Leveraging Weather Datasets for Resource Planning in India

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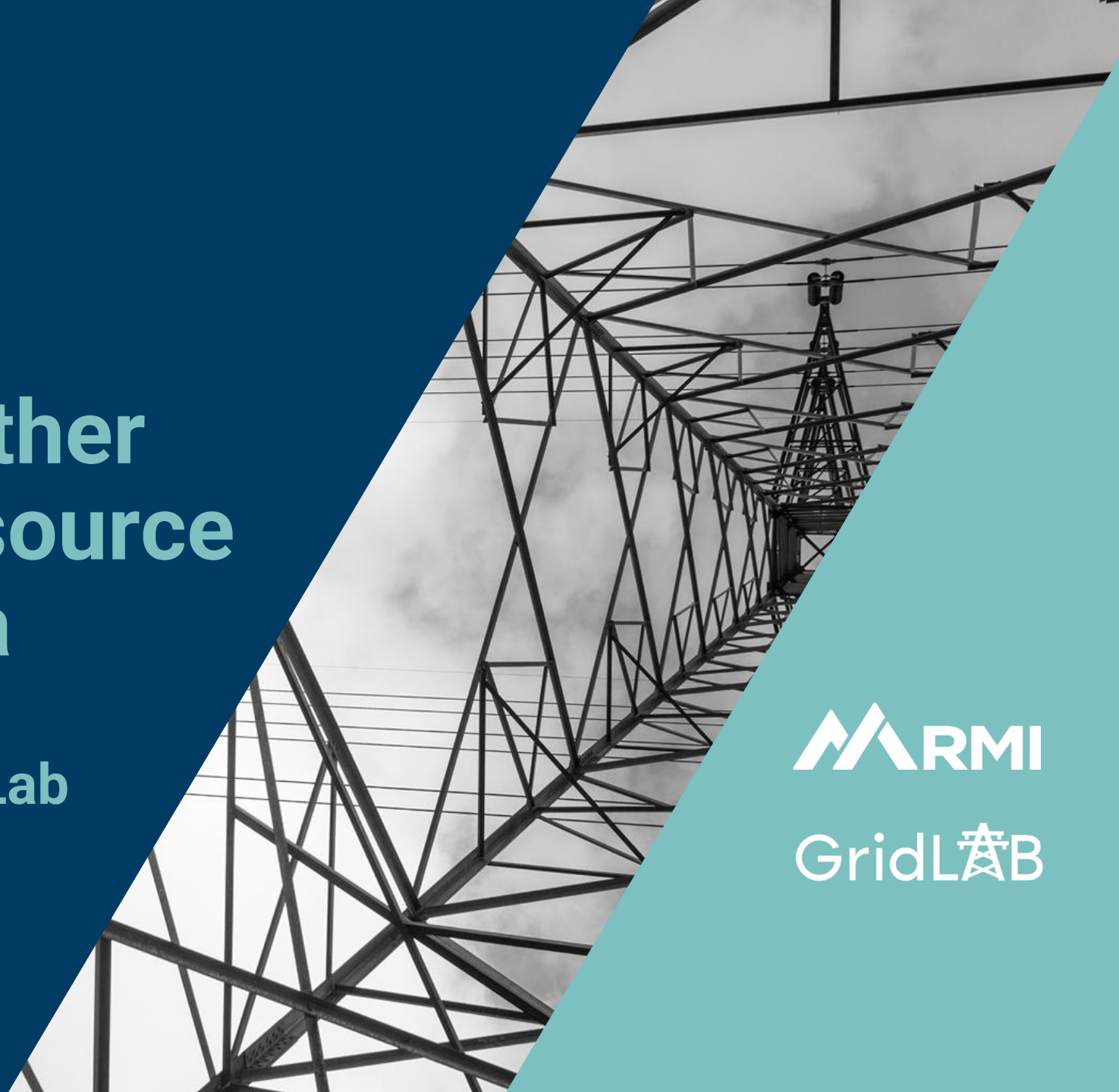

RMI

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Project background: weather-planning links

- Weather is an increasingly important risk factor to understand for power system planning, especially in countries like India
  - 50% and 60% non-fossil capacity targets by 2030 and 2035
  - Growing demand, along with climate vulnerability
- Weather data is nascent, especially granular datasets
- Best practices for understanding weather related risk emphasizes weather-coherence between demand and generation
- State of the art is evolving especially on load forecasting

Lead Organizations

GridLAB

RMI
ENERGY. TRANSFORMED.

Key Partners

TATA POWER

National Laboratory of the Rockies

VAISALA

EPRI

eds environmental design solutions

Project objectives and approach

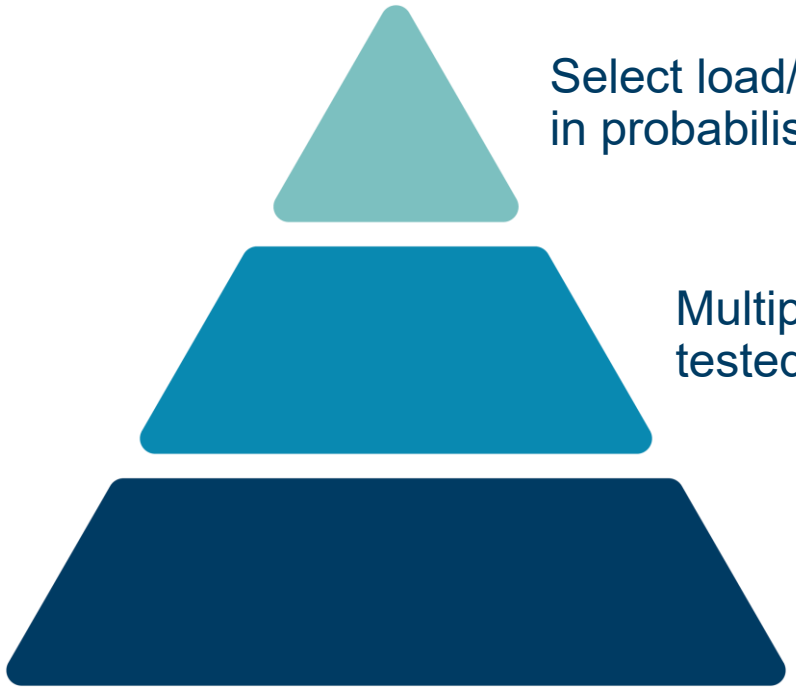
- Identify paths that reliably meet 60%-80% clean power in 2040
  - Assess economic/reliability tradeoffs
  - Develop public weather, renewable and load datasets
  - Account for load, technology cost, and other uncertainties

What demand do we expect in the next 10-20 years?	What resources should we build?	Can the portfolio reliably meet demand across diverse weather conditions?	Can the portfolio reliably meet demand under stress conditions?
Load forecasting	Capacity expansion model	Production cost model	Production cost model
Hybrid top-down and bottom-up approach	Economic optimization of existing fleet and candidate resources	Hourly modeling across multiple weather years	Hourly modeling focused challenging grid stresses (e.g., low hydro)

Probabilistic resource adequacy analysis vs. multi-weather year and stress testing analysis

- Probabilistic RA analysis
  - One portfolio/load future analyzed at a time
  - Deep dive on generator forced outages
- Multi-weather year and stress testing analysis
  - Not a risk analysis
  - Explore more uncertainties with less computation
  - Helps build intuition

Pyramid framework for using these tools in long-term planning



Select load/portfolios tested in probabilistic RA analysis

Multiple load/resource futures tested in “what-if” stress cases

Multiple load/resource futures tested against weather inter-annual variability

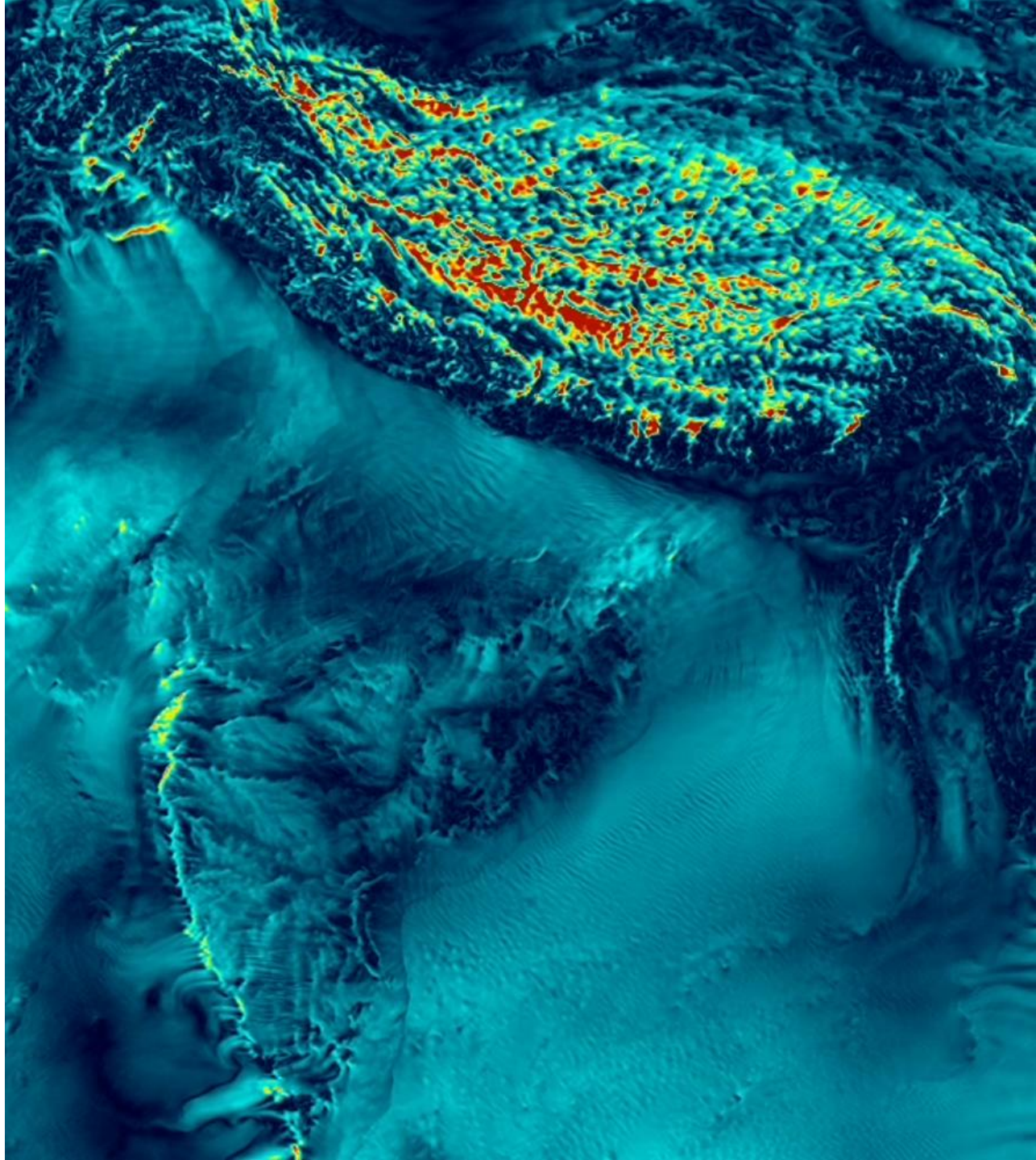
Focus of this study:
bottom and middle of pyramid

Key weather-to-grid elements of the project

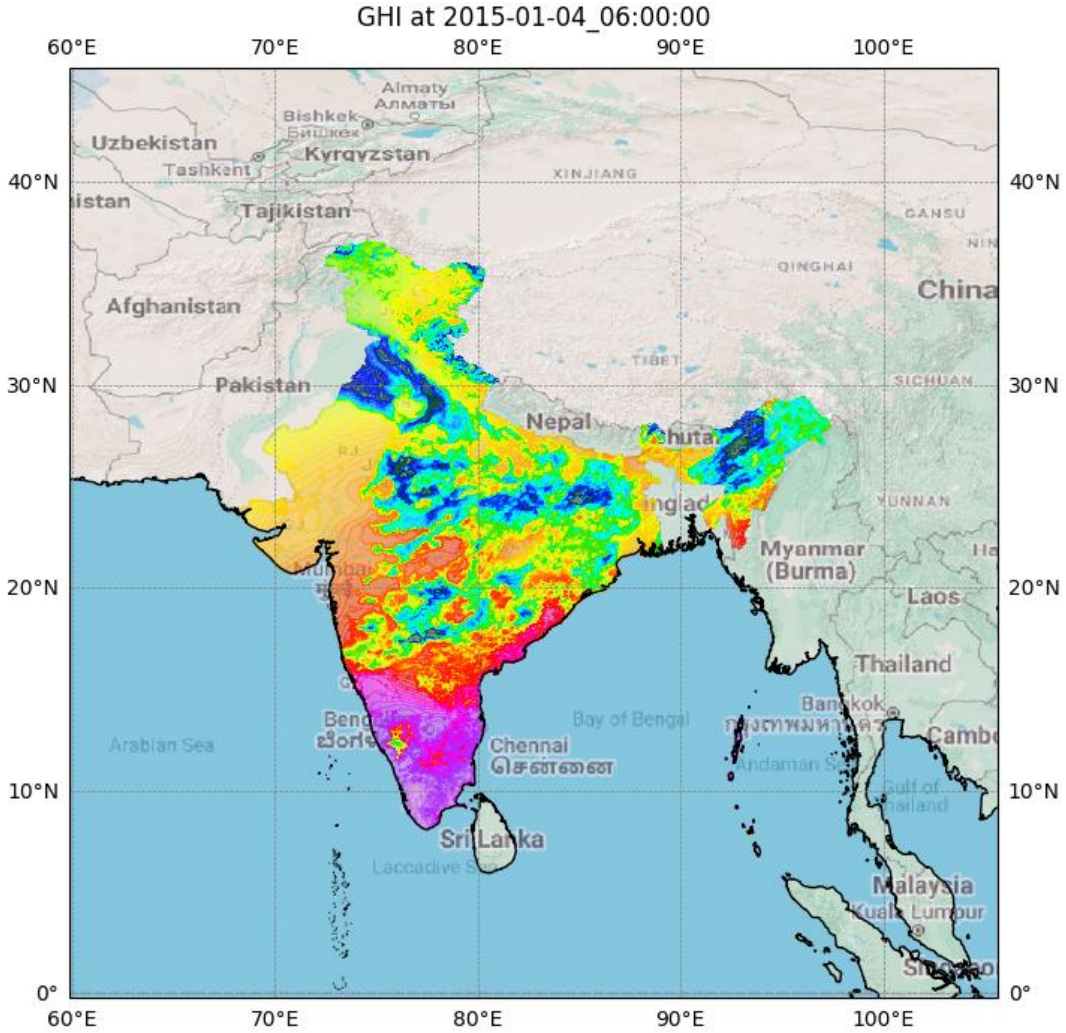
- Raw weather data (5 km) and aggregate RE 8760 shapes for 2015-2024 released publicly *(gridlab.org/india_weatherdata)*
- Weather coherent load forecasts that include disaggregated/bottom-up projections for cooling load and EV load based on charging data
- Multi-year weather analysis in PCM and stress testing to assess weather related risk

Wind datasets developed by Vaisala available for download

- 10 years 15 min data 5 km/5 km grid generated by NWP (WRF model)
- Each simulation was 15 days (seam at 4:30 am)
- Wind speed, temp, other parameters available
- Light validation done



Solar datasets developed by Vaisala available for download

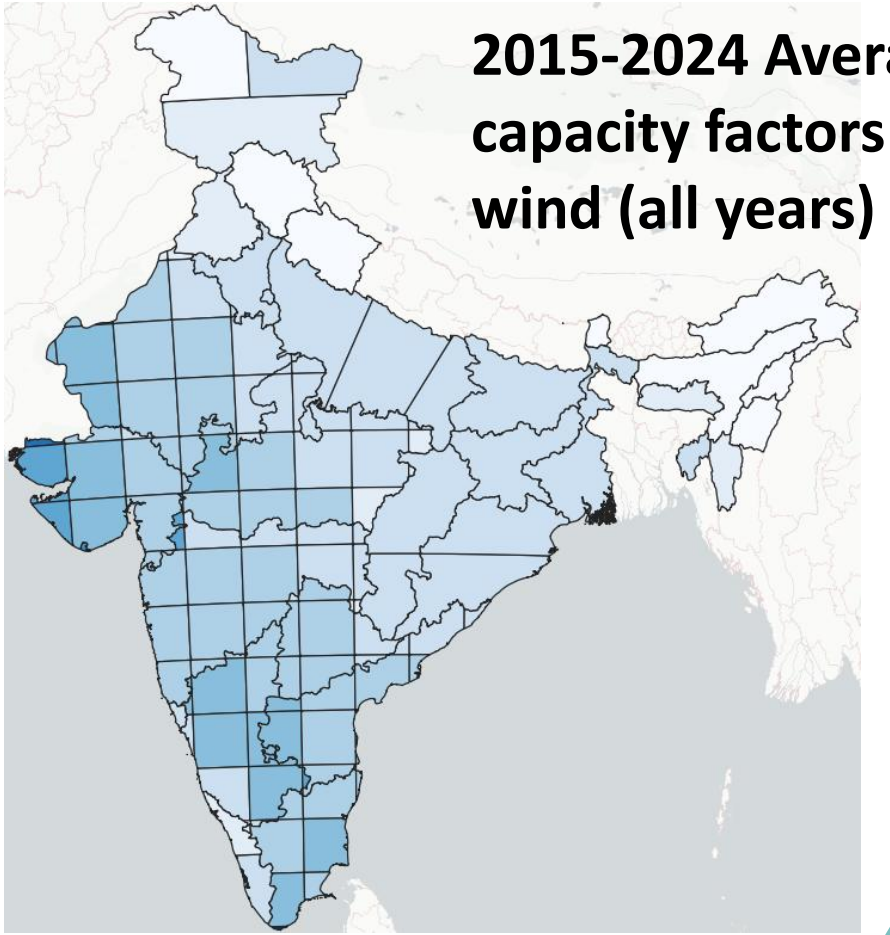


- 10 years 15 min data 5 km/5 km grid
- Solar variables from satellite data with application of Vaisala algorithms: GHI, DNI, DIF etc.
- Other weather variables from ERA5: temp, pressure etc.

Details available on the website (gridlab.org/india_weatherdata)

Overview of processed weather datasets available for download

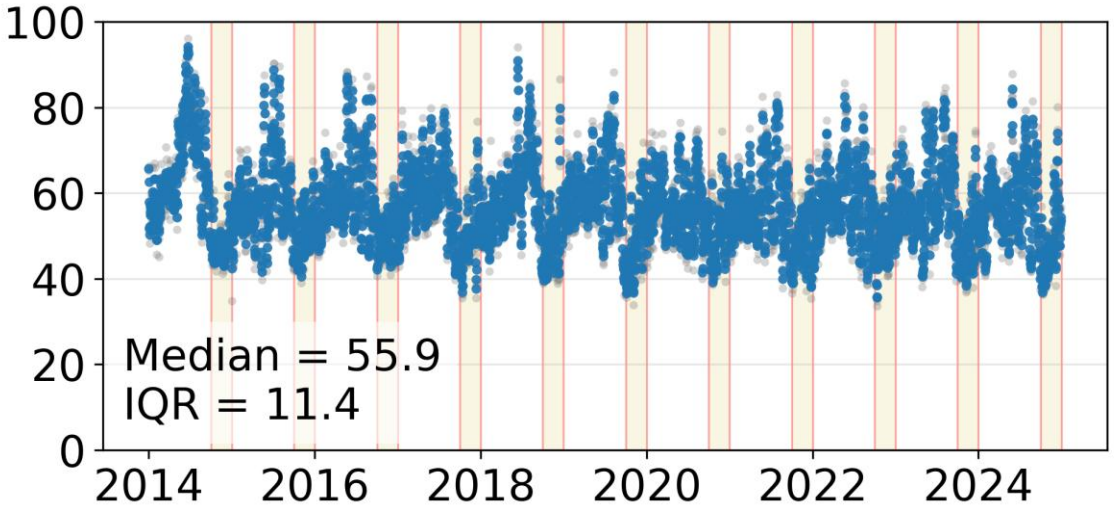
- Weather data converted by NLR to representative hourly renewable profiles for 147 regions in India
  - Utility scale, distributed PV, onshore and offshore wind available
  - Zonal 8760s for each of the 10 weather years available for download
  - 5 km shapes available upon request
  - Validation on select sites underway using PNNL tool “WE-Validate”



2015-2024 Average capacity factors for wind (all years)

Draft results: observing low renewable periods across different weather years

- This figure shows the performance of the “least cost” portfolio (1 of 4 different portfolios developed)
- Portfolios designed with a 60% non-fossil by 2040 input
- The figure shows both daily % VRE (grey dots) and the 3-day rolling average for each weather year from 2014-2024



"daily" % VRE

3-day rolling average of % VRE

Oct-Dec which appear to be the lowest VRE periods for each weather year

Load forecasting overall methodology for developing weather-coherent profiles

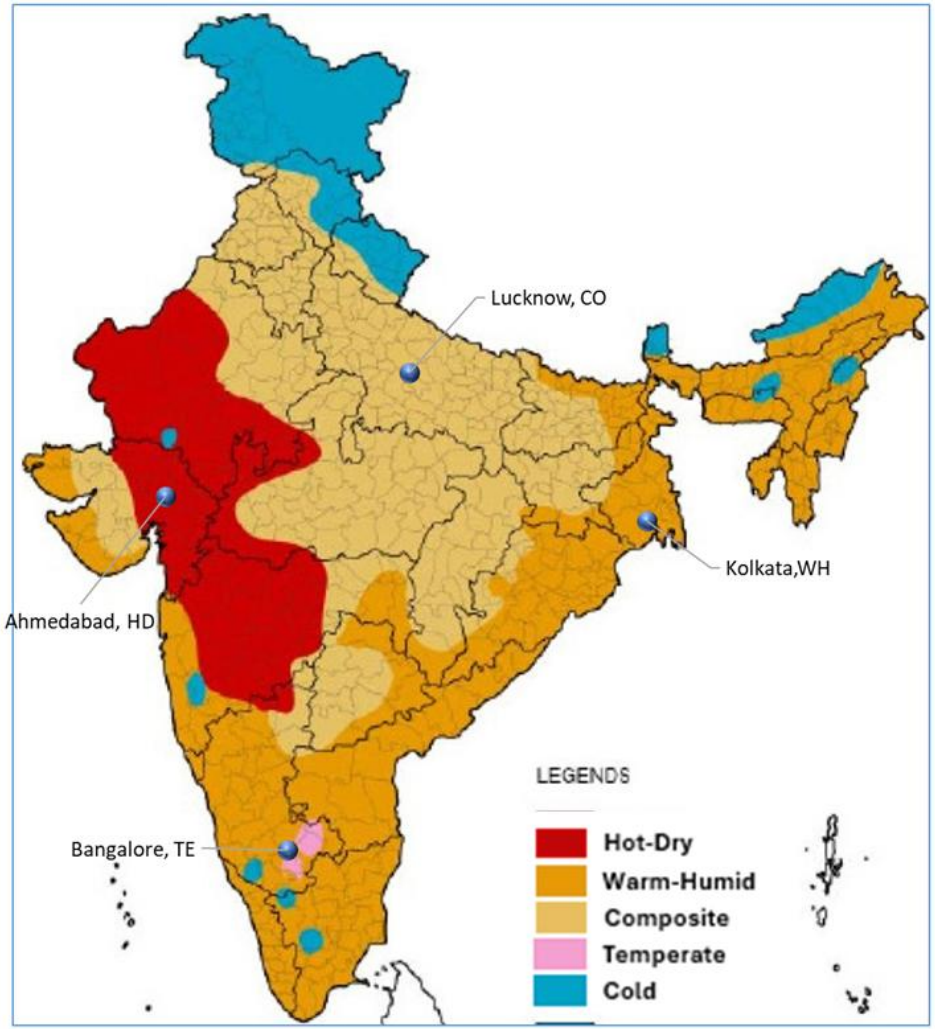
	Baseload forecast using historical energy consumption			Emerging Loads (EV and cooling loads shown)			
Data Inputs	GDP data	Weather	Historic load	National projections	State Allocation	Building characteristics, occupancy and weather (fed to a building energy simulation tool)	Building Stock Projections
				Charging Profiles	EV Adoption		
Method	Regression approach based on historical data generated for each weather year			Bottom-up modeling for EVs and cooling energy consumption which are added to the baseload forecast (with reconciliation)			
Output	**Hourly state-wise load projections from 2025-2040** for multiple weather years (2014-2024) with bottom-up scenarios to account for emerging technology, and agricultural load shifting; double counting avoided.						

Integrating Top-Down and Bottom-Up Approaches

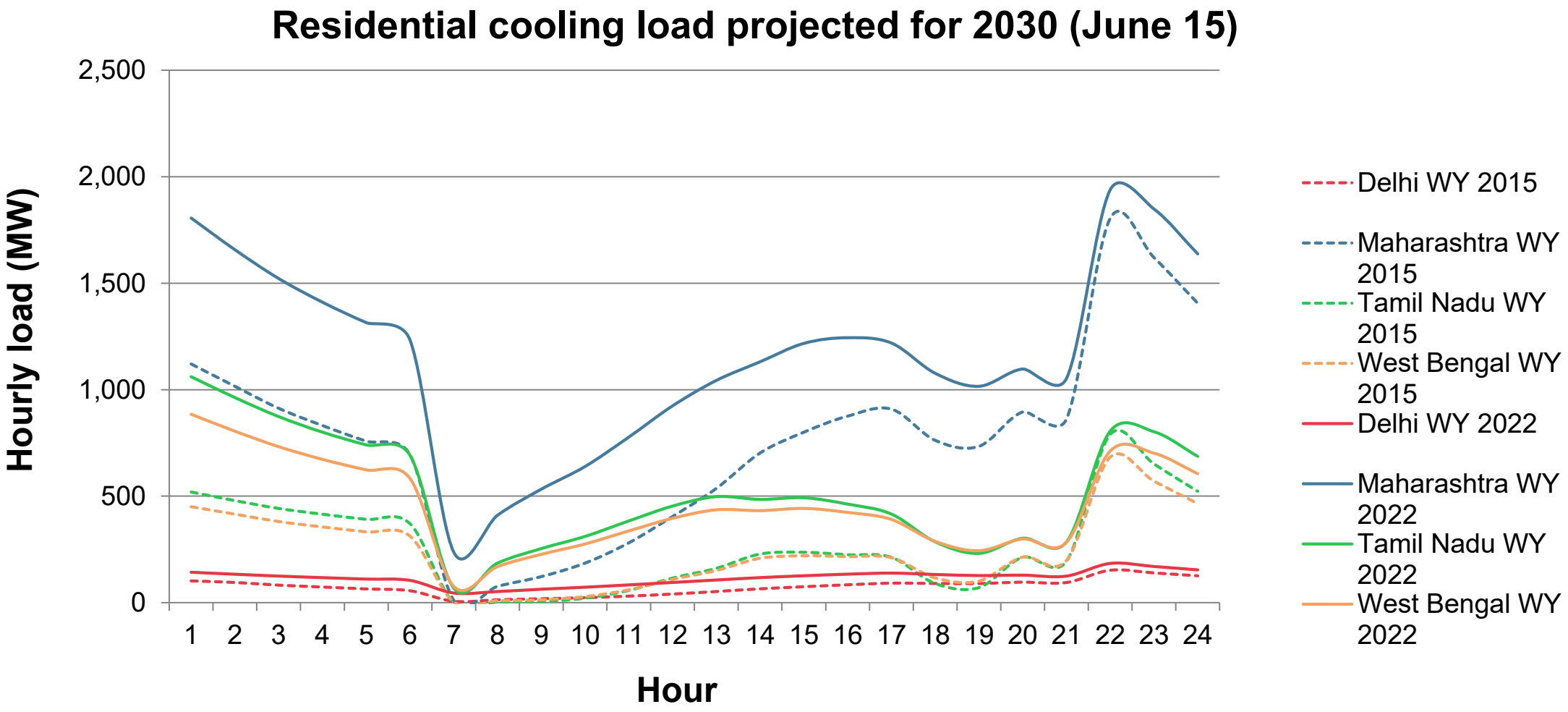
Baseload model adapted from Dharik Mallapragada et al. “Scenarios of future Indian electricity demand accounting for space cooling and electric vehicle adoption”

Bottom-up approach for cooling load

- Representative buildings' hourly load estimated by EDS using a building energy simulation model (EnergyPlus)
  - Shapes for all weather years and different climate zones developed
  - Weather inputs are from ERA5-land and satellite data
  - 3 scenarios developed for different levels of energy efficiency
- Normalized shapes applied to building stock to develop aggregate state level cooling load



Draft bottom-up cooling load results: climatic variation for residential buildings



Insights on weather-planning links

- Assessing multiple weather years can identify how consistent VRE trends are such as low-RE generation or curtailment risk
- Understanding interannual weather variability can help planners assess tradeoffs between generation resource types
- 10 years of granular data provided here are a contribution but augmentation will be important for the future
- Though not ideal, it's difficult to avoid having to combine different sources of weather data
  - Satellite better for solar, downscaled NWP better for wind
  - Building simulation modeling required combining ERA5 land and satellite data into a single model

Thank you!

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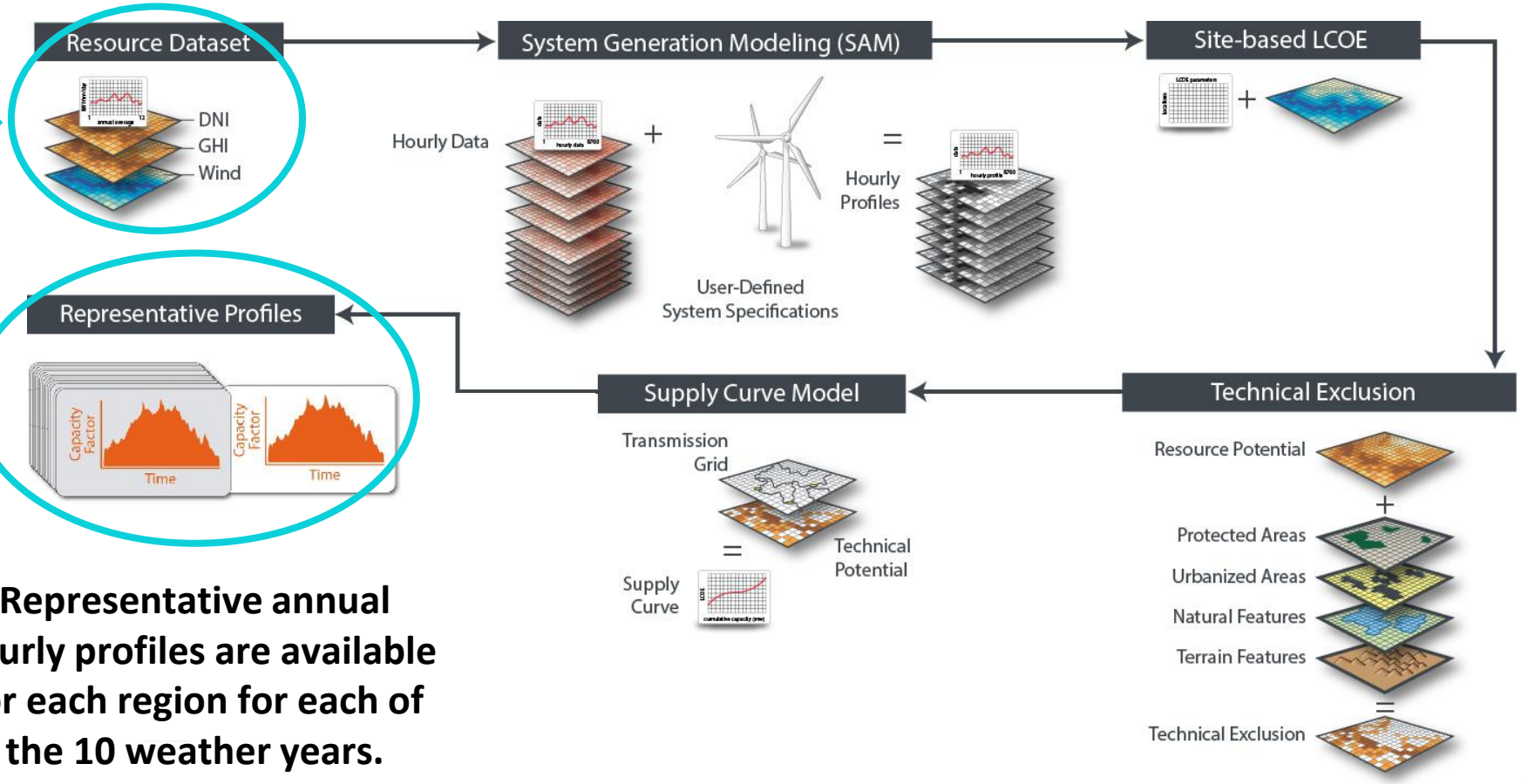
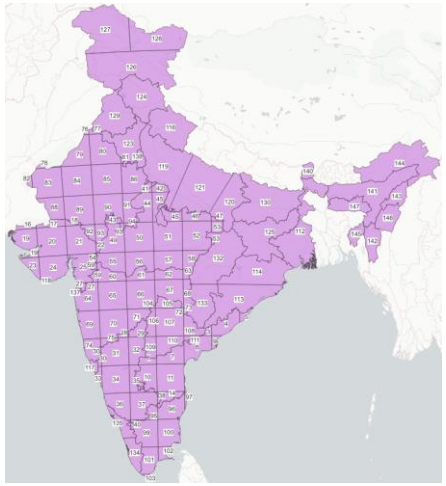
Appendix slides

Renewable Energy Potential (reV) Model Workflow

Data from Vaisala





147 Resource Regions for India

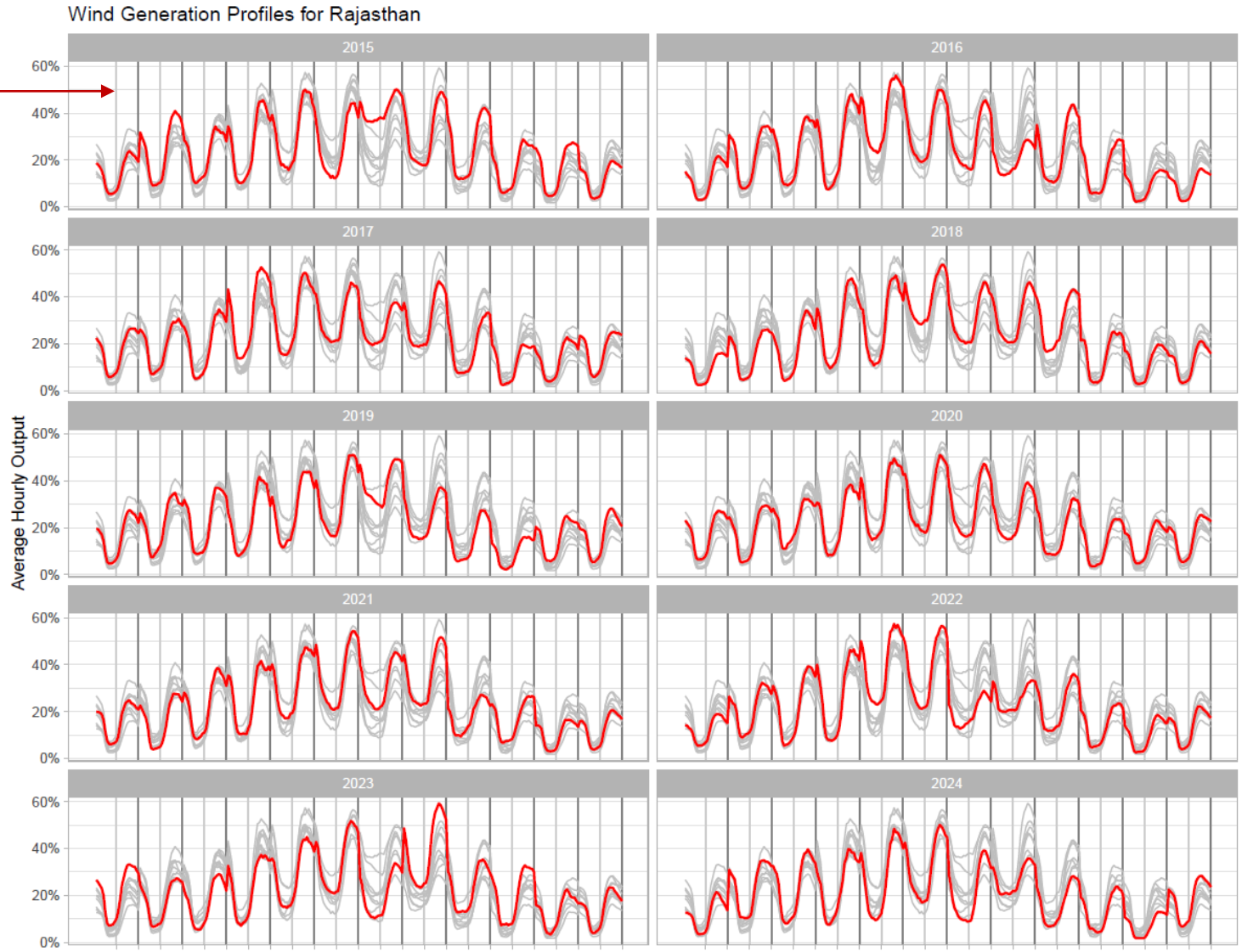
Representative annual hourly profiles are available for each region for each of the 10 weather years.

Source: Maclaurin et al. (2021)

Data that can be shared

Example: Wind Generation Profiles for Rajasthan

Grey lines represent all years (2015-2024), and red line represents the particular year.



x-axis represents hour-of-day averages for each month

Draft results: comparing low renewable periods across portfolios and weather years

- Comparing portfolios for multiple weather years helps identify tradeoffs in terms of which portfolios are more robust to weather dependent variability