नीति आयोग
National Institution for Transforming India

First meeting of the Technical Committee

CEA, Sewa Bhavan
23/02/2017

Confederation of Indian Industry

1 Scale of Renewable Energy in different states and achievements

"175 GW capacity and over 15% share of grid power through renewables by 2022 and 40% by 2030"

RE Source	2022 Target	Achieved 31.12.16*
Solar	100	9.03
Wind	60	28.7
Biomass	10	7.9
SHP	5	4.4
Total	**175**	**50.02**

- India **crossed 1/4th of the 2022 capacity targets**
- **~75% of the capacity** to be added in **8 RE Rich States**
- **Differing set of issues** for RE rich and poor states
- **Multitude of efforts** underway at various levels

State	RE Target	Share	Achieved	% of target	In Pipeline
Andhra Pradesh	17,934	**10%**	3,572	20%	1,004
Gujarat	17,133	**10%**	5,230	31%	250
Karnataka	11,997	**7%**	5,715	48%	7,600
Madhya Pradesh	14,394	**8%**	3,221	22%	800
Maharashtra	19,526	**11%**	6,613	34%	500
Rajasthan	17,886	**10%**	5,396	30%	1,168
Tamil Nadu	20,784	**12%**	9,449	45%	485
Telangana*	9,377	**5%**	1,029	11%	2,600
Punjab	4,772	**3%**	1,200	25%	400
Assam	663	**0%**	34	5%	170
Other States	44,525	**26%**			
Total	**1,74,534**				

Expected outcomes from this exercise

Objective

To provide a platform to promote coordination among various states and central actors to achieve the national renewable energy and climate change targets

1

Advisory Board

- Vice Chairman, NITI
- Minister, Energy
- Ministers of Energy of different states

2

Steering Committee

- CEO, NITI Aayog
- Secretary, MoP
- Secretary, MNRE
- Principal Secretaries of Energy of different states

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CII

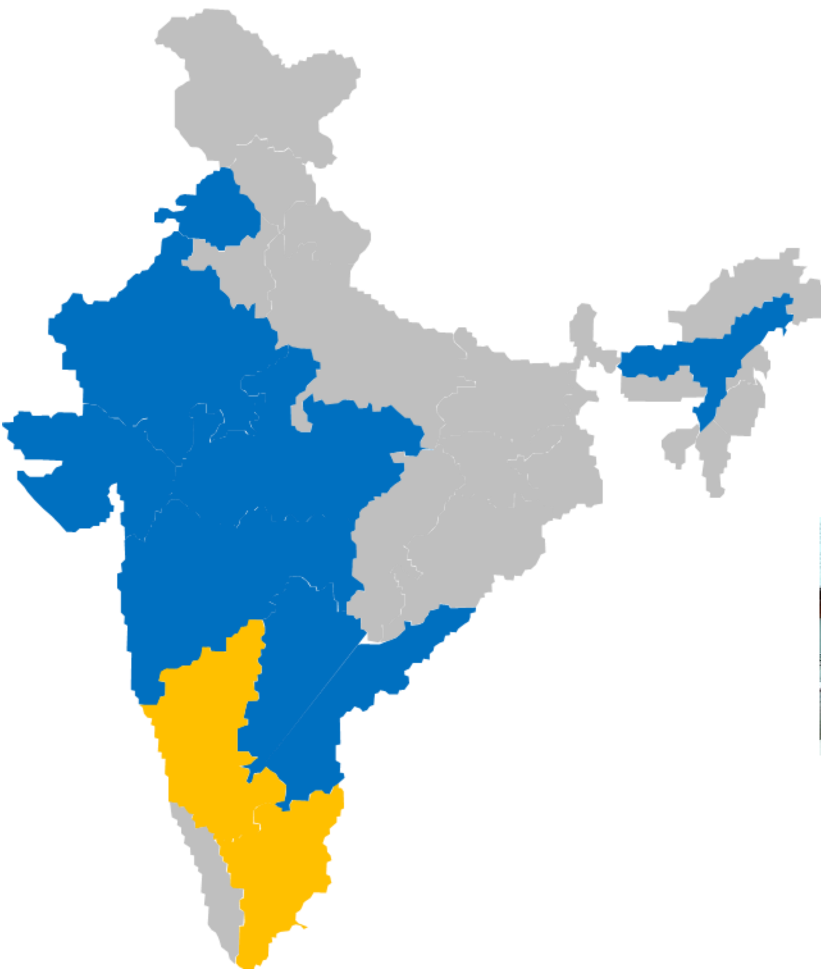
Objective

To provide a platform to promote coordination among various states and central actors to achieve the national renewable energy and climate change targets

Expected Outcomes

	A	B
Expected Outcomes	**A** State RE Roadmap 2022 & Mission 2030	**B** Increased Coordination among stakeholders
Activities	Setting up **State RE Working Groups** and organizing **State consultations**	Provision of a **common platform** for States and National agencies to engage
	Developing **State Action Plan** for achieving 2022 RE targets	Forum to address **market and infrastructural issues** arising for RE
	Preparation of a longer term **State RE mission till 2030** with NDC focus	**Knowledge sharing** of various kinds of efforts underway and being planned

State RE Roadmap – Progress Report



● Work initiated ● Yet to initiate

State	Constitution of SWG	State level meeting
Rajasthan	✔	✔
Tamil Nadu	✘	✘
Karnataka	✔	✘
Gujarat	✔	✔
Assam	✔	✔
Maharashtra	✔	✔
Andhra. P	✔	✔
Telangana	✔	✔
Madhya. P	✔	✔
Punjab	✔	✔

5 Common issues cited by the states

Marketplace for RE Power

- *RPO targets in achievable range for many states*
- *Need to start balancing RPO obligations/ Country objectives – RE Certs or physical sale*

Balancing

- *ISTS network, Improved and more real-time forecasting*
- *Request for setting up of REMCs in every state – increased coordination between Central and State Govt agencies to set these up*

Infrastructure

- *Pace of ISTS network and Green Energy Corridor Phase I rollout to be enhanced – plans for GECII to be defined*

Finance

- *Financial support to DISCOMs for handling more RE power*
- *Allocation of NCEF to states for promotion of renewable energy*
- *Liberal Goods and Service Tax regime for NRSE*

Tapering Demand and available conventional capacity


Thank you

Technology and Policy Leapfrogs in India's Energy Sector

Dr. Amol Phadke
Dr. Nikit Abhyankar

International Energy Studies Group
Lawrence Berkeley National Laboratory

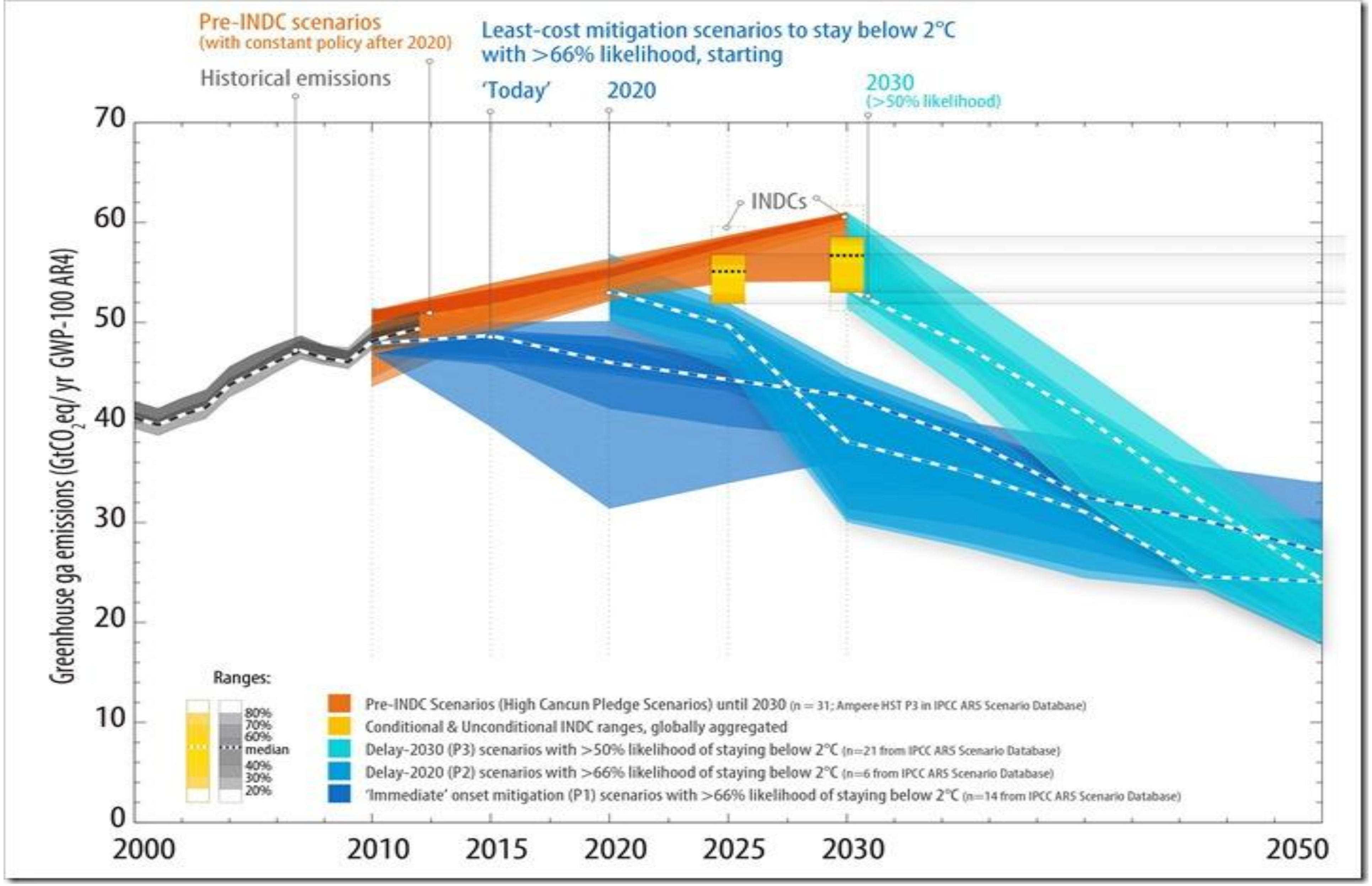
Introduction to Lawrence Berkeley National Laboratory

Managed by the University of California for the United States Department of Energy

Lawrence Berkeley National Laboratory

13 — Nobel Prizes
13 — National Medal of Science recipients
4,200 — Employees
200 — Site acreage

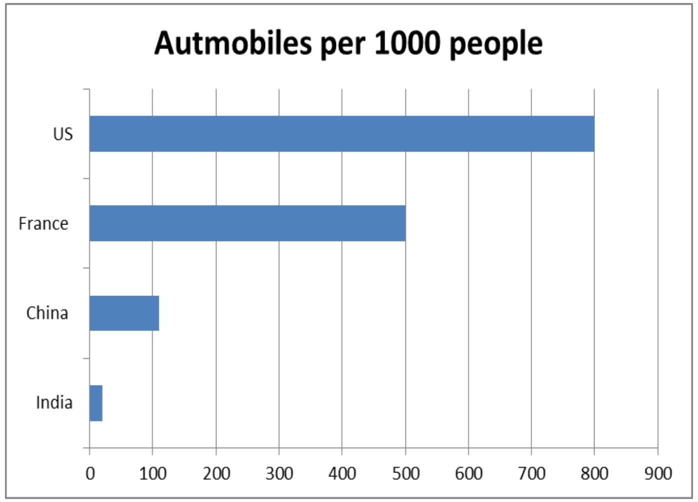
- **Dedicated to solving the most pressing scientific problems facing humankind**
  - Basic science for a secure energy future
  - Science of living systems to improve the environment and energy supply
  - Understanding and control of matter and energy in the universe
  - Translation to applied energy programs
- **Build and safely operate world-class scientific facilities**
- **Train the next generation of scientists and engineers**

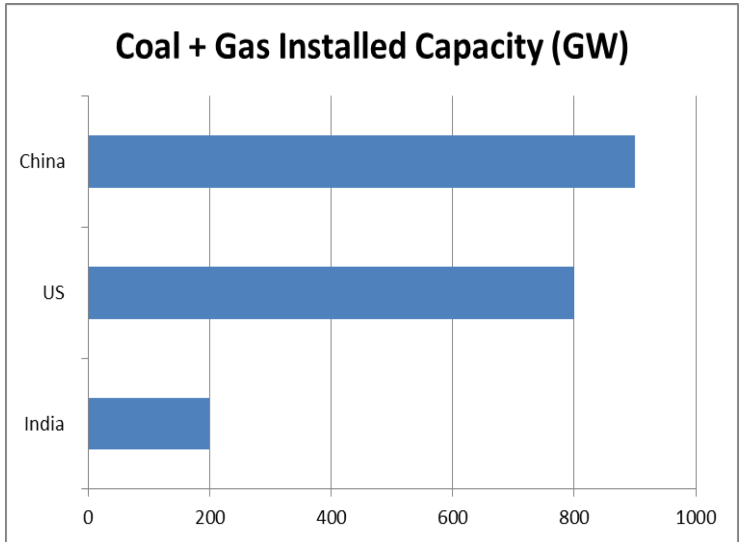


India without coal and oil will address air quality, import dependence, and the need for deep GHG emission cuts

Why India can leapfrog to a clean energy future?

Most is yet to be built: India lags ~$ 1-2 trillion in fossil assets; clean energy increasingly competitive





Cool Roofs (or White roofs) can lower the buildings cooling energy consumption by ~20%

How rooftops of the two cities differ ?

Delhi

Jaisalmer

Electricity access beyond lighting

Less than 20W smart and efficient home system that includes: 2 lights, 23-inch TV, table fan, radio/clock, mobile charger

Entire system can be powered using a 40W solar panel (see picture) and a 30Ah battery

Leapfrog to Renewable, Electrified Transportation

Exploding Personal Vehicle Ownership

Air Pollution

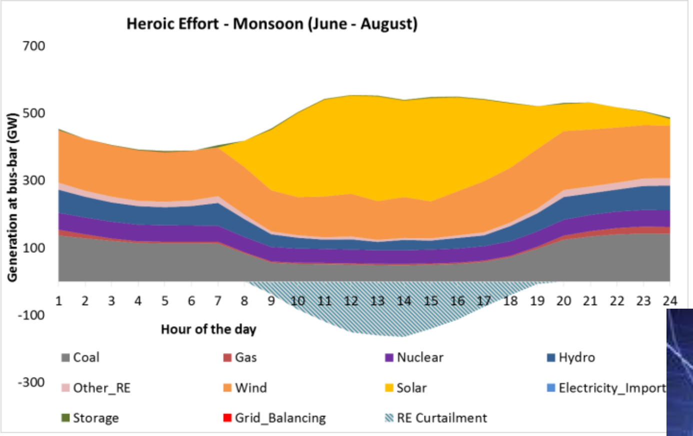
Oil Imports

- Electric cars have much higher benefits in India
- Public procurement can accelerate the initial market adoption

Thank you !

Amol Phadke
Nikit Abhyankar
Anand Gopal
Ranjit Deshmukh
Nihar Shah

India Raising Ambition: How a Future Without Coal and Oil can be Achieved in India



RE based Power

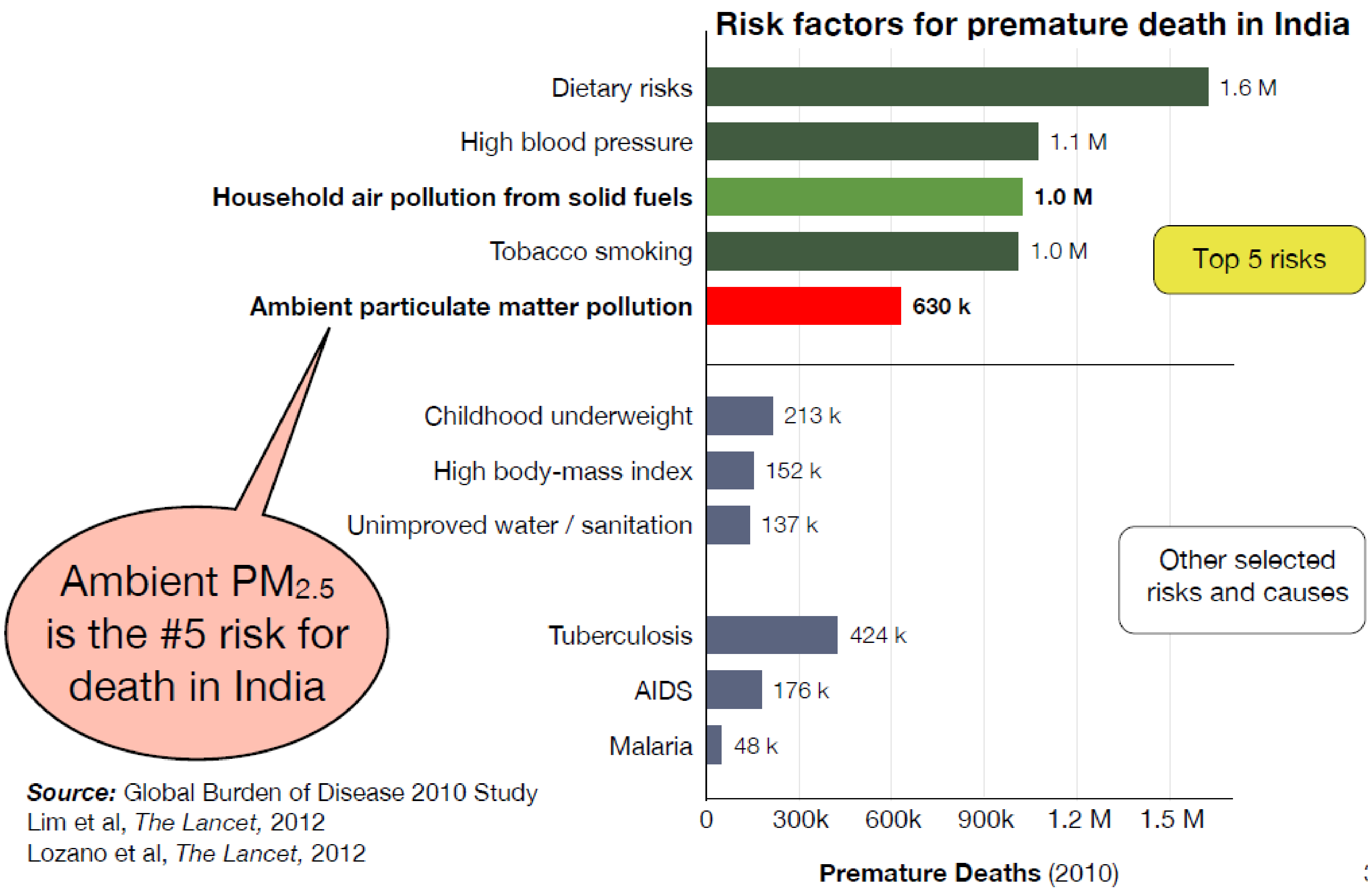
Electrified transport

Integrated markets

Smart and innovative storage

Smart and super efficient demand

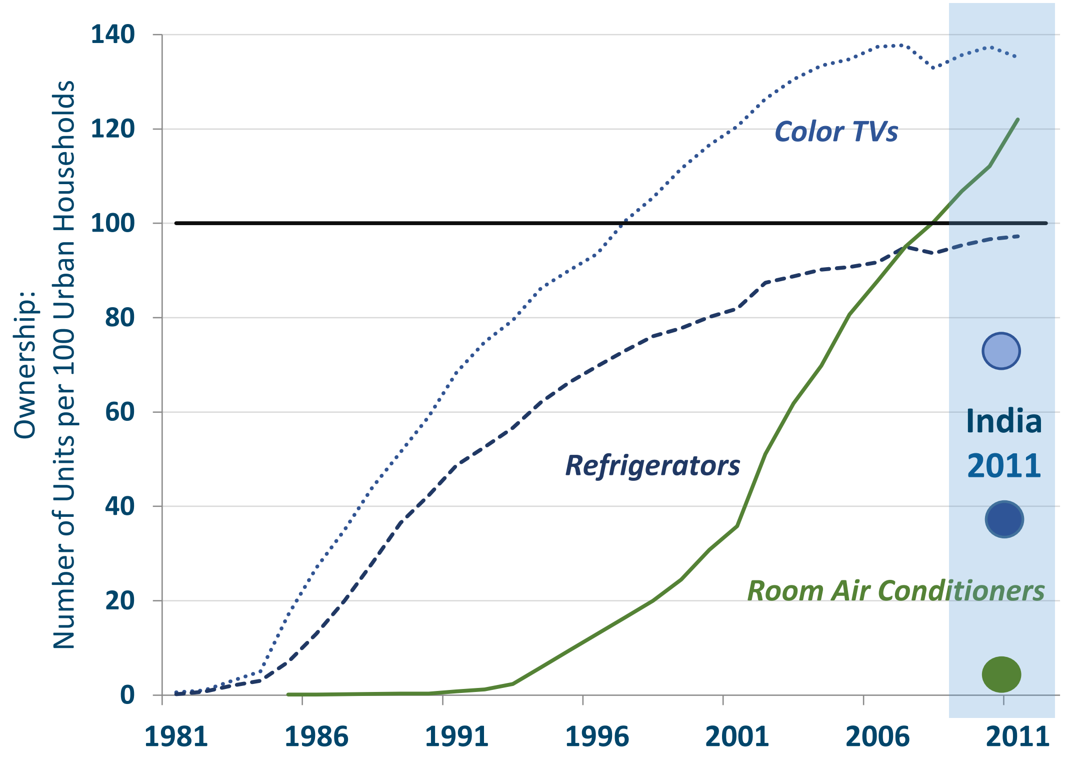
Comprehensive Strategies for Clean Air



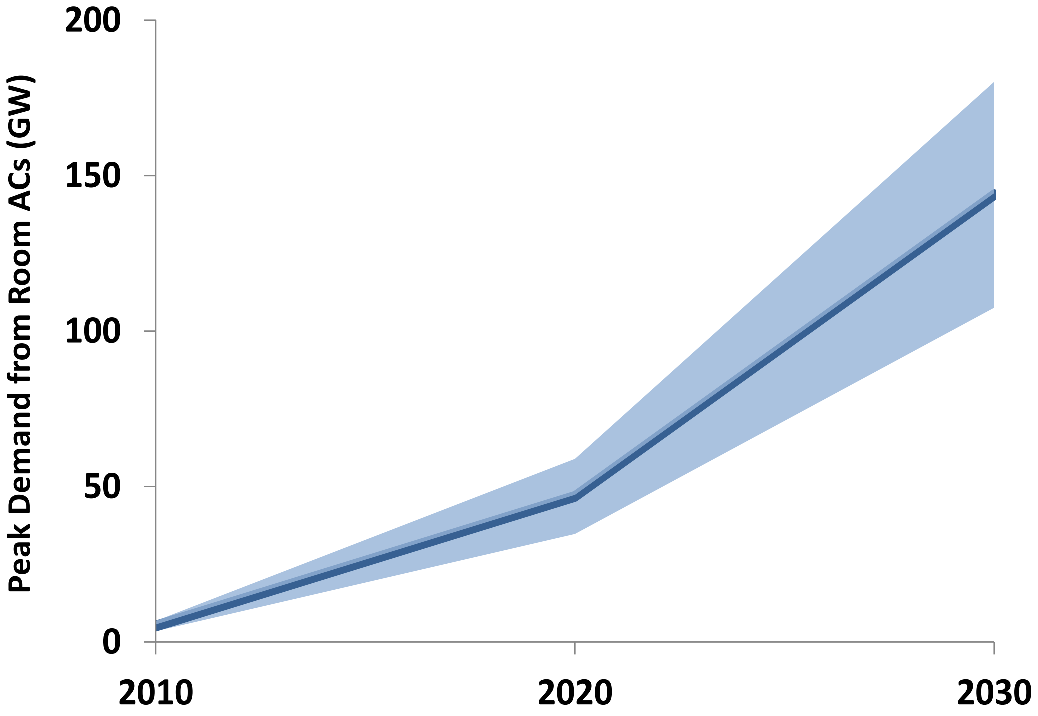
Source: Global Burden of Disease 2010 Study
Lim et al, *The Lancet*, 2012
Lozano et al, *The Lancet*, 2012

Managing the Air Conditioning Demand: Crucial for Power Sector

Growth in China's AC Market



AC Peak Demand Projections for India



RE Procurement and Grid Integration: Assessing the least cost strategy

- India is planning to make ~$1 Trillion investments in the power sector over next 20 years

- Substantial potential exists in RE procurement (especially wind) cost reduction
  - E.g. solar costs dropped over 80% over the last 10 years; wind costs virtually unchanged for the last 10-15 years

- Significant opportunity to identify the leapfrogging least cost integration strategies
  - For example, what kind of investments are needed to balance RE – can fast-ramp coal plants be useful or investments in gas are essential ? What is the role of Demand Response / EVs?
  - Ultra-Mega Power Plant for RE?

➔ Identify and support smart investments

GREENING THE GRID

RE Grid Integration Study

Jaquelin Cochran, Ph.D.
National Renewable Energy Laboratory
CEA, 23 February 2017

Sponsors and official GOI lead

GOVERNMENT OF INDIA
MINISTRY OF POWER

USAID
FROM THE AMERICAN PEOPLE

21st Century
POWER PARTNERSHIP
Accelerating the transformation of power systems

WORLD BANK GROUP

ESMAP
Energy Sector Management Assistance Program

Grid Integration Studies: Our Purpose

- If India develops <u>100</u> GW of solar and <u>60</u> GW of wind energy, how would the system operate in 2022?
- What can policy makers do to lower the cost of <u>operating</u> this system?
  - Note: Fixed costs considered as sunk cost

Modeling team

Members of the core modeling team from:

NLDC
- S.R. Narasimhan
- N. Nallarasan
- Mohit Joshi
- Phani Bala Krishna
- L N Barnwal

SRLDC
- S.P. Kumar
- Madhukar Goodelli
- L. Sharath Chand
- Sanyasi Naidu

WRLDC
- Raj Kumar Anumasula
- Mahendranath Malla
- Chitrankshi

Other RLDCs
- Riza Naqvi
- Shyam Sunder Goyal
- Manoj Thakur
- Biswajit Mondal
- Arun Bharti
- Pritom Nath

Maharashtra
- M.D. Imran Khan
- Amit U. Vala
- M.A.Q Siddiqui

GETCO
- G.J. Mistry
- D.H. Kalsaria

Tamil Nadu
- P. Rajagunanidhi
- P. Murugavelan

Karnataka
- Vani, Swathi
- Madhu, Mohan

AP
- P. V. Satya Ramesh

CEA
- Pardeep Jindal
- Shivani Sharma

PGCIL
- Kashish Bhambhani
- Chinmay Sharma
- Ajay Dahiya

NREL
- David Palchak
- Ali Ehlen
- Brendan McBennett

LBNL
- Ranjit Deshmukh
- Nikit Abhyankar

Stakeholder Participation

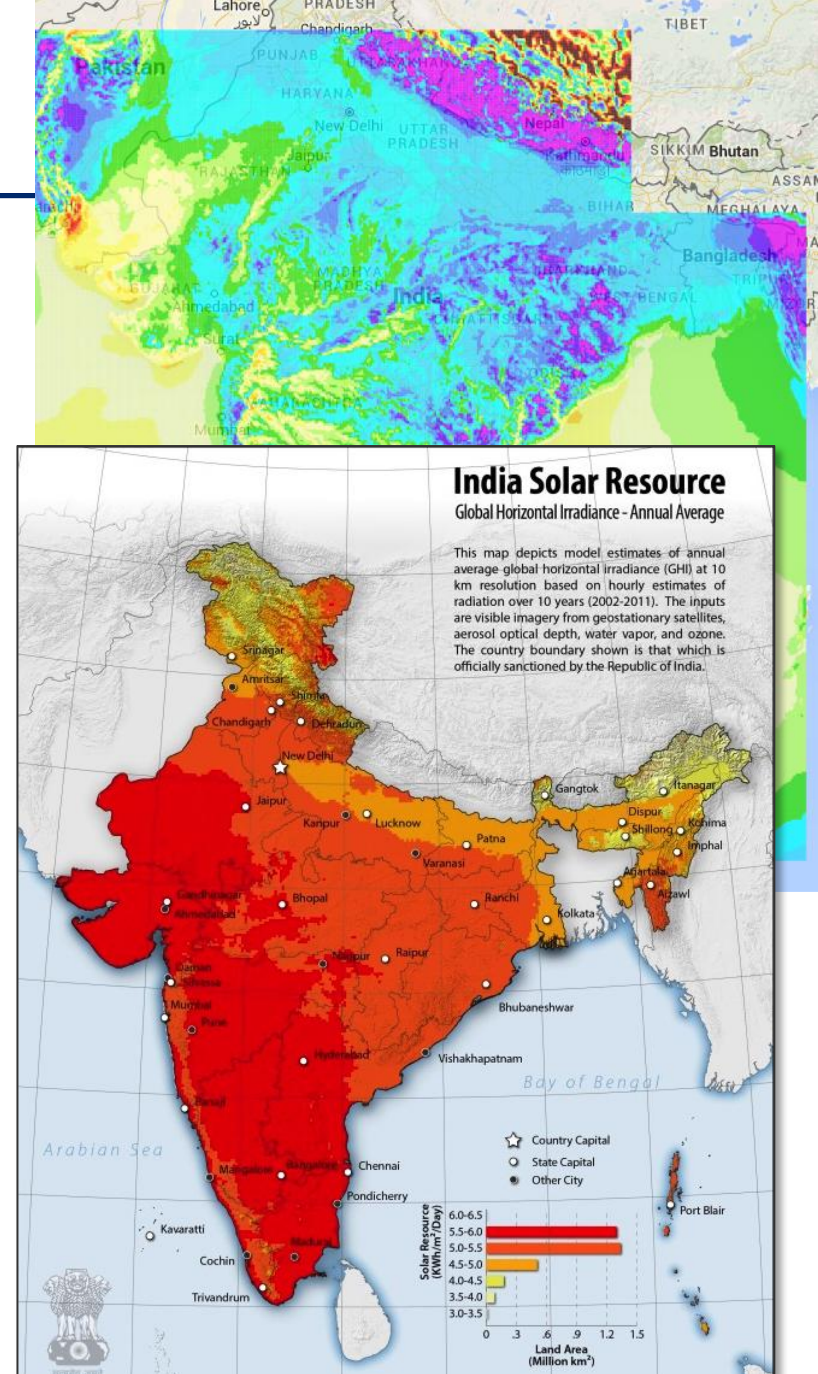
- Grid Integration Review Committee
  - Peer Review and Guidance
  - Over 150 Experts
  - Three sets of meetings

	National (New Delhi)	Southern (Bengaluru)	Western (Mumbai)
1st GIRC	13/10/15	15/10/15	19/10/15
2nd GIRC	19/4/16	21/4/16	22/4/16
3rd GIRC	18/7/16	20/7/16	22/7/16
4th GIRC	17/2/17	20/2/17	22/2/17

More than 2000 person hours

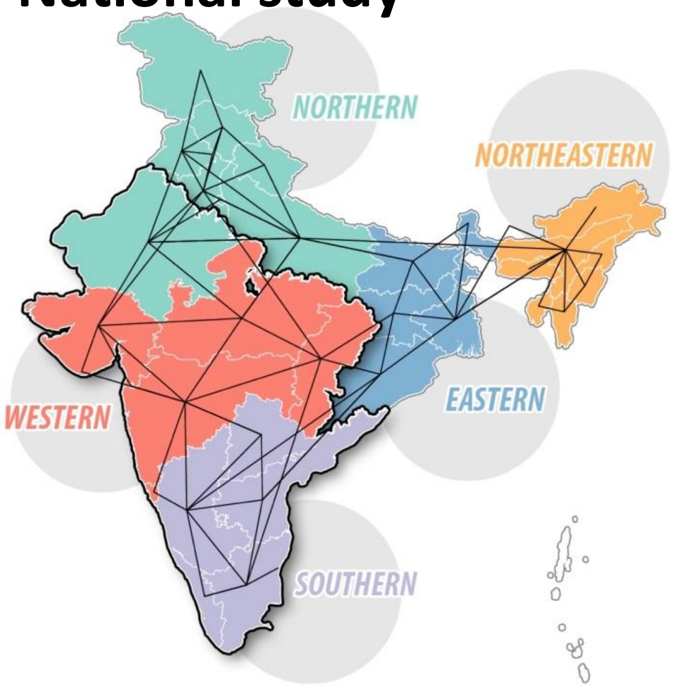
Modeling features

- High-resolution wind and solar resource data (both forecasts and actuals)
  - Wind: 5-minute weather profiles for each 3 x 3 km^2 area
  - Solar: 1-hour weather profiles for each 10 x 10 km^2 area, including impact of aerosols
- Unique properties for each generator
- CEA/CTU projections of properties and locations of new lines and power plants for 2022
- Enforced state-to-state transmission flows
- Interregional transmission limits that adhere to reliability standards



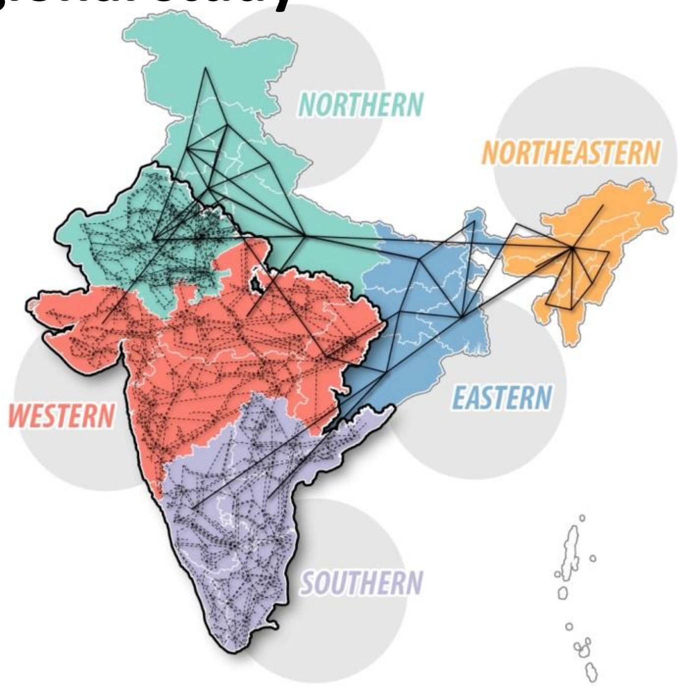
Transmission representation in the model

National study



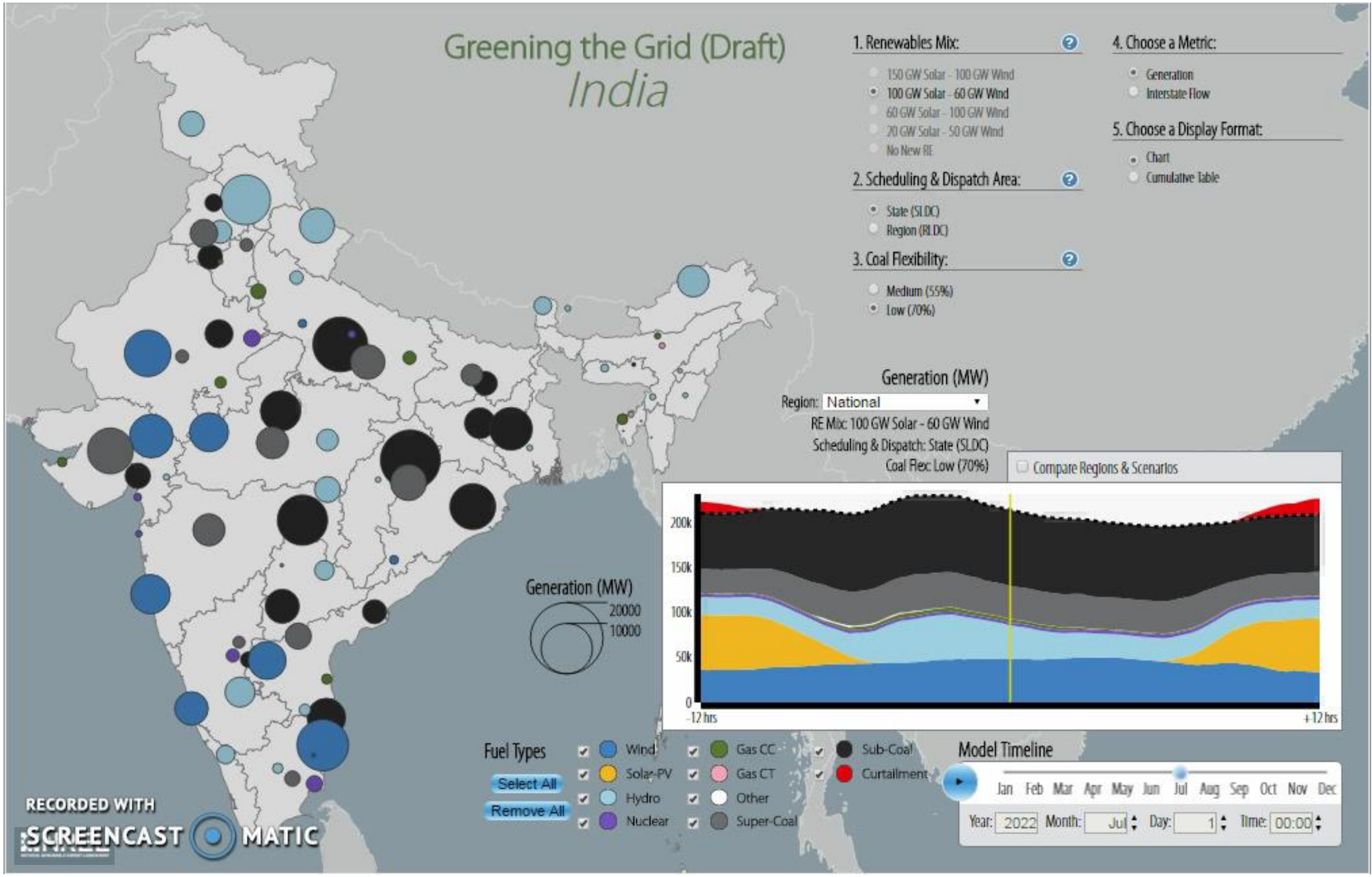
- All generation and transmission located on a single node per state plus union territories (36 nodes total)
- No enforced intrastate transmission constraints

Regional study

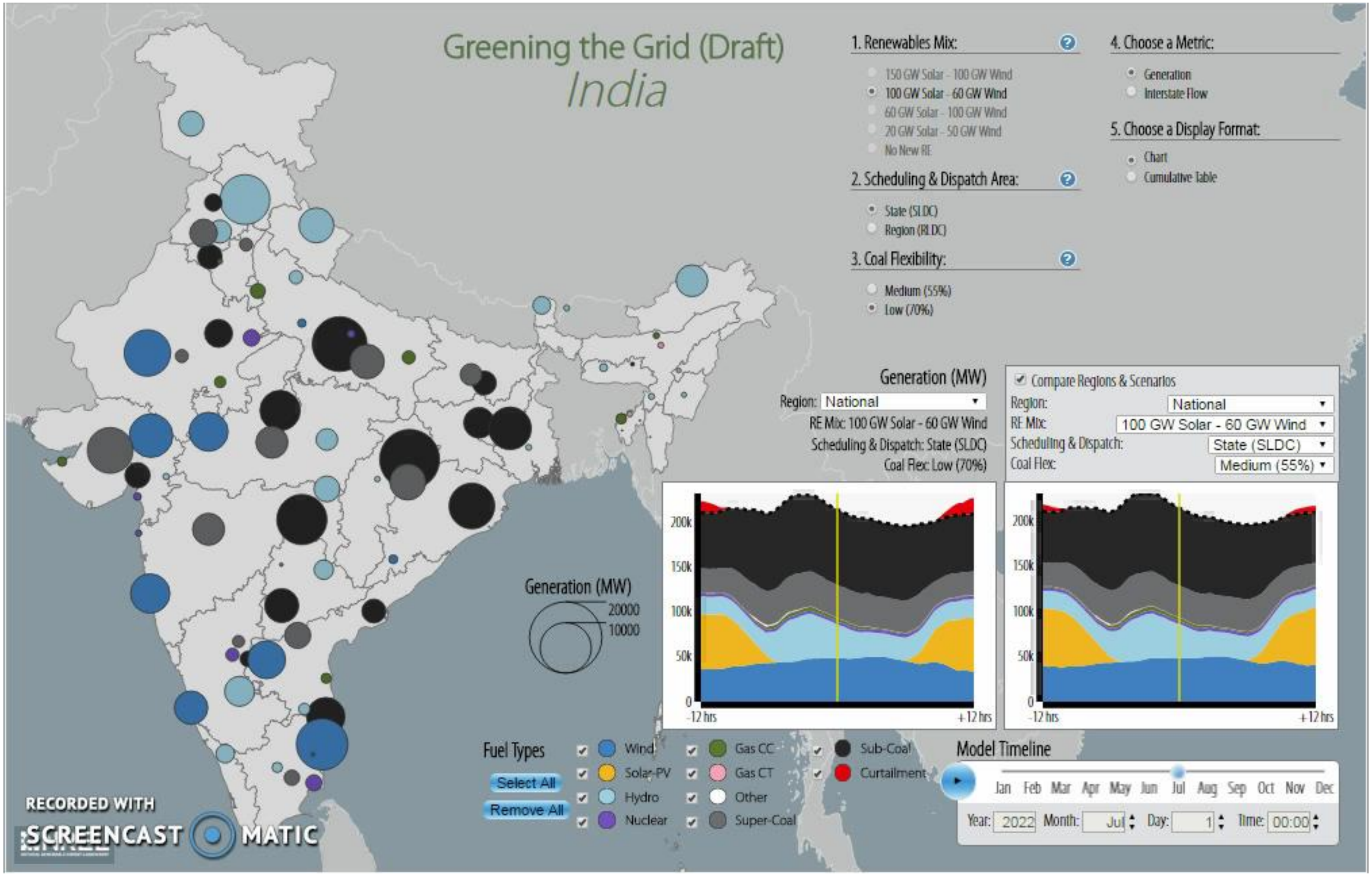


- Full, planned transmission system in Southern and Western Regions plus Rajasthan (3,280 nodes)
- Loading limits enforced on all relevant intrastate lines; congestion limits enforced on all high-volume intrastate lines (>400 kV)

Curtailment increases during monsoon

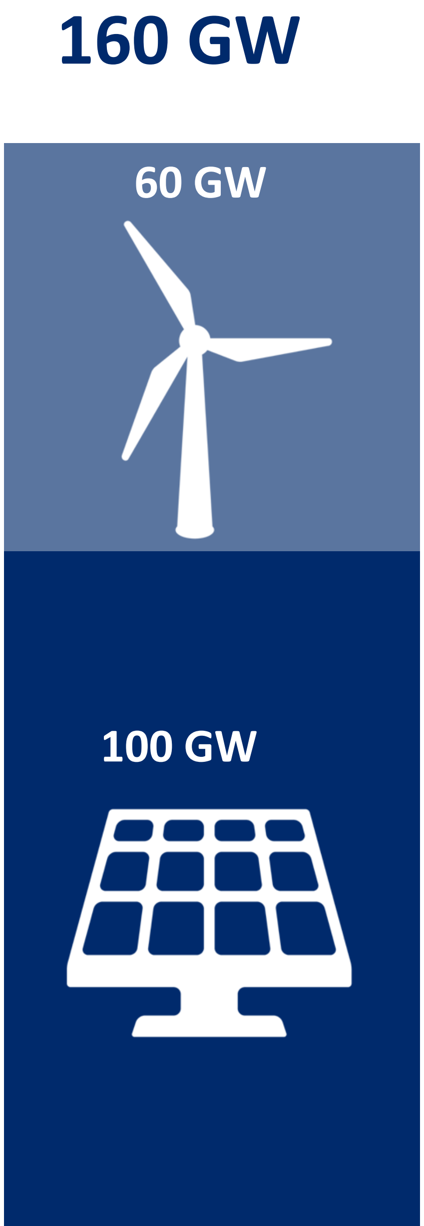


We compare operations under different scenarios of coal flexibility



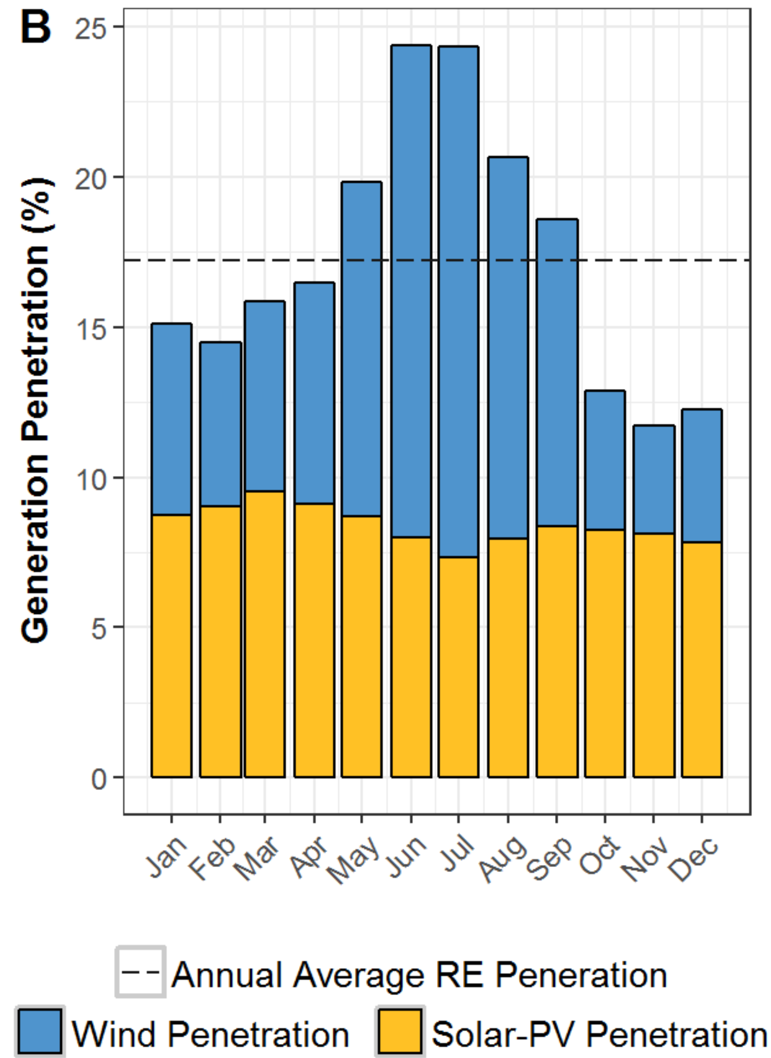
Key Finding #1: 160 GW wind & solar can be integrated to the grid with continued efforts to improve access to existing system flexibility

- Based on GOI's projected power system plans and regulations, and with optimal siting of RE with regards to intrastate transmission…
    - ➢ The 2022 power system with 100 GW solar and 60 GW wind <u>can balance</u> every 15 minutes of the year with minimal RE curtailment
    - ➢ The system can handle forecast errors, net load changes, and exchanges of energy between regions
    - ➢ Physically, the system has the flexibility to manage; the challenge going forward is accessing this flexibility through appropriate regulations, operational rules, etc.

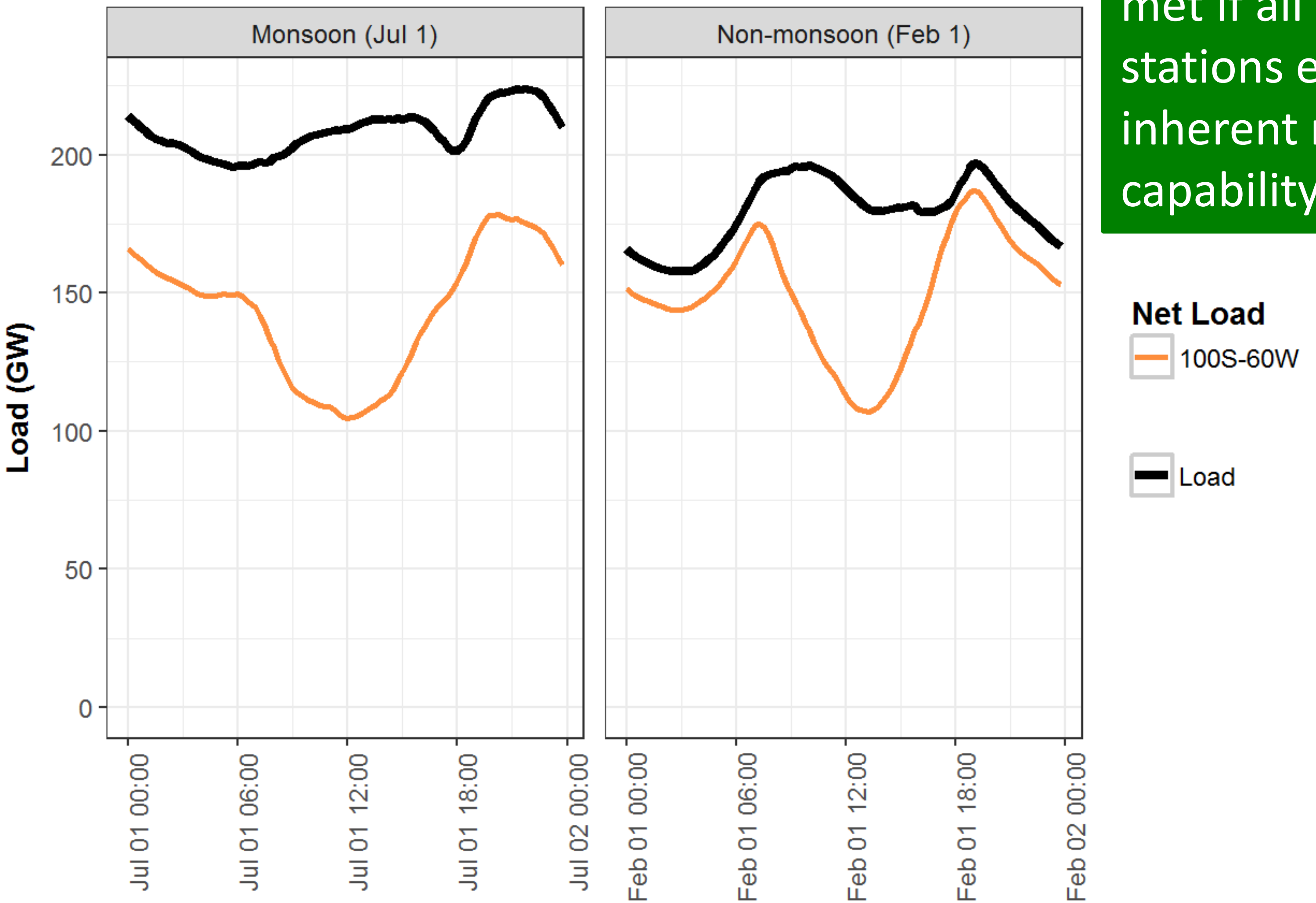


Key Finding #2: With effective state-level planning, curtailment may not be a barrier to RE investment

- Curtailment risk is a large concern to RE developers and investors
- Study finds curtailment averages only 1% nationally, based on no intrastate congestion
- Curtailment is highest in the southern region but still less than 3%



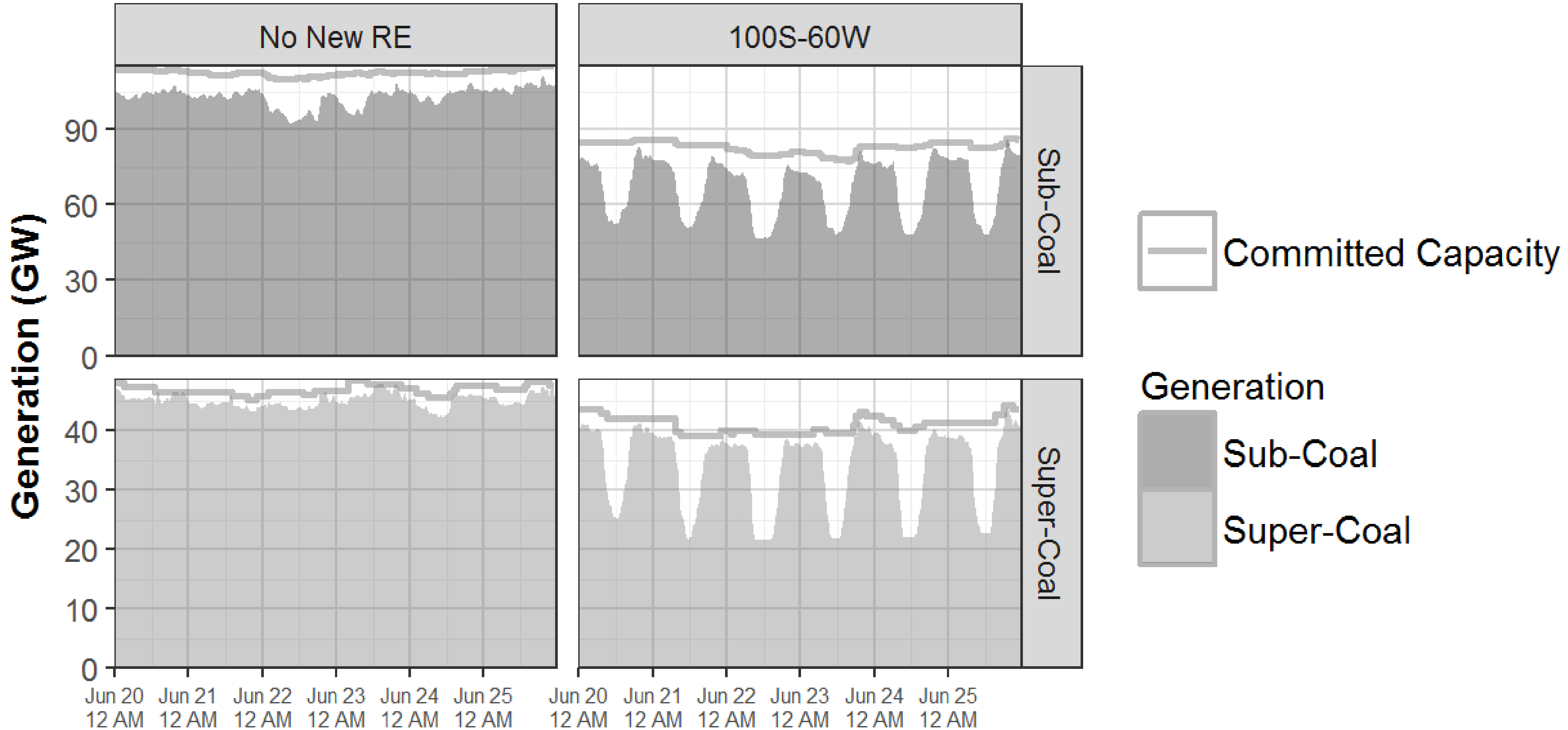
Key Finding #3: Peak system-wide ramp increases 28% compared to a system with no new RE, to almost 32 GW per hour (530 MW/min)



This ramp rate can be met if all generating stations exploit their inherent ramping capability.

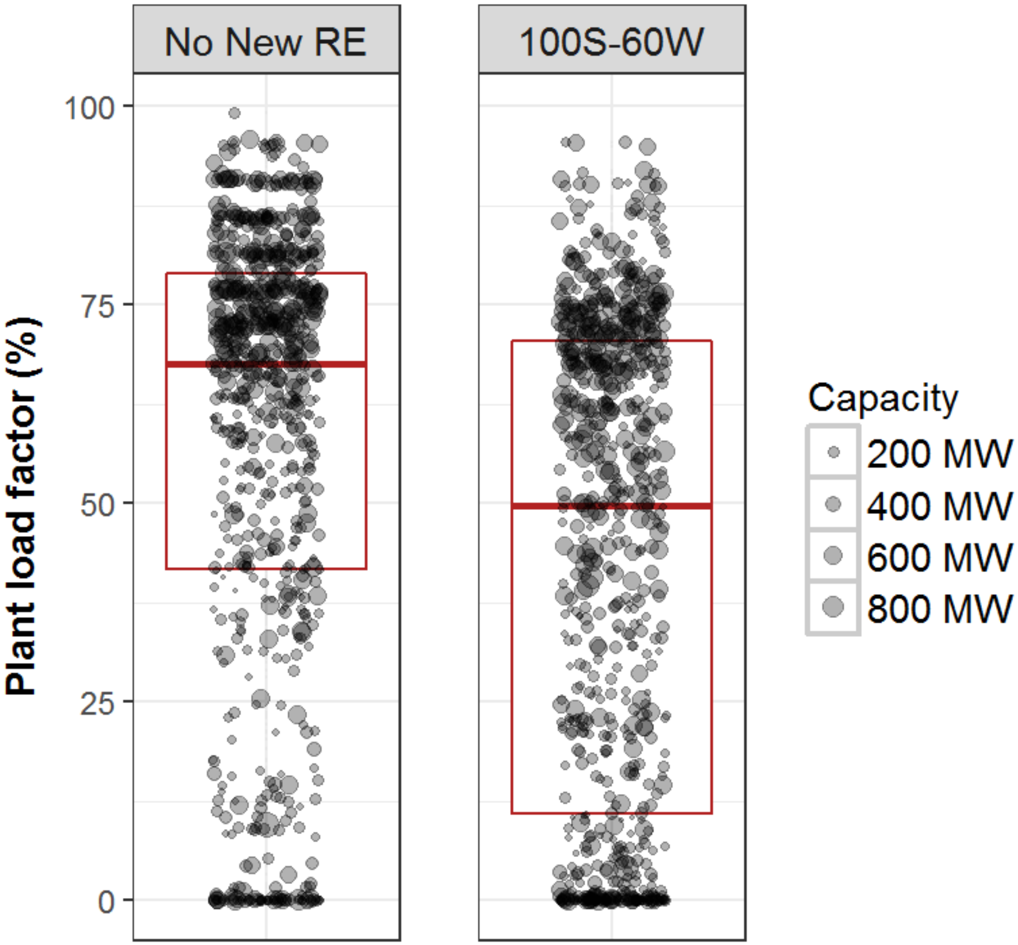
Net load on a monsoon and non-monsoon day

Key Finding #4: Coal units are typically backed down midday



Coal commitment and dispatch for one week in June

Key Finding #5: Average coal plant load factors fall 63% to 49%, with over 19 GW of capacity that never starts*



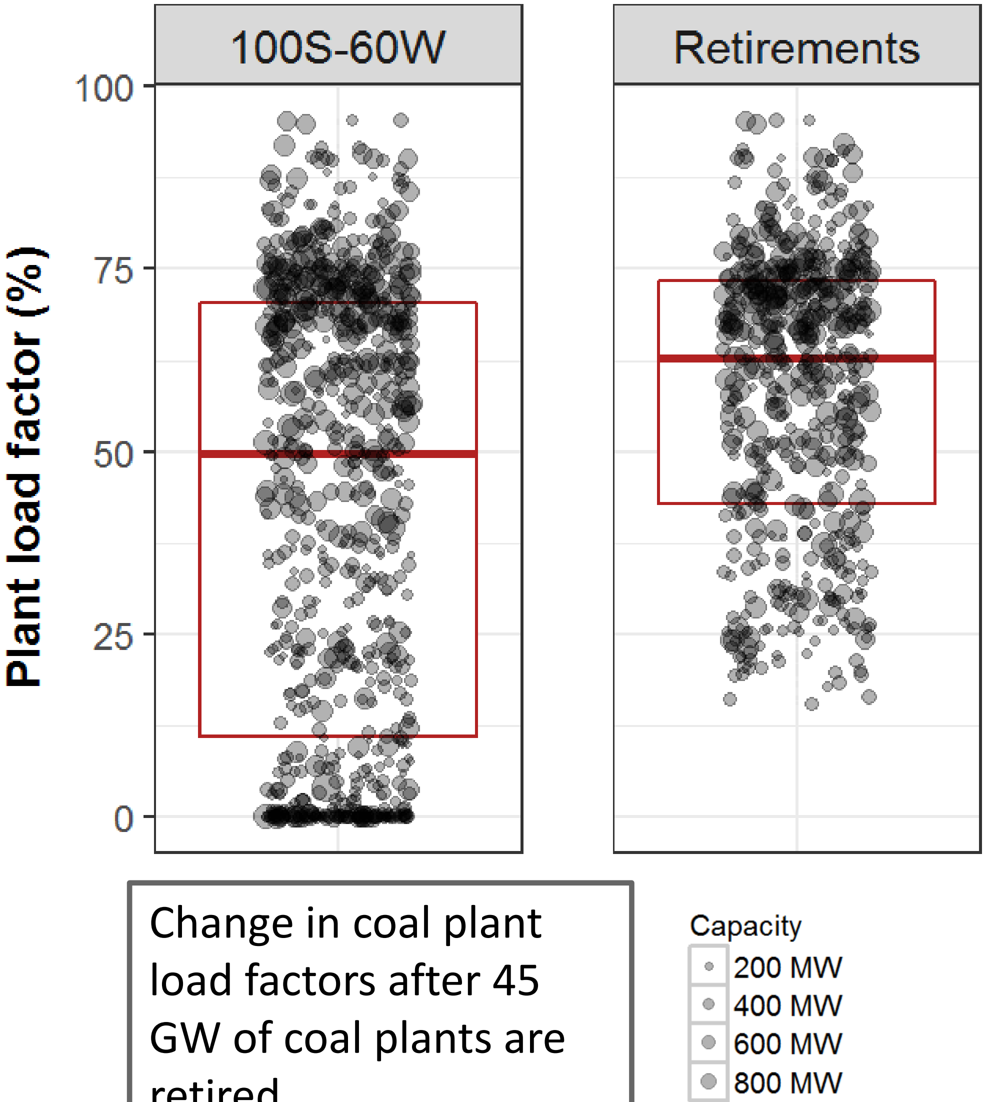
Coal capacity below 25%, and above 75% PLF

PLF	No New RE	100S-60W
<25% PLF	30 GW	60 GW
>75% PLF	92 GW	36 GW

* Compared to No New RE; Plant load factor (PLF) is calculated using weighted averages

Key Finding #6: Retiring 45 GW of coal does not adversely affect system flexibility

- 45 GW coal (198 plants) operate on average less than 15% capacity and contribute just 1% to annual coal generation
- System still operates effectively without these plants, based on adequate intrastate transmission
- Plant load factors of remaining plants increase from 49% to 61%



Change in coal plant load factors after 45 GW of coal plants are retired

Key Finding #7: Changes to operations can reduce the cost of RE integration and reduce curtailment

Improved merit order dispatch and resource sharing across state and regional boundaries lower costs

- 3% annual savings from regional optimization
- Fewer coal plants need to run at part load
- More efficient use of coal plants means long-run investment costs likely lower with fewer coal plants needed

Lower turn-down plant levels biggest driver to reduce RE curtailment

- 70% = 3.4% RE curtailment
- 55% = 1.1%
- 40% = 0.5%

Other aspects of coal plant flexibility (e.g., ramp rates) and increased interregional transmission capacity are critical but changing these had small impact on system operations and RE integration

Key Finding #8: Batteries do not add value to RE integration from scheduling/dispatch perspective

- 2.5 GW batteries reduce RE curtailment and peak coal consumption
- But batteries charge during the day, in part on coal, and have efficiency losses
- Electricity savings from reduced RE curtailment (1.1 TWh) is offset by battery efficiency losses (1.7 TWh)
- Total coal generation is not affected
- CO_2 emissions do not decline

Batteries could have value for other reasons outside scope of study:

  - **Local transmission congestion, ancillary services…**

BATTERY STORAGE

100 GW SOLAR, 60 GW WIND

NORMAL OPERATIONS (NO BATTERY STORAGE)	2.5 GW BATTERY STORAGE
220,000 INR Crore Annual Production Cost	**0.20%** Increased cost annually
1.1% Renewable Energy Curtailment	**0.82%** Renewable Energy Curtailment

Priority policy takeaways

1 Evaluate policy/regulatory options to improve merit order dispatch

2 Set comprehensive standards for coal flexibility (CERC and SERCs)

3 Support states to identify necessary intrastate transmission

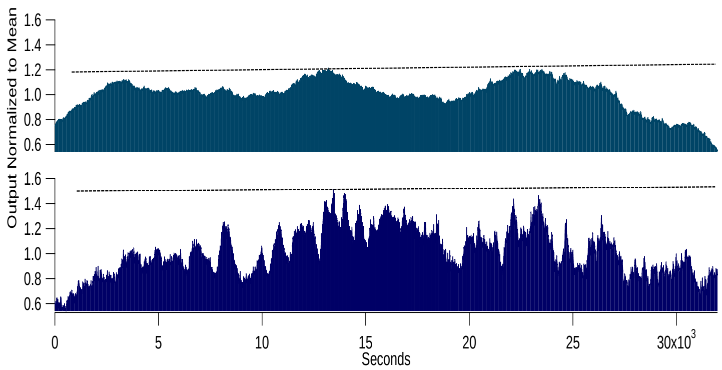
4 Develop least-cost generation and transmission plans that consider fixed and variable costs as well as operational impacts

5 Evaluate options to manage financial impacts from lower PLFs of thermal fleet

Other Greening the Grid Components

Example: An Integrated GTG Pilot

GOAL: Improved Ability to Meet RE Targets



System Planning at High RE Scenarios

Capacity Building & Lessons for Operators & Regulators

Improved Cooperation between States for Balancing

BUSINESS CASE

Demonstrate cost savings and smoothing of variability from balancing area coordination

PEER EXCHANGE

Analysis of market-based approaches for F/S/B
Bootcamps for A/S

PILOT

Test Energy Imbalance Market across multiple states for shared balancing resources

Thank you!

Jaquelin.Cochran
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Techno-Economic Assessment of Integrating 175GW of Renewable Energy into the Indian Grid by 2022

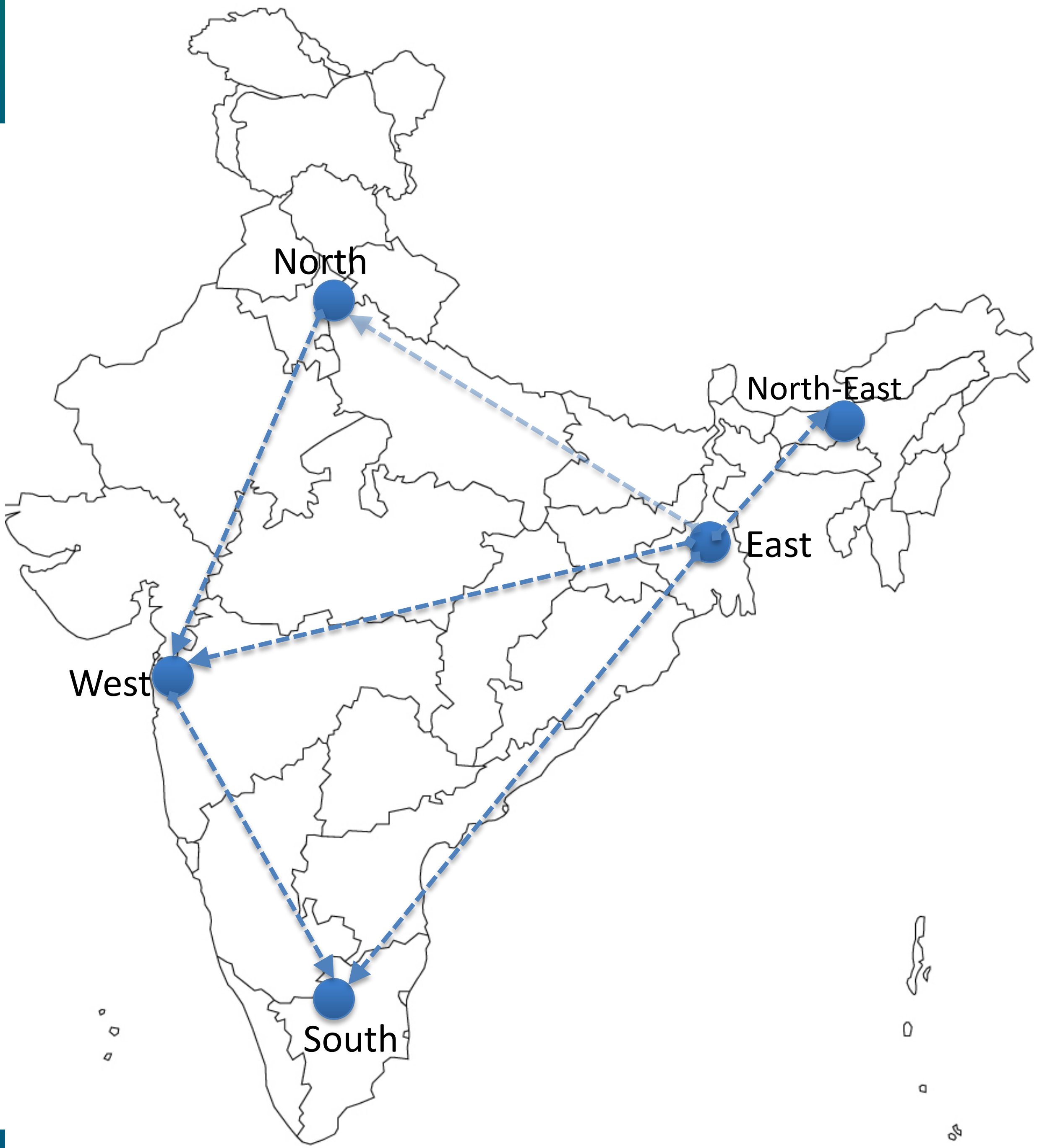
Nikit Abhyankar
Ranjit Deshmukh
Amol Phadke

Central Electricity Authority
February 2017

Introduction

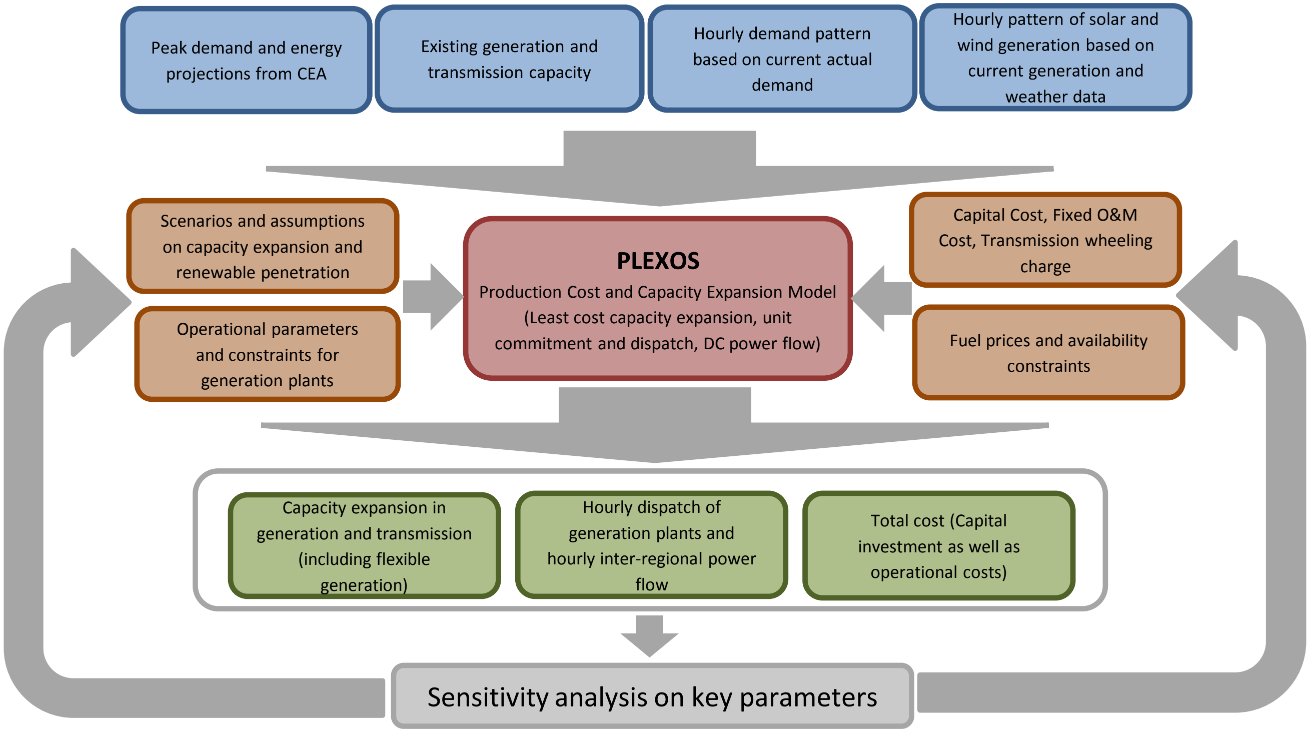
- Given the 175 GW RE target, designing appropriate policy, regulatory, and commercial strategies for RE grid integration is crucial
  - Although large scale RE grid integration has been analyzed widely in the US and European context, there is limited literature in India

- The objective of this study is to assess the impact on power sector investments, operations, and electricity supply costs of the 175GW of RE target by 2022:
  - What is the impact of integrating RE on the capacity addition and capacity factors of conventional generators?
  - Are there any additional ramp requirements and if so how can they be met in a least cost fashion?
  - How do inter-regional transmission flows and investment requirement change?
  - What is the impact on the wholesale electricity supply cost (at region boundary)?


North
North-East
East
West
South

Summary of the Method – Modeling Framework

- We conduct our analysis using PLEXOS, an industry-standard production cost model
- For various levels of RE penetration targets, PLEXOS identifies the least cost investment and economic dispatch subject to a range of operational constraints



- We model the Indian electricity grid using 5 nodes – one node for every region which allows us to broadly assess the transfer capacities across regions assuming each region as a balancing area

Summary of the Method – Scenarios for FY 2022

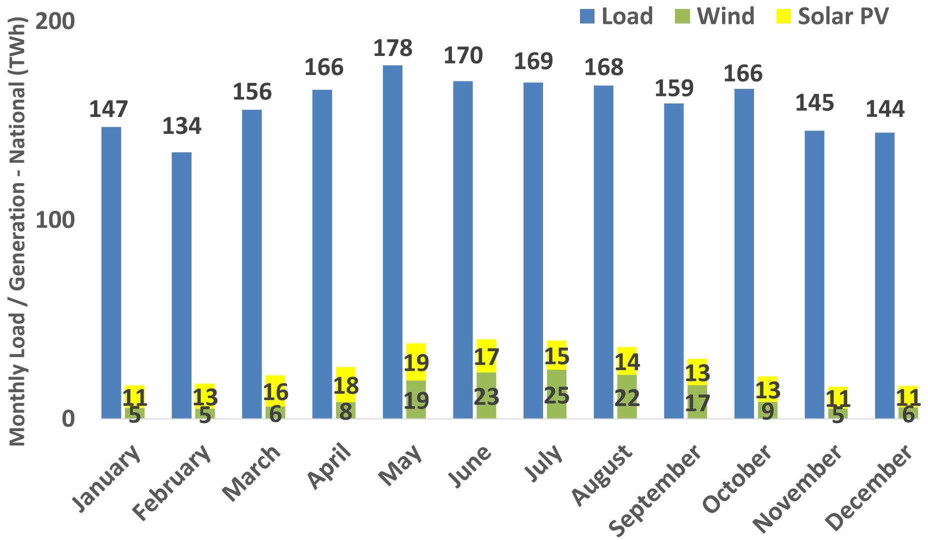
- ***13th Plan*** (41GW Wind, 22GW Solar, 15GW Other RE)
  - This scenario serves as the baseline and uses the generation capacity addition for all technologies as projected in the Government of India's 12th Five-Year Plan document that includes projections up to the 13th Plan period (2022)

- ***RE Missions*** (60GW Wind, 100GW Solar, 15GW Other RE)
  - This scenario models the Government of India's announcement in 2015 to increase the total installed capacity of solar energy to 100GW and wind energy to 60 GW by FY 2022
  - Coal and gas capacity expansion is "optimized" by the model; Hydro, Nuclear, and Other RE capacity assumed same as the 13th Plan

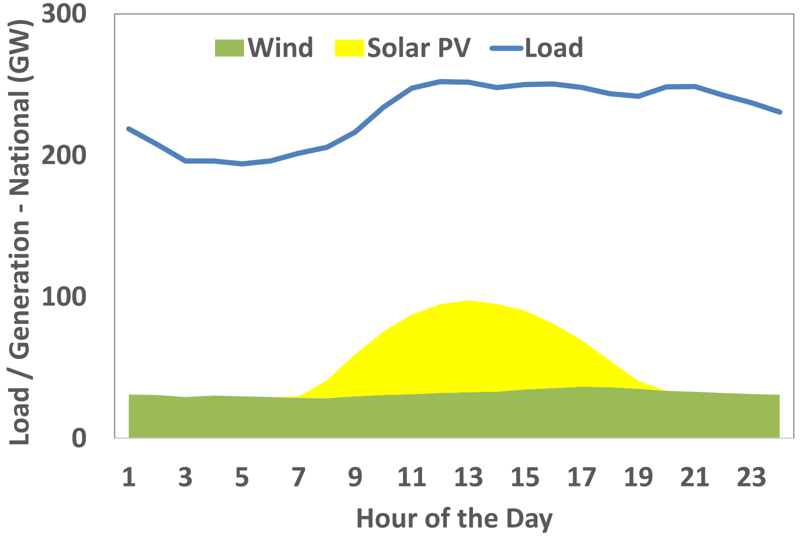
- ***National Action Plan on Climate Change (NAPCC)*** (108GW Wind, 58GW Solar, 15GW Other RE)
  - This scenario models the RE target described in India's NAPCC (2009) - 15% electricity (by energy) by 2020 and ~20% by 2022 (extrapolated)
  - Keeping the other RE capacity same as the 13th Plan, we split the rest of the NAPCC target into wind and solar PV capacity using a 75:25 ratio*
  - Coal and gas capacity expansion is "optimized" by the model; Hydro, Nuclear, and Other RE capacity assumed same as the 13th Plan

Key Results

Solar and Wind Energy Have Complementary Profiles: Seasonally and Diurnally



Monthly Load and RE Generation - National
(RE Missions Scenario – 100GW Solar, 60GW Wind)



National Average Hourly Load and RE Generation (June-Sep)
(RE Missions Scenario – 100GW Solar, 60GW Wind)

- Wind generation peaks in Monsoon (June-Sep) while solar generation peaks in the Summer (April-May)
- In winter, wind generation drops significantly while the drop in solar generation is modest
- Diurnally, solar generation peaks between 12 and 1 PM; wind generation peaks between 5 and 7 PM (when solar PV generation starts dropping rapidly)
- Regional diversity in wind generation creates a favorable national aggregate hourly profile

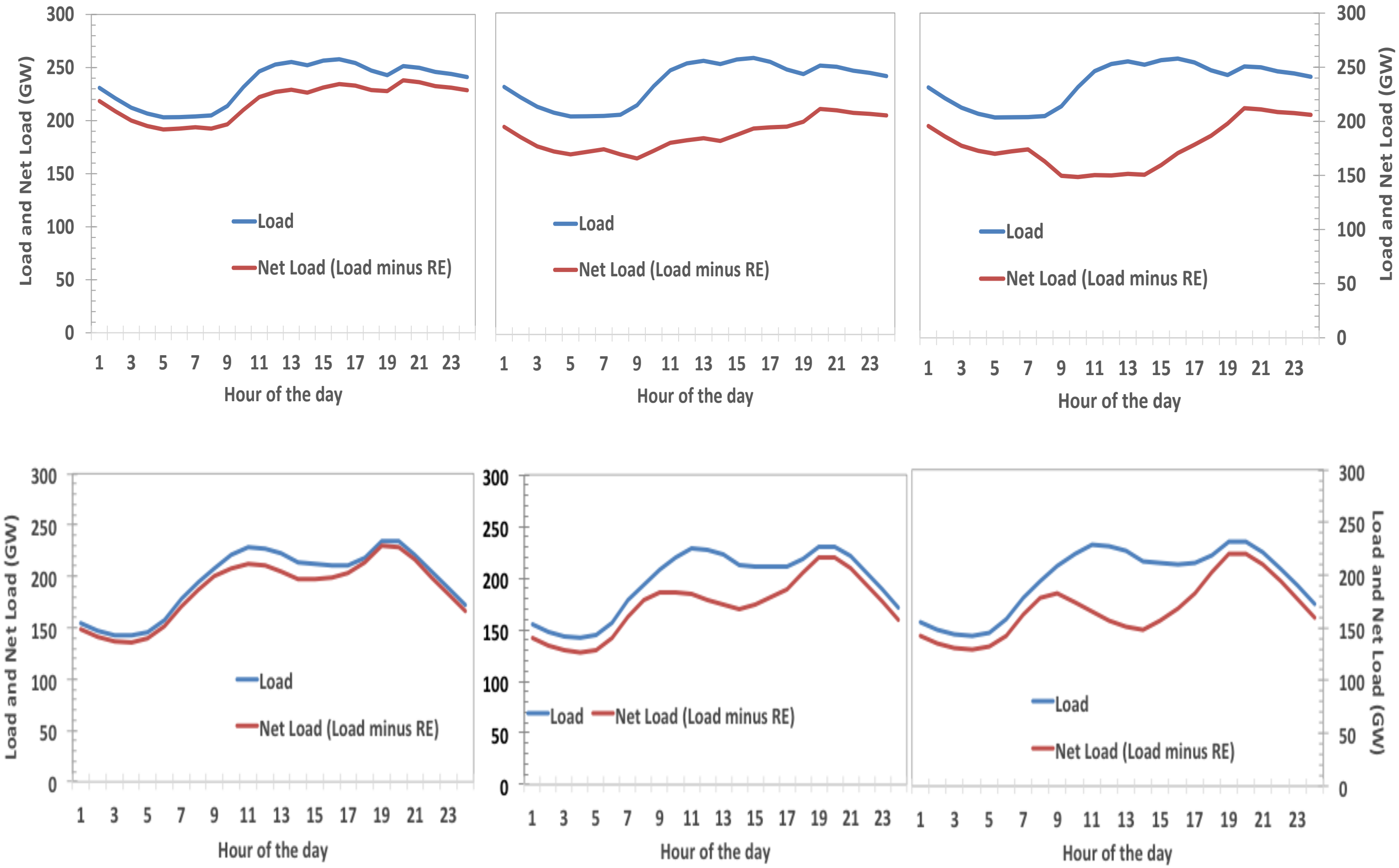
Overall, RE generation has good correlation with load; winter evening peak may drive the need for low fixed cost capacity

BERKELEY LAB

13th Plan (41GW Wind, 22GW Solar) | **NAPCC** (108GW Wind, 58GW Solar) | **RE Missions** (60GW Wind, 100GW Solar)

Monsoon
(June - September)

Winter
(December - February)



In Summer and Monsoon, RE generation has good correlation with the peak load (afternoon) and can avoid significant conventional generation. However, in Winter (especially evening peak load hours), RE generation drops significantly.

Significant coal capacity can be avoided; moderate additions to the gas capacity required

	13th Plan		RE Missions		NAPCC	
	Installed Capacity (GW)	Annual Capacity Factor (%)	Installed Capacity (GW)	Annual Capacity Factor (%)	Installed Capacity (GW)	Annual Capacity Factor (%)
Coal	243	64%	182	71%	182	73%
Gas (CCGT / CT)	23	7%	33	7%	25	9%
Diesel	1	0%	1	0%	1	0%
Nuclear	25	89%	25	89%	25	89%
Hydro (Incl. small hydro)	66	37%	66	37%	66	36%
Biomass + Cogen.	8	1%	8	2%	8	2%
Wind	41	25%	60	29%	108	29%
Solar	22	19%	100	19%	58	19%
Total	**425 GW**		**476 GW**		**472 GW**	

- In both the RE heavy scenarios, significant new coal capacity could be avoided relative to the 13th Plan scenario (the baseline)

- Moderate additions to gas based capacity are needed in both RE heavy scenarios
  - ~10GW in case of RE Missions and ~2GW in case of NAPCC
  - These additions need not be technology specific; if other sources provide such services (e.g. hydro or demand response etc.), the need for gas based capacity addition would reduce

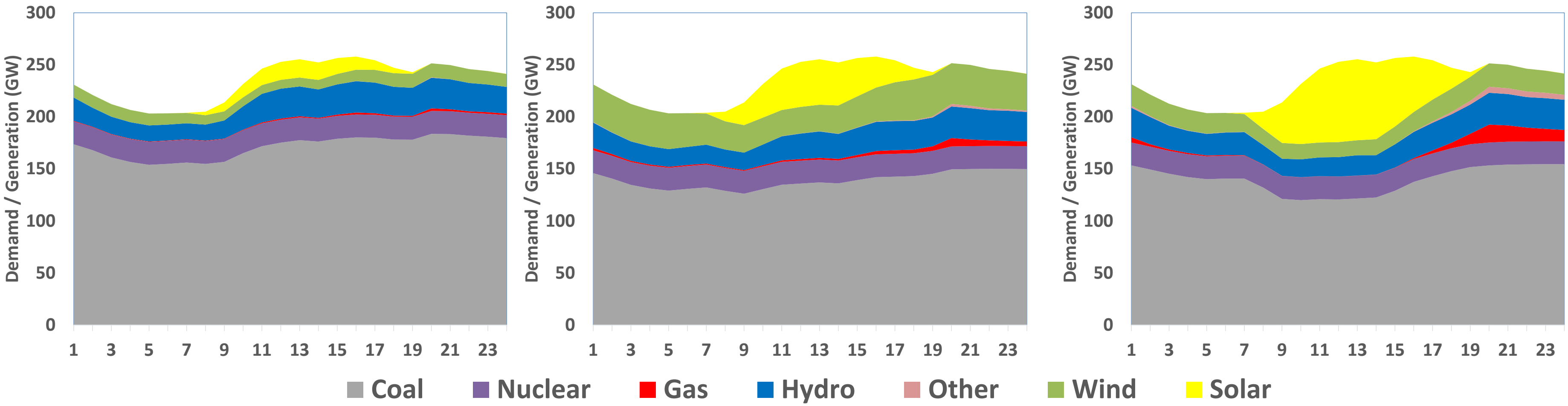
- Gas plants operate with a capacity factor of 7-9% implying that they are primarily used as a peaking resource or for providing additional flexibility to the system

Average Hourly National Dispatch (FY 2022) – Summer (April- May)

13th Plan (41GW Wind, 22GW Solar)

NAPCC (108GW Wind, 58GW Solar)

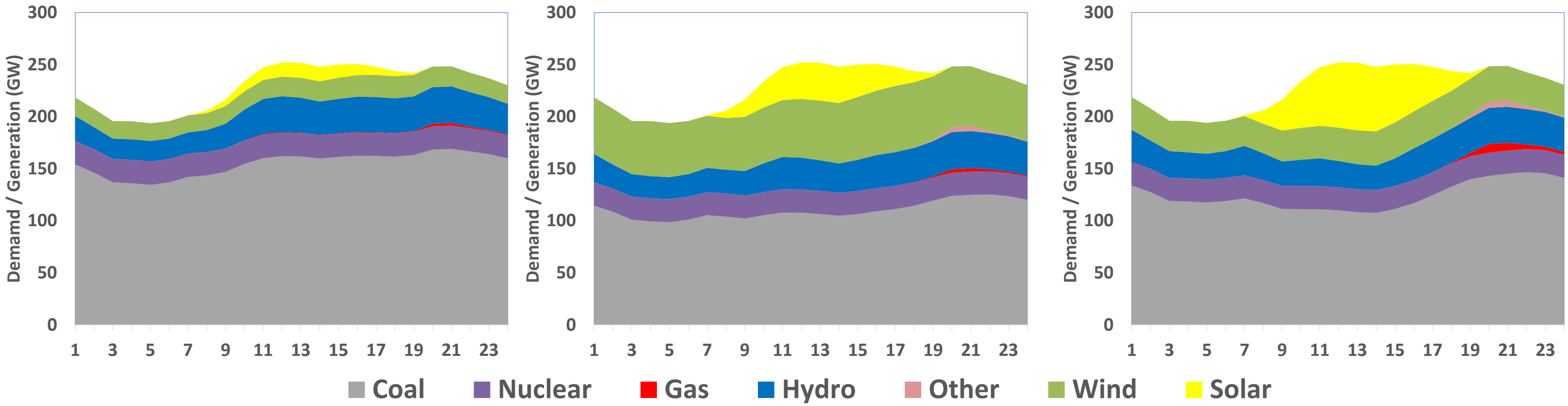
RE Missions (60GW Wind, 100GW Solar)



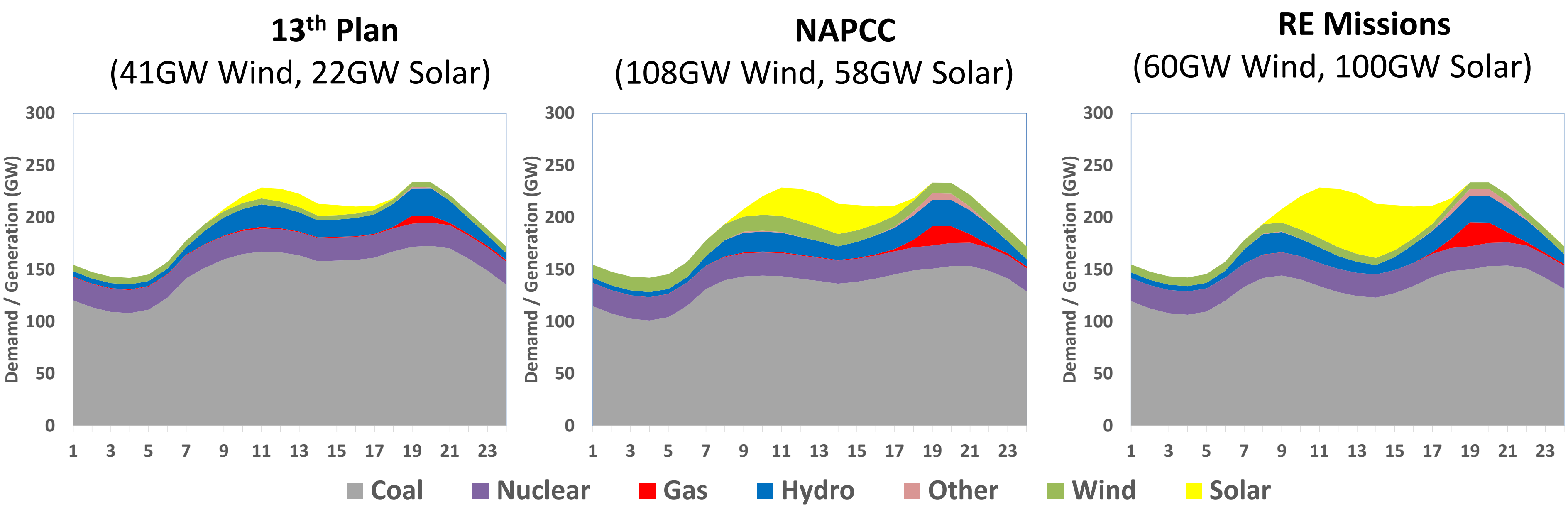
- In all scenarios, most coal units are dispatched as base load units
- In summer, solar output is the highest; however, the generation is limited to afternoon peak load hours
- Gas based capacity (or other flexible capacity) is crucial for the evening ramp-up and energy support, especially in the RE Missions scenario
  - Hydro has limited applicability since ~50% of the installed capacity is run of the river (ROR) and the rest has significant dispatch restrictions
- No RE curtailment is found to be necessary

Average Hourly National Dispatch (FY 2022) – Monsoon (June-Sep)

13th Plan (41GW Wind, 22GW Solar) | **NAPCC** (108GW Wind, 58GW Solar) | **RE Missions** (60GW Wind, 100GW Solar)



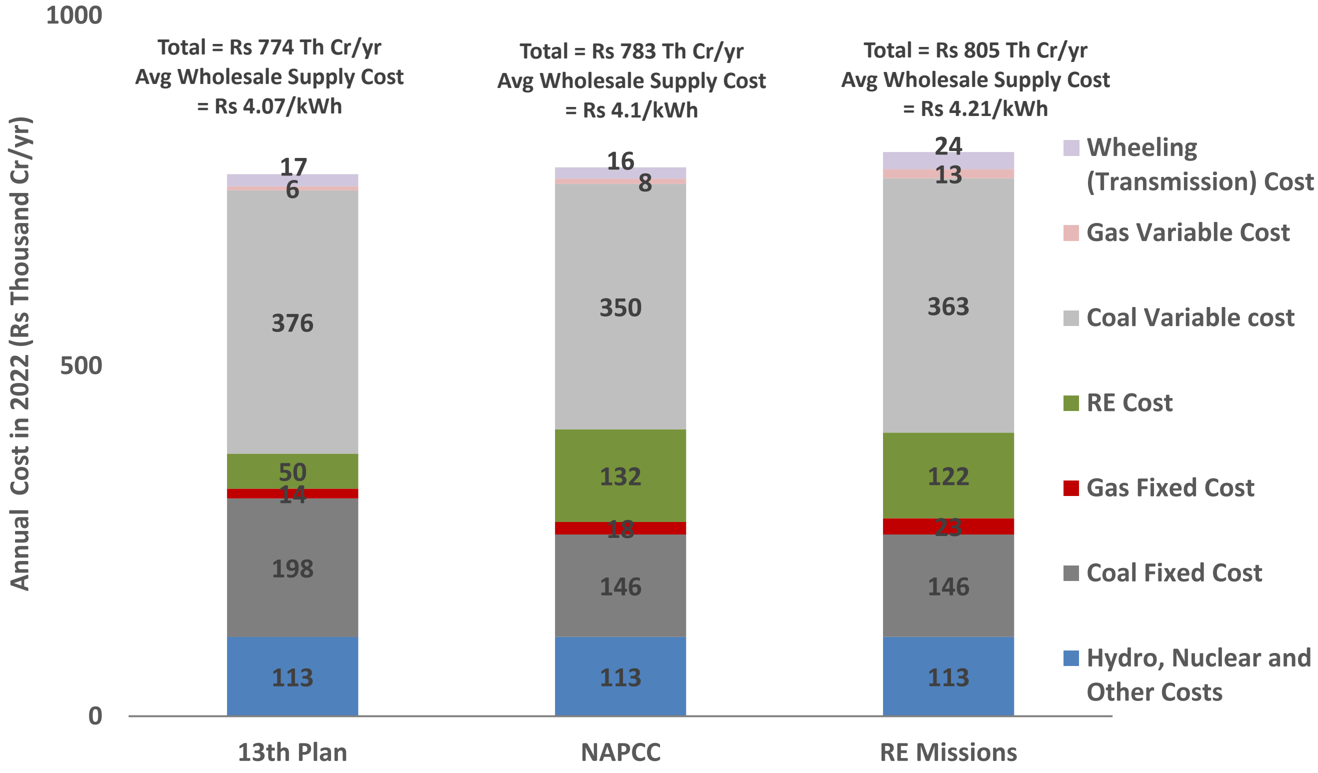
- In monsoon, wind generations peaks and also has good correlation with the evening peak load
- Increased wind generation also helps with managing the evening ramp-up
  - The need for gas based capacity (or other flexible capacity) is lower
- Despite significant increase in the RE generation (due to wind), no RE curtailment is found to be necessary



- In winter, wind (as well as solar) output drops significantly relative to other seasons
- However, demand is lower relative to other seasons as well
- Hydro capacity (especially run-of-river) is significantly restricted in winter
- Thus, evening peak support from gas power plants (or other flexible capacity) becomes crucial
    - Building local gas storage and avoiding take-or-pay gas contracts is important

Incremental Cost of the RE Scenarios is up to Rs 32,000 Cr/yr (4-6% of the baseline)

- The incremental wholesale cost of supply in NAPCC and RE Missions scenarios is found to be ***Rs 10,000 Cr/yr (1%)*** and ***Rs 32,000 Cr/yr (4%)*** respectively relative to the 13th Plan
  - Total cost of the 13th Plan scenario at region boundary is Rs 774,000 Cr/yr by 2022
  - Incremental Increase in the average wholesale supply cost: 3p/kWh (NAPCC) and 14p/kWh (RE Missions)
  - If thermal capacity not optimized, cost of RE Missions = Rs 4.37/kWh (~Rs 70,000 Cr/yr)



These costs include majority of the RE integration cost such as additional investments in flexible capacity (such as gas etc.) or operation of expensive gas or diesel plants, and inter-regional transmission cost etc.

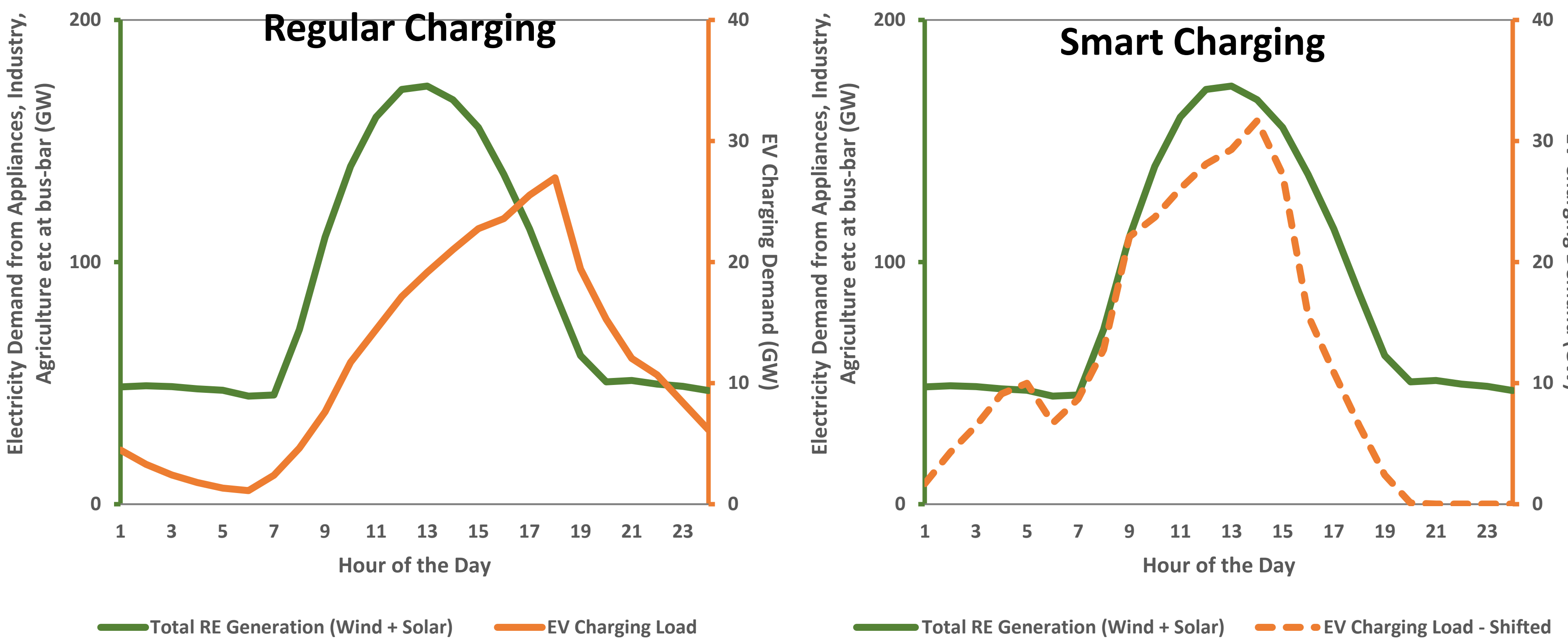
Does not include procurement of additional ancillary services. Several other studies have found these costs to be minor.

Does not consider new norms for Particulate Matter, SOx, and NOx emissions (2015), which may increase coal fixed costs by over ~10% and reduce the cost-differential between the 13th Plan and RE Dominant scenarios.

Demand response could be one of the most cost-effective sources of flexibility (e.g. smart EV charging)

Most of the EV charging load could be shifted to the middle of the day **without impacting mobility demand**, to help RE grid integration; however, access to public charging infrastructure is crucial

Average hourly load (non-BEV and EV Charging) in May 2030



EV Charging Load Shifting could reduce the RE integration cost by ~5%

Conclusions

- We find that 175GW of RE can be reliably integrated into the grid by 2022 at an incremental wholesale electricity supply cost (at region boundary) of ~Rs 32,000 Cr/yr (increase in average wholesale supply cost of 14-22p/kWh or 4-6% over the baseline)
  - However, we have not considered the environmental and energy security benefits of RE generation
- Only moderate levels of additional grid balancing resources are required
  - Complementarity between wind and solar generation and the regional diversity in load and RE generation helps
  - 2 to 10 GW of additional gas or other flexible capacity by 2022; need to provide cross-seasonal support
- Due to increased RE penetration, significantly less coal capacity is required than planned to minimize the total cost and avoid lowering of capacity factors of coal power plants
  - About 75% coal imports could be avoided as a result of increased RE penetration
- The following strategies will likely limit the cost increase to the levels found in this study
  - Transmission corridors, especially those from/to the Southern region are strengthened
  - Cost of wind energy is reduced by developing highest quality wind resource through competitive bidding
  - Power system dispatch is coordinated at the regional level through markets or other mechanisms
  - Several market, policy, and regulatory mechanisms are in place e.g. RE forecasting, flexible markets etc.
- This analysis uses several simplifying assumptions especially regarding the transmission system; significant refinement is necessary for actual power system planning purposes

Acknowledgements

- LBNL would like to thank Regulatory Assistance Project and the US Department of Energy (21st Century Power Partnership) for providing financial support to this work.

- LBNL greatly appreciates the technical insights from several Government of India entities including the Ministry of Power, the Central Electricity Regulatory Commission, and the Power Systems Operations Corporation, without which this study would not have been possible. In particular, we are thankful to S K Soonee and S R Narasimhan of Power System Operation Corporation, and Sushanta Chatterjee of Central Electricity Regulatory Commission.

- We also thank Daniel Noll of US Department of Energy, Andrew Mills of Lawrence Berkeley National Laboratory, Venkat Krishnan and Jeffrey Logan of National Renewable Energy Laboratory, Fernando De Sisternes of The World Bank for their helpful comments and suggestions.

- We appreciate the insights and suggestions from Kashish Bhambhani and Dr. Subir Sen of PowerGrid Corporation of India, Ranjit Bharvirkar, Bob Lieberman, and Cathie Murray of Regulatory Assistance Project, and Deepak Gupta and Disha Aggarwal of Shakti Sustainable Energy Foundation, and Forum of Regulators on the earlier versions of this analysis. Any errors or omissions are authors' responsibility.

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Full report can be downloaded here:

https://eetd.lbl.gov/sites/all/files/pdf_7.pdf

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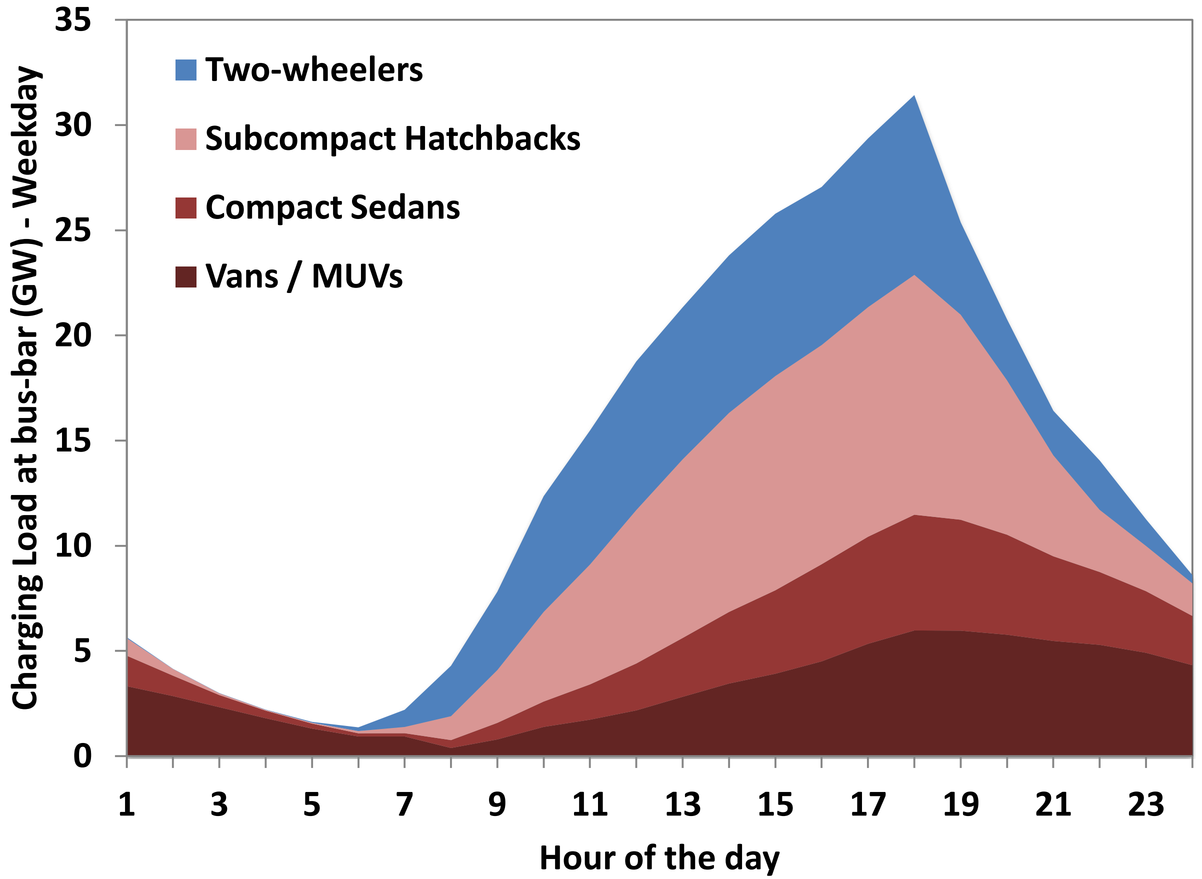
510-486-5681

BEV charging demand: no smart charging scenario



- Moderate correlation with the summer peak demand (space cooling); but can introduce significant ramps on the system in the evening, especially with high solar penetration.
- If smart charging of BEVs occur:

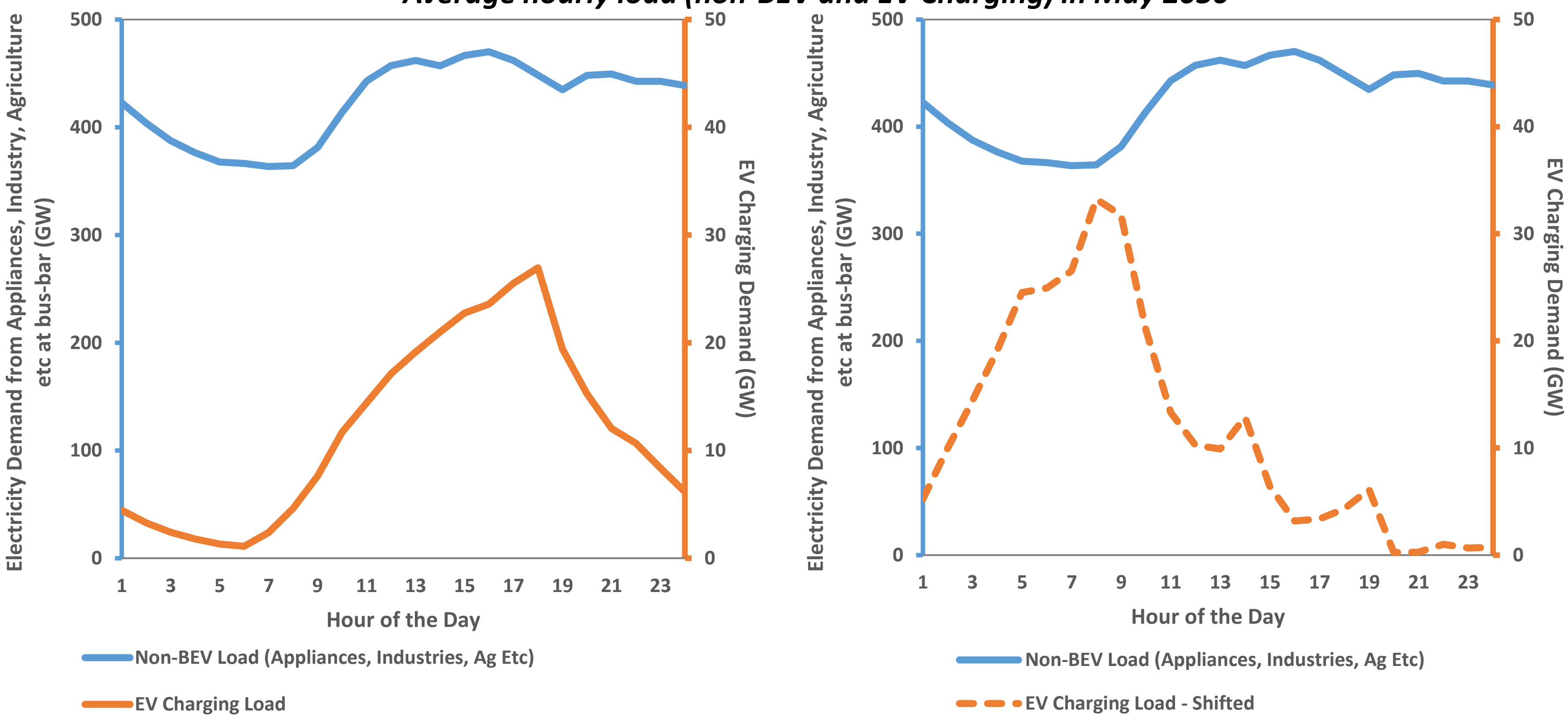
➔ Can help in managing the evening ramping requirements and system peak demand in general

➔ Lower the cost of RE grid integration

Benefits of Smart Charging – Baseline Scenario

Most of the EV charging load could be shifted to early morning when the coal heavy system is the least constrained, **without impacting mobility demand**

Average hourly load (non-BEV and EV Charging) in May 2030

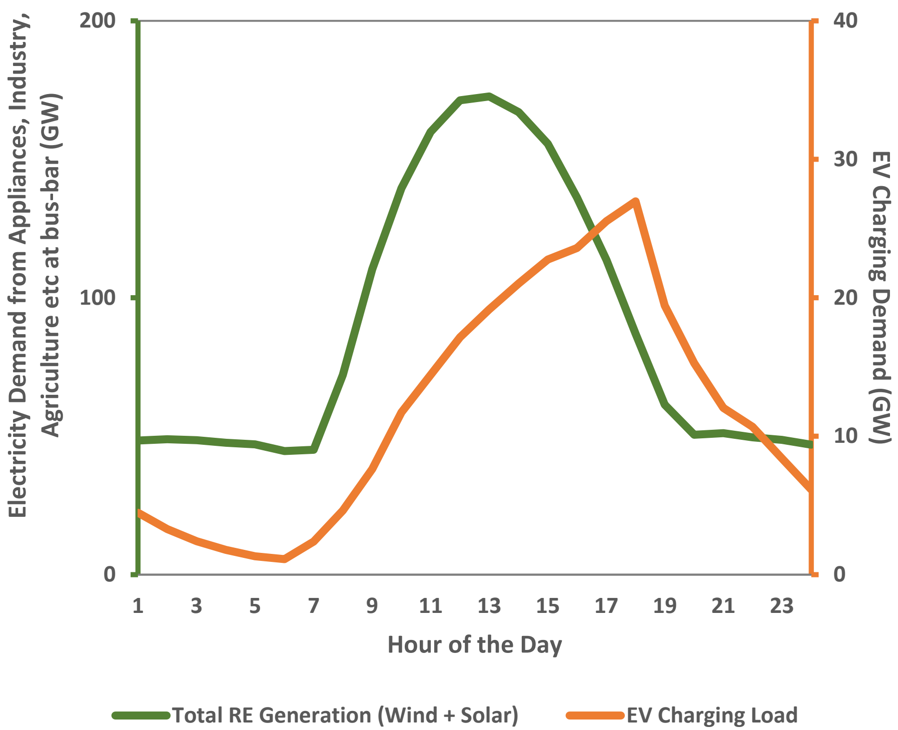


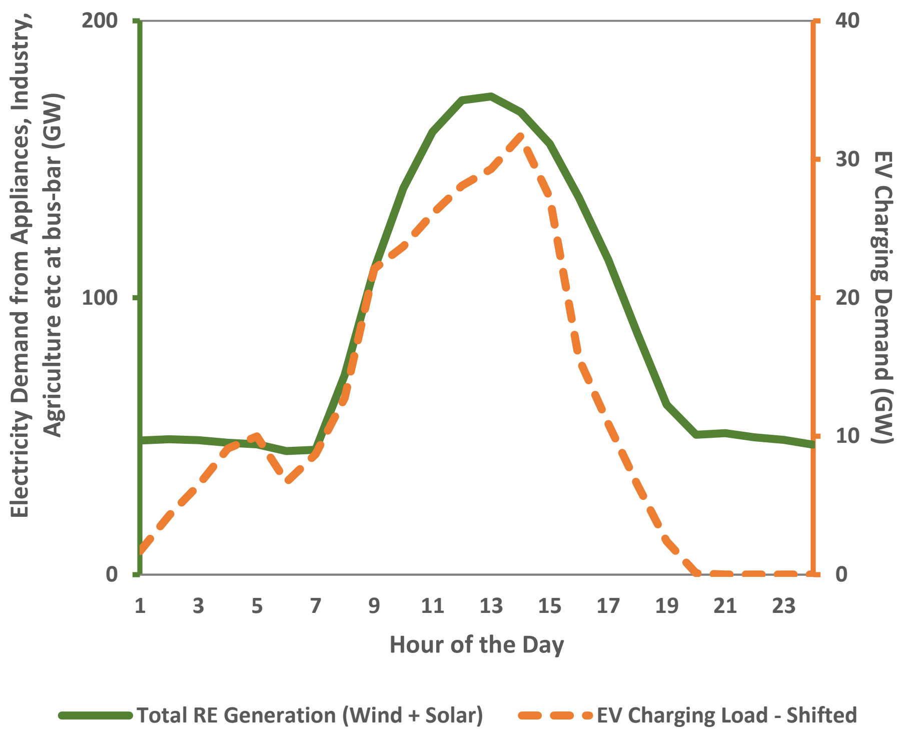
EV Charging Load shifting could reduce the average cost of generation of power by ~1% (due to better utilization factor of the generation and transmission assets)

Benefits of Smart Charging – NDC Compliant Scenario

Most of the EV charging load could be shifted to the middle of the day **without impacting mobility demand**, to help RE grid integration; however, access to public charging infrastructure is crucial

Average hourly load (non-BEV and EV Charging) in May 2030

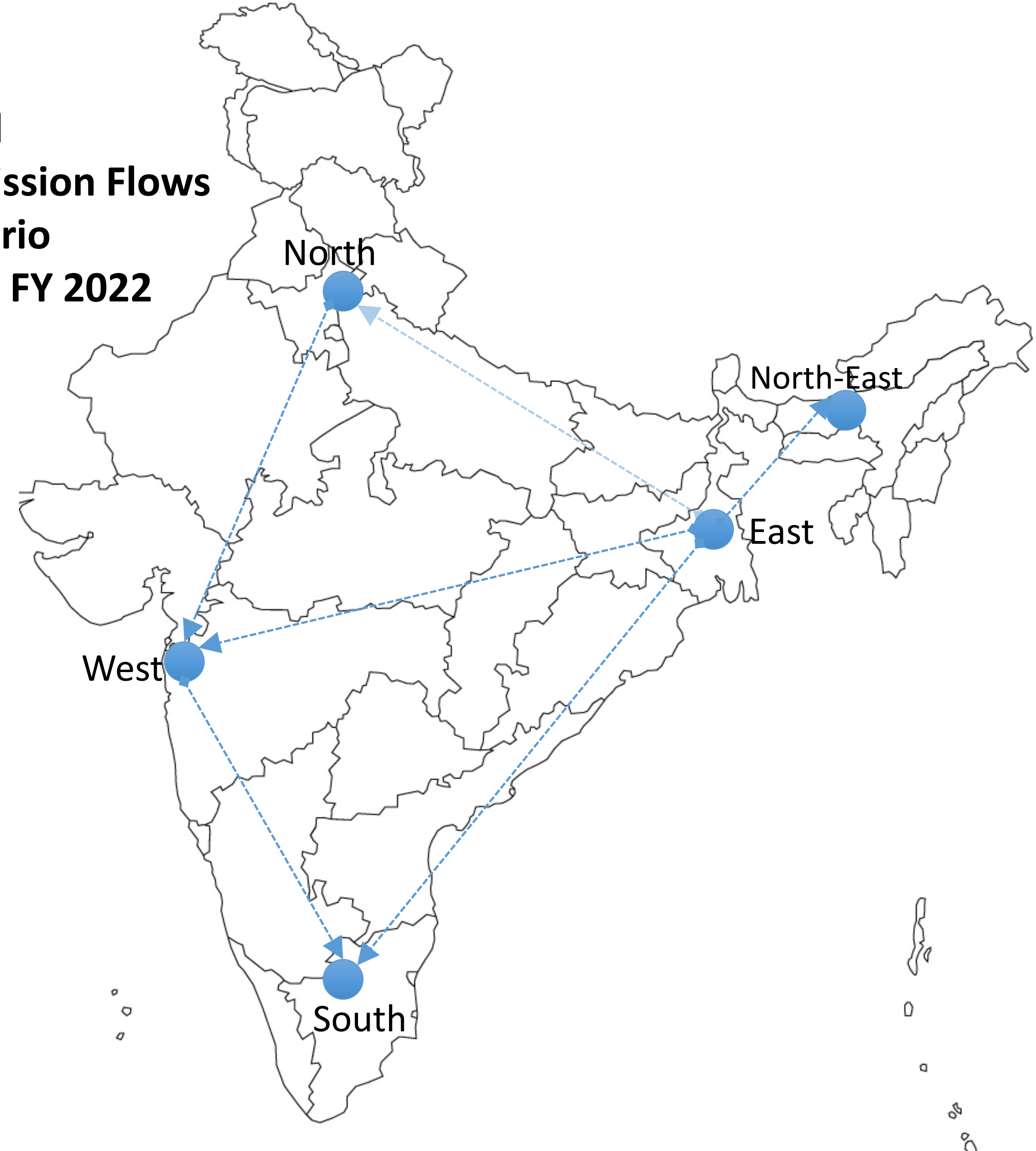


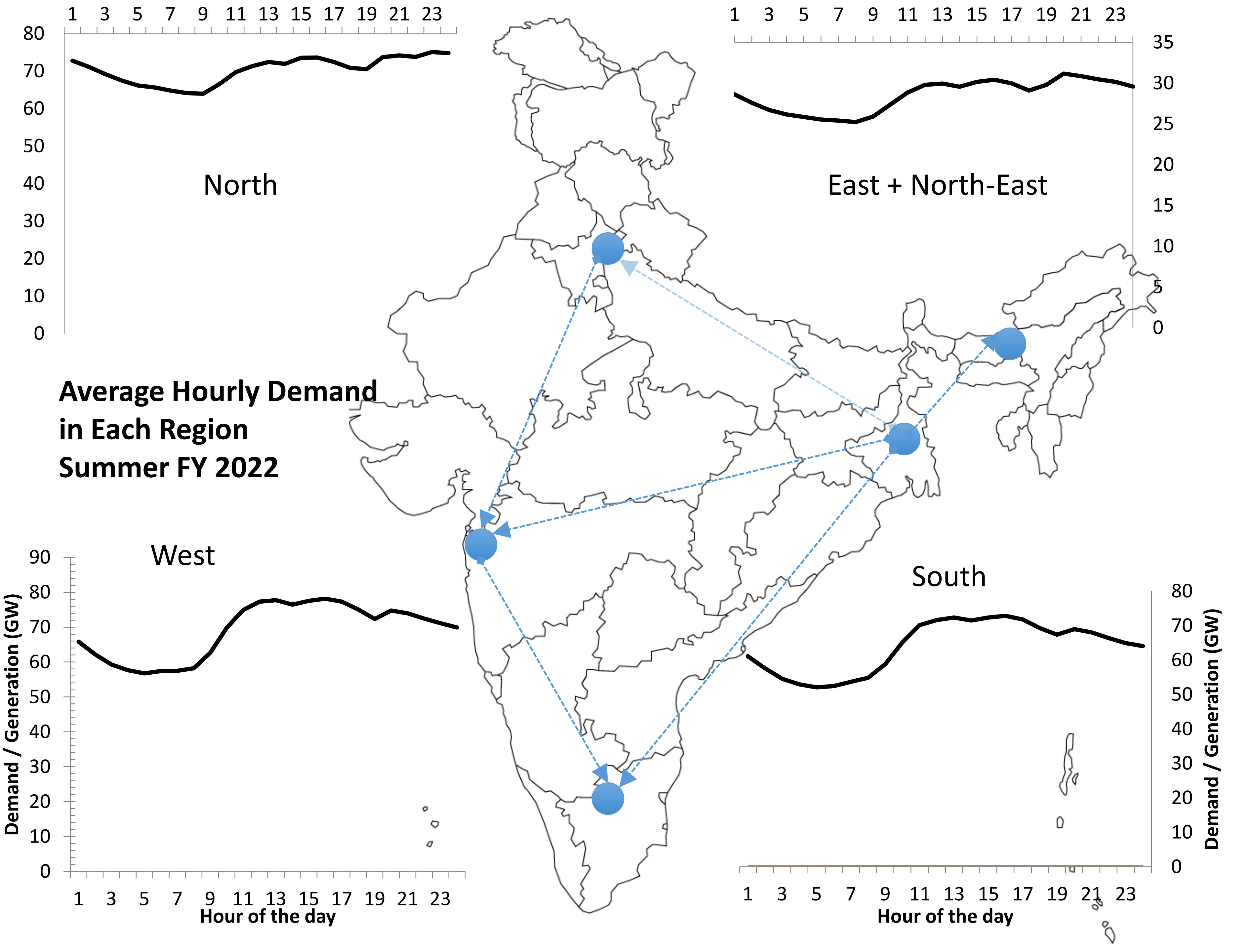


EV Charging Load Shifting could reduce the RE integration cost by ~5%

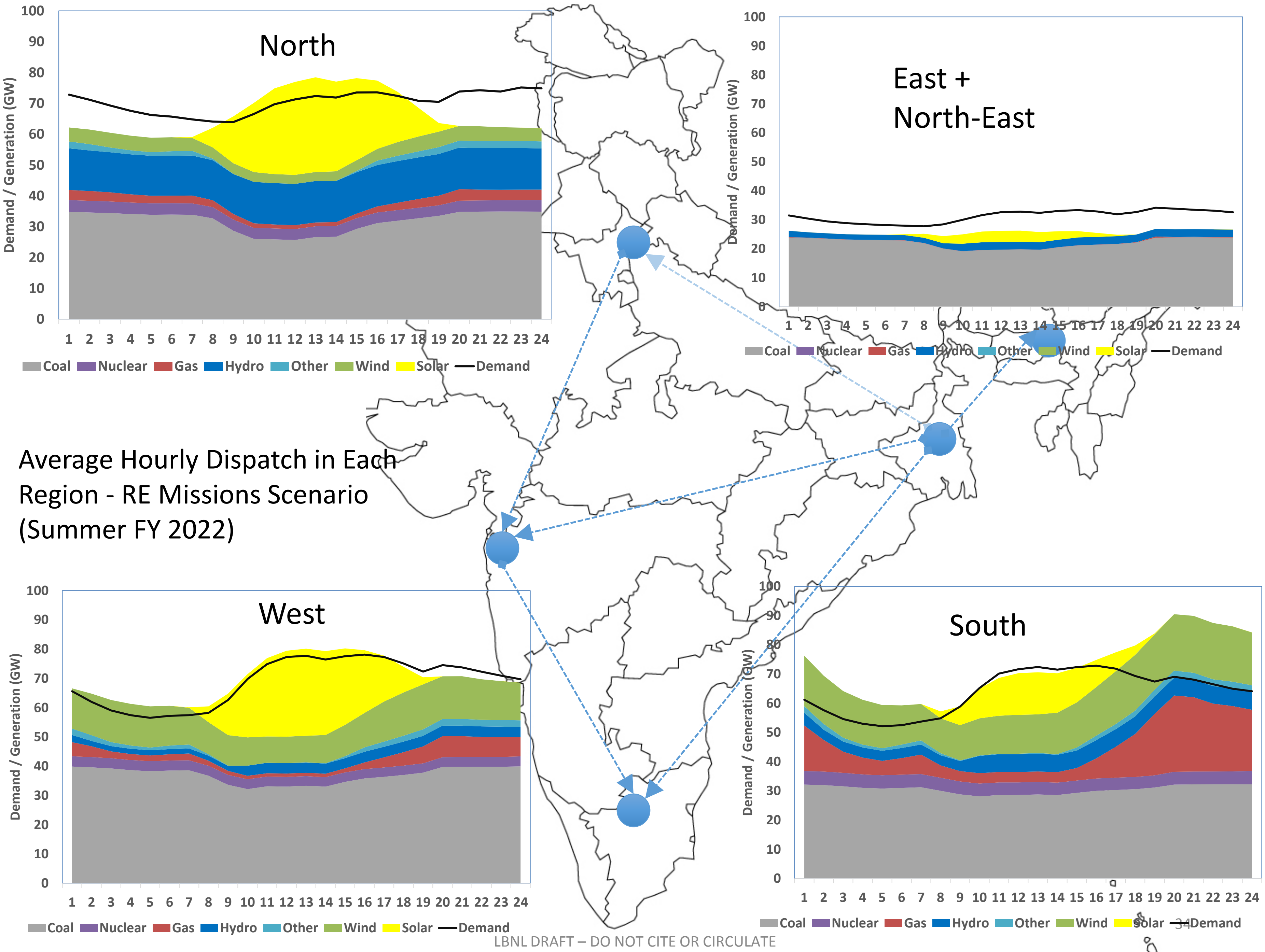
Appendix:
Inter-regional Flows – Example

Average Hourly Regional Dispatch and Inter-regional Transmission Flows For RE Missions Scenario Summer (April – May) FY 2022

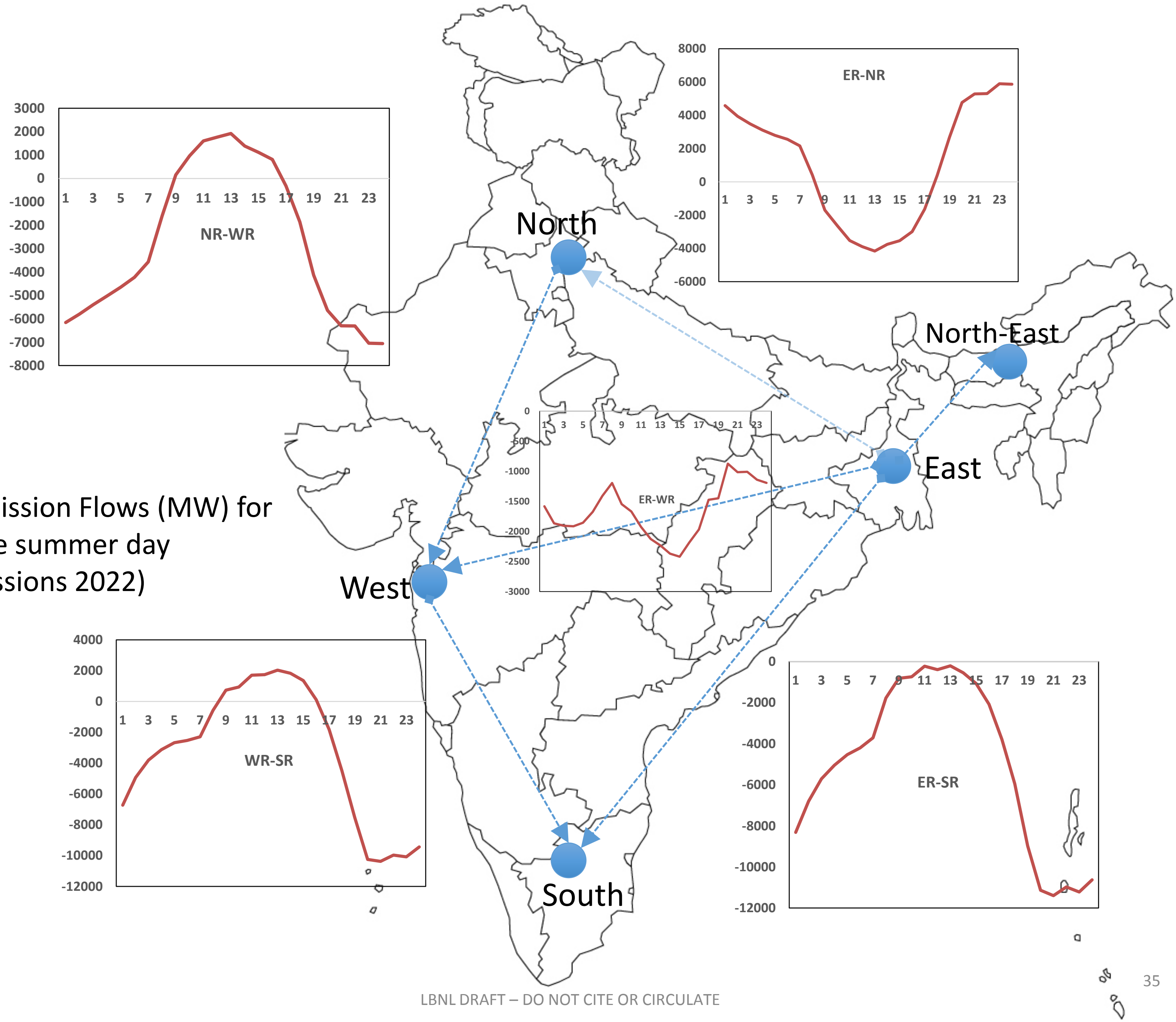




Average Hourly Demand
in Each Region
Summer FY 2022
North
East + North-East
West
South
Demand / Generation (GW)
Hour of the day


North
East +
North-East
West
South
Demand / Generation (GW)
Coal Nuclear Gas Hydro Other Wind Solar Demand
Average Hourly Dispatch in Each Region - RE Missions Scenario (Summer FY 2022)

Transmission Flows (MW) for average summer day (RE Missions 2022)



STATE LOAD DESPATCH CENTRE
MPPTCL, JABALPUR

23-FEB-2017

RE INTEGRATION IN MP SYSTEM

RE Source	Commissioned Capacity		
	31.03.2015	31.03.2016	20.02.2017
WIND	844	2007	2240
SOLAR	422	715	801
BIOMASS/ BIOGAS	32	63	63
MSW	0	0	12
SMALL HYDRO	81	81	81
TOTAL	1379	2866	3197

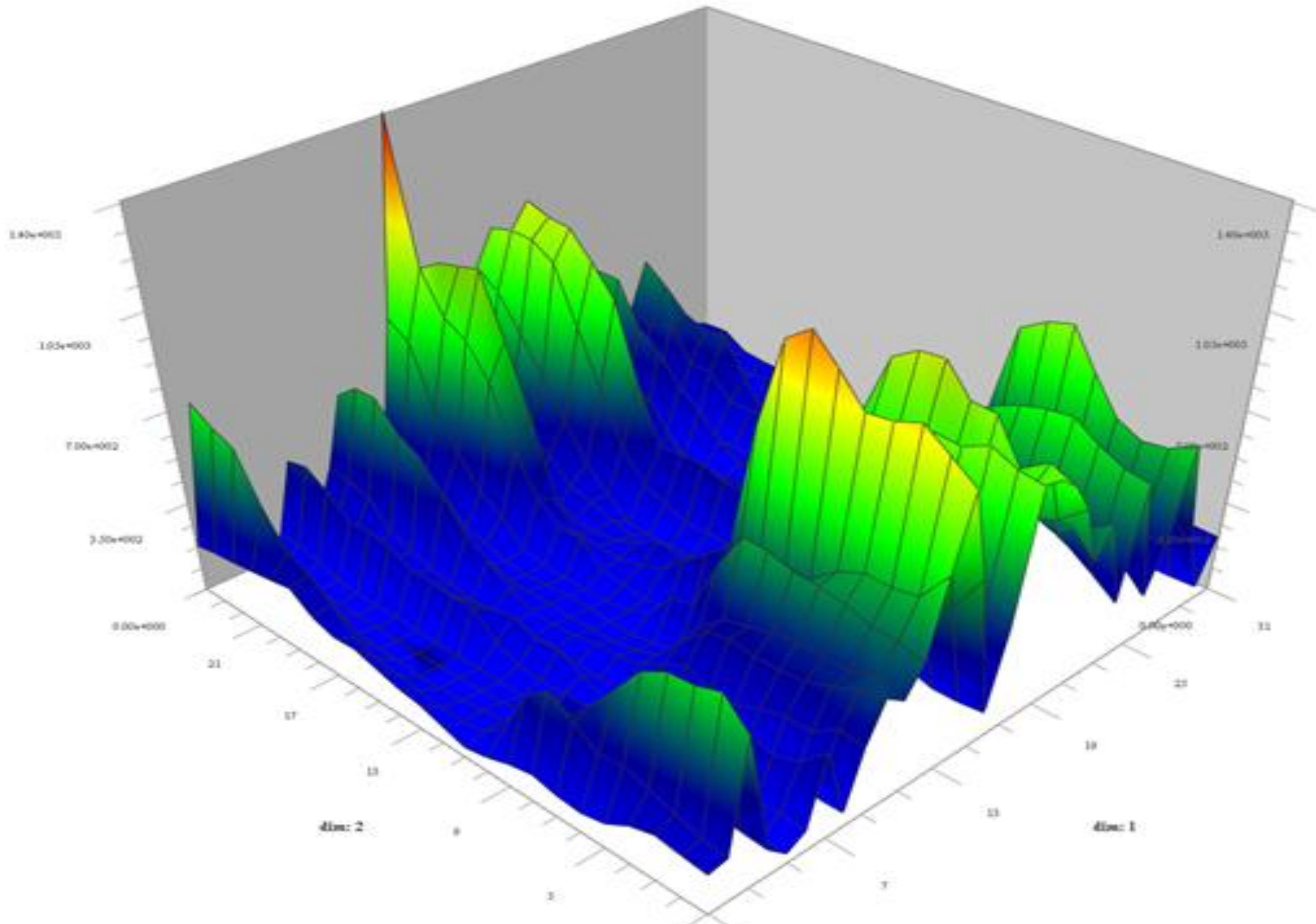
PROBLEMS IN DEALING WITH VALIABLE & INTERMITTENT GENERATION FROM RE

- MP is surplus power state. The irrigation demand is almost 30 % of annual peak.
- MP need to surrender its long term power even during rabi season as irrigation load peaking is during day time.
- Monsoon period base demand goes as low as 5000 MW.
- Power surrender up to Jan 2017 was 24600 MU against energy supply of 53221 MUs .i.e. 32% of total power available.
- Problem of not attending telemetry affects grid operation.
- Injection permission is given only when AMR, Telemetry and other requirements are fulfilled by the Generator.
- Intermittency and variability of Wind generation is handled by power surrender and regulation of Hydro potential (915+1520+826+45=3306 MW).
- So far MP has not started curtailment of generation from Wind and Solar. As per regulatory provisions curtailment of power from Biomass generators started from Jan 2017,

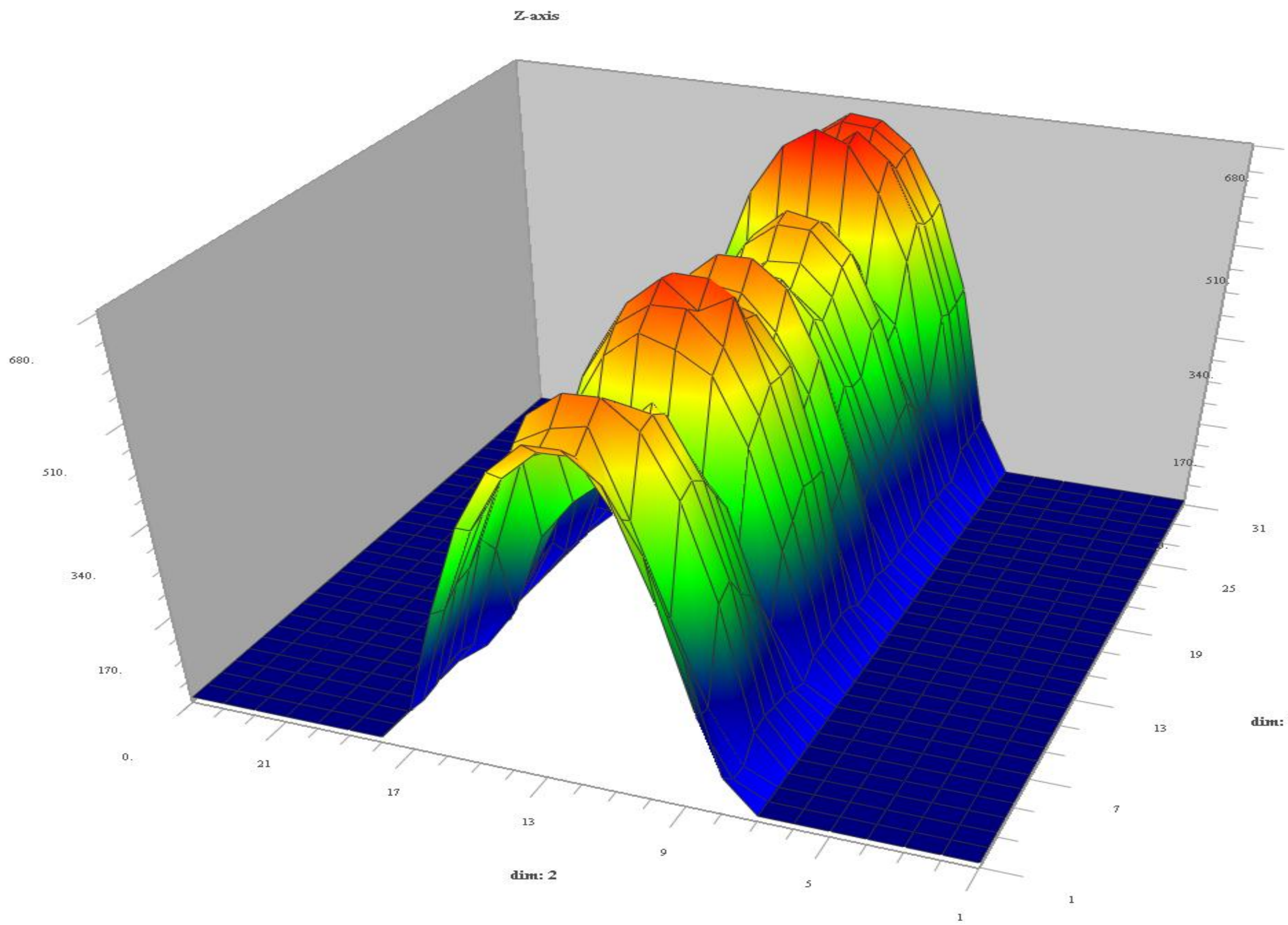
Surrender Power (MU) : 2016-17

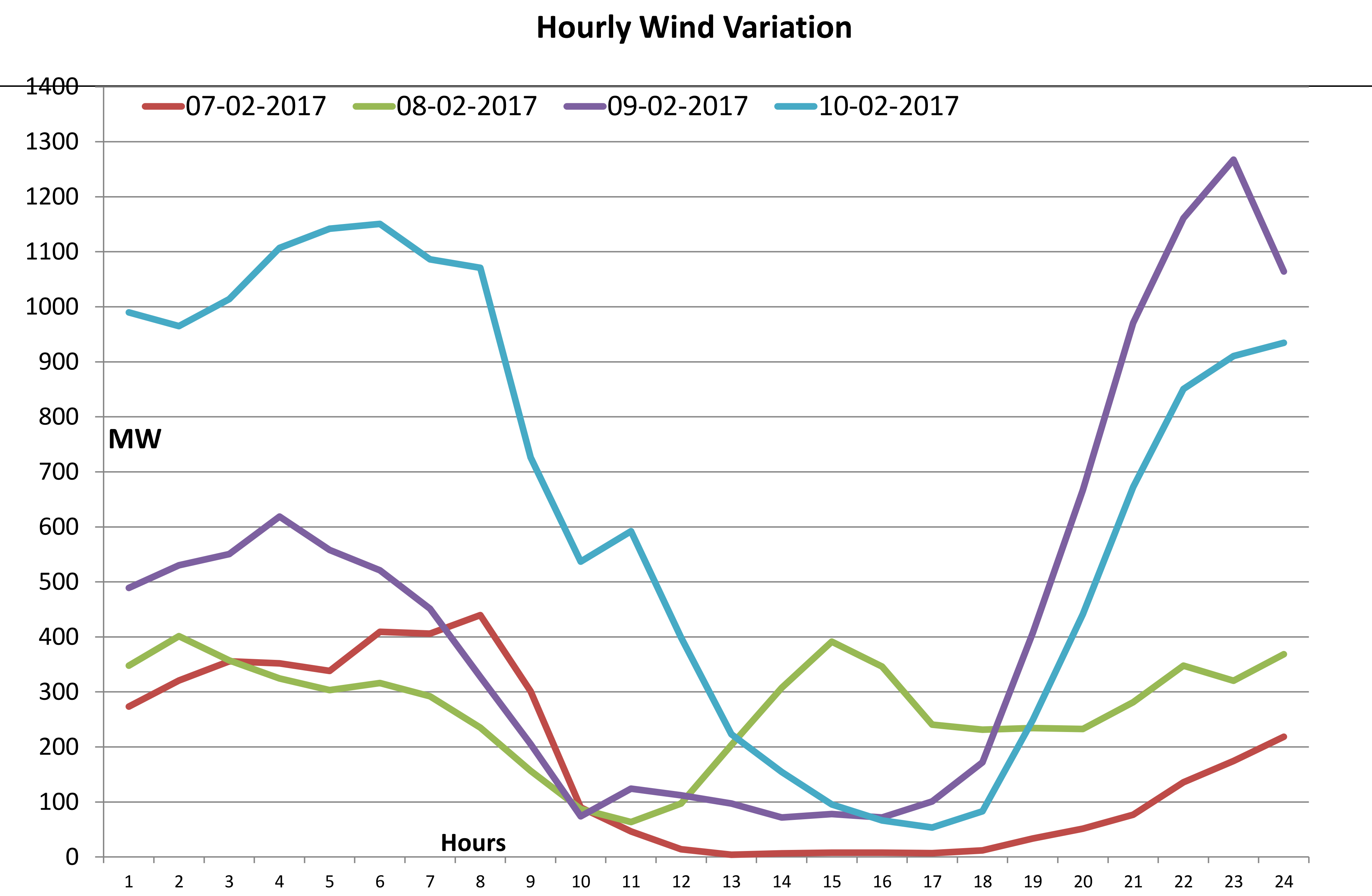
Month	SSGS	ISGS	Sasan	IPP	Total
APR	873.93	296.39	0.00	375.60	1545.91
MAY	1490.85	736.36	25.62	480.73	2733.56
JUN	1860.48	452.13	0.00	525.82	2838.43
JUL	1809.26	846.88	27.23	874.00	3557.37
AUG	1422.75	1130.38	73.26	884.78	3511.16
SEP	1189.88	573.74	5.42	716.84	2485.88
OCT	1390.89	664.29	45.11	732.20	2832.49
NOV	992.87	384.41	0.00	520.81	1898.10
DEC	654.49	286.56	0.22	414.29	1355.56
JAN	948.13	519.97	1.09	364.46	1833.65
Total	**12633.53**	**5891.11**	**177.94**	**5889.53**	**24592.11**

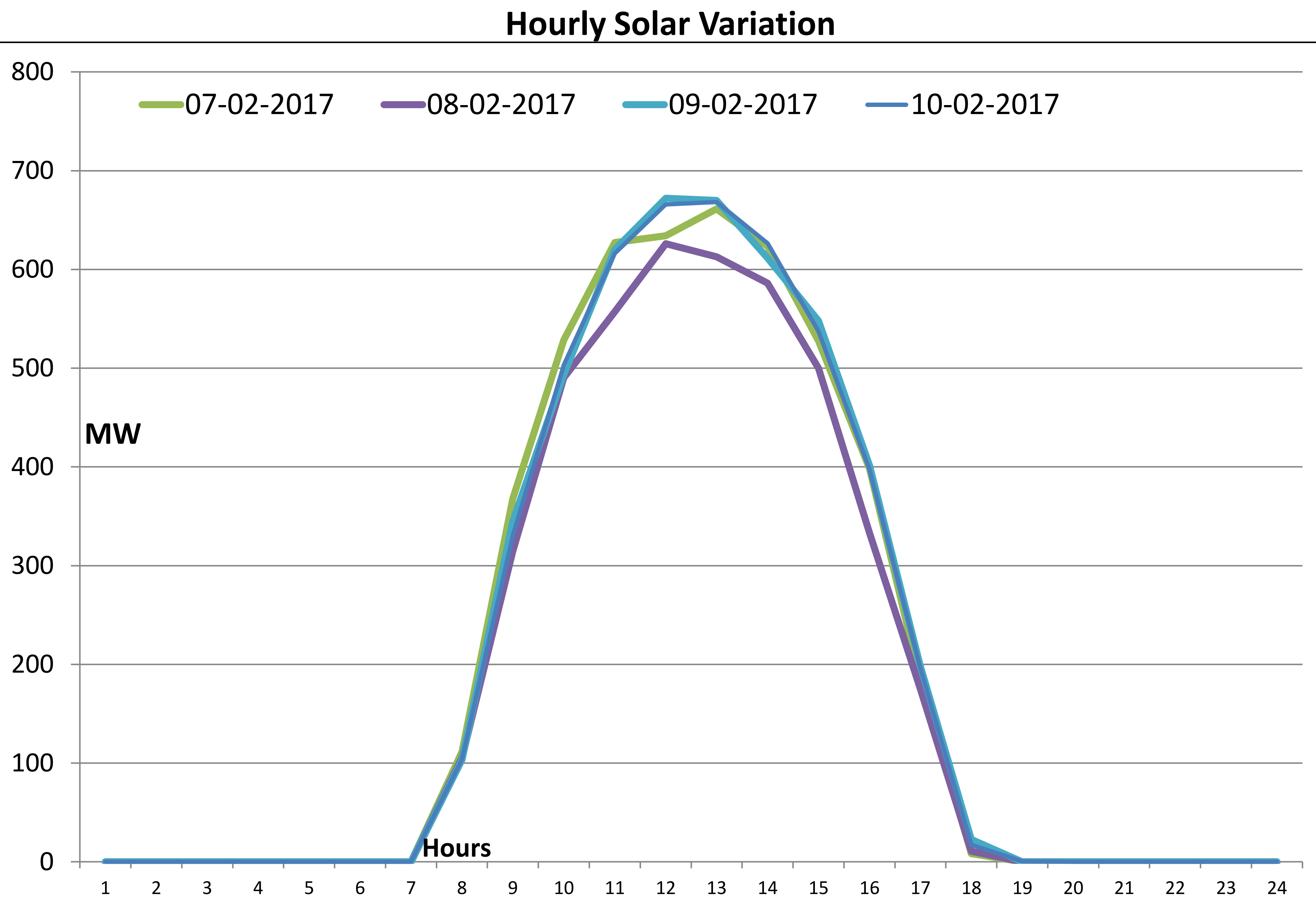
Wind Generation during January 2017



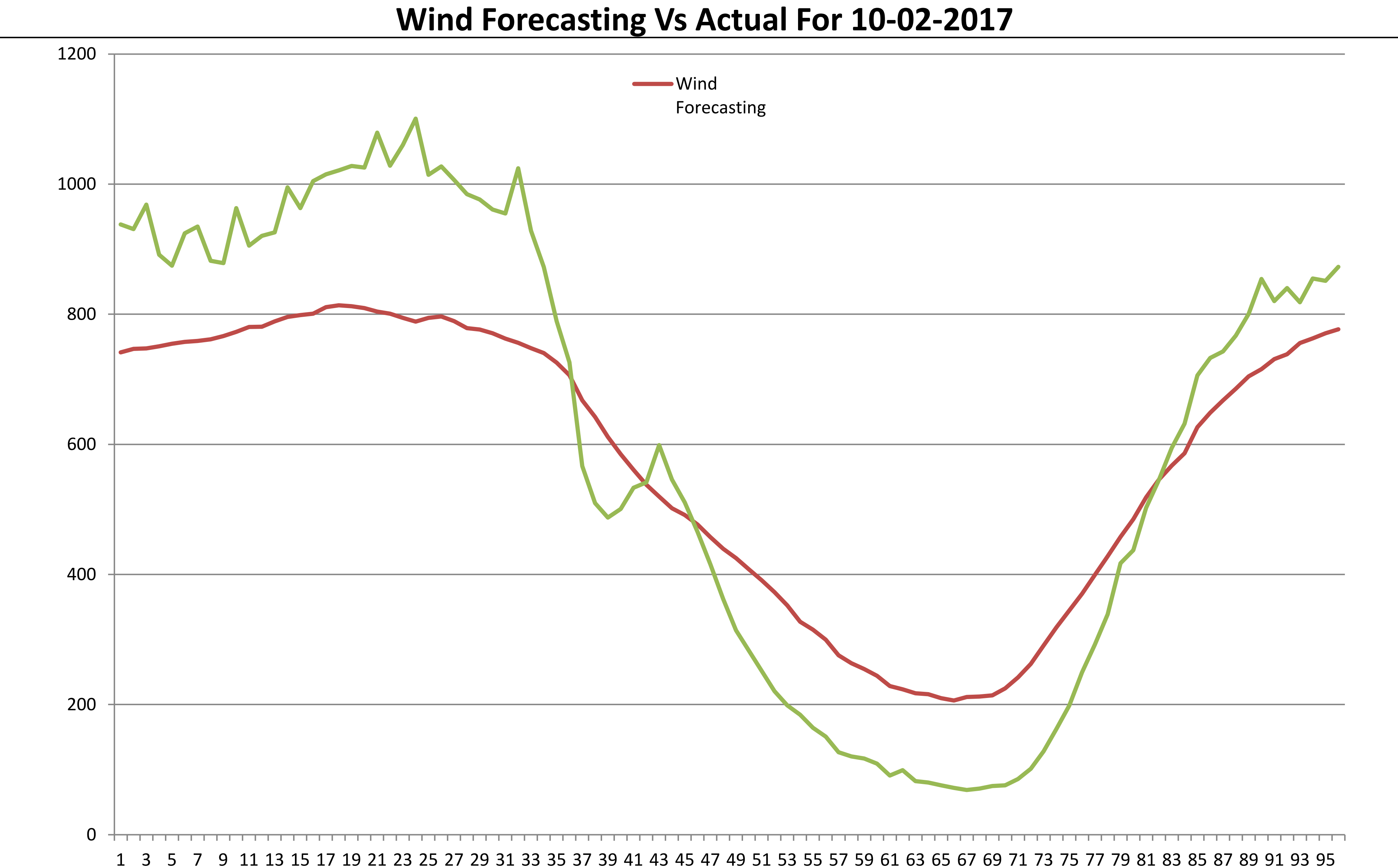
Solar Generation January 2017



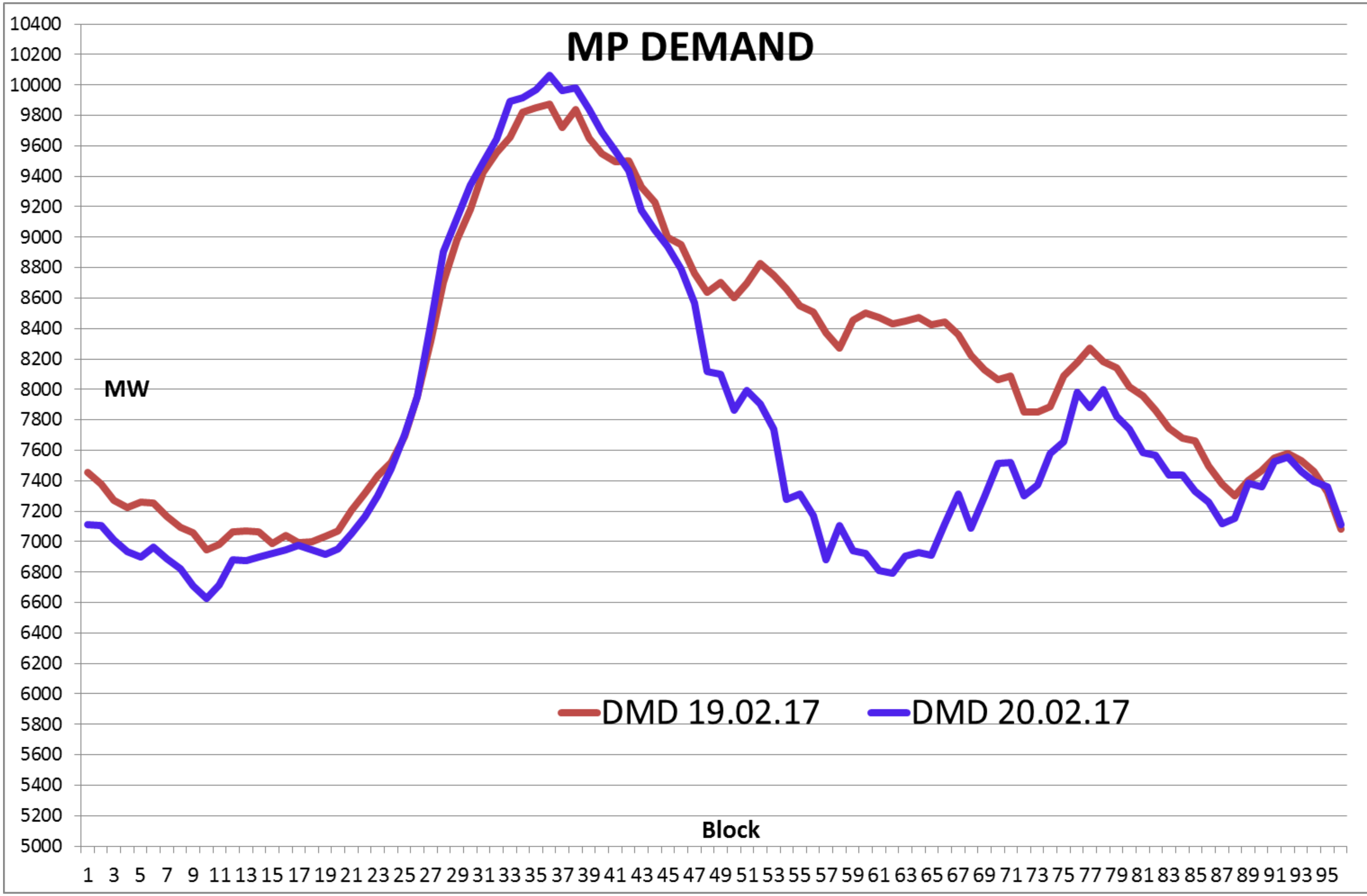

Hourly Wind Variation
07-02-2017
08-02-2017
09-02-2017
10-02-2017
MW
Hours
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24



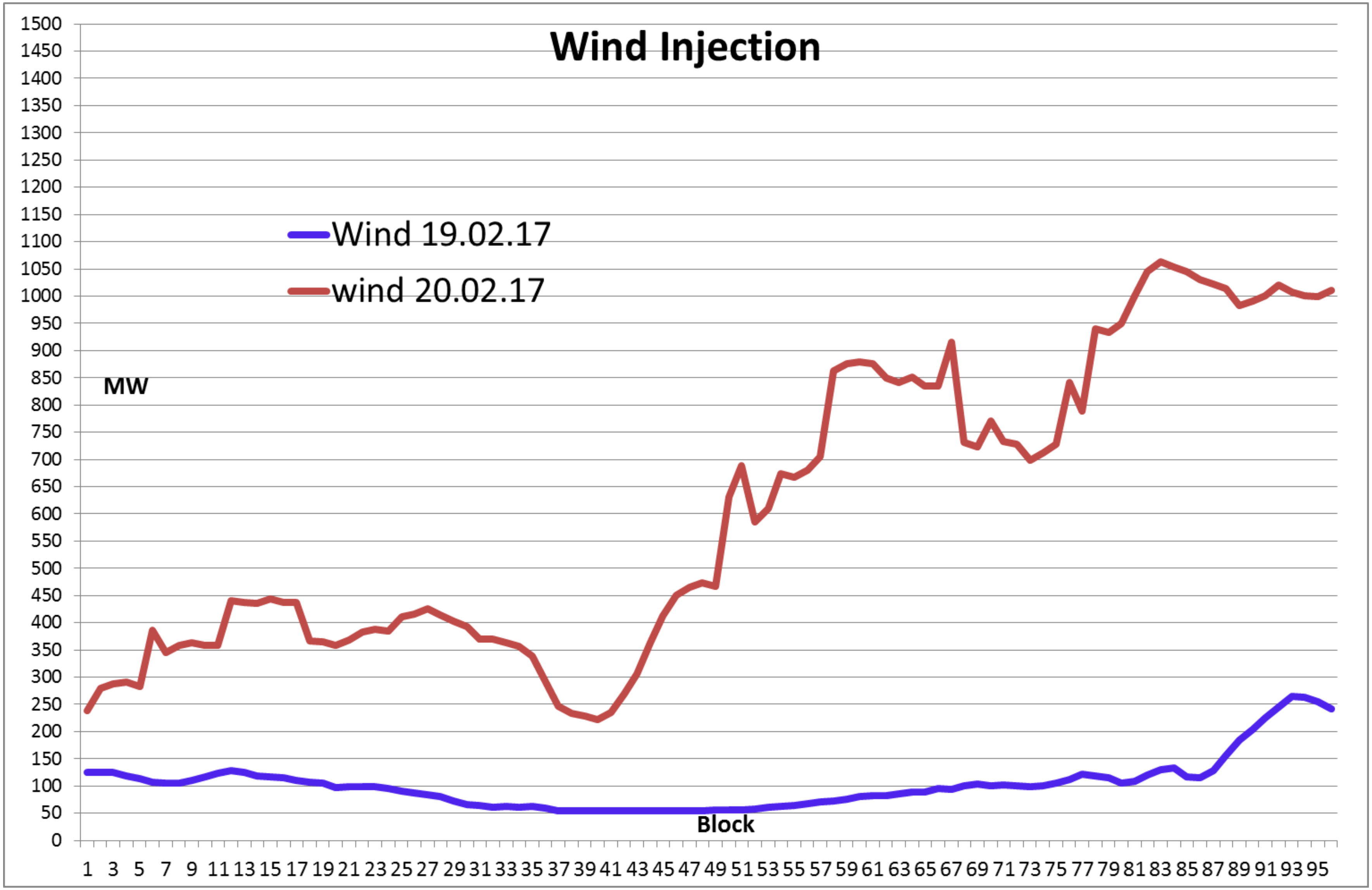
Hourly Solar Variation
07-02-2017
08-02-2017
09-02-2017
10-02-2017
MW
Hours
0
100
200
300
400
500
600
700
800
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24



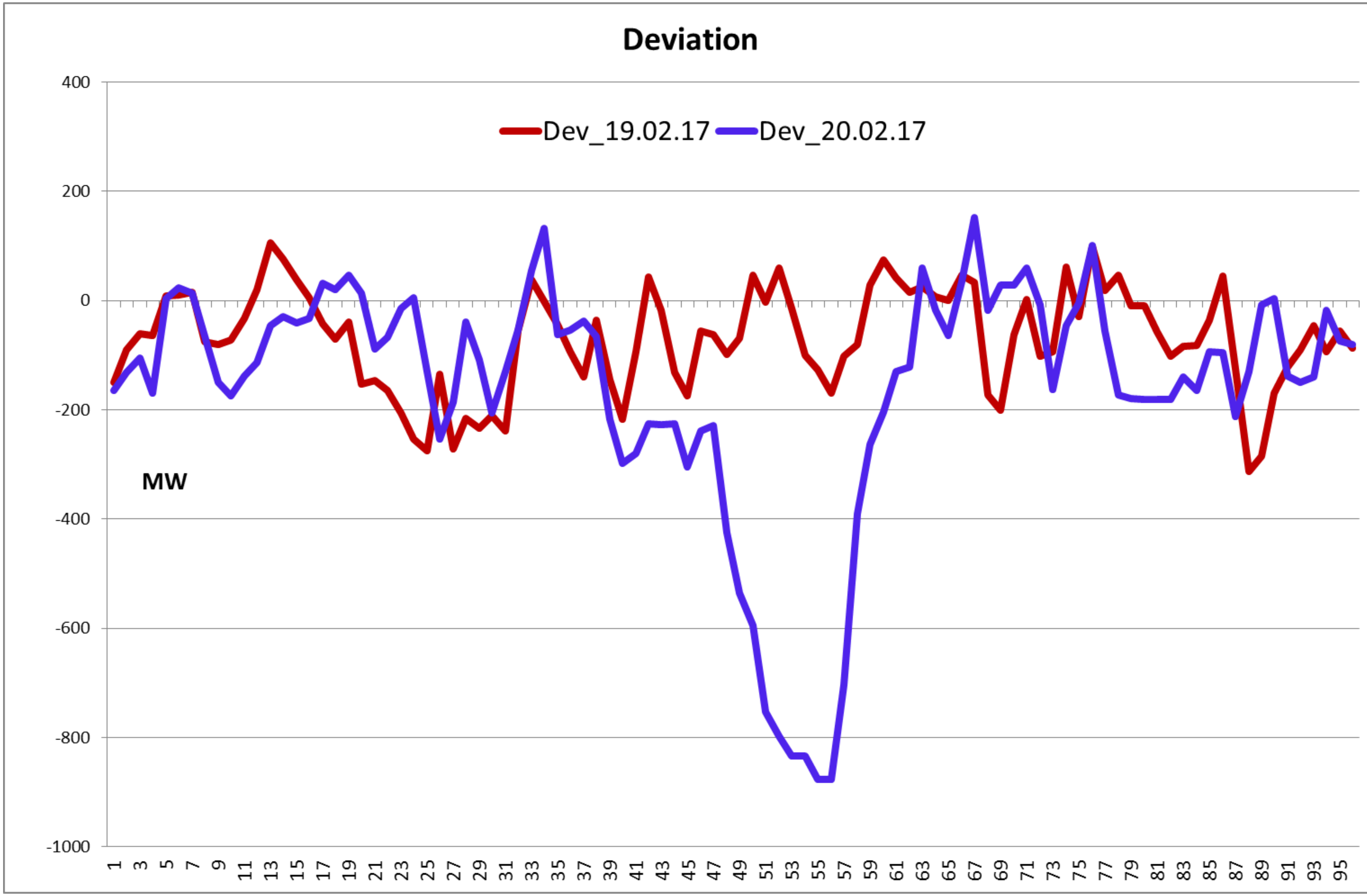
Wind Forecasting Vs Actual For 10-02-2017
1200
1000
800
600
400
200
0
Wind
Forecasting
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95

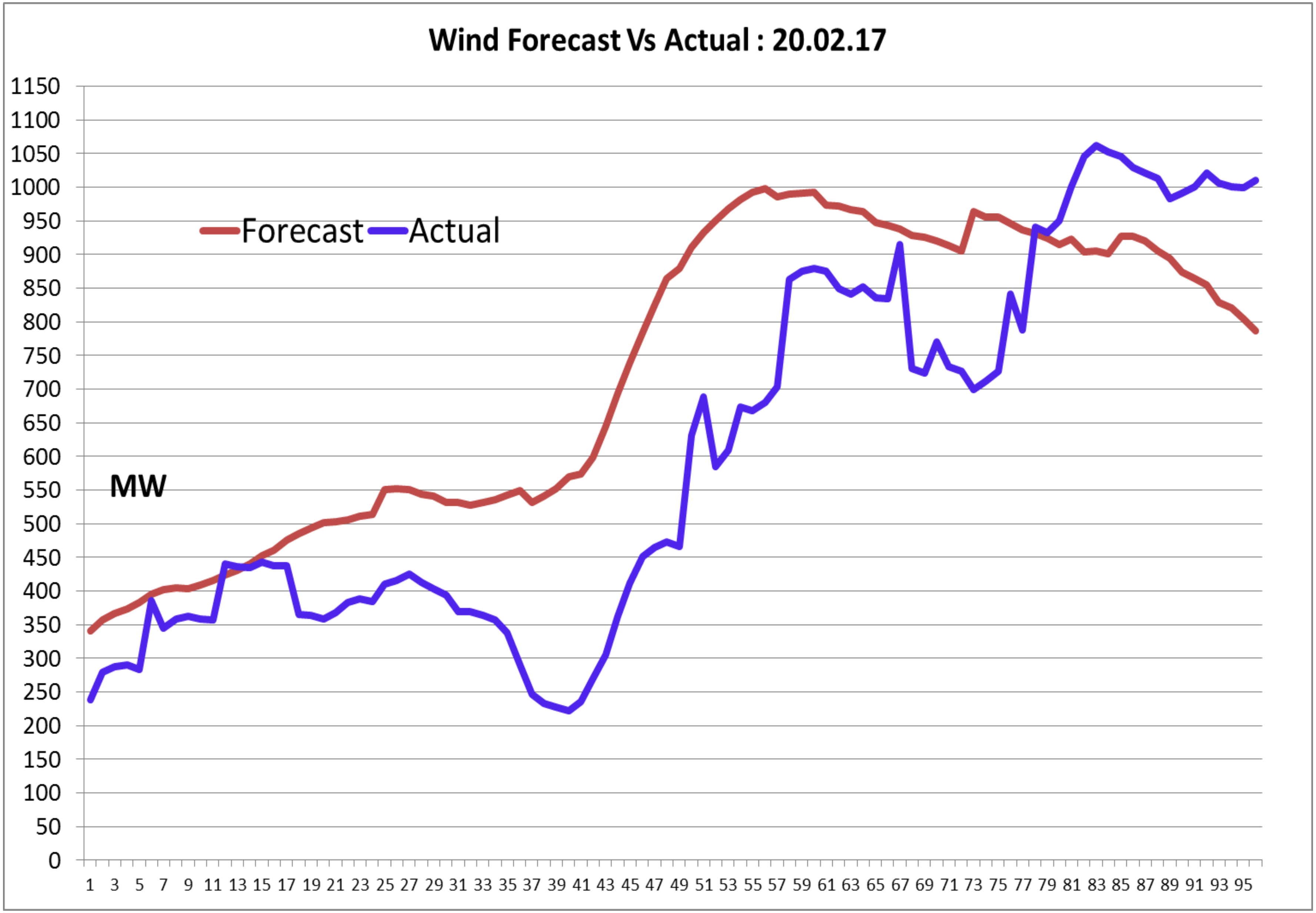


MP DEMAND
MW
Block
DMD 19.02.17
DMD 20.02.17
10400
10200
10000
9800
9600
9400
9200
9000
8800
8600
8400
8200
8000
7800
7600
7400
7200
7000
6800
6600
6400
6200
6000
5800
5600
5400
5200
5000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95



Wind Injection
Wind 19.02.17
wind 20.02.17
MW
Block
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95


Deviation
Dev_19.02.17
Dev_20.02.17
MW
400
200
0
-200
-400
-600
-800
-1000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95



Wind Forecast Vs Actual : 20.02.17
Forecast
Actual
MW
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95

Thank You !

Grid Integration of Renewable Energy Sources – Challenges and Approach

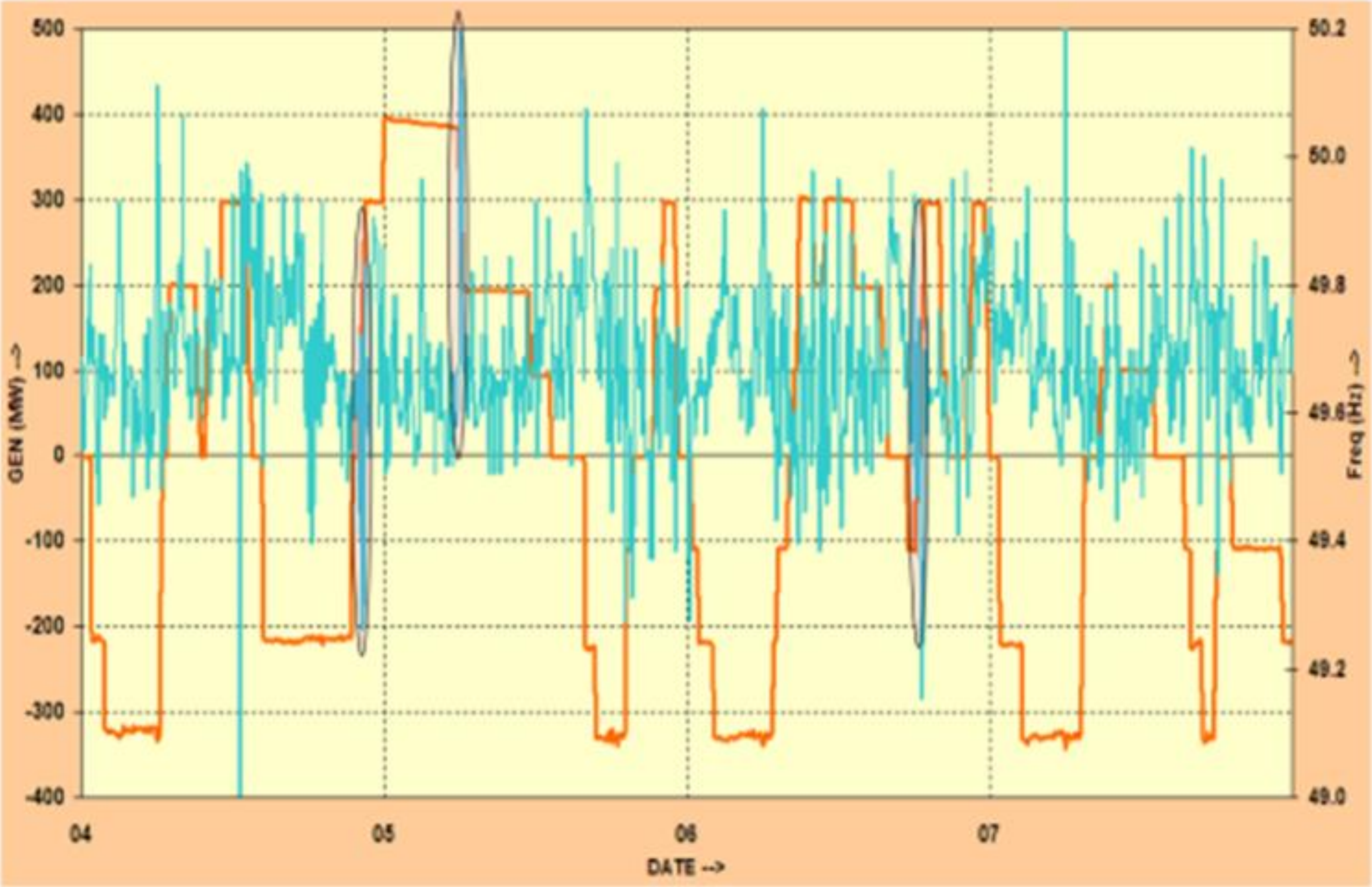
Issues and Challenges in Grid Integration of Renewable Energy Sources

- Frequency Stability
- Voltage Stability
- Transmission congestion
- Angular Stability

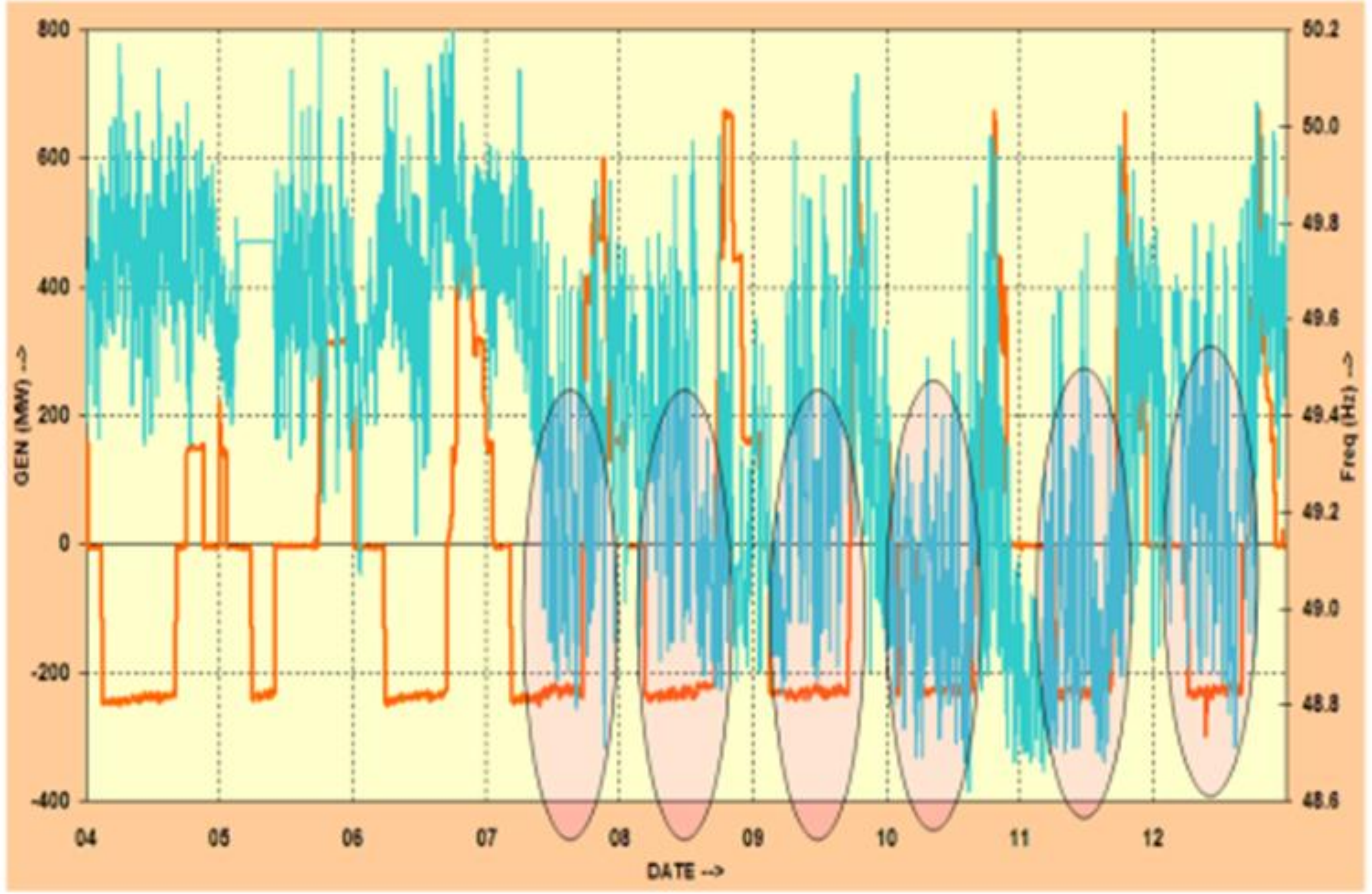
Frequency Stability measures

- Intermittency of power to be balanced by **quick acting generation** like **hydro** (storage, pondage or pumped-storage) and **gas based generating stations.**
- Other balancing sources, like MW scale batteries, Compressed Air Energy Storage (CAES), flywheel, thermal storage, etc. can also be considered for deployment.
- Pumped storage plants, batteries, CAES, flywheel are all plants that have a double benefit of absorbing excess power and releasing the same when needed.
- **Preferable to have the balancing sources close to the wind and solar generation** for optimum utilisation of the intermittent generation and the transmission system.

OPERATION OF PUMP STORAGE PLANT wrt FREQUENCY AT KADAMPARAI



OPERATION OF PUMP STORAGE PLANT wrto FREQUENCY AT PURULIA PS



Voltage Stability

Fluctuating wind and solar generation causes variation in reactive power exchange of the wind and solar generators with the grid, and, therefore, the fluctuations of voltage in the grid.

Mitigation measures of the effects of the multiple start-ups include provision of **dynamic reactive power compensation i.e. SVC (Static VAR compensators)/ STATCOM (Static Synchronous Compensator).**

Most of the advanced energy storage systems can also provide reactive power support without need for consuming active energy.

Locational requirement for reactive power could help in determining appropriate location for deploying energy storage systems that can provide multiple value propositions to the grid.

Transmission congestion

Flexible AC Transmission System (FACTS) devices like phase shifting transformers should be installed to shift power from heavily loaded lines to lightly loaded lines in parallel paths.

Strategically placed energy storage devices can also help in relieving transmission congestion by time shifting the flow of energy across constrained paths

Alternately, In order to harness the huge potential of RES in specific States, **high capacity Inter-State and Inter-Regional corridors transmission corridors could be constructed linking high concentration renewable generation areas to balancing generation already located elsewhere in the grid. Market Integration** would have to be provisioned.

Angular Stability

Various type of FACTS devices, which would need to change dynamically, to change the power system parameters in accordance with changing topology of intermittent generation from renewable energy sources, may need to be installed.

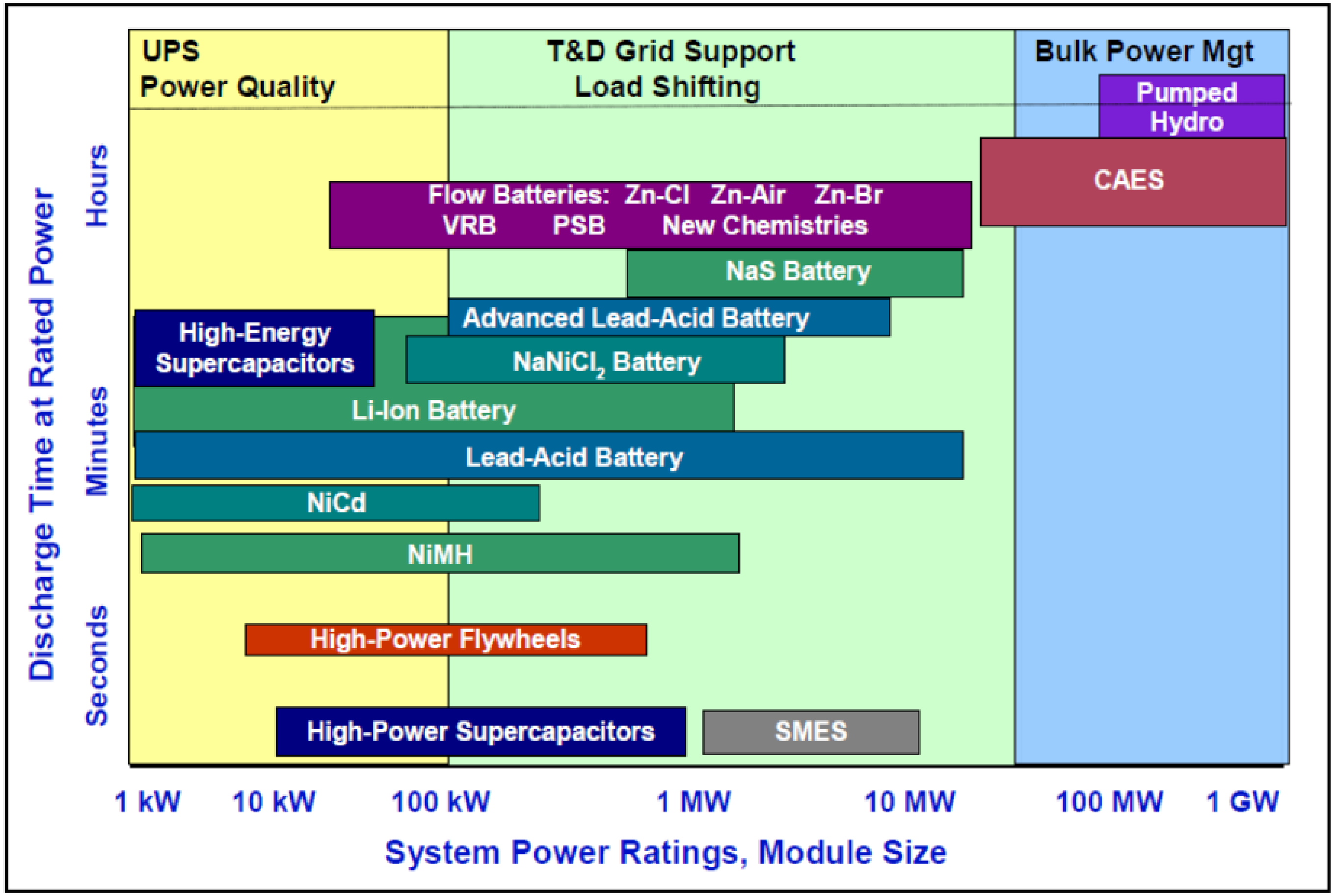
System Operator should be aided in this by Phasor Measurement Units (PMUs) installed at critical points in the grid, for visibility in the grid w.r.t. real-time angular difference.

Economics of Energy Storage

While deciding economics of energy storage for renewable integration, a number of key factors need to be considered. These include

- Size of storage (Power vs energy)
- Cycle life
- Depth of Discharge during each cycle (has impact on number of cycles for most electro chemical batteries)
- Charge / Discharge rate (C rate)
- Space and geographical requirements (specially required for pumped hydro and CAES projects)

Available energy storage technologies (Power vs Discharge Duration) (Source: EPRI / DOE Energy Storage Handbook)



Demand Response

- One of the biggest sources of balancing the intermittency, which is being increasingly used in developed countries, is ***demand response***.
- Immediately available
- Rules and Smart Meters need to be put into place
- Essential and non-essential loads accompanied with 24x7 and Interruptible tariff

Renewable Power and Smart Grid

- With the increase in the capacity of Renewable Power ,tariff restructuring in the grid is required for demand response along with optimization of generation of different generators.

- This underlines the need for Smart Grid which provides following benefits as per EPRI cost benefit analysis:

    - Optimized Generator Operation.

    - Reduced generation and transmission and distribution capacity.

Renewable Power and Smart Grid

- Reduced Ancillary Cost.
- Reduced Congestion Cost.
- Reduced equipment failure.
- Reduced meter reading cost.
- Reduced electricity theft.
- Reduced losses.

Renewable Power and Smart Grid

- Reduced outages.
- Reduced fossil fuel usage.
- Reduced CO_2, SO_x, NO_x emissions.
- Reduced Sags and Swells.

Thank You



MAHATRANSCO
Maharashtra State Electricity Transmission Co. Ltd.

CEA-Technical Committee for Study of Balancing requirement to facilitate large scale RE integration and associated issues

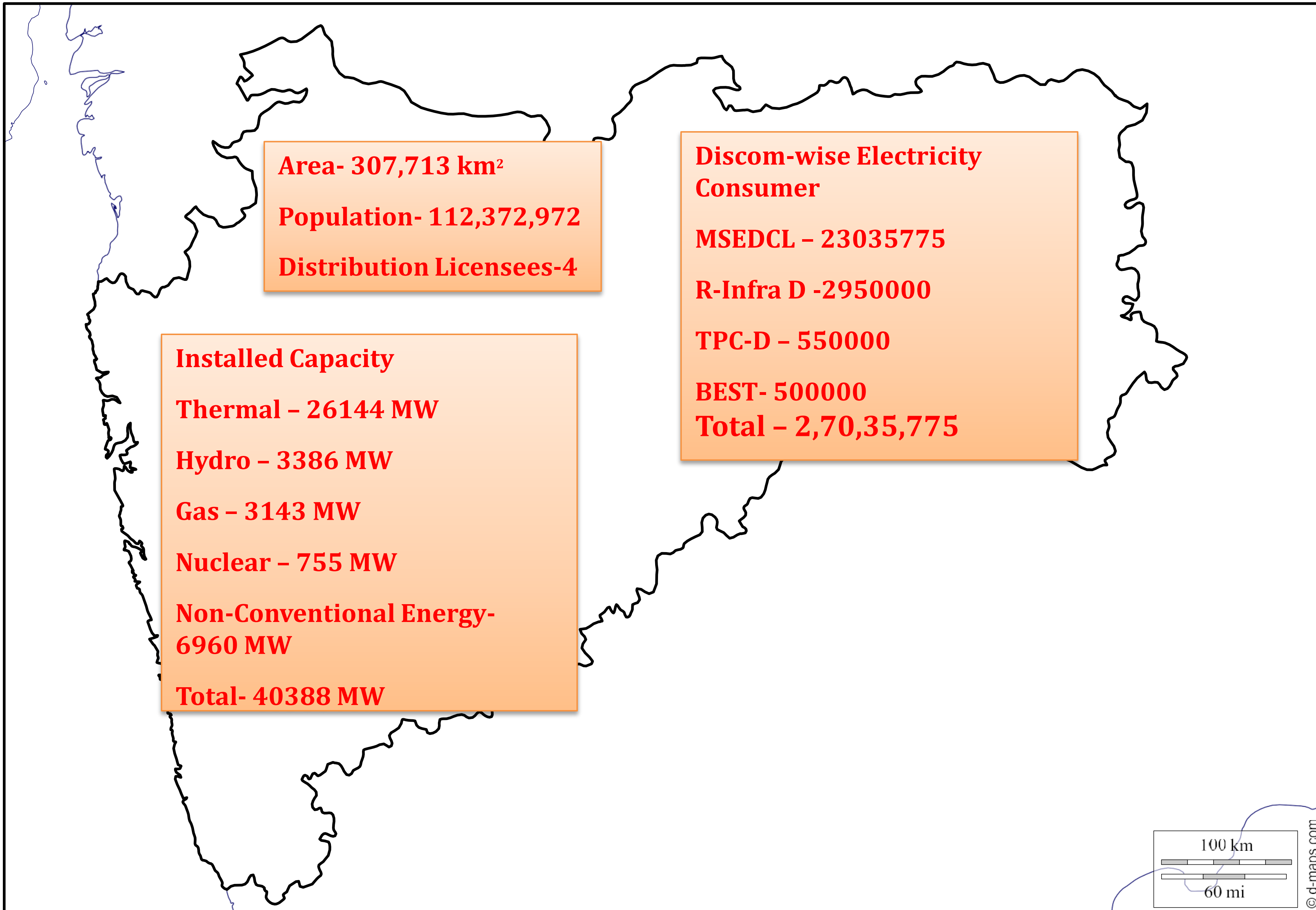
Presentation by

MAHARASHTRA STATE LOAD DESPATCH CENTRE

23rd February 2017

Maharashtra System Overview as on 31.01.2017

MAHATRANSCO
Maharashtra State Electricity Transmission Co. Ltd.



Area- 307,713 km²

Population- 112,372,972

Distribution Licensees-4

Installed Capacity

Thermal – 26144 MW

Hydro – 3386 MW

Gas – 3143 MW

Nuclear – 755 MW

Non-Conventional Energy- 6960 MW

Total- 40388 MW

Discom-wise Electricity Consumer

MSEDCL – 23035775

R-Infra D -2950000

TPC-D – 550000

BEST- 500000

Total – 2,70,35,775

MAHATRANSCO
Maharashtra State Electricity Transmission Co. Ltd.

Installed Capacity of Maharashtra State

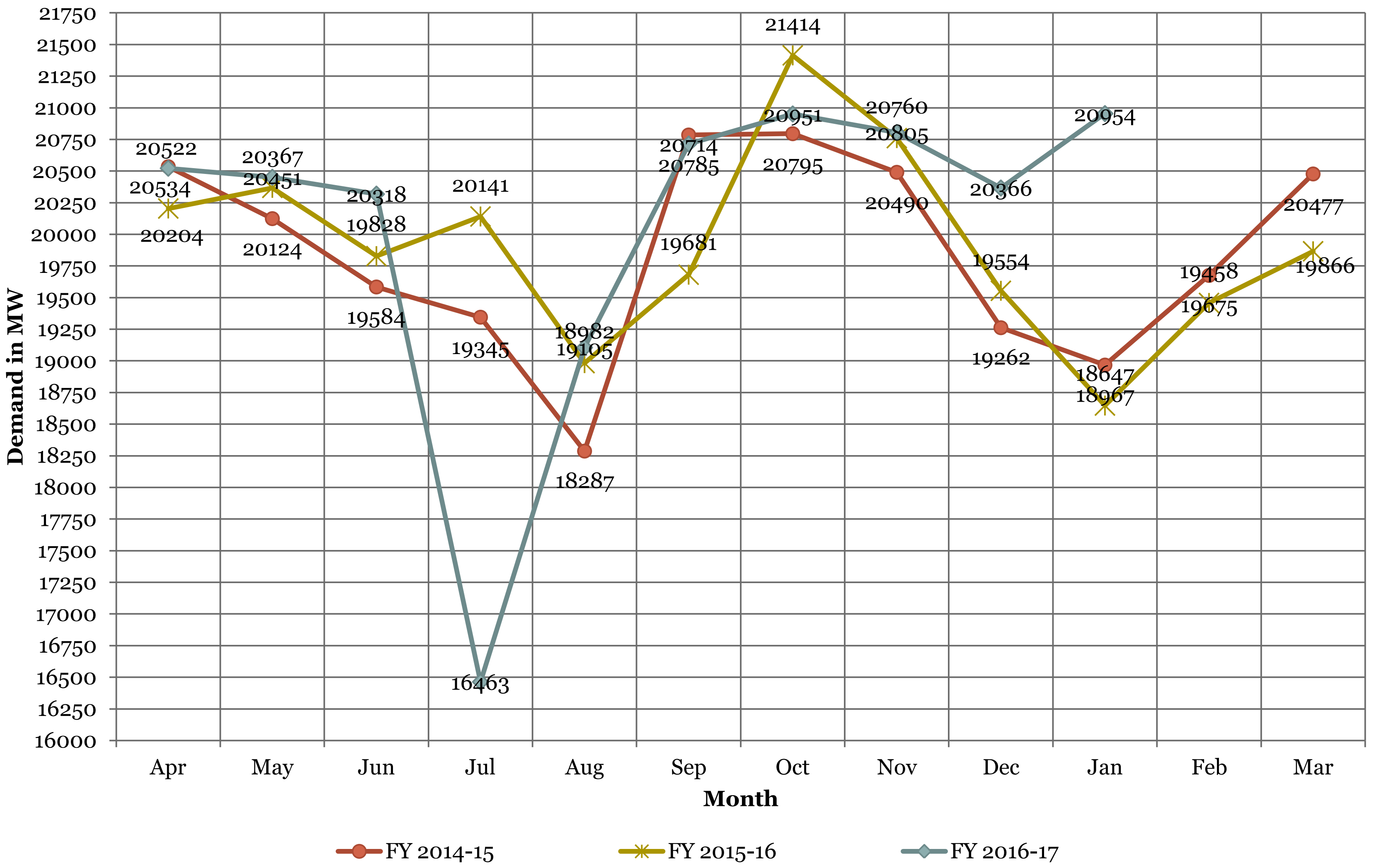
(as on 31-12-2016)

Maharashtra System Peak Installed Derated Capacity along with its CS Share						
Particulars	Hydro	Thermal	Gas	Nuclear	NCE	Total
MSPGCL	2450	10580	672	0	0	**13702**
TPCL	447	1250	180	0	0	**1877**
REL	0	500	0	0	0	**500**
IPP / CPP	44	9125	388	0	6960	**16517**
CS(MS)	445	4689	1903	755	0	**7792**
Total	**3386**	**26144**	**3143**	**755**	**6960**	**40388**

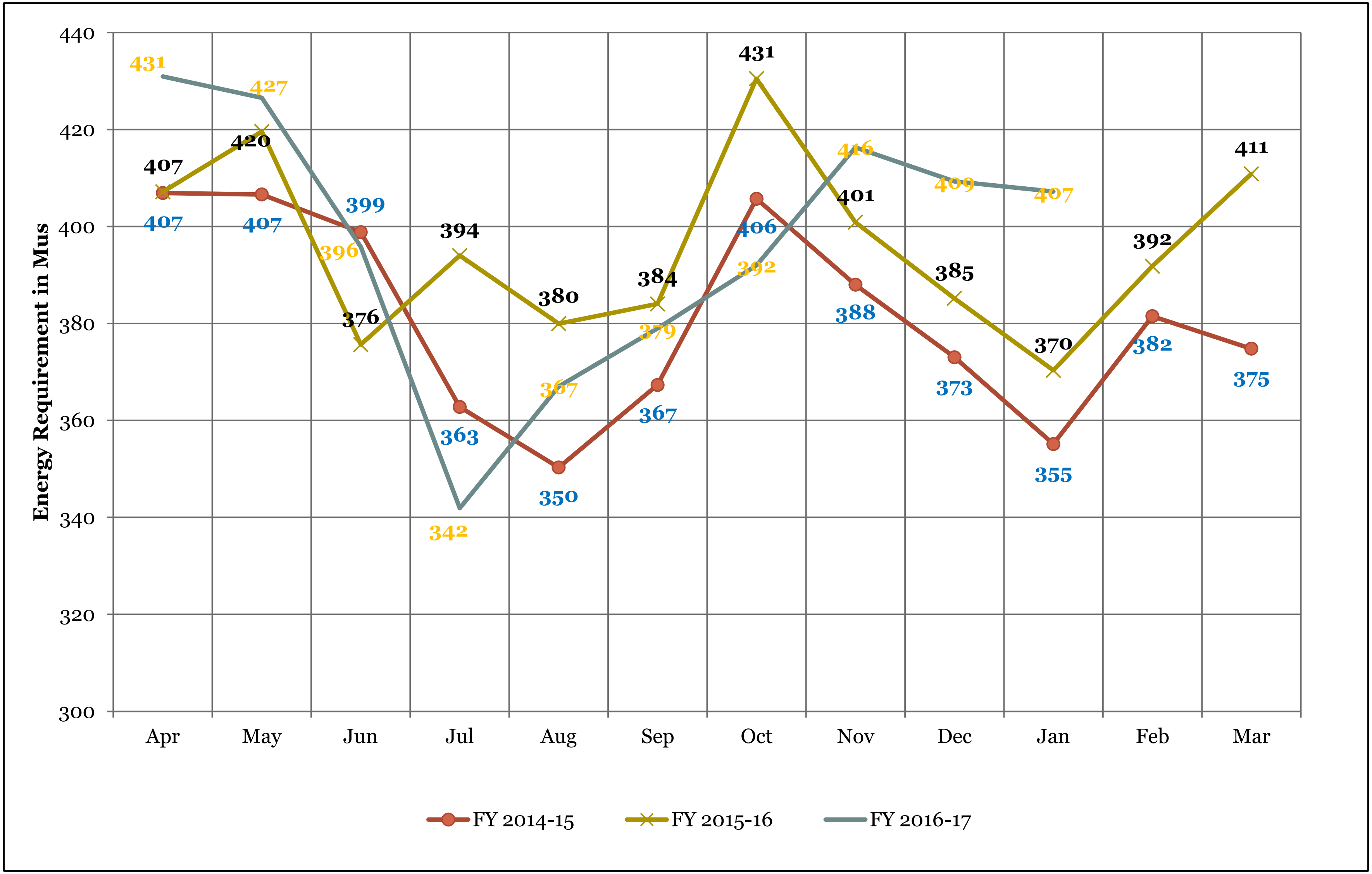
NON CONVENTIONAL ENERGY (NCE)SOURCES		
Source:- MEDA NOTE AS ON 31.03.2016	**Wind**	**4662**
	Small Hydro	**284**
	Bio-Mass	**200**
	Bagasse Co-Gen	**1415**
	Urban Waste	**3**
	Solar Power	**362**
	Industrial Waste	**34**
	Total NCE	**6960**

- **State has catered 21818MW with out any constraints on 20.02.2017 at 12:00Hrs.**
- **Wind Power maximum injection was 2578 MW on 02.08.2016 at 06:00 Hrs without any curtailment.**

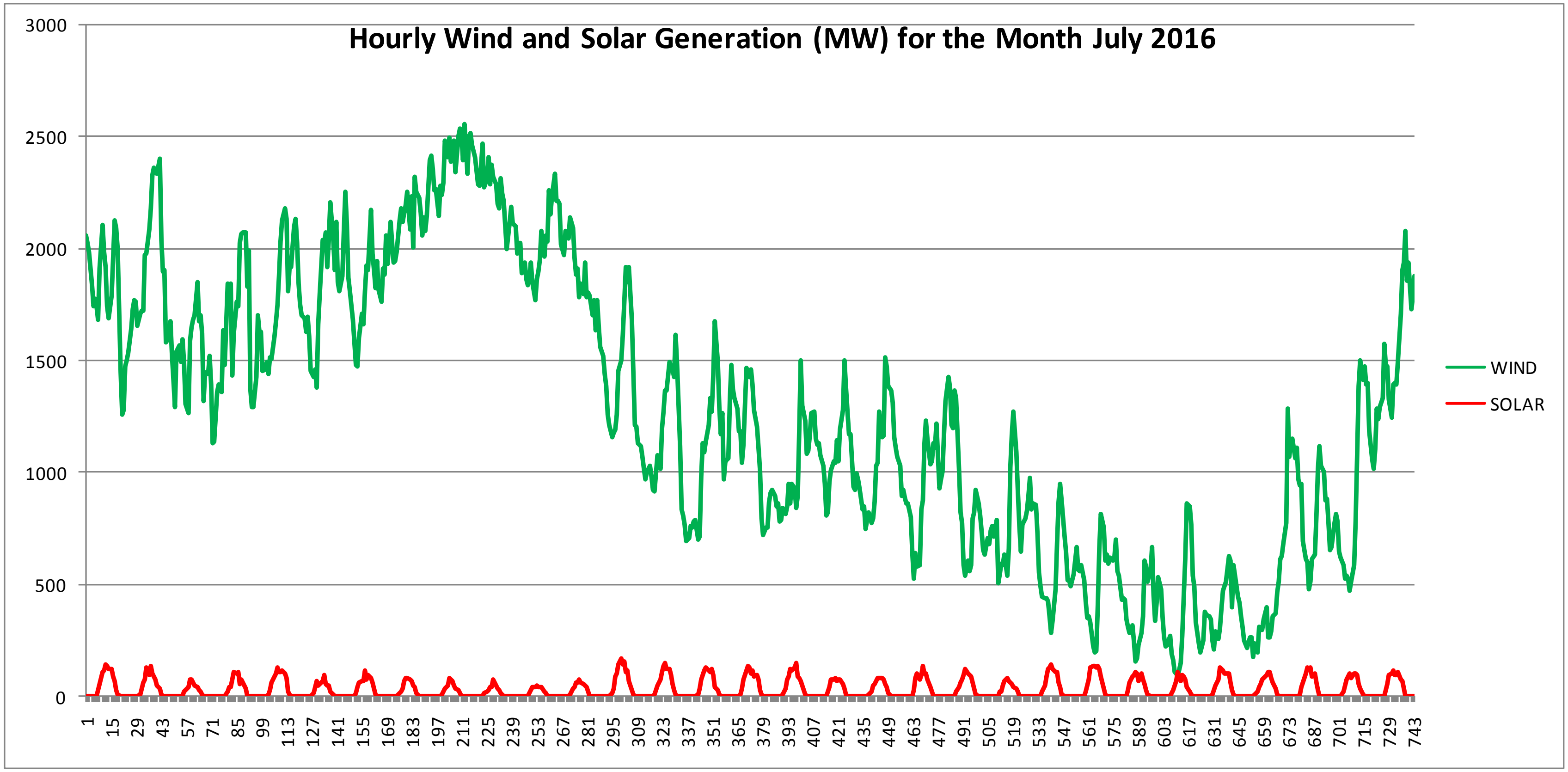
Maharashtra State Monthly Max Demand For the Period Apr-2014 to Jan-2017



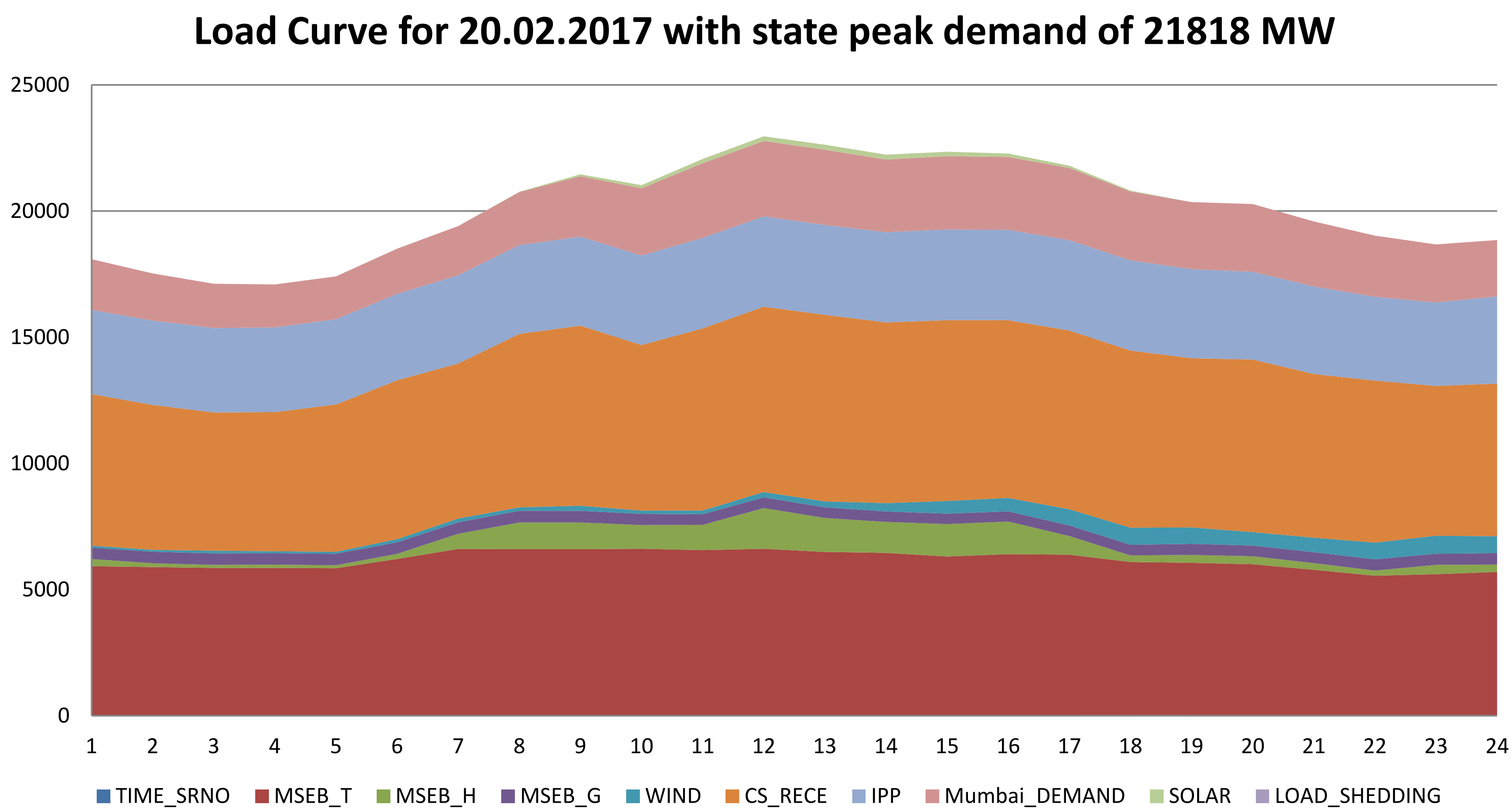
Maharashtra State Monthly Average Energy Req. For the Period Apr-14 to Jan-17



Maharashtra State Hourly Wind and Solar injection for the month of July 2016



Maharashtra State Load Curve for 20.02.2017 with peak demand of 21818 MW



Large Scale RE integration

1. Studies made under USAID project by MoP and MNRE

a) Impact on Grid operation- Backing down of thermal generation and balancing requirement

b) Variation analysis at National and regional level

c) Challenges of balancing requirement and strategic development

2. Studies made by Lawrence Berkeley National Laboratory-US

Techno economic assessment of integrating 100S+60W RE

a) 13th Plan scenario

b) RE mission considering 100S+60W+15others

c) National action plan on climate change (NAPCC)

3. Studies made by NITI Ayog on State RE integration- Strategic development

State RE plan and strategic development studies at state level

4. Forecasting and Scheduling of RE Power

Technology and IT support with weather forecast to build-up forecasting capability for better grid management with reference to RE power.
Regulatory framework required for addressing deviations of RE.

Large Scale RE integration: State specific issues

Studies made by NITI Ayog on State RE integration- Strategic development

State RE plan and strategic development studies at state level

- **USAID and LBNL studies are limited to National and Regional level which shown different characteristic and balancing requirement or curtailment projections in a different way.**
- **There is need to include State model in the studies as every state system has different RE mix, characteristic behavior and different balancing needs. Further 70 % of the RE energy is expected to integrate at State level.**
- **Robust transmission and flexibility in generation are key factors**
- **Existing PSP and future needs for ramping up/ down capacity is also different at state level than at Regional or National level**
- **SLDC development at state level need to be focused as essential requirement, including REMC establishment and real time visibility.**
- **Regulatory framework requirement at state level**

- THANK YOU

TS TRANSCO
TS SLDC

RENEWABLE ENERGY
INSTALLED CAPACITY AS ON 21-02-2017

Sl.No	District	Solar(MW)	Wind(MW)	Total(MW)
1	Mahabubnagar	492	0	492
2	Medak	320	0	320
3	Nalgonda	69	0	69
4	Ranga Reddy	155	99	254
5	Nizamabad	31	0	31
6	Karimnagar	40	0	40
7	Warangal	10	0	10
8	Adilabad	58	0	58
	Total	**1174**	**99**	**1273**

INSTALLED CAPACITY IN MAHABOOBNAGAR DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	100	0	100
2	132 KV	155	0	155
3	33 KV	235	0	235
4	11 KV	2	0	2
Total		492	0	492

INSTALLED CAPACITY IN MEDAK DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	119	0	119
3	33 KV	201	0	201
4	11 KV	1	0	1
Total		**320**	**0**	**320**

INSTALLED CAPACITY IN NALGONDA DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	0	0	0
3	33 KV	68	0	68
4	11 KV	1	0	1
Total		**69**	**0**	**69**

INSTALLED CAPACITY IN RANGA REDDY DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	80	99	179
3	33 KV	74	0	74
4	11 KV	1	0	1
Total		**155**	**99**	**254**

INSTALLED CAPACITY IN NIZAMABAD DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	20	0	20
3	33 KV	11	0	11
4	11 KV	0	0	0
Total		**31**	**0**	**31**

INSTALLED CAPACITY IN KARIMNAGAR DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	25	0	25
3	33 KV	15	0	15
4	11 KV	0	0	0
Total		**40**	**0**	**40**

INSTALLED CAPACITY IN WARANGAL DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	0	0	0
3	33 KV	10	0	10
4	11 KV	0	0	0
Total		**10**	**0**	**10**

INSTALLED CAPACITY IN ADILABAD DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	48	0	48
3	33 KV	10	0	10
4	11 KV	0	0	0
Total		**58**	**0**	**58**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017

Sl.No	District	Solar(MW)	Wind(MW)	Total(MW)
1	Mahabubnagar	409	0	409
2	Medak	415	0	415
3	Nalgonda	266	0	266
4	Ranga Reddy	24	100	124
5	Nizamabad	377	0	377
6	Karimnagar	165	0	165
7	Warangal	104	0	104
8	Adilabad	130	0	130
9	Khammam	5	0	5
	Total	1895	100	1995

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN MAHABOOBNAGAR DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	200	0	200
2	132 KV	100	0	100
3	33 KV	109	0	109
Total		**409**	**0**	**409**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN MEDAK DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	45	0	45
2	132 KV	305	0	305
3	33 KV	65	0	65
Total		**415**	**0**	**415**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN NALGONDA DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	100	0	100
2	132 KV	98	0	98
3	33 KV	68	0	68
Total		**266**	**0**	**266**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN RANGA REDDY DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	0	100	100
3	33 KV	24	0	24
Total		**24**	**0**	**124**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN NIZAMABAD DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	50	0	50
2	132 KV	227	0	227
3	33 KV	100	0	100
Total		**377**	**0**	**377**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN KARIMNAGAR DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	90	0	90
3	33 KV	75	0	75
Total		**165**	**0**	**165**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN WARANGAL DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	87	0	87
3	33 KV	17	0	17
Total		**104**	**0**	**104**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN ADILABAD DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	100	0	100
3	33 KV	30	0	30
Total		**130**	**0**	**130**

RENEWABLE ENERGY CAPACITY UNDER PROGRESS AS ON 21-02-2017 IN KHAMMAM DISTRICT

Sl.No	Voltage level	Solar(MW)	Wind(MW)	Total(MW)
1	220 KV	0	0	0
2	132 KV	0	0	0
3	33 KV	5	0	5
Total		**5**	**0**	**5**

PROBLEMS ENCOUNTERED IN DEALING WITH VARIABLE AND INTERMITTTENT GENERATION FROM RENEWABLES

- Forecasting.
  - Weather data.
- Agricultural demand increased 25% in a year and depends on the monsoons.
- Demand side management. Adjusting Agl loads.
- Transmission connectivity.
- Storage.
- Effect of other states in regional grid.

Steps taken to handle the problem

- TS has only 98 MW wind generation.
- Better forecasting.
- Grid integrated solar ~1100 MW and coming ~2000 MW. Planned agriculture supply in the day time.
- Two pumped storage works are in progress.
- Initiate storage capacity addition in solar rich districts.
- To meet future demand building up transmission network.
- By increasing/decreasing Thermal and Hydel Generation as per requirement.

AVAILABLE PUMPED HYDRO PROJECTS

S.NO.	NAME OF THE STATION	UNIT WISE CAPACITY	CAPACITY IN MW
1	Srisailam Left Bank Power House(SSLM LBPH)	6x176MW	1056MW
2	Nargarjuna Sagar Power House	7x122MW	854MW

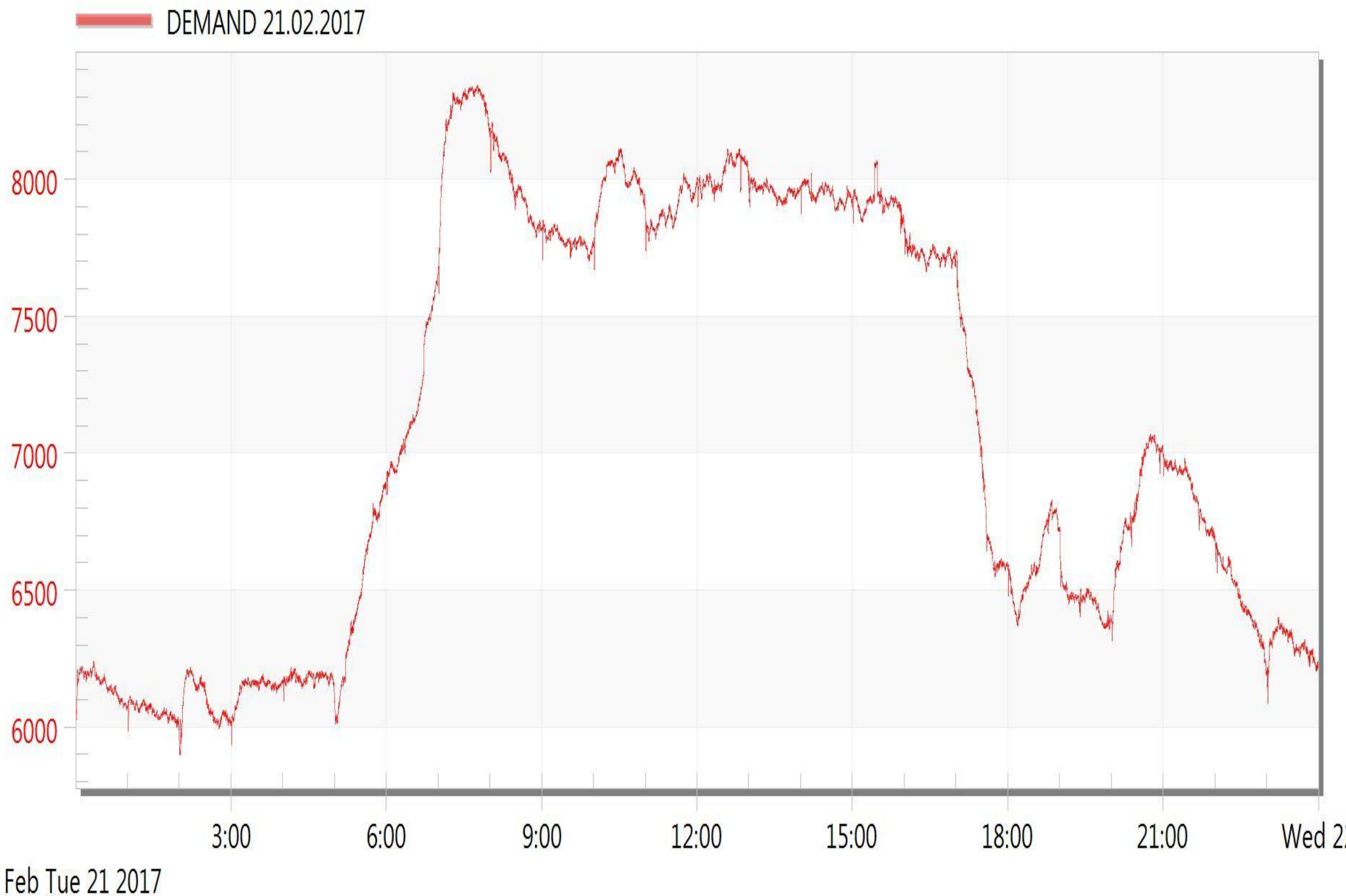
LIMITATIONS

- Srisailam Left Bank Power House (SSLM LBPH) will be available only when Nagarjuna Sagar reservoir level is above 540 ft (Net head should be more than 100 ft). If the Nagarjuna Sagar level is below this 540 ft, a Wear Dam is required which is under renovation.
- Nagarjuna Sagar Power House Pumps will be available only after completion of Tailpond works which are in progress.

Intra-state transmission/distribution system facing congestion due to RE generation

- Solar generation in TS is distributed.
- Wind only 100 MW.
- To meet additional solar, strengthening the transmission/distribution system.

TS DEMAND



DEMAND 21.02.2017
8000
7500
7000
6500
6000
3:00
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9:00
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15:00
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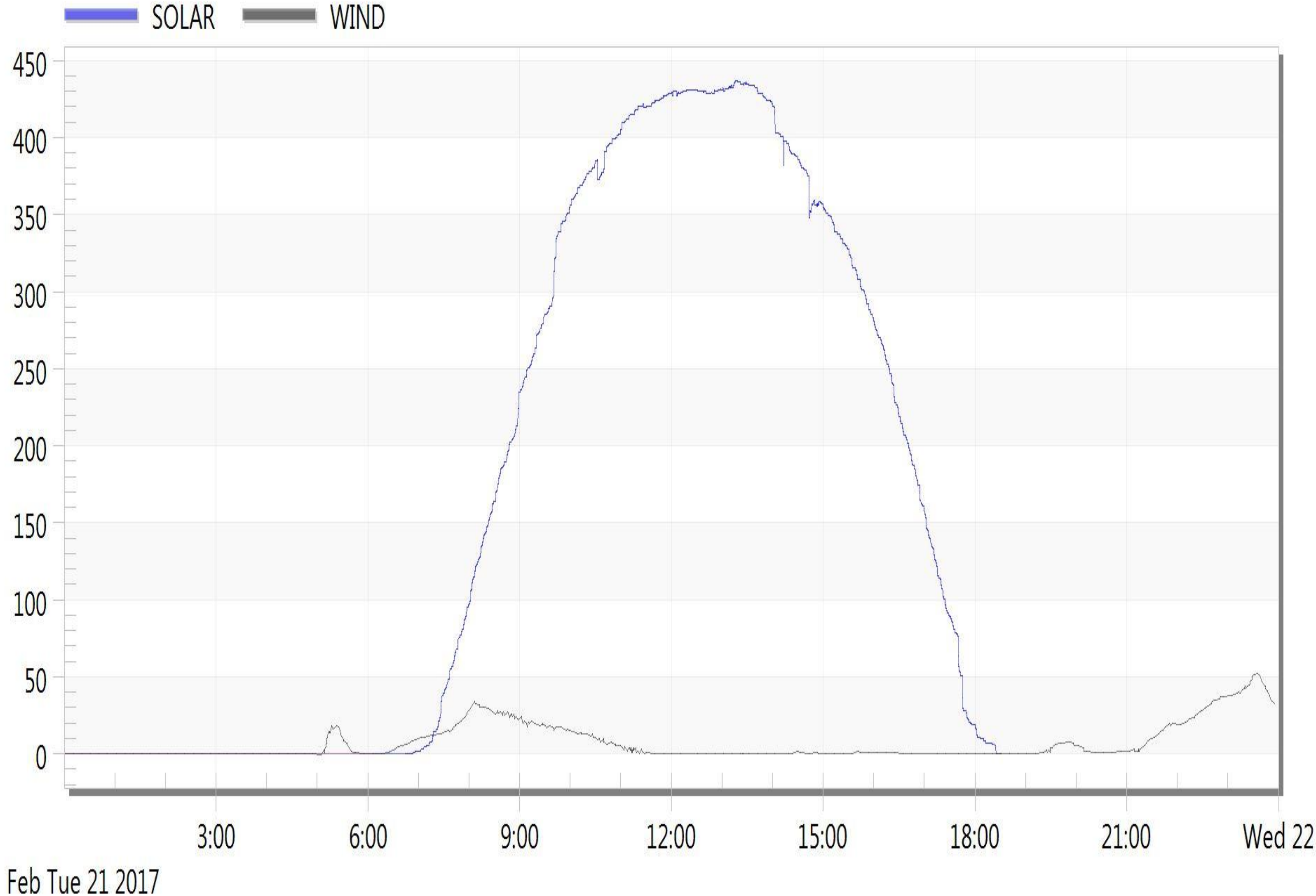
21:00
Wed 22
Feb Tue 21 2017

SOLAR AND WIND 21-02-2017



THANK YOU