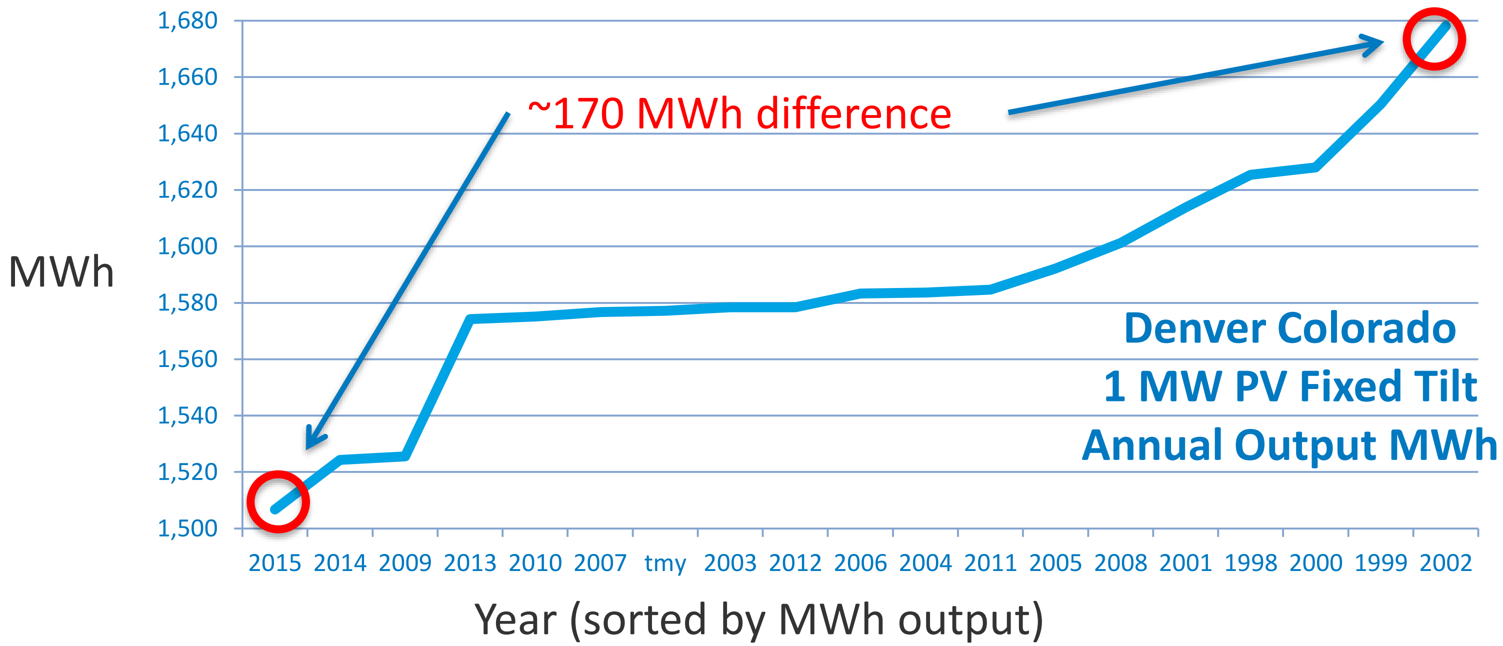
Variations on Supply Curve Analysis

- Results shown here look at the site-based LCOE costs
- Can include grid connection costs
  - Spur line cost to closest grid feature
  - Allocation based on grid capacity
- Model impacts of projected future system costs
- Model impacts of projected future performance improvements
- Analysis to be added to RED-E

Inter-Annual Variability in South Asia Solar Data

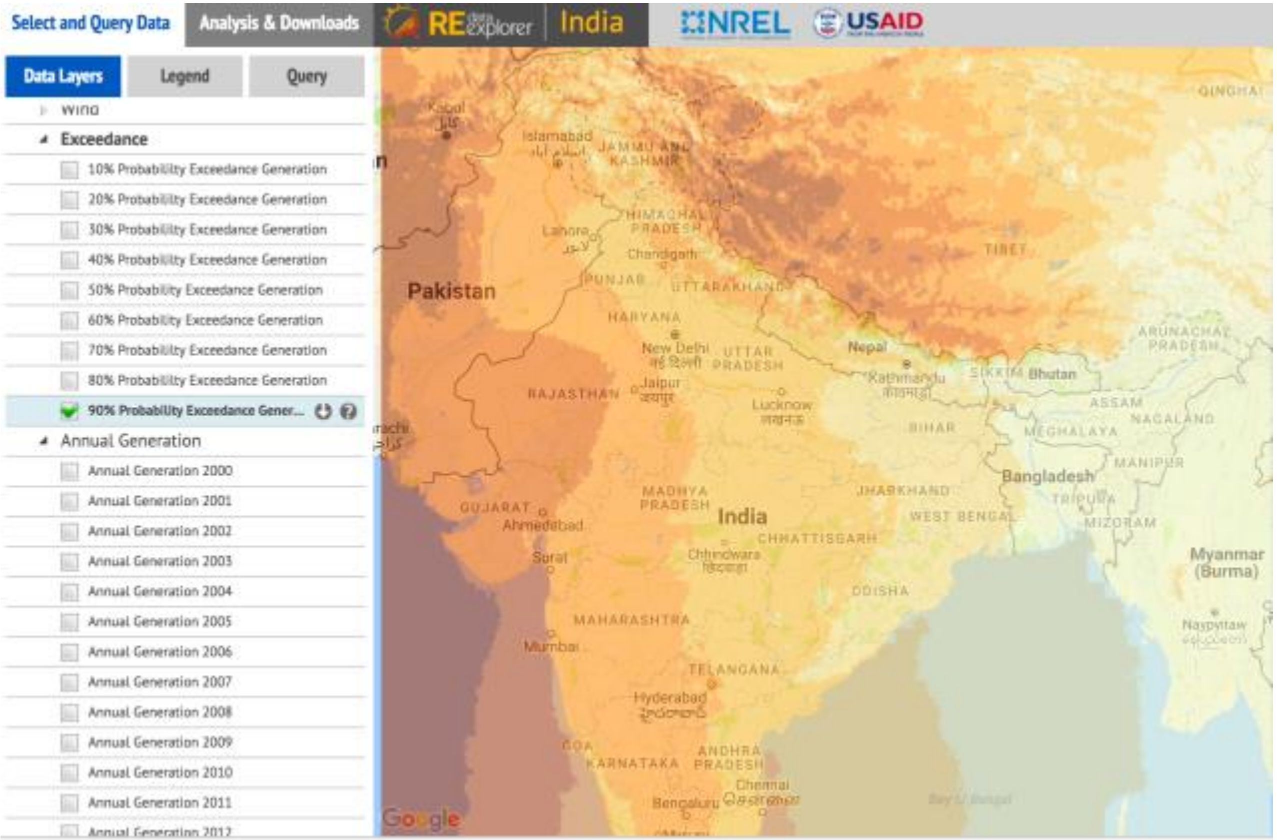
Inter-annual variability

- "Exceedance probabilities" used to determine the amount of energy expected to be produced by a specific plant
- Uses many years of data
- Used to secure competitive financing by evaluating the economic risk associated with inter-annual variability
- Typically performed on solar output – determined using solar generator modeling software



Accessing the Data

- Exceedance probabilities and individual year generation estimates can be visualized and downloaded from the Renewable Energy Data Explorer (RED-E).



https://www.re-explorer.org/

Thank You

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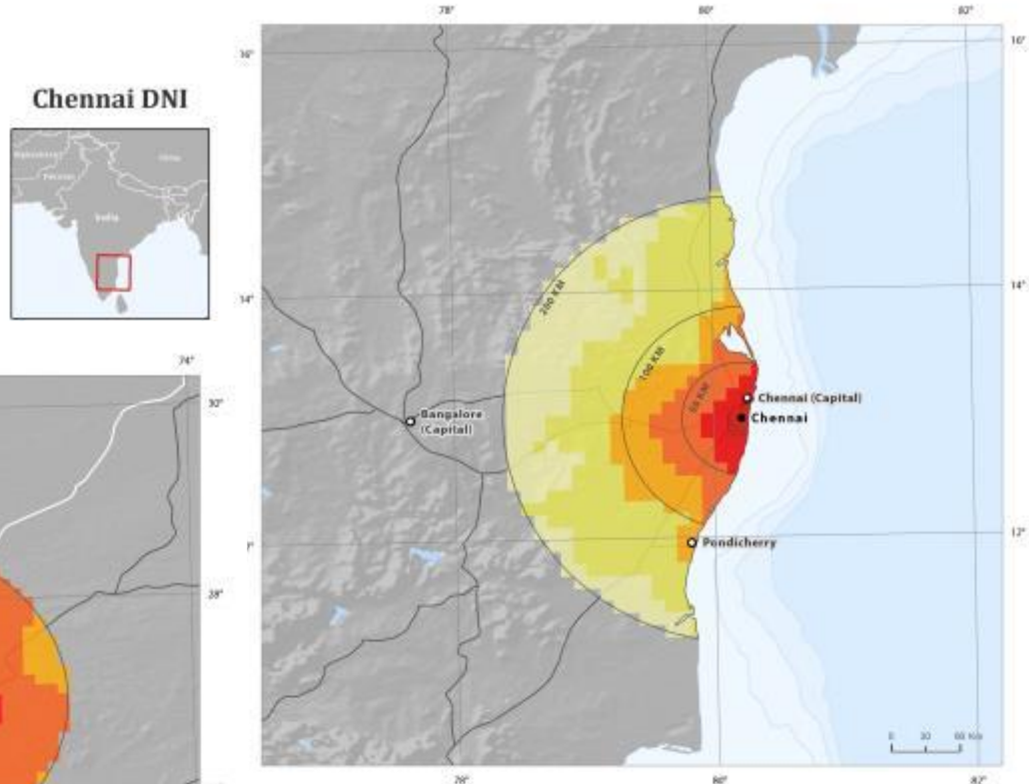
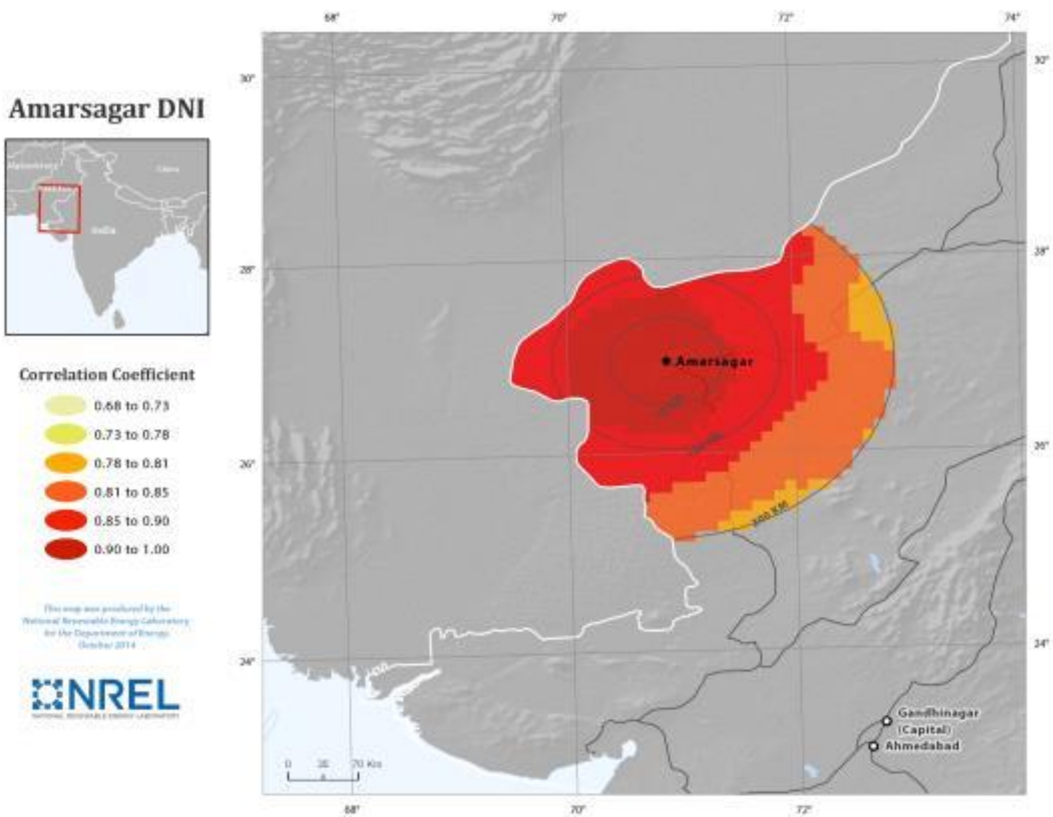
Extra Slides

Spatial Variability

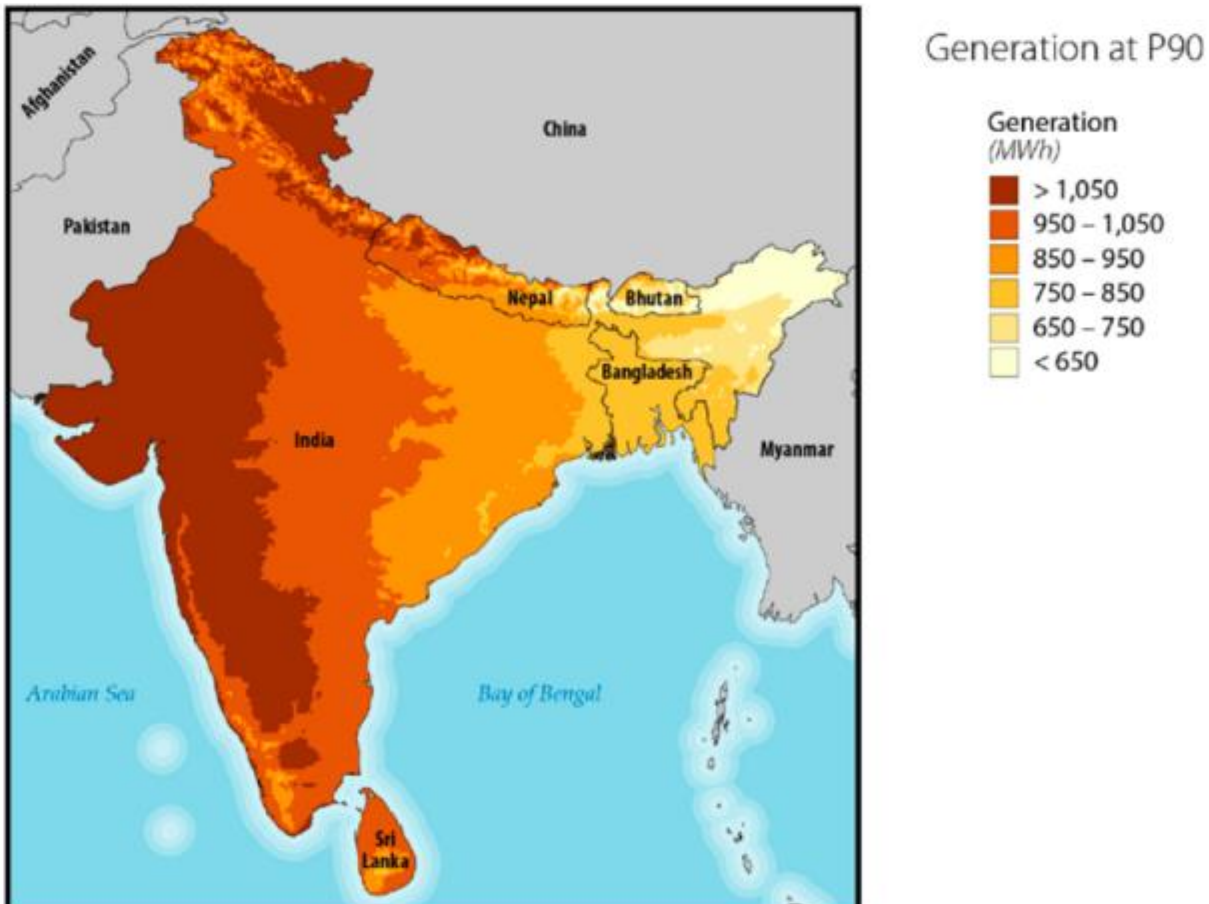
- **The degree of change of a phenomenon over space**
- Solar resource can have high or low spatial variability dependent upon local/regional climate conditions



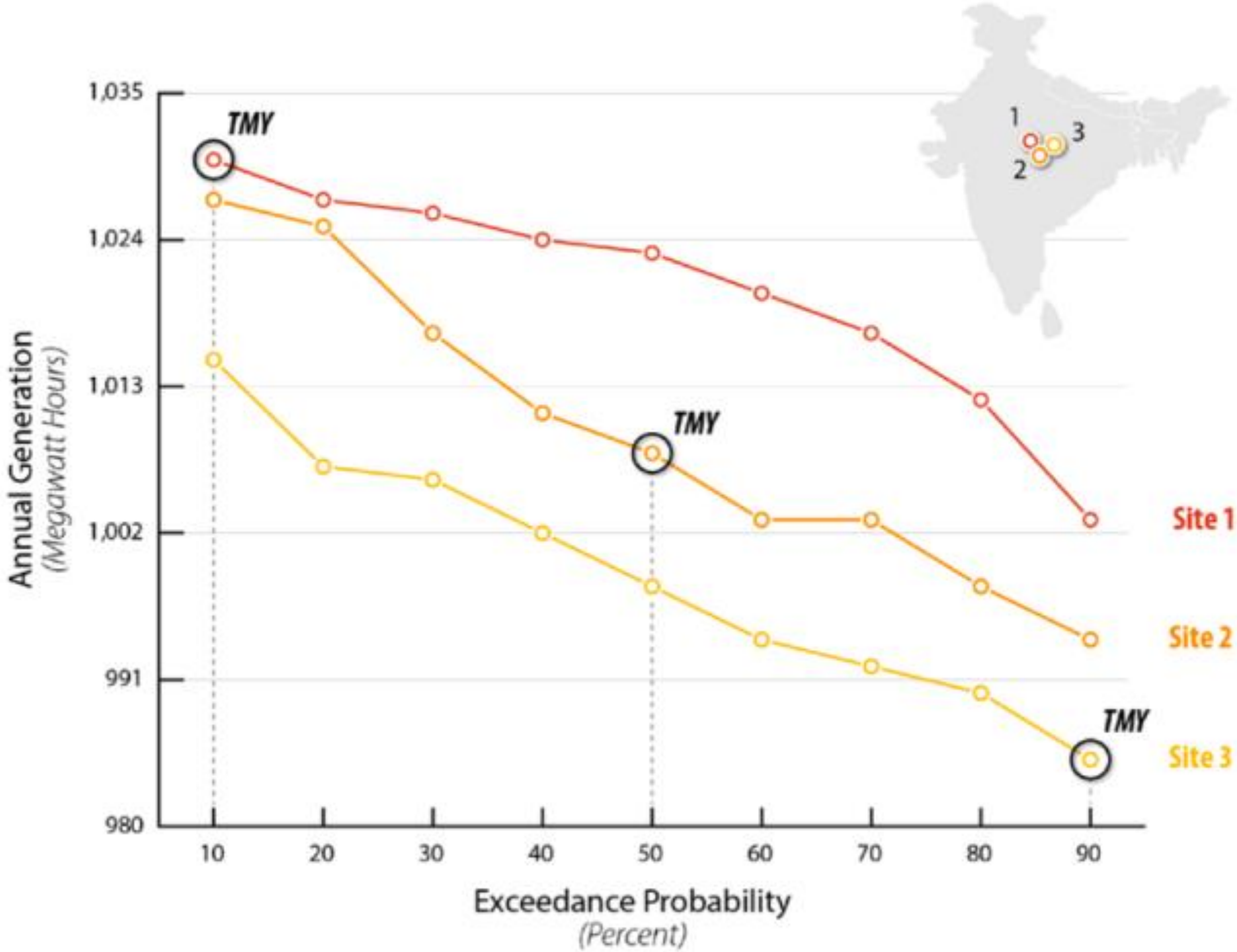


Results

Map shows expected generation output from a 1 MW PV plant (Fixed-Tilt, tilted at latitude) with a 90% probability



Results show mixed success for TMY generation estimates, that theoretically should align with the P50



Takeaways

- Inter-annual variability and climate anomalies pose additional uncertainty in a number of energy modeling activities
- Micro-climates could impact model representativeness of grid stability
- TMY’s long-term representatives is spatially dependent and thus might not be suitable for regional projects or for assessing large investment opportunities
- Resource integrated into the Renewable Energy Potential (reV) model. Enabling exceedance probability analysis, supply curves, and now provides a framework for subsequent analysis and research.