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Renewable Energy Resource Adequacy Planning to meet RPO by the States in India

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(FEBRUARY 2024)

Suggested Citation

Mothkoor V, Jain A, Ram R. Renewable energy resource adequacy planning to meet RPO by the states in India. NITI Aayog, Government of India. 2024 February.

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BACKGROUND

India has unleashed its climate ambitions with the announcement of updated Nationally Determined Contributions (NDCs) and submission of the Long-Term Low Carbon Development Strategy laying down the path for resilient, inclusive, and sustainable growth. In line with these announcements, the Ministry of Power (MoP), vide F. No. 09/13/2021-RCM dated 19.09.22, has notified a year-wise trajectory of Renewable Purchase Obligations (RPOs) including Energy Storage Obligations till 2030. According to this, the obligated entities, mainly DISCOMs, in each state, are required to meet their minimum share (24.3% in 2023 to 43.3% in 2030) of electricity purchase from Renewable Energy (RE) sources. These obligations will ensure the consumption of renewable in the country and subsequently will help to achieve the climate action goals of the government wherein it aims to increase the share of non-fossil fuel-based power capacity to 50% by 2030. However, RE sources have inherent spatial and temporal variability that leads to uneven potential and energy yield in each state. States may exhibit surplus or deficit RE potential to meet annual renewable obligations. Further, the requirement of energy storage may also change considering the temporal variability of RE, available flexible resources for power generation within the states and inter-state electricity trade.

In this context, the study, carried out with the support of CEA and MNRE, presents a detailed analysis of i) RE technical potential that can be harnessed to meet RPOs of each state ii) RE capacity that needs to be procured by the deficit states from other RE-rich states iii) Storage requirement to meet required grid balancing, by looking into various parameters such as RE capacity utilization factors, available potential, past generation and expected technological improvements. The utmost care has been taken for RE procurement decisions by deficit states from neighbouring states to reduce transmission infrastructure and related costs. This study provides a state-wise capacity addition plan for India which can be leveraged both by state governments and RE developers. The government can use the estimates for developing a bidding calendar while industry can use it for undertaking necessary investments in the respective states.

1. Introduction

India is now the most populous country with 18% of the world's population and fifth largest economy in the world at 3.3 billion USD (2022) and third largest in terms of Purchasing Power Parity (PPP). However, in per-capita terms, India's per capita GDP is USD 2,379, a fraction compared to China's GDP of USD 12,814, and the US GDP of USD 76,348[1]. Also, India's per-capita primary energy consumption is 1/3rd of global average and 1/10th of the USA[2]. The Prime Minister of India during his Independence Day speech on 15 August 2022, made a clarion call for India to become a developed nation by 2047. This necessitates a multifold increase in infrastructure requirements and improvement in the living standards. Energy requirements will grow manifold as India embarks on path to a developed nation by 2047.

Historically, economic development has been synonymous with fossil fuel consumption and dependency. India, when confronted with the same challenge, has chosen a sustainable path to achieve the country's developmental goals. India has contributed only about 4% of the global cumulative greenhouse gas emissions between 1850 and 2019[3] and India's per-capita emissions stand at half of the global average, 1/4th of China and 1/8th of the USA[4]. India is amongst the top 5 best-performing countries in Climate Change Performance Index (CCPI 2023) and is best among G-20 countries. India has the world's fourth highest renewable installed capacity after China, the USA, and Germany.

India has unleashed its climate ambitions with the announcement of updated National Determined Contributions (NDCs) and submission of the "Long-Term Low Carbon Development Strategy". The achievement of 50% cumulative power installed capacity from non-fossil sources is one of the quantitative commitments under updated NDCs.

Since 2010-11, the Ministry of Power, Government of India, has been relying upon the use of Renewable Purchase Obligation (RPO) as an instrument to meet the Intended National Determined Contributions (INDCs) and promote renewable energy deployment in the country[5]. In the erstwhile RPO, the obligations are categorized under Solar and Non-Solar obligations. Due to technology maturity and strong commercial market, solar capacity addition increased rapidly while other technologies such as Wind and Hydro did not increase at same scale. Ministry of Power has amended the erstwhile trajectory with an objective to promote development of Wind and Hydro with targets for each till 2030. Solar has been clubbed with other RE sources such as Biomass[6]. This will facilitate deployment of technologies with high Capacity Utilization Factors (CUFs) and also technologies which play a critical role in providing grid flexibility. According to the new trajectory announced, each state is obligated to meet a minimum of 43.3% of the power demand from renewable sources by 2030.

[1] International Monetary Fund (IMF), World Economic Outlook, April 2023.

[2] BP, Statistical Review of World Energy, 2021

[3] India's Long-Term Low-Carbon Development Strategy (LT LEDS): Submission to the United Nations Framework Convention on Climate Change, Ministry of Environment, Forest and Climate Change, Government of India.

[4] BP, Statistical Review of World Energy, 2021.

[5] List of RPO regulations accessed from https://www.recregistryindia.nic.in/index.php/publics/Reference_Documents (as on 15-June-2023)

[6] RPO notification, Ministry of Power, Government of India. Accessed from https://powermin.gov.in/sites/default/files/Renewable_Purchase_Obligation_and_Energy_Storage_Obligation_Trajectory_till_2029_30.pdf

The effectiveness of RPO depends on many factors such as the perception of the state on competitiveness of renewable energy compared with other fossil sources, availability of grid infrastructure to integrate RE and existence of strong compliance mechanism. 17th Standing Committee on Energy has analyzed the RPO performance across states and found that RPO compliance in 2019-20 varies from 3.7% in Manipur to 250% in Karnataka. The report found that only six states have achieved full compliance with notified RPO trajectory[7]. Therefore, the role of states becomes critical in achieving RPO. The Draft Electricity Amendment Bill 2022 has proposed the penalty punishment for non-compliance.

The capacity planning has been an after-thought in most states as a result of which RPO compliance has been unsatisfactory. The capacity planning is more critical primarily on account of varying CUF and available RE potential across the states. Figure 1 shows varying solar and wind CUFs in states with RE capacities. As can be observed from the figure, the solar CUF varies from 1.3%-27%, while for wind, it varies from 13.4%-32%.

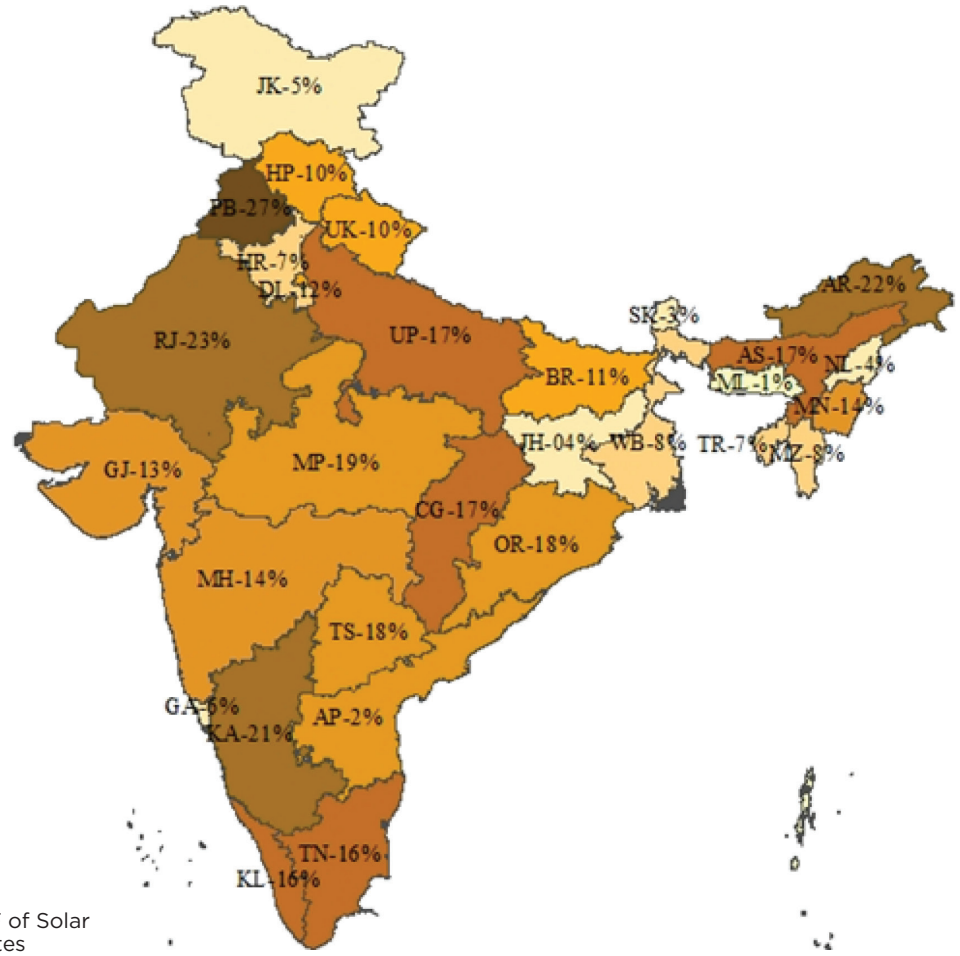

Figure-1a: CUF of Solar across the states

[7] 17th Parliamentary Standing Committee Report. Accessed from https://eparlib.nic.in/bitstream/123456789/800881/1/17_Energy_17.pdf#search=null%20Departmentally%20Related%20Standing%20Committees%20Committee%20on%20Energy

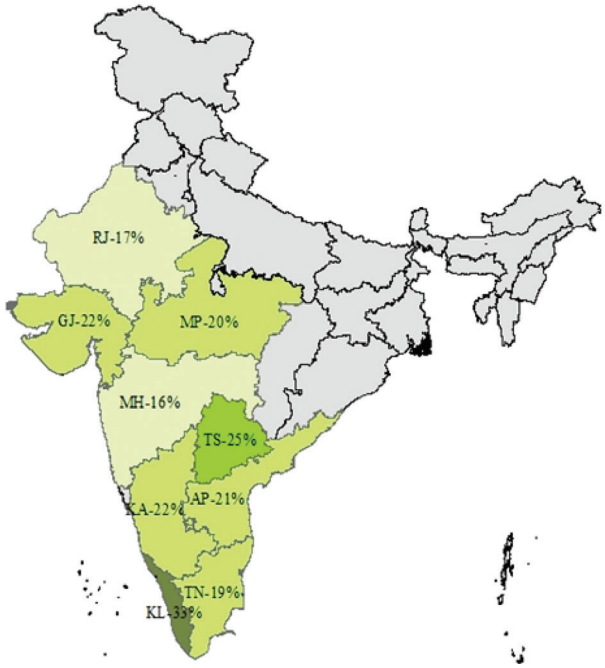

Figure-1b: CUF of Wind across the states

1.1 Objective

The aim of this study is to fill this critical gap by providing state-wise capacity that can be mobilized within the state to meet the RPO target and capacity that needs to be procured from other states. The mobilization of potential within the state also results in the creation of co-benefits in the form of local employment and economy boost apart from ability to generate renewable energy. This study also estimates the amount of storage requirement in each region to facilitate the smooth integration of RE into grid and preserve the resilience of grid.

2. Methodology

This section provides an overview of the data and methodology adopted to estimate the capacity that needs to be installed from within the state's potential and/or procured from other states to meet the RPO target. The care has been taken to source RE from neighbouring states to reduce cost of transportation. The methodology for estimation of storage is also described in the section below.

2.1 Data

The data on state-wise installed & allocated capacities, generation, and estimated resource potential of RE till FY 2021-22 has been obtained from the Ministry of New and Renewable Energy (MNRE), Government of India[8,9,10,11] (See Annexure-1 for state-wise resource potential). The 20th EPS report

[8] Installed capacities and generation data retrieved from CEA-CEEW-Centre for Energy Finance dashboard https:// www.renewablesindia.in/ (Accessed as on 15 June 2023)

[9] State-wise resource potential data of Solar, Bioenergy and Small Hydro accessed from https://data.gov.in/resource/state-wise-potential-various-renewable-energy-technologies-2022

[10] CUF data accessed from https://niwe.res.in/assets/Docu/India%27s_Wind_Potential_Atlas_at_120m_agl.pdf

[11] State-wise resource potential and CUF data of Wind accessed from https://maps.niwe.res.in/media/150m-report.pdf

published by Central Electricity Authority (CEA) is considered for the state-wise electricity demand in 2030[12]. For the estimation of wind CUFs in 2030, National Institute of Wind Energy (NIWE) data is considered at varying CUF ranges (from small to high CUFs). State-wise weighted average CUF is calculated for capacities of higher CUF areas which have higher probability of installation. This weighted CUF is later increased due to expected efficiency improvements and installations at higher hub heights.

CUF for solar energy in 2030 has been assumed based on current utilization pattern (as shown in Figure 1a) and adjusted to be 10% higher due to adoption of high efficiency solar PV cells.

2.2 Methodology for Renewable Capacity Estimation

The state-wise electricity demand that needs to be met from RE is estimated by application of RPO guidelines to the total electricity demand provided in 20th EPS. As specified in the RPO notification, demand is calculated separately for Wind, Hydro and Others (including solar, bioenergy). The resource specific RPO (Hydro, Wind and Other) demand is first met from existing allocated capacities. Second, the study estimates the balance demand that needs to be mobilized from the potential (resource-specific) available within the state. In-case of shortfall in a particular resource, the study then refers to availability of fungible resources as specified in RPO notification. As per RPO guidelines, Wind is fungible with Hydro and vice-versa, others are fungible with Hydro/Wind. For example, insufficiency to meet wind RPO can be met from its hydro potential.. Third, for Bioenergy, the study does not consider the full potential provided by MNRE as the growth of bioenergy has been slow due to competing demands for its use and limited availability.

In-case of deficiency of potential within the state including fungibility, the study then estimates the capacity that needs to be procured from other states with surplus RE potential. The study also highlights the states where substantial resource potential exists which can be mobilized to meet targets of deficit states. The required capacity is estimated with assumed CUFs in 2030.

2.3 Methodology for Storage Assessment

The storage requirement is estimated using regional optimization models using TIMES (The Integrated MARKAL-EFOM System) modeling framework. Indian electricity grid is demarcated into five regional grids namely, Northern Region (NR), Western Region (WR), Eastern Region (ER), Southern Region (SR) and North-Eastern Region (NER). These regional grids are interconnected with each other to form a synchronized national grid operating at 50 Hz frequency. The study estimates the storage requirement at regional grid level as regional electricity dispatch is controlled and operated by separate though synchronized load dispatch centres.

The assessment of storage capacity requires capturing demand and supply side variability and operational aspects of power sector. Therefore, the model adopts high temporal granularity of hourly level to facilitate the incorporation of hourly load profiles and capacity utilization factors of solar and wind. The model has 288 sub-annual timeslices formed by considering all 24 hours of one representative day of each month (288=24*12). The hourly temporal resolution facilitates charging and discharging of energy storage during excess and deficit generation periods respectively.

[12] 20th Electric Power Survey Report accessed from https://cea.nic.in/wp-content/uploads/ps___lf/2022/11/20th_EPS____Report___Final___16.11.2022.pdf

3. Results and Analysis

As per the methodology described above, the study estimates the capacity requirements to meet the RPO target of 30 states/UTs in the country, twenty one states will be able to meet the RPO target by mobilizing the potential within the state and nine states need to procure RE power from other surplus states, as shown in Table 1.

3.1 Region-wise analysis of states' ability to meet RPO targets

In the Northern Region consisting of eight states, states of Rajasthan, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir will be able to meet both total and individual RPO targets of Wind, Hydro and Others by mobilizing the potential within the state. States of Punjab, Haryana,

Table 1: State-wise capacities for meeting RPO target

State	Allocated/ Installed capacity as of Mar-22 (GW)				Cumulative capacity required to meet RPO (GW)				Purchase from other states to meet unmet RPO (GW)			Surplus capacity (GW)			
	Wind	Hydro	Solar	Biomass	Wind	Hydro	Solar	Biomass	Wind	Hydro	Others	Wind	Hydro	Solar	Biomass
Northern Region															
PB	0.00	4.10	1.11	0.49	0.43	4.35	2.81	1.23	1.98	0.51	3.46	0.00	0.00	0.00	2.21
HR	0.00	2.40	0.93	0.26	0.59	2.50	4.56	0.62	1.98	0.79	13.36	0.00	0.00	0.00	1.09
RJ	4.50	1.97	14.06	0.13	9.72	2.04	20.04	0.13	0.00	0.00	0.00	274.53	0.00	122.27	1.17
DL	0.00	0.72	0.21	0.06	0.00	0.72	2.05	0.06	1.17	0.42	7.25	0.00	0.00	0.00	0.00
UP	0.00	3.47	2.24	2.19	0.51	4.32	22.83	3.57	5.09	1.17	13.09	0.00	0.00	0.00	4.15
UK	0.00	2.19	0.57	0.14	0.05	2.76	0.57	0.14	0.00	0.00	0.00	0.00	16.90	16.23	0.17
HP	0.00	4.20	0.08	0.01	0.24	4.51	0.08	0.01	0.00	0.00	0.00	0.00	17.77	33.76	0.06
JK	0.00	2.47	0.05	0.00	0.00	2.97	0.05	0.00	0.00	0.00	0.00	0.00	12.89	111.00	0.08
Western Region															
CG	0.00	0.31	0.53	0.28	1.66	0.77	10.52	0.28	0.00	0.00	0.00	1.08	2.57	7.75	0.07
GJ	9.35	0.86	7.78	0.11	18.61	0.86	35.77	0.88	0.00	0.00	0.00	162.18	0.00	0.00	2.31
MP	2.52	3.32	2.75	0.13	7.23	3.95	20.44	0.13	0.00	0.00	0.00	48.19	0.00	41.22	2.39
MH	5.01	3.71	2.67	2.63	11.85	4.83	48.49	2.63	0.00	0.00	0.00	162.02	0.00	15.83	3.92
GA	0.00	0.00	0.02	0.00	0.01	0.57	0.88	0.01	0.00	0.00	0.81	0.00	0.28	0.00	0.02
Southern Region															
AP	4.10	1.84	4.39	0.57	6.76	3.31	15.85	0.57	0.00	0.00	0.00	116.57	0.00	22.59	1.71
TS	0.13	2.57	4.55	0.22	3.78	2.57	18.16	0.22	0.00	0.00	0.00	50.93	0.00	2.25	1.58
KA	5.20	4.91	7.60	1.90	6.33	5.63	7.60	1.90	0.00	0.00	0.00	162.93	4.70	17.10	1.66
KL	0.06	2.10	0.40	0.00	0.84	2.31	1.92	0.00	0.00	0.00	0.00	1.78	1.85	4.19	0.78
TN	9.87	2.30	5.57	1.04	16.86	2.53	17.67	1.33	0.00	0.00	0.00	78.25	0.00	0.00	0.87
Eastern Region															
BR	0.00	0.18	0.19	0.13	4.02	0.31	11.20	0.42	0.00	0.00	5.41	0.00	0.29	0.00	0.89
JH	0.00	0.38	0.09	0.00	0.02	1.15	18.18	0.04	0.34	0.00	1.37	0.00	0.00	0.00	0.11
OR	0.00	2.27	0.45	0.06	1.60	2.77	6.72	0.06	0.00	0.00	0.00	10.53	0.51	19.06	0.24
WB	0.00	1.49	0.18	0.32	1.28	3.25	6.26	0.68	0.59	0.00	10.95	0.00	0.00	0.00	1.07
SK	0.00	0.69	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	3.85	4.94	0.00
North-eastern Region															
AR	0.00	0.68	0.01	0.00	0.03	0.68	0.01	0.00	0.00	0.00	0.00	0.22	51.71	8.64	0.02
AS	0.00	0.56	0.14	0.00	0.46	0.90	3.16	0.00	0.00	0.00	0.00	0.00	0.00	10.60	0.32
MN	0.00	0.10	0.01	0.00	0.00	0.13	0.08	0.00	0.00	0.00	0.00	0.00	1.75	10.55	0.06
ML	0.00	0.40	0.00	0.01	0.06	0.13	0.00	0.01	0.00	0.00	0.00	0.00	2.50	5.86	0.06
MZ	0.00	0.13	0.01	0.00	0.00	0.19	0.29	0.00	0.00	0.00	0.00	0.00	2.17	8.80	0.00
NL	0.00	0.10	0.00	0.00	0.00	0.14	0.40	0.00	0.00	0.00	0.00	0.00	1.62	6.89	0.05
TR	0.00	0.08	0.02	0.00	0.00	0.12	1.08	0.00	0.06	0.01	0.00	0.00	0.00	1.00	0.03

Delhi and Uttar Pradesh will fall short of the target even after mobilizing the full potential within the state. These states need to engage in procurement of Hydro, Wind and Solar from other states to meet the individual and total RPO targets.

In the Western Region, four states namely Chhattisgarh, Gujarat, Madhya Pradesh and Maharashtra will be able to meet both total and individual RPO targets of Wind, Hydro and Others by mobilizing the potential within the state. Goa however will fall short of Others RPO target. Goa may engage in procuring additional solar power from other states to meet the target.

All five states in the Southern Region namely Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu will be able to meet total RPO & individual RPO targets of Wind, Hydro and Others by mobilizing the potential within the state. In the Eastern Region, only Odisha and Sikkim states will be able to meet all RPO targets of Wind, Hydro and Others by mobilizing the potential within the state. Other Eastern states namely Bihar, Jharkhand and West Bengal fall short of Others RPO target for which they can engage in procurement of solar from other states. Jharkhand and West Bengal also need to procure Wind power from other states.

Lastly, in the North-Eastern Region, out of the seven states, Tripura will fall short of target in Wind and Hydro RPO for which they can engage in procurement from other states. Other states of the region namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram and Nagaland will be able to meet both total and individual RPO targets of Wind, Hydro and Others by mobilizing the potential within the state. See Figure 2 for details.

3.2 Capacity requirements at national level

As on July 2023, the total RE installed capacity in the country stands at 177.74 GW. Based on the analysis done by the study, 269.79 is expected to be additional installed capacity that can be mobilized within state potential and 69.81 GW needs to be procured from other states. The total capacity required at 2029-30 for meeting RPO target is 517.34 GW of which 177.74 GW is already installed while 339.6 GW needs to be installed.

In terms of individual RE sources, of the total 517.34 GW installed capacity, 104.16 GW of Wind, 64.88 GW of Hydro, 333.38 GW of Solar and 14.92 GW of Bio-energy is required by 2029-30 to meet the RPO target. As on July 2023, the total installed capacity is 177.74 GW of which solar is 71.14 GW, Wind is 43.94 GW, Hydro is 51.83 GW and Bioenergy is 10.81 GW. In terms of balance requirement from July 2023, Solar of 262.24 GW, Wind of 60.22 GW, Hydro of 13.05 GW and Bioenergy of 4.1 GW need to be installed in the next 7 years. Total of ~340 GW needs to be installed in the next 7 years.

According to bidding calendar notified by MNRE, the government intends to mobilize 50 GW of RE with at least 10 GW of Wind till 2027-28. Based on the study estimates 48.5 GW of RE needs to be installed per year till 2029-30 for meeting the RPO target. The bidding calendar issued is in line with our estimates.

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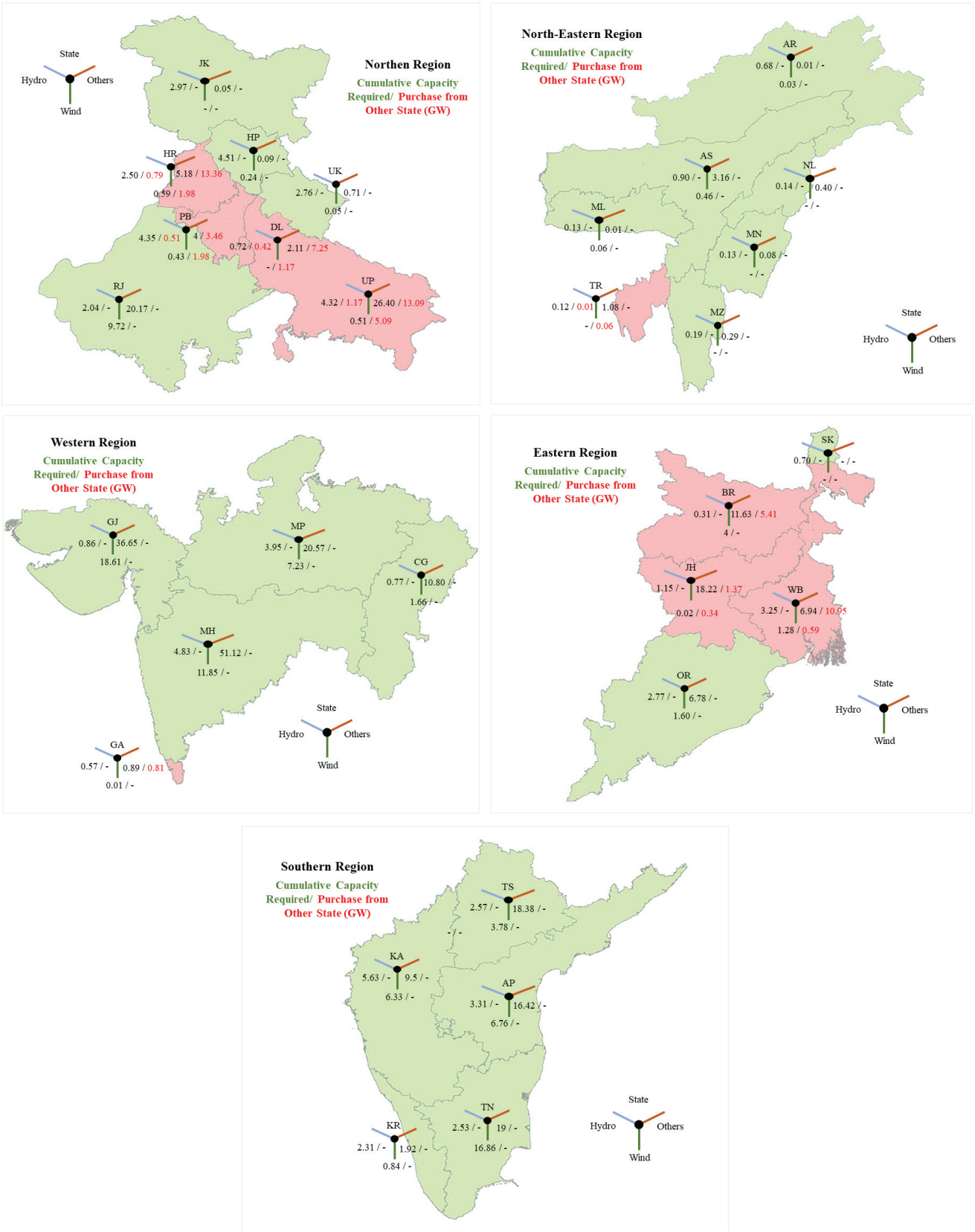

Figure 2: State-wise RE capacity to meet the RPO targets

3.3 Estimation of storage requirement

The study estimates storage at regional level using optimization tool of TIMES-VEDA. The study considers around 18.6 GW of Pumped Hydro that will be available by 2029-30 for balancing the variable RE input to the grid. The study considers 5-hour Battery Energy Storage System (BESS) as an additional mechanism through which balancing of RE can be undertaken. The total BESS capacity of 5-hour duration is estimated at 41.13 GW, and the Pumped storage is 18.6 GW. See Table 2 for more details.

Table 2: Storage requirement at regional level

Region	BESS Capacity requirement (In GW)
Northern Region	17.043
Southern Region	2.74
Eastern Region	9.40
Western Region	11.742
North-eastern Region	0.208

3.4 Funding requirements

As per the unit cost data available in CEA technology catalogue[13], the study estimates that INR 18.55 lakh crore is required for the installation of RE with storage (see Table 3 for detailed funding split-up). We have also estimated the investment requirements as INR 24.9 lakh crore, considering the 2020 cost of technologies. This investment requirement assumes that there is no impact of technological improvements and economies of scale on cost. The above financial need for additional capacity requirement is estimated based on existing installation as on July 2023. The total investment requirement thus varies within INR 18.55-24.9 lakh crore.

Table 3: Funding estimates

Region	Funding requirement (in lakh crore)
Solar	10.23
Wind (Onshore)	3.06
Wind (offshore)	1.55
Hydro	1.08
Bioenergy	0.21
Pumped Hydro	0.83
Battery Storage	1.59
Total	**18.55**

[13] CEA technology catalogue accessed from https://cea.nic.in/wp-content/uploads/irp/2022/02/First_Indian_Technology_Catalogue_Generation_and_Storage_of_Electricity-2.pdf

4. Conclusion

The study may be helpful for the policy-makers at the Central and State levels on RE capacity planning that can harness the state RE potential to reduce transmission requirements and associated costs, and also capacity that needs to be procured from other states for meeting RPOs. According to the study, 269.79 GW is expected to be mobilized within state potential and 69.81 GW required to be procured from other states for meeting the RPO target in 2029-30. Of 30 states/UTs in the country, twenty-one states will be able to meet the RPO target by mobilizing the potential within the state, and nine states need to procure RE power from other surplus states. The study's result also reveals that over 48.5 GW of capacity needs to be installed each year in-line with MNRE bidding calendar estimate of 50 GW. In-terms of adherence to individual targets of RPO, seven states need to procure wind from other states, five states need to procure hydro from other states and eight states need to procure solar from other states.

The study also estimates storage requirement at 59.73 GW with 41.13 GW of 5-hour battery storage system and 18.6 GW of Pumped Hydro. In terms of funding requirements, the study estimates that an investment in the range of INR 18.55-24.9 lakh crore is required to meet the RPO target in 2029-30.

Annexure I:

	Large Hydro	Small Hydro	Solar	Wind	Bioenergy
Northern Region					
Punjab (PB)	0.97	0.58	2.81	0.428	3.44
Haryana (HR)	0.06	0.11	4.56	0.593	1.72
Rajasthan (RJ)	0.48	0.05	142.31	284.25	1.30
Delhi (DL)	0.00	0.00	2.05	0.00	0.06
Uttar Pradesh (UP)	0.72	0.46	22.83	0.51	7.73
Uttarakhand (UK)	18.00	1.66	16.80	0.049	0.31
Himachal Pradesh (HP)	18.82	3.46	33.84	0.239	0.07
Jammu and Kashmir (JK)	14.15	1.71	111.05	0.0010	0.08
Western Region					
Chhattisgarh (CG)	2.24	1.10	18.27	2.749	0.35
Gujarat (GJ)	0.62	0.20	35.77	180.79	3.19
Madhya Pradesh (MP)	2.24	0.82	61.66	55.423	2.52
Maharashtra (MH)	3.77	0.79	64.32	173.87	6.55

	Large Hydro	Small Hydro	Solar	Wind	Bioenergy
Southern Region					
Andhra Pradesh (AP)	2.37	0.41	38.44	123.37	2.28
Telangana (TS)	2.06	0.10	20.41	54.717	1.80
Karnataka (KA)	6.60	3.73	24.70	169.251	3.56
Kerala (KL)	3.51	0.65	6.11	2.6210	0.78
Tamil Nadu (TN)	1.92	0.60	17.67	95.107	2.20
Eastern Region					
Bihar (BR)	0.07	0.53	11.20	4.023	1.31
Jharkhand (JH)	0.75	0.23	18.18	0.016	0.15
Odisha (OR)	3.00	0.29	25.78	12.129	0.30
West Bengal (WB)	2.84	0.39	6.26	1.281	1.74
Sikkim (SK)	4.29	0.27	4.94	0.00	0.00
North-Eastern Region					
Arunachal Pradesh (AR)	50.33	2.06	8.65	0.246	0.02
Assam (AS)	0.68	0.20	13.76	0.459	0.32
Manipur (MN)	1.78	0.10	10.63	0.00	0.06
Meghalaya (ML)	2.39	0.23	5.86	0.055	0.07
Mizoram (MZ)	2.20	0.17	9.09	0.00	0.00
Nagaland (NL)	1.57	0.18	7.29	0.00	0.05
Tripura (TR)	0.02	0.05	2.08	0.00	0.03

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