Decarbonising India's Electricity Sector towards Net-Zero: Insights from National and Sub-national Studies

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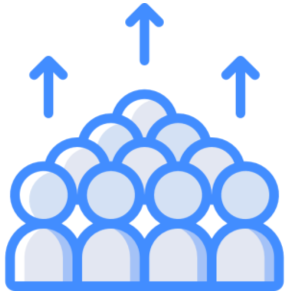
Energy transition in India : Backdrop



We are almost a **fifth of the global population** and increasing.
Rural to urban migration is expected to tilt the proportion living in urban centres to over 40%.

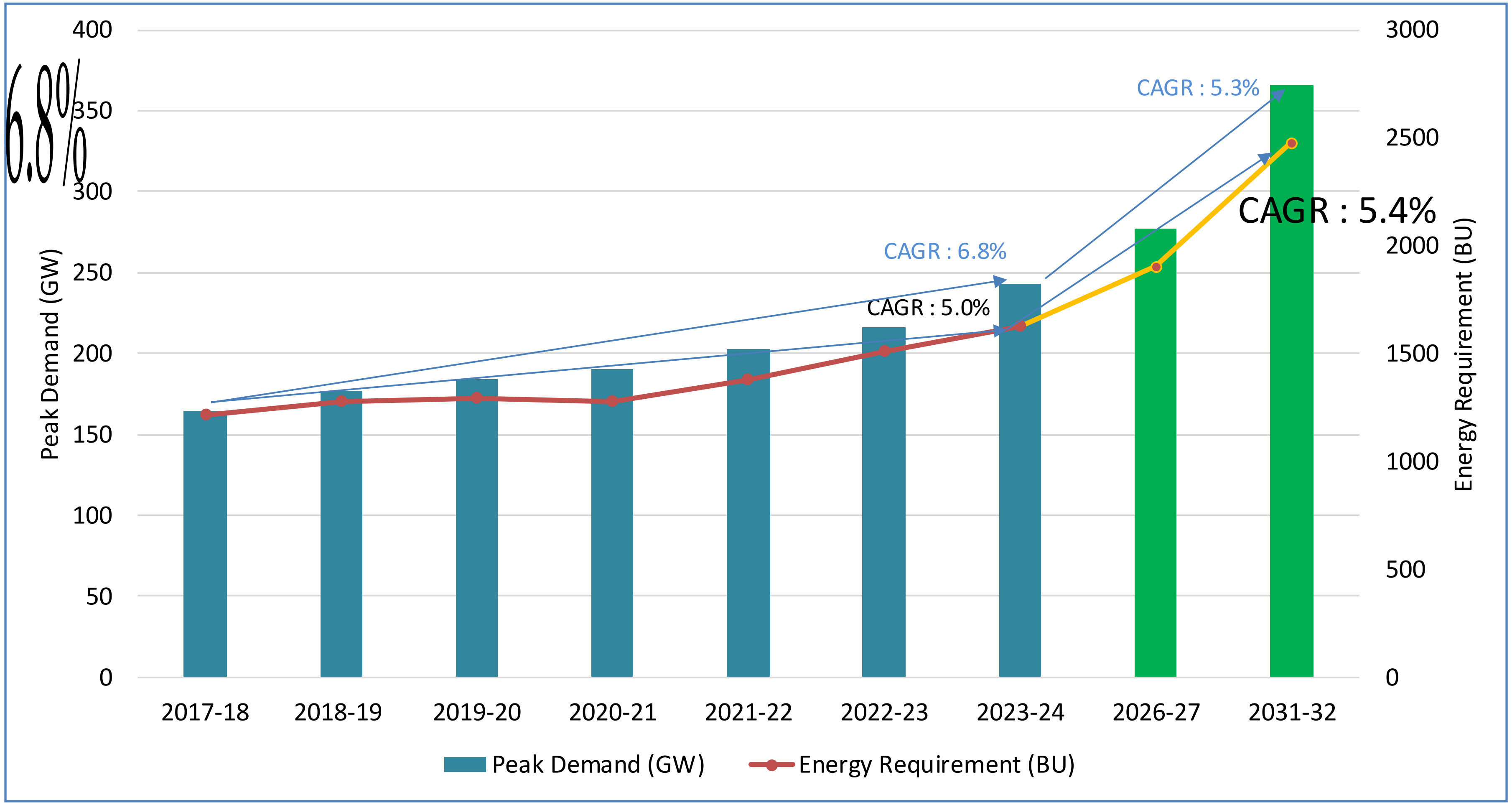
Energy consumption has already **more than doubled** since 2000 with 80% of demand still being met by coal, oil and solid biomass.
By 2040, energy demand growth could account for a quarter of global energy demand growth.

India has contributed only about 4% of the global cumulative greenhouse gas emissions between 1850 and 2019, and its per capita emissions are about one-third of the world average

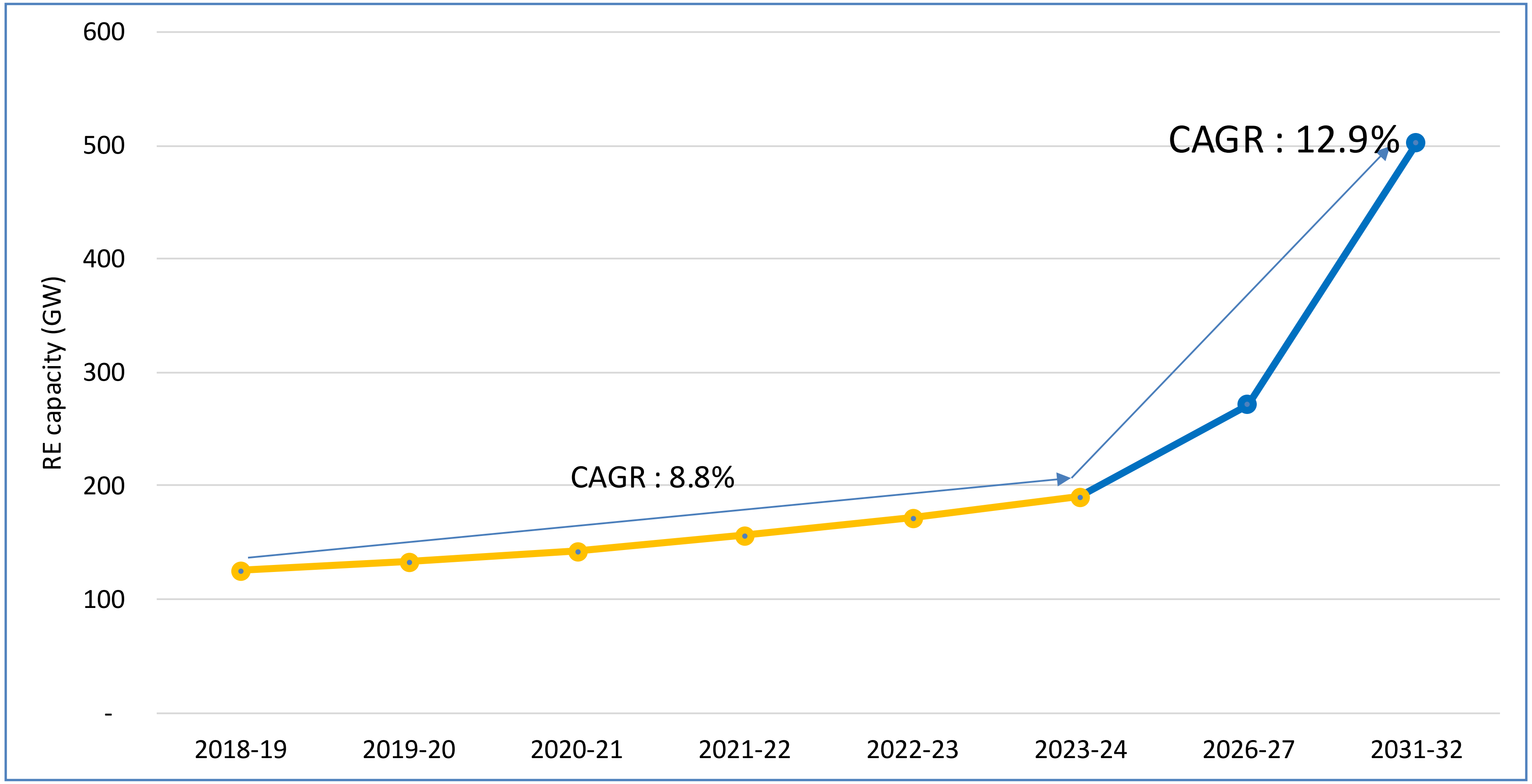
India's Energy Transition needs to benefit its citizens.

This transition needs to be *just* for all.

Peak Demand and Energy Requirement

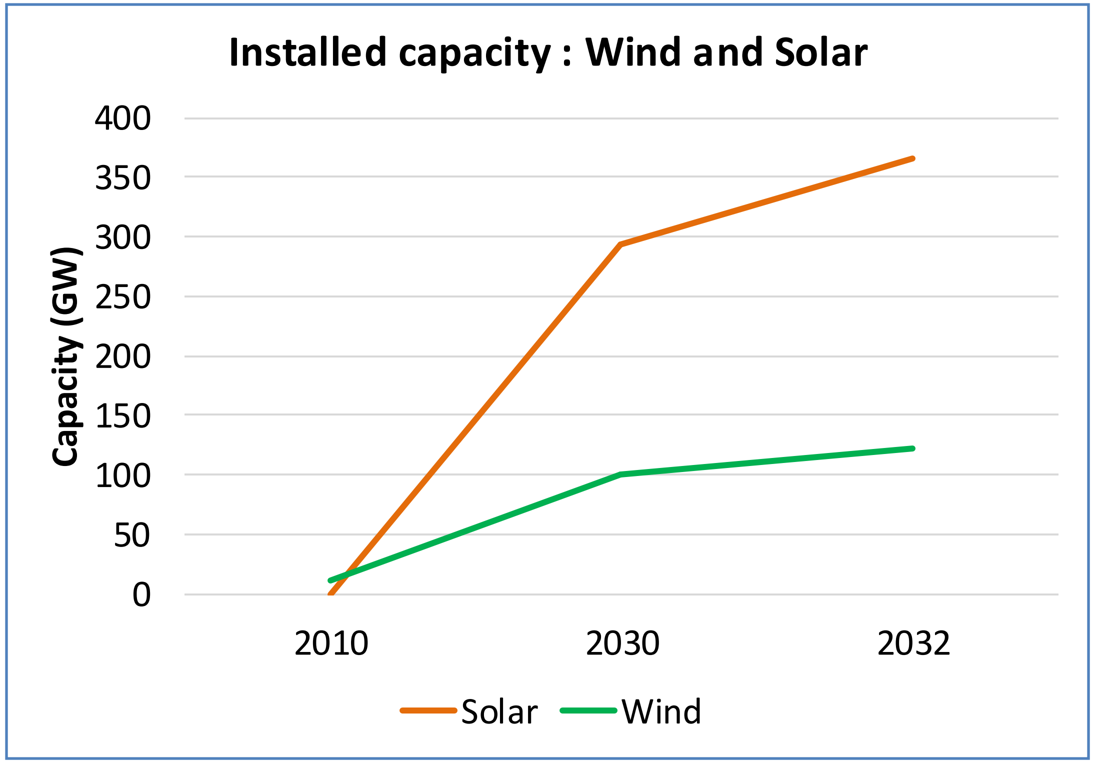


Growth of Renewable Energy Capacity

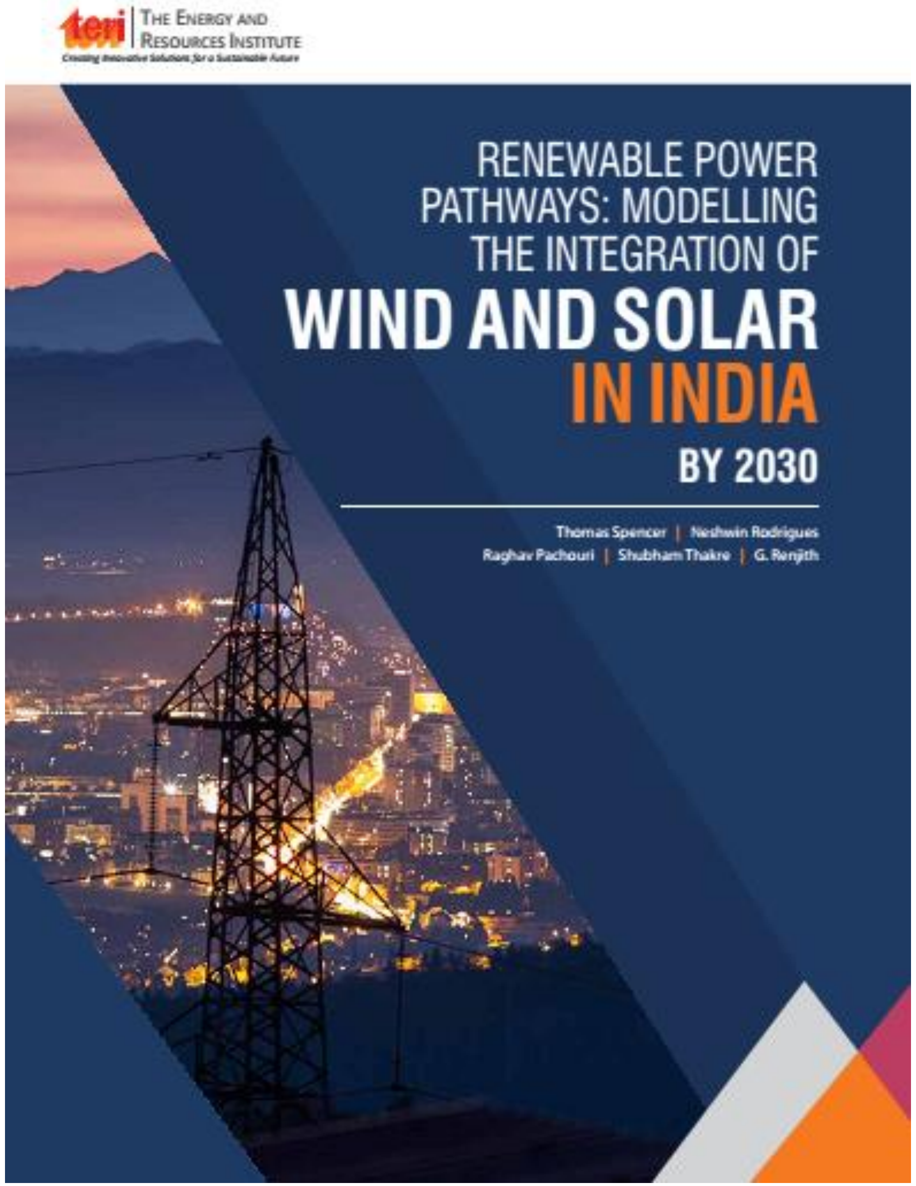


Non-fossil fuel Capacity Projections

S. No.	Fuel Type	Unit	Installed Capacity	
			2030	2032
1	Solar	GW	293	365
2	Wind	GW	100	122
3	Hydro	GW	59	67
3	Nuclear	GW	15	20
4	PSP	GW	18.5	27
5	Bio-power	GW	14.5	16
	Total Capacity	GW	500	617
	BESS (GW/GWh)		42/208	47/236



Source: Optimal capacity mix by 2030, Ver. 2, CEA
National Electricity Plan, 2023, CEA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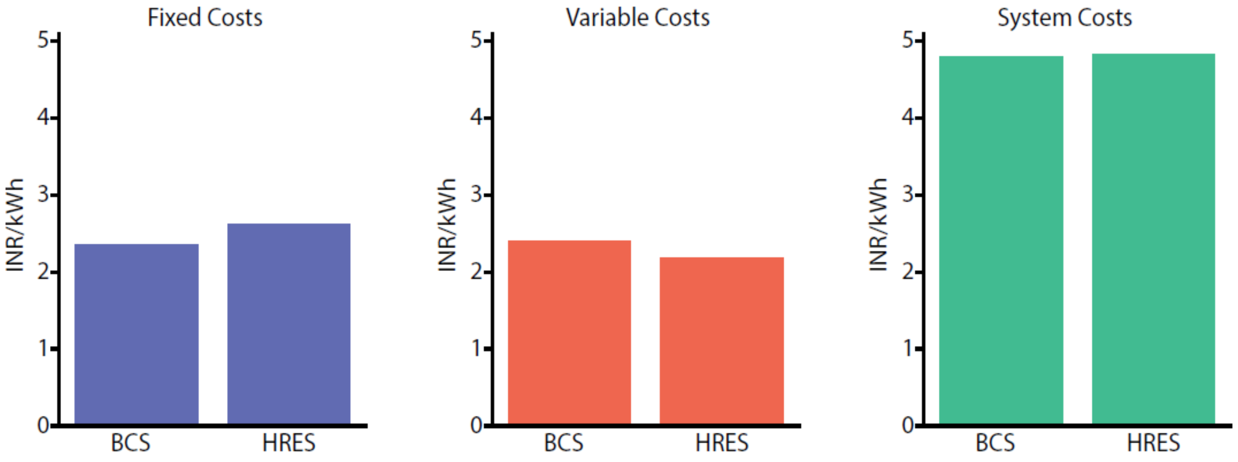
THE ENERGY AND RESOURCES INSTITUTE
RENEWABLE POWER PATHWAYS: MODELLING THE INTEGRATION OF
WIND AND SOLAR
IN INDIA
BY 2030
Thomas Spencer | Neshwin Rodrigues
Raghav Pachouri | Shubham Thakre | G. Renjith

India Can Integrate High Shares of Renewables Into Its Power System By 2030 At No Extra System Cost

2030 System-Wide Costs in the Baseline Capacities Scenario (BCS) and High Renewable Energy Scenario (HRES)



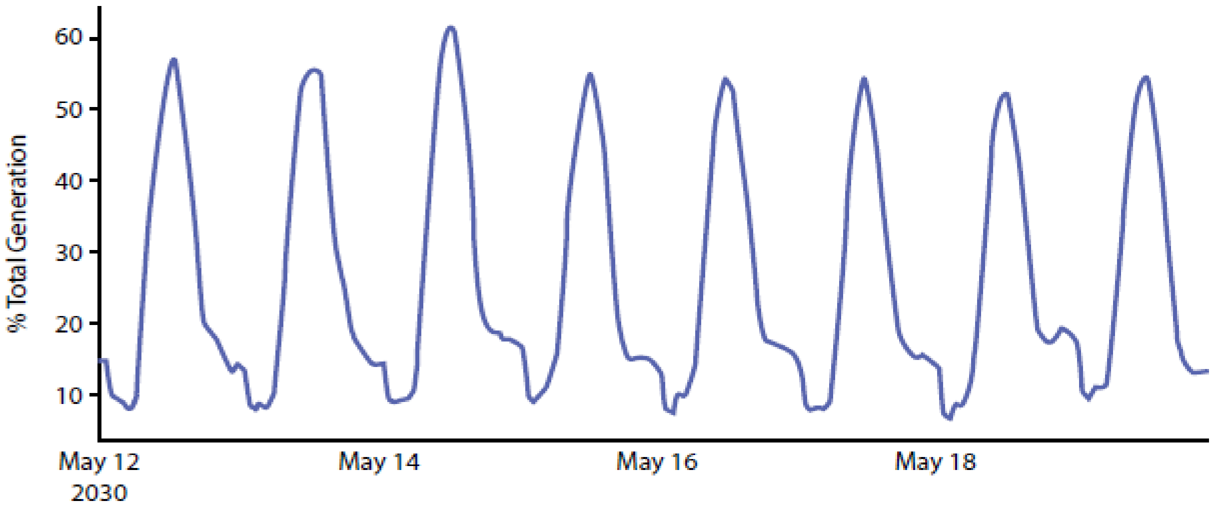
Source: TERI (2020), "Renewable Power Pathways: Modelling the Integration of Wind and Solar in India by 2030", Figure E1.

- BCS entails a scenario of solid renewable energy growth
- HRES entails a scenario of very high renewable energy growth
- Solar and wind accounting for

  BCS : **26% of total generation** and 47% of total generation capacity.

  HRES : **32% of total generation** and 53% of total generation capacity.
- Due to the substitution between investment and operational costs, the system-wide generation cost is essentially the same between the two scenarios.

Daily Share of Wind and Solar in Total Generation, 2030, HRES Scenario



Source: TERI (2020), "Renewable Power Pathways: Modelling the Integration of Wind and Solar in India by 2030", Figure E2.

- HRES : wind and solar account for 32% of total annual generation.
- However, across the days and seasons of the year, their share varies substantially, from typically less than 10% on a summer night to more than 50% during peak solar generation >

  > rest of the power system needs to adapt to provide between 40-90% of residual power demand over the course of a typical summer day.
- There is thus a dramatic need for enhanced **power system flexibility**.

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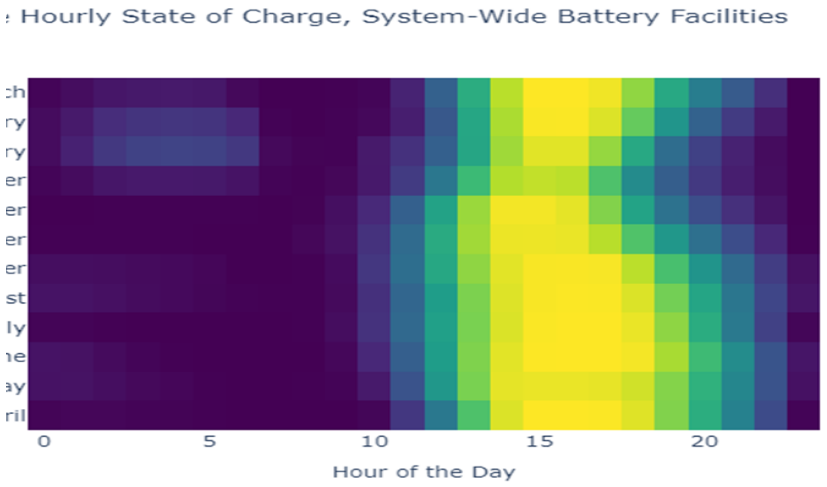
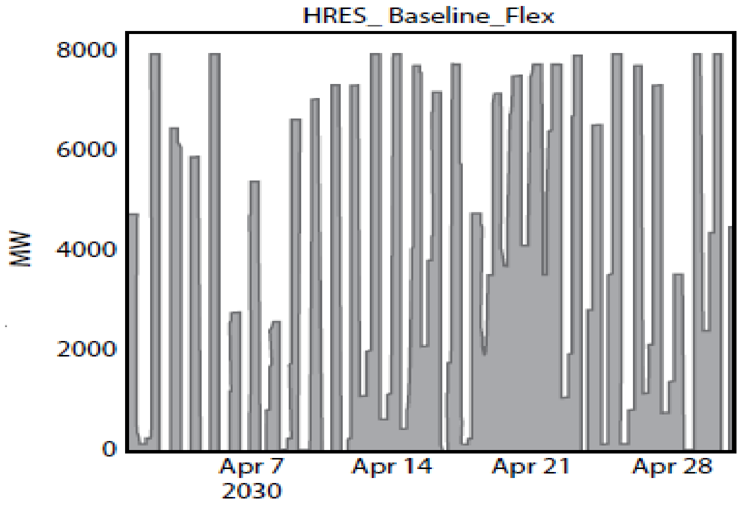
Integrating High Levels of Renewables ill Require Something Akin to A "National Mission For Power System Flexibility"

State of Charge of the Battery Facilities in the Model



Hourly Output of the Most Aggressively Cycled Coal, One Week in April



Source: TERI (2020), "Renewable Power Pathways: Modelling the Integration of Wind and Solar in India by 2030", Figure 16, Figure 14, and Figure 11.

- The high need for flexibility from the power system to accommodate variable renewables will require a comprehensive approach to developing the various levers of power system flexibility:
    - Optimisation of scheduling and dispatch across states and regions, facilitated by India's integrated grid and market and regulatory reform (Figure 4).
    - Development of battery storage and pumped hydro storage facilities (LHS).
    - Supply-side flexibility from the existing coal and hydro fleet (RHS)
    - Driven by a high-level policy framework to provide the necessary political impetus.

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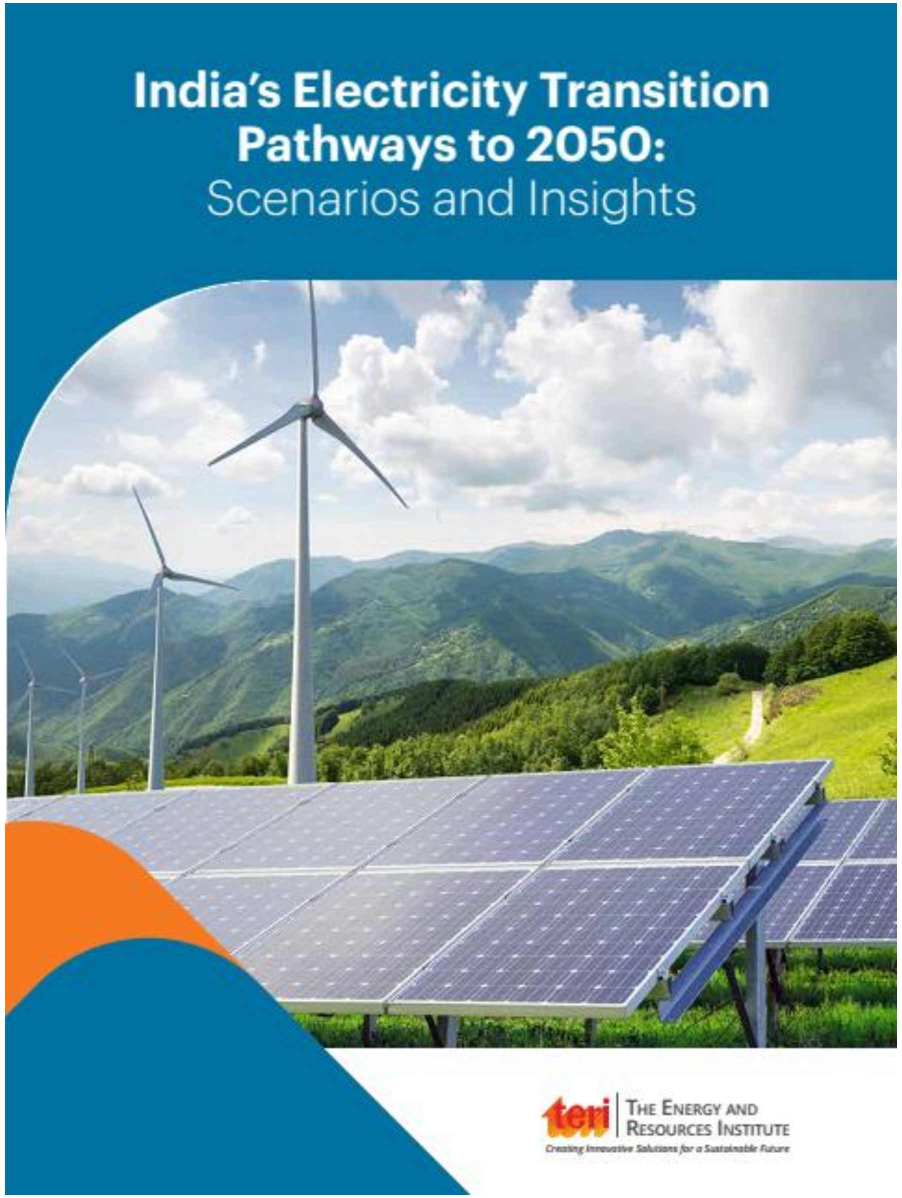
India's Electricity Transition
Pathways to 2050:
Scenarios and Insights
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The Energy and
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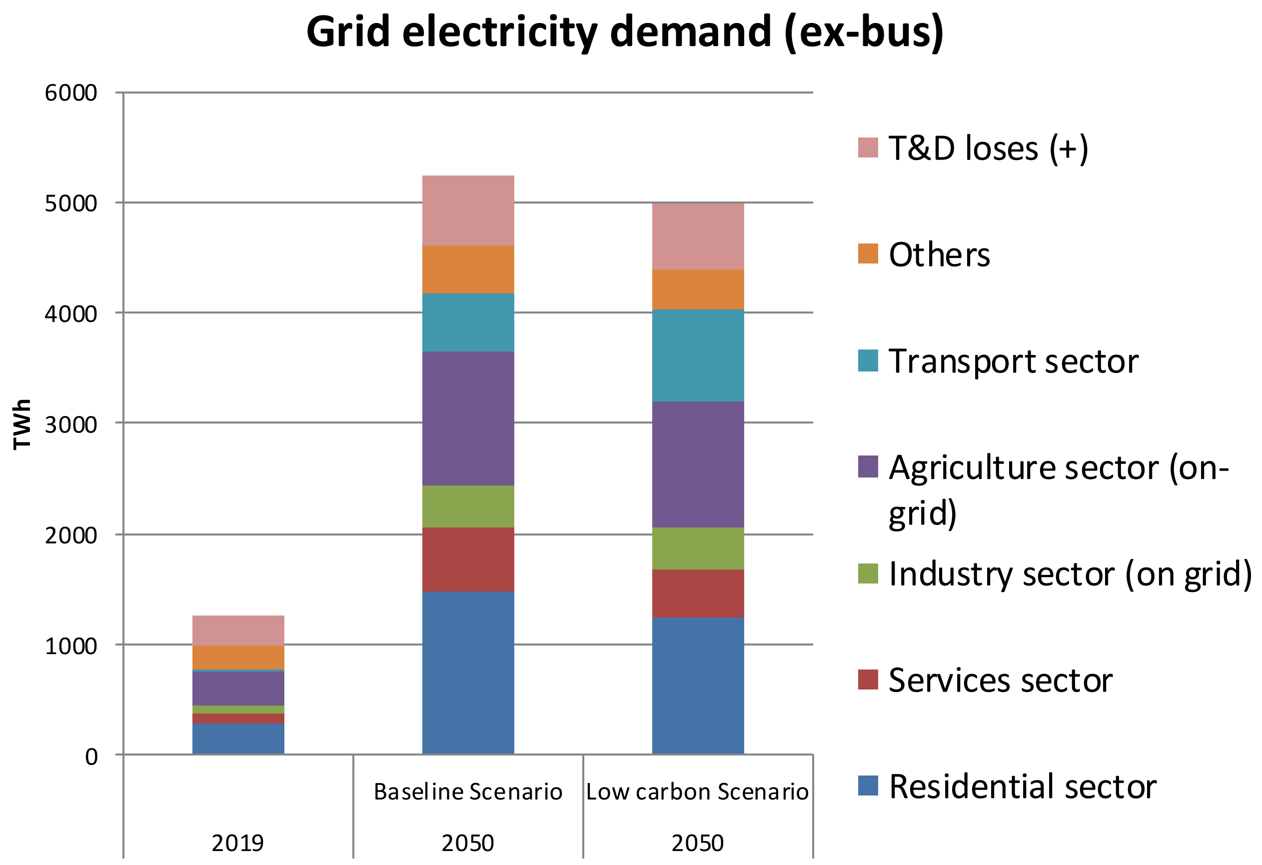
Creating Innovative Solutions for a Sustainable Future

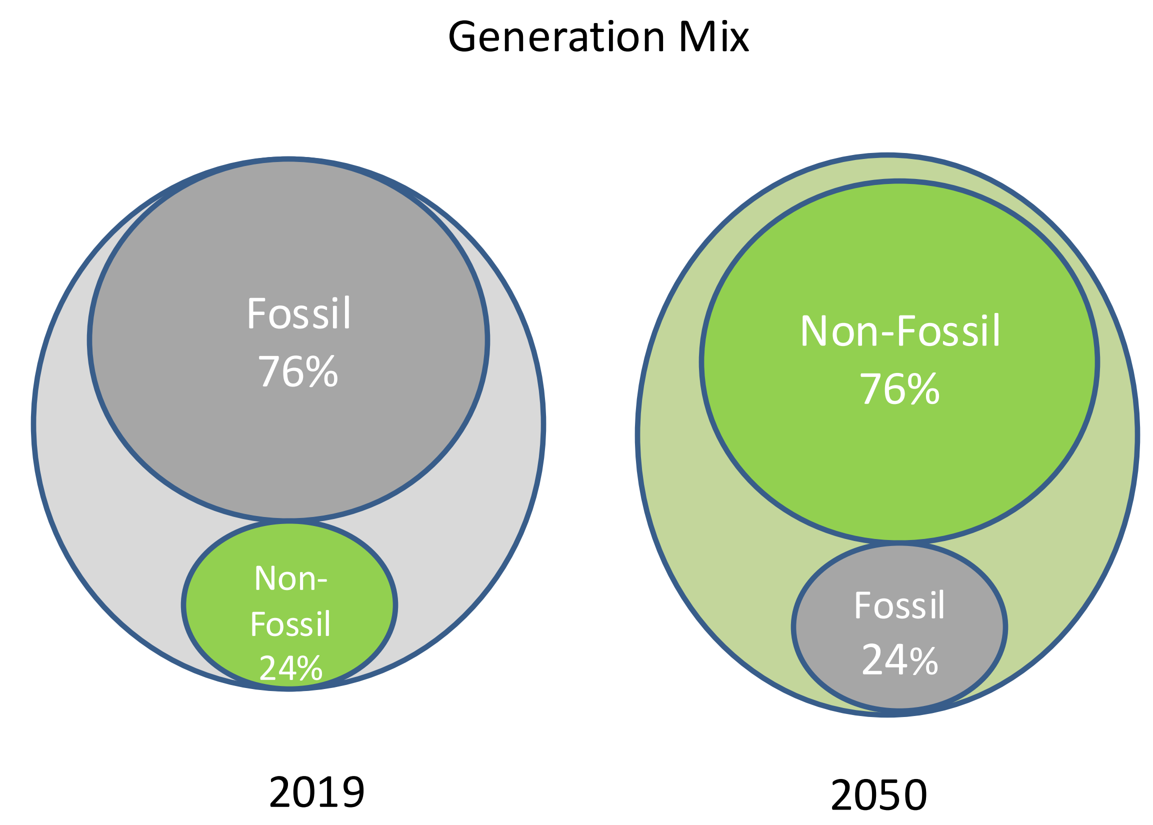
#1 : India’s Grid Electricity Demand (ex-bus) is projected to increase four-fold by 2050



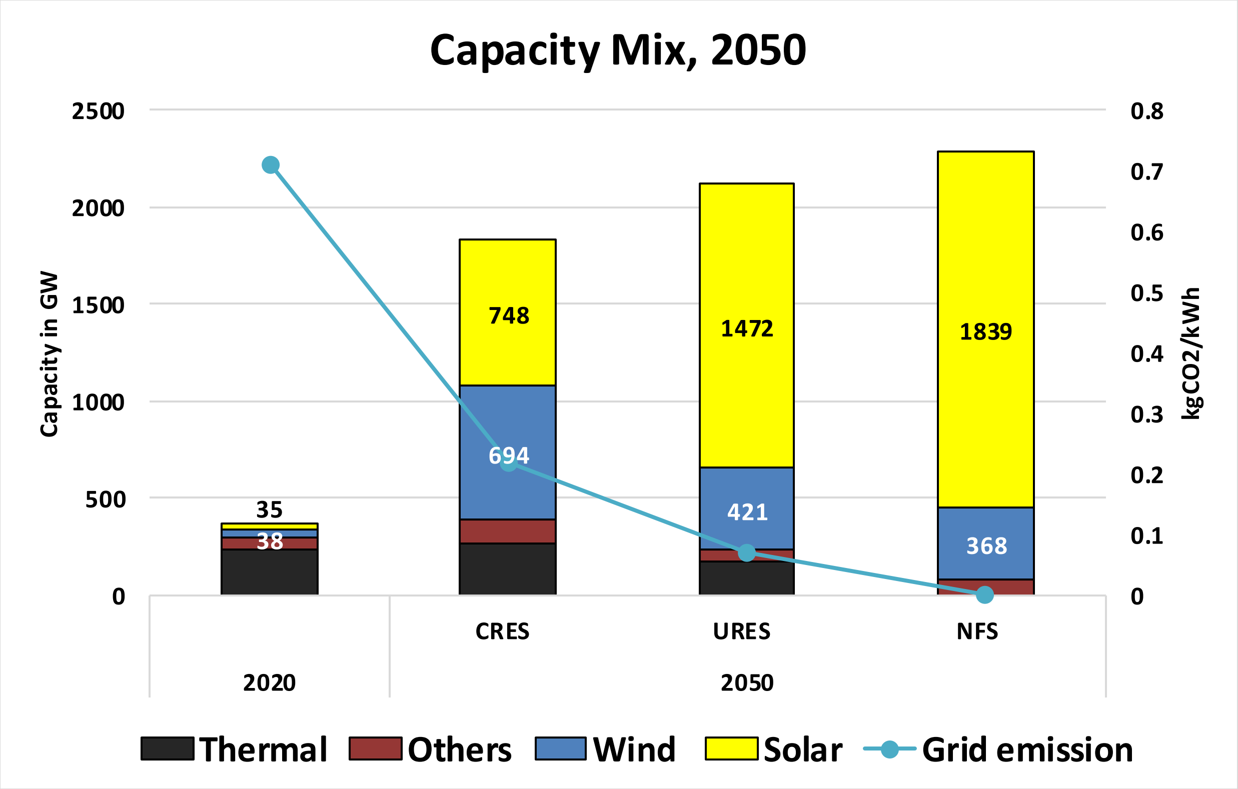
Year	Scenario	Electricity Demand (TWh)	Peak Demand (GW)
2019	-	1210	175
2050	Baseline	5246	750
2050	Low carbon	4985	700

#2 : Installed capacity is projected to be ~5 to 6 times
#3 : Non-fossil fuel generation increases 3 times

Year	2019	2050		
		CRES	URES	NFS
Installed Capacity (GW)				
Total	367	1828	2124	2291
Ex-bus generation (TWh)				
Total	1370	5246	5246	5246
BESS				
Capacity (GW)		380	864	1169
Storage (Hours)		6.0	6.0	6.1



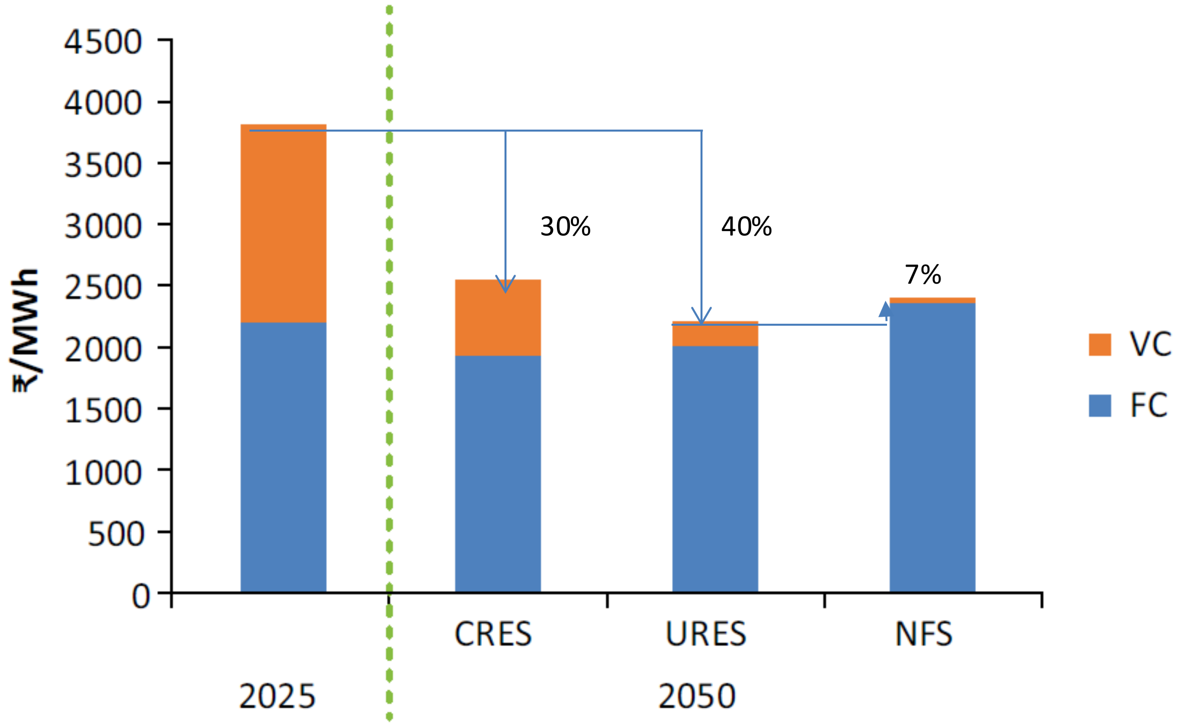
#4 : Carbon Intensity : 70%-90% reduction from the current level



- Solar and wind capacity up to 80%–90% by 2050 is plausible, at a relatively low system cost considering a suite of flexible supply options.

Scenario	Grid Emission Intensity ($kgCO_2/kWh$)	Installed Capacity (GW)
CRES	0.22	1828
URES	0.07	2124
NFS	0	2291

#5 : Decarbonization of the power sector is expected to reduce the system costs*

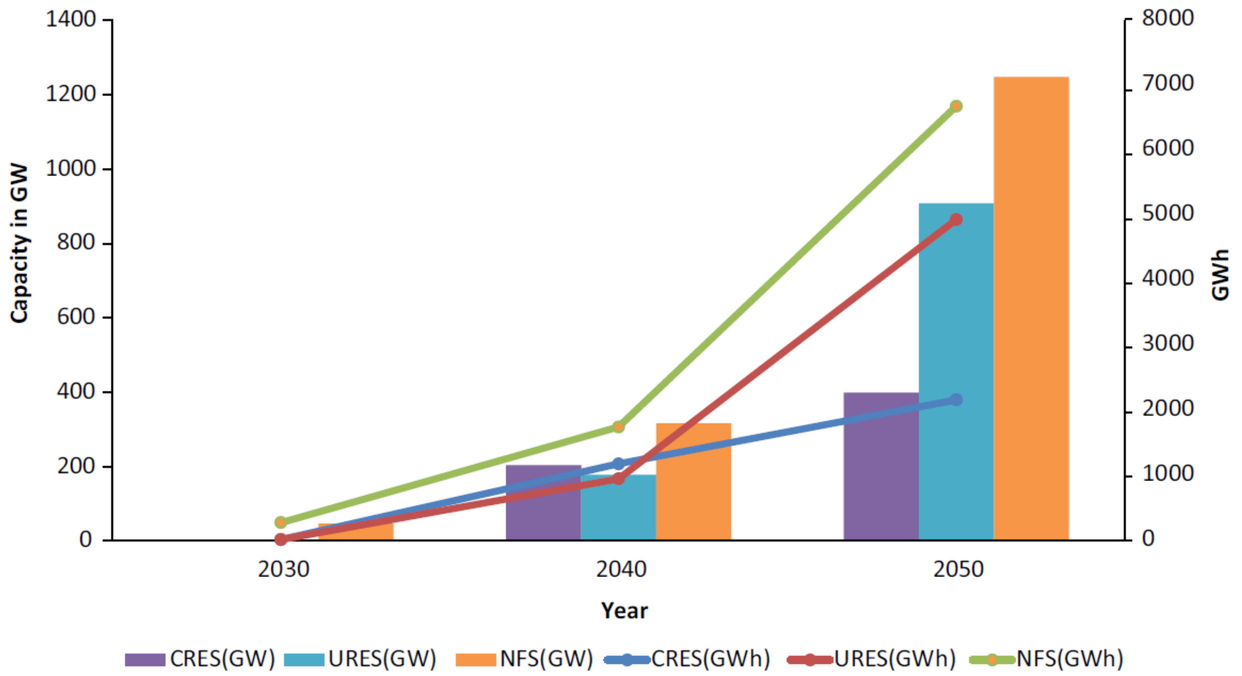


*Annual Fixed Charges (AFC), Fuel and Start-up cost, Battery Energy Storage System (BESS) cost.

System cost :

- URES : ~ (-) 40%
- NFS : ~ 7% over URES
- CRES : ~ 10% over URES.

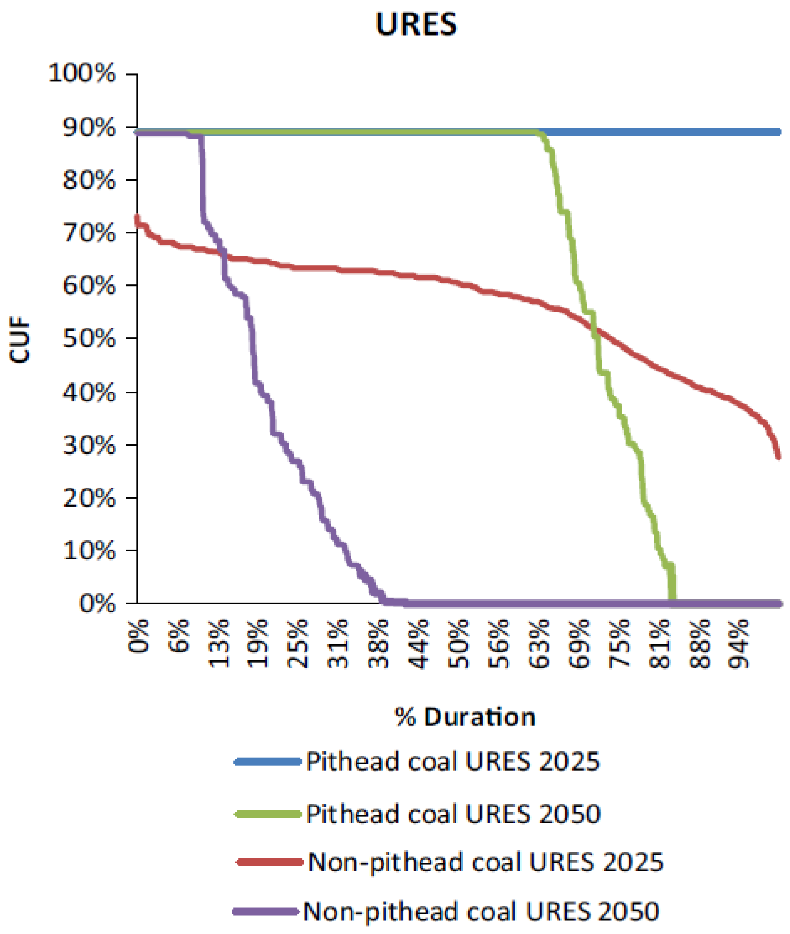
#6 : Energy Storage
Time-bound deployment will be necessary to drive the RE uptake



- BESS capacity :
  ~ 5200 GWh (URES) to
  ~ 7000 GWh (NFS)

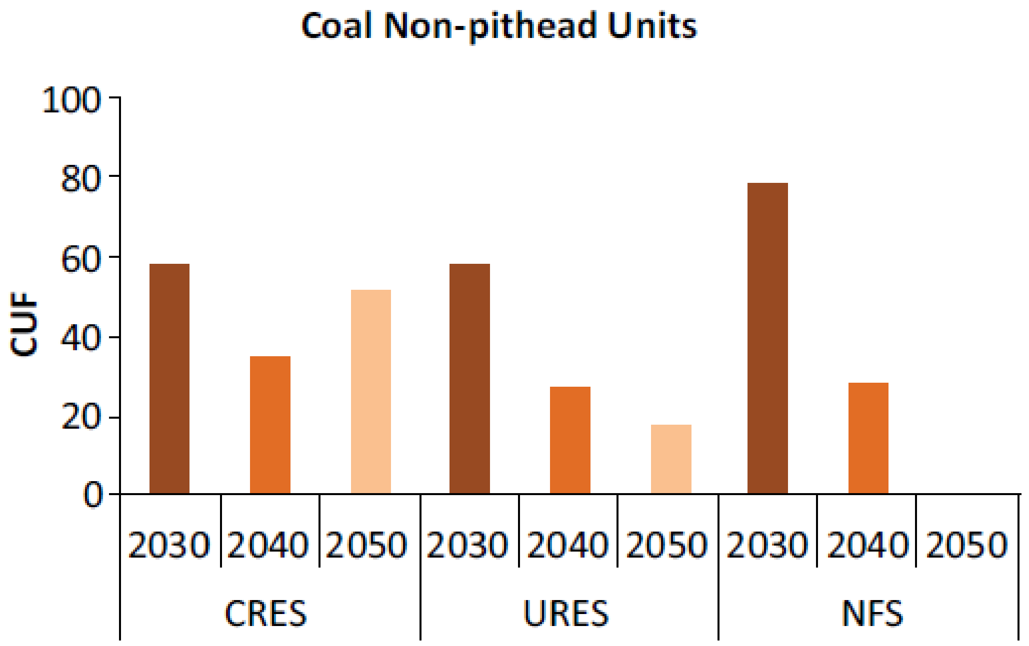
- The decline in BESS costs is imperative for bringing down the system costs.
- In the cost optimal scenario, ~1950 GW of non-fossil fuel capacity and 5200 GWh of BESS is anticipated.

#7.1 : Coal fleet could provide flexibility in integrating high share of renewables by mid-century

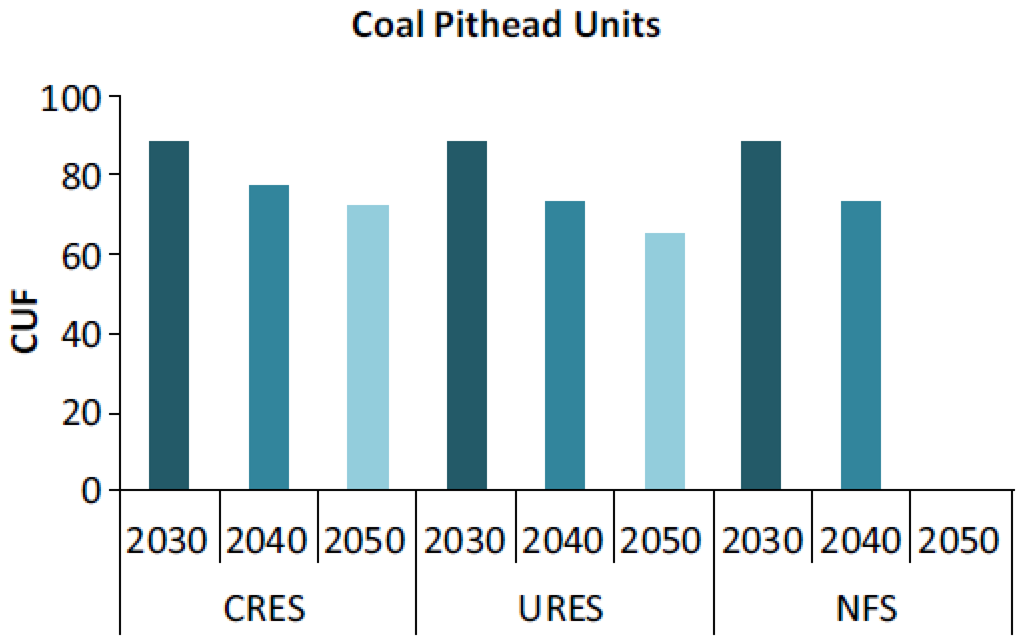


- By 2050, pit-head coal plants will witness operation at full capacity for ~2/3rd of the time.
- Non pit-head coal plants may have to operate at full capacity only for 1/6th of the time.
- The non pit-head coal plants might need to resort to two shift operation.

7.3 : PLF of coal plants is expected to reduce with an increase in RE share but capacity is still needed to balance supply and demand

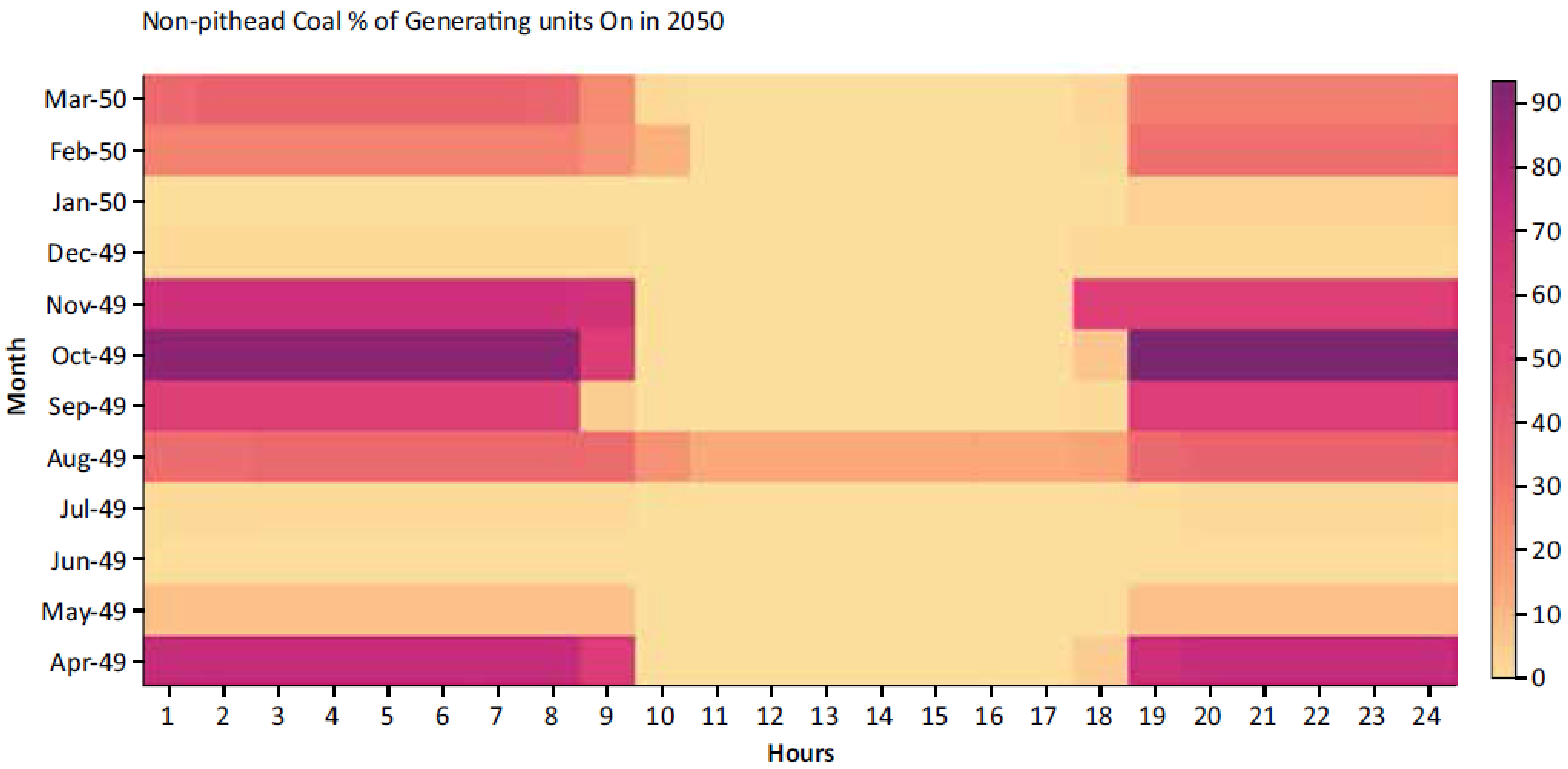


PLF of Non-pithead plants across the scenarios



PLF of Pithead plants across the scenarios

7.4 : Coal fleet's role in 2050 in most scenarios is to provide seasonal balancing in the absence of long duration storage and to avoid overbuilding RE and storage capacity (4/4)



Temporal Distribution status of Non-pithead units running in URES in 2050

State sector insights : Madhya Pradesh

- **Generation capacity** set to rise by 2X, **RE capacity** to contribute ~42-57% of the capacity mix in 2030.
- Technology-specific buildup is sensitive to technology costs, but the cost of capital could significantly influence the integration of RE.
- Share of technology buildup is sensitive to not only electricity demand but also peak load.
- Increase in **RE-based generation** beyond 38% of the total generation is not cost optimal
- **BESS Build-up:** 2025-30 could see a start of BESS BESS buil-up. Further cost declines in subsequent years would be required to further increase the BESS capacity.
- **Grid flexibility : The onus would significantly depend on the variable costs of generation.**
  - Existing coal generators most cost-effective source; play an import role in RE integration in the medium term.
  - As their roles change the Techno-economic assessment of coal-based flexibility in this role is critical.
- **Coal Fleet Despatch:**
  - Pithead coal fleet: gets dispatched to its full capacity for almost ~85% of the time .
  - Limited flexibility required from pithead generators.
- **Non-pithead coal fleet:** Gets full dispatch for less than 22% of the time.
  - Almost no dispatch for ~15% of the time.
  - Frequent two-shift operation for non-pithead.
- **Coal flexibility** and storage could add a marginal premium on the cost of electricity.
- The **inherent shape of the MP load curve** and **Solar PV generation** profile would require a relatively lower addition of storage capacity, at least in the medium term.

Summing Up

- **Demand Side Management interventions** including Demand Response can reduce the severity of the problem; **Time-of-Use tariffs**

- **RE capacity addition** is steadily increasing; **acceleration** is needed to achieve the NDC targets and decarbonisation of power sector

- **Solar generation** will be the **key enabler**.

- **Energy storage** will hold the key to achieve net-zero; priority order - pumped storage, concentrated solar thermal with storage, battery storage and hydrogen for catering to long and short duration storage in various time-frames.

- Products such as RE-RTC, FDRE are helpful in providing a bouquet.

- **Policy and regulations** with recognition of value of service provided will facilitate faster transition

- Speeding up implementation of **mature technologies**, implementing **pilot projects in newer technologies**, providing support till the technologies become cost effective would go a long way in meeting the challenge of scale, speed and economy.

Summing Up

- **Reduction in cost of RE technologies and storage is good news**, needs further enabling by reducing cost of financing, etc.

- Extend **PLI scheme** to cover the full value chain of solar panels, pumped storage turbines, mirrors for solar thermal plants and green hydrogen.

- **Grid security:** power system stability studies need to be initiated for various scenarios.

- **State specific measures and initiatives** depending on demand and its characteristics, resource mix and cost effectiveness of harnessing them need additional thrust.

- **Cross Border Electricity Trade** and **CCUS**

- **RE potential re-assessment** is essentially required to meet the demand with an increasing trajectory

- **Periodic review of demand profile** as well as medium and long-term studies is a must.

TERI Institute of Energy Transition (IoET)

Vision

At IoET, we envision a world class knowledge hub that bolsters cutting edge research/analysis/studies on technology development and its adaptation, while understanding and analyzing the context-specific appropriateness and cost-effectiveness of such technologies.

Mission

To promote research, innovation, and education in clean energy technologies, fostering interdisciplinary collaborations and partnerships that contribute to sustainable energy transition pathways, addressing the challenges of energy transition, climate change and resource efficiency.

Objective : To undertake inter-disciplinary research and analysis, study/modelling/mapping of transition resources, strategizing the path for transition, specific advisory at the policy as well as project level

1.Clean Energy Technologies:

- Solar, wind, biofuels, and emerging green technologies such as green hydrogen and CCUS (Carbon Capture, Utilization, and Storage).
- Applications and validation of these technologies.

2.Energy Storage Solutions:

- Battery Energy Storage Systems (BESS), Pumped Storage Plants (PSPs), Concentrated Solar Plants (CSPs), etc.

3.Net Zero Solutions:

- Net zero emission solutions.

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4.Sustainability and Resource Management:

- Life cycle analysis and waste treatment.
- Waste management, energy efficiency, Demand Side Management (DSM).

5.Sector-Specific Initiatives:

- Solarization of agriculture.
- Cooling action plan for buildings.

6.Fossil Fuels and Transition Impact:

- Value chain analysis of fossil fuels.
- Impact of energy transition on these sectors.

7.Sustainable and People-Centered Energy Transition:

- Focus on ensuring a just and inclusive transition
that benefits all stakeholders

Thank You