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TECHNICAL PAPER - 6
NOVEMBER 2024

Strengthening the Resource Adequacy Framework for an RE-Rich Future

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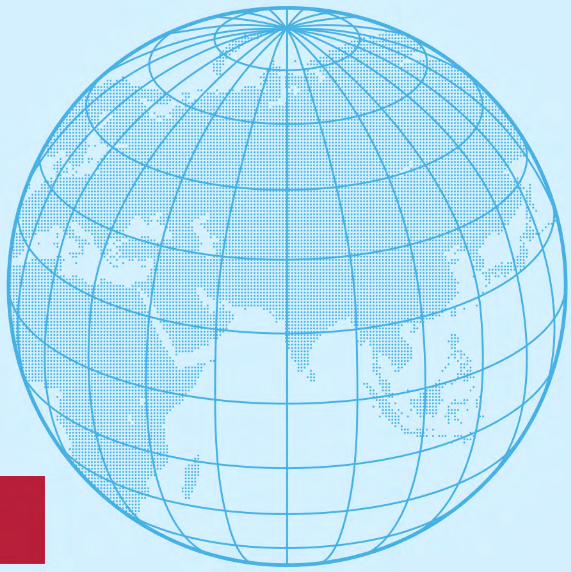

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Recommended citation:
Singh, D., Chitnis, A. (2024). *Strengthening the Resource Adequacy Framework for an RE-Rich Future* (CSEP Technical Paper 6). New Delhi: Centre for Social and Economic Progress.

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Strengthening the Resource Adequacy Framework for an RE-Rich Future

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In the preparation of this paper, the authors benefited greatly from inputs and suggestions from many people. Puneet Chitkara of the Lantau Group and Srihari Dukkipati of the Prayas Energy Group reviewed an earlier draft of this paper and provided very useful comments. CSEP held a roundtable on the framework for planning and resource adequacy in September 2024, where there was vibrant discussion on these issues. Comments and suggestions from the participants have been incorporated in the paper. The authors also benefited greatly from comments and suggestions on this paper from Laveesh Bhandari, Veda Vaidyanathan, and Shymasis Das—all from CSEP; Sushanta Chatterjee of the Central Electricity Regulatory Commission; and Meru Gokhale and Diya Isha—both of Editrix Solutions. Amitesh Sirvaiya and Srishti Katoch provided research support. The authors thank all these individuals for their inputs and assistance. However, the views and opinions expressed in the paper are the authors' own, and they remain responsible for all errors of fact or interpretation.

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Abbreviations

CEA	Central Electricity Authority
EENS	Expected Energy Not Served
ELCC	Expected Load Carrying Capacity
ENTSO-E	The European Network of Transmission System Operators for Electricity
EVs	Electric Vehicles
FoR	Forum of Regulators
GWh	Giga-Watt-hours
JERC	Joint Electricity Regulatory Commission
LOLE	Loss of Load Expectation
LOLEv	Loss of Load Events
LOLH	Loss of Load Hours
LOLP	Loss of Load Probability
LSE	Load Serving Entities
LT-NRAP	Long-Term National Resource Adequacy Plan
MoP	Ministry of Power
MT-DRAP	Medium-Term Distribution Resource Adequacy Plan
MW	Mega Watt
NENS	Net Energy Not Served
PRM	Planning Reserve Margin
PVRR	Present Value of Required Revenues
RA	Resource Adequacy
RAR	Resource Adequacy Requirement
RE	Renewable Energy
RPO	Renewable Purchase Obligation
SERC	State Electricity Regulatory Commission
ST-DRAP	Short-Term Distribution Resource Adequacy Plan

Executive Summary

With greater additions of renewable energy (RE) to the generation mix, ensuring reliability of the power system will be a challenge. Resource Adequacy (RA) is an assessment to determine whether a power system has sufficient resources to meet the demand for electricity at all times. While resource adequacy has always been of concern, the addition of non-dispatchable and non-controllable resources, such as RE, to the system is making it more challenging to ensure resource adequacy. Recognising this challenge, the Ministry of Power (MoP) recently issued guidelines that give a recommended framework for ensuring resource adequacy. The MoP framework relies on three reliability metrics to ensure resource adequacy: (1) loss of load probability (LOLP); (2) planning reserve margin (PRM); and (3) normalised energy not served (NENS). This paper argues that, while the framework is a good starting point, it requires significant modifications to effectively address the challenges posed by a rapidly transforming power sector increasingly reliant on RE.

The MoP framework and similar ones used in other parts of the world were developed for power systems driven by fossil fuels. This paper suggests several modifications that will make it more suitable for the RE-rich system of the future. While reliability is paramount for power sector planners, minimising its cost is also crucial. This paper proposes modifications to the MoP framework with this dual goal in mind, and most of the recommended modifications to the framework fall into one of two categories: (1) those that enhance reliability; and (2) those that increase the cost-effectiveness of the resource adequacy measures. We also suggest measures to improve implementation by making a few changes to the roles and responsibilities of the institutions involved in the current framework.

For enhancing reliability, we recommend that, because LOLP is not a very intuitive metric, planners use an alternative metric—the number of loss of load hours (LOLH) in a year. In addition, we point out that the depth (in MW) and duration of individual generation shortfalls, and the frequency of shortfalls, are important because they affect the level of distress consumers experience from outages. Therefore, we recommend that, in addition to LOLH, the following metrics, along with their probability distribution over the year, be assessed in any RA planning exercise: (1) duration of individual shortfalls; (2) depth of shortfalls in MW; and (3) frequency of shortfalls given by the metric, loss of load events (LOLEv).

For enhancing reliability, we recommend caution when using PRM and capacity credits because these are much more appropriate for fossil-fuel-driven power systems and not for RE-rich systems of the future. Another major drawback of using PRM and capacity credits is that it assumes that failures or generation shortfalls at individual plants are independent of each other. However, that is not always the case. Common-mode or correlated failures or shortfalls can occur, particularly during extreme weather events. Extreme weather events can lead to shortfalls across entire regions. One example is the extreme winter storm in Texas, USA in February 2021. The forecast for the winter had predicted there would be reserves of 28% of the expected peak load after accounting for planned and estimated unplanned outages. But the peak load exceeded the forecast, and 32% of the generation capacity failed to operate, leading to widespread blackouts and extreme distress for people.

RA planning must also account for extreme weather events. As such events become more frequent, we recommend that the proposed system be stress-tested through modelling a few potential high-impact, low-probability events. Changing weather patterns and the increasing frequency of extreme weather events will also affect future patterns of RE generation and electricity demand, and these are likely to be very different from the past. Therefore, we suggest that planning models not rely on historical data alone, particularly for RE generation patterns and electricity demand. We suggest that, instead, electricity planners collaborate with climatologists to develop better forecasts of weather patterns.

In order to enhance cost-effectiveness of measures to ensure resource adequacy, we recommend that there be a re-evaluation of the economic justification for the selected RA criteria, such as an LOLP of 0.2% and NENS of 0.05% over the year. This is because the relationship between reliability and cost is highly non-linear, and a small relaxation in the reliability metrics can lead to a significantly larger reduction in costs. In addition, because consumers are indifferent to the cause of any outage, we suggest that it will be good to compare, on an energy basis (say, GWh), the outages caused by bulk system outages versus those caused by distribution network faults. If the outages, in GWh terms, due to distribution network outages are much larger than bulk power system outages, then it would be an indication that we are overspending on grid resource adequacy and underspending on upgrading the distribution network.

For enhancing cost-effectiveness, we also recommend that instead of developing just a single plan and subjecting it to various uncertainties, planners should evaluate a few alternate plans so that the preferred plan is the one that best balances value and risk. Furthermore, because good resource planning can reduce system costs considerably, we recommend that there be sufficient time and training for effective long-term resource planning. More specifically, we recommend that long-term resource plans be required only once every two years, as usually done in the US, instead of requiring it to be completed in two months as mandated in the MoP framework.

The MoP framework puts the onus of resource adequacy planning on the discoms alone. We think that, given the extent of consumer migration to other suppliers, it may be fairer and also cost-effective that all load serving entities (LSEs) be required to do resource adequacy planning. Furthermore, to capture synergies between all LSEs, including discoms, in the approval process for resource plans, SERCs should review them in a holistic manner for the entire State to ensure that electricity is delivered in the most optimal manner for the entire State.

We recognise that some of these changes to the RA framework may increase the complexity of the RA process, and some could also be challenging for discoms to carry out. Discoms in India are just beginning to consider resource planning. Therefore, we have recommended a gradual transition to our recommended framework. However, it is important that these changes are not ignored because doing so could lead to decreased reliability and increased costs that consumers will have to pay for electricity service. Power procurement costs constitute 70–80% of the costs of electricity that consumers pay, and effective resource planning can help significantly reduce those costs. Neglecting these recommended changes could lead to the entrenchment of outdated practices, making future framework revisions more difficult.

1. Introduction

Resource Adequacy (RA) is an assessment to determine whether a power system has sufficient resources to meet the electricity demand at all times. Power systems work within very tight bands of performance. In India, the frequency, typically 50 Hz, is required to stay within a band of 49.90–50.05 Hz. Therefore, it is essential that, at any time, sufficient resources of the right type are available. Resource adequacy has always been important for the power sector. It has become even more significant as more services, such as transport, are electrified. The increasing importance of power system reliability coincides with the integration of non-dispatchable resources, like RE, making reliability assurance more complex. Therefore, assessments of RA have become even more crucial than before.

In June 2023, the Ministry of Power (MoP) issued 'Guidelines for Resource Adequacy Planning Framework for India.' All 'institutions and stakeholders' responsible for ensuring resource adequacy need to follow these guidelines. The Forum of Regulators (FoR) has issued Model Regulations for RA. We commend the MoP and FoR for paying attention to the critical issue of RA. This paper argues that while the MoP framework for resource adequacy planning is a good starting point, it requires significant modifications to effectively address the challenges posed by a rapidly transforming power sector increasingly reliant on RE.

The next section of this paper briefly describes the main features of the framework as recommended in the MoP Guidelines. Section 3 discusses technical issues in the Guidelines and suggests improvements. Section 4 discusses procedural issues in the Guidelines and some suggested improvements. We end with Section 5, which contains our conclusions and recommendations for improving the framework for ensuring RA.

2. Main Features of the Guidelines Issued by the Ministry of Power (MoP)

The MoP Guidelines recommend using the loss of load probability (LOLP) and normalised energy not served (NENS) as the metrics to assess resource adequacy. LOLP is the probability that a system's load may exceed the generation and firm contracts available to meet that load. NENS is calculated from the Expected Energy Not Served (EENS), which is the expected amount of energy that may not be served in a year. NENS is calculated by dividing EENS by the total energy supplied by the system in the year.

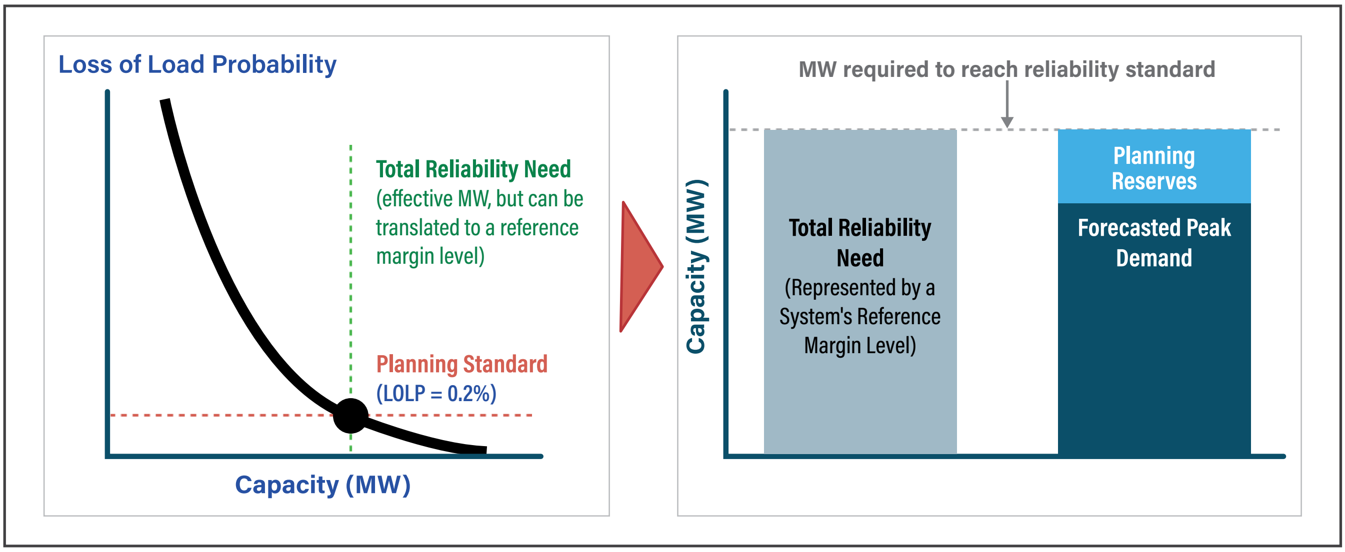
The prescribed level of LOLP is used to calculate the planning reserve margin (PRM)—essentially the reserve capacity beyond peak load to maintain the actual LOLP below the limit. This process is illustrated in Figure 1. The planning model has a constraint on EENS, derived from the specified level of NENS. After the model is run, if the prescribed limit on LOLP is exceeded, the PRM is increased until the resulting LOLP is less than the prescribed limit.

The Central Electricity Authority (CEA) sets the desired values for LOLP and NENS and develops a Long-Term National Resource Adequacy Plan (LT-NRAP) that meets these reliability criteria. The capacity required in the LT-NRAP establishes the PRM required at the national level to meet the target values of LOLP and NENS.

The national capacity requirement is calculated to be (1 + PRM) × National Peak Load.

The national capacity requirement is divided among distribution companies (discoms) in proportion to their contributions to the national peak. Each discom is then expected to develop an optimal (least-cost) resource plan to meet its share of the national capacity requirement, also known as its Resource Adequacy Requirement (RAR).

Figure 1: Deriving PRM from LOLP



Source: NARUC (2023, November). Resource Adequacy for State Regulators: Current Practices and Emerging Reforms. National Association of Regulatory Utility Commissioners, Washington, DC, USA. (With some modifications).

Each discom will have to demonstrate to its respective State Electricity Regulatory Commission (SERC) that it has the required firm capacity tied up to meet its RAR. Firm capacity for each generation technology is derived by multiplying the installed capacity for that technology by the capacity credit for it. Capacity credit is a measure of firm capacity as a fraction of the installed capacity. For thermal plants, the capacity credit is calculated by accounting for auxiliary consumption and the forced outage rate. Estimating a capacity credit for RE is more complicated, which we will discuss later in this paper. For assessing whether sufficient capacity has been tied up, the total capacity tied up is calculated using the following equation:

$$Total\ Capacity\ Tied\ Up\ = \sum_i \sum_j (Installed\ Capacity)_{ij} \times CC_{ij}$$

where:

i = 1…number of generation technologies;

j = 1…number of plants of technology i;

CC_{ij} is the capacity credit for the respective plant or contract.

3. Modifications to the Framework

Measures such as LOLP and PRM were developed for power systems based on fossil fuels. Increasing contribution from RE, a much greater use of energy storage, and much greater variability in the weather will make the power system of the future very different from today's system. It will require a change in the reliability metrics and the modelling and analysis tools. Many states in the US currently use an RA framework similar to the one in the MoP Guidelines. They start, in most cases, with a limit of 0.1 days per year of Loss of Load Expectation (LOLE) and derive a PRM from it. However, there is a growing recognition that this method is not suited for RE-rich systems of the future, and that more advanced techniques for assessing RA are required (NARUC, 2023; Carvallo et al., 2023).

Two recent reliability failures in the US have highlighted the need to modernise the approach to assessing and ensuring resource adequacy (ESIG, 2021). The first was two days of rolling outages in California in August 2020, and the second was an extreme winter storm in Texas in February 2021, that led to widespread power outages and caused great distress and damage. In our review of the MoP RA framework and suggestions for improvement, we draw on the literature that supports many of these ideas for reframing RA assessment.

In India and elsewhere, a much higher level of uncertainty is expected for the power sector in the future. The electrical load will likely increase more rapidly because of new loads, such as electric vehicles (EVs) and data centres, and the increased use of existing end-uses, such as space cooling. These changes will also alter the load profile faced by discoms. On the supply side too, there will be considerable uncertainty about the availability and costs of several new technologies on the horizon: batteries and small modular (nuclear) reactors. The adoption of behindthe-meter technologies, like rooftop solar, increases forecasting uncertainty for discoms due to their limited visibility into customer deployment and usage. Changing weather patterns and a much greater incidence of extreme weather events contribute to further uncertainty. Furthermore, changes in weather patterns will affect both demand and supply, and also impact RE generation. The MoP framework recommends reliance on historical data for many parts of the analysis, such as load forecasts, RE generation profiles, and RE capacity credits. However, given the changing weather patterns, the future will be different from the past. Two lessons from recent extreme weather events in India and the world are that, first, 'the unthinkable [is] quickly becoming the norm', and second, that we can no longer ignore such events by passing them off as unforeseeable or unexpected, but must instead prepare for them in our planning (Newman, 2021; Singh, 2021a).

In addition, the discom's consumer mix is also undergoing rapid changes. As large numbers of commercial and industrial consumers migrate away to open access and/or captive generation, pricing the capacity procured for ensuring resource adequacy for the entire State will be a tricky issue. Therefore, the framework needs to ensure that not only are the costs imposed by the RA mandate the lowest possible, but also that their recovery mechanisms are just and fair.

In India, at the national level, contribution from variable RE in generation is still low (12.6% in FY 2022–23), and that from thermal plants is high (74.6%) (CEA, 2024). Therefore, the MoP framework could possibly be adequate for ensuring RA now. However, even presently, not all states share a supply mix similar to the national level, and the contribution from RE is quite significant for some states, such as Karnataka. Going forward, as the contribution from RE in the generation mix increases rapidly, it will be important to make changes to the RA framework to ensure that it is appropriate for a RE-rich power system. Otherwise, some of the practices from the 'older' framework may become embedded in the planning processes and may be difficult to change later.

In the following sub-sections, we discuss potential modifications to the RA framework in more detail. Since incorporating all these modifications immediately may not be easy, we suggest a gradual transition to an RA framework more appropriate for an RE-rich system.

3.1 Limitations of Using PRM for RE-Rich Systems

The use of PRM was appropriate for systems driven by fossil fuels because the peak was when the system was most vulnerable to a supply shortage. If a system had sufficient generating capacity to meet the peak load, it would meet the load at any other time. However, when a power system has a significant contribution from RE, the maximum vulnerability may not be at the peak load time but at another time. For example, for a system that usually peaks during the summer and relies significantly on RE and hydropower, the time of maximum vulnerability may not be during the summer but on cloudy days—when solar generation is low and when hydro reservoirs have been emptied.

Another reason PRM is inappropriate for RE-rich systems is related to how firm capacity is calculated. As discussed earlier, for thermal power plants, the total installed capacity is multiplied by the forced outage rate for thermal plants. For example, if a system has a total installed capacity of thermal plants of 10 GW and the forced outage rate is 20%, the firm capacity is calculated to be 8 GW. A similar calculation takes place for RE plants, where the capacity credit is based on the average generation from RE plants at times of peak load or peak net load. We discuss the shortcomings of calculating capacity credits for RE in detail later in this paper. This calculation of firm capacity assumes that the outages or shortfalls in generation are independent of each other, an assumption that doesn't always hold true. Due to heavy dependence on weather, RE-rich systems can experience 'common mode' or correlated generation shortfalls or failures (NARUC, 2023; ESIG, 2023). Correlated failures are those where failures are not independent of each other but occur simultaneously over a region. In the following paragraphs, we give examples of actual correlated failures, in both RE and thermal plants.

In Spain in March 2022, an extreme dust storm halved the capacity factor of the national solar photovoltaic (PV) installations for more than two weeks (Micheli et al., 2024). On the worst day, the drop was 80% nationally. The second example is the severe winter storm (Uri) in Texas, mentioned earlier, that caused widespread outages in February 2021. About 32% of the generation capacity failed to operate (University of Texas at Austin, 2021). A significant fraction of the failures was due to gas plants not operating, often because the gas valves were frozen. Gas plants accounted for 42% of installed capacity at that time.

Correlated outages are a recurring issue in India because of coal supply shortages, especially around the months of September–October and March–April—when demand soars, but domestic coal supply is not adequate (Prayas, 2019). In a 2023 statement, the Union Minister for Power said, 'If coal had not been imported for blending, coal stock would have become zero in September 2022, leading to widespread power cuts and blackouts' (PIB, 2023). The problem is exacerbated by freight shortages, as all states scamper for coal, and a sufficient number of railway rakes are not available for transportation (*The Hindu*, 2022). At such times, despite having adequate tie-up for firm thermal capacity to meet the demand, states have to resort to large-scale load shedding.

Because of their dependence on the weather, hydroelectric plants are also susceptible to correlated shortages. Recent experience in India highlights this vulnerability of hydropower. Erratic rainfall during FY 2023–24 led to a 16.3% decrease in hydropower generation in the country (Varadhan & Yap, 2024). According to Varadhan and Yap (2024), this was the sharpest drop in hydropower generation in 38 years.

These examples show that both RE and thermal plants can suffer correlated shortfalls in generation or failures. Therefore, there can be shortfalls in required generation even though the PRM requirements are met. In India, we must consider the impacts of events, such as region-wide heat waves, flooding, or dust storms; widespread problems with coal supply due to flooding or lack of rakes for transportation; and widespread droughts.

The Guidelines recognise that the time of maximum system vulnerability may not be at the time of peak load and, therefore, rightly recommend chronological evaluation of all hours. Evaluating all hours captures the variability in RE generation. Chronological evaluation ensures that inter-hour and inter-season variability is also captured and, therefore, it also captures the sequence of variability when batteries or other energy storage assets are used (ESIG, 2024). For energy storage devices to be useful, it is crucial to ensure that they are charged and ready when required.

It seems that the MoP Framework uses PRM along with capacity credits to arrive at a minimum level of generating capacity. It ensures that the reliability requirements (LOLP and NENS) are met by evaluating the performance of the system using chronological evaluation of all 8,760 hours in the year. Therefore, the framework does not rely solely on PRM to ensure RA, and therefore, the concern about PRM not being appropriate for a RE-rich system is mitigated to some extent, but the issue of correlated failures or shortages remains. Additionally, concerns about the use of capacity credits to calculate the capacity tied up by the discom still remain, and we discuss that in the next sub-section.

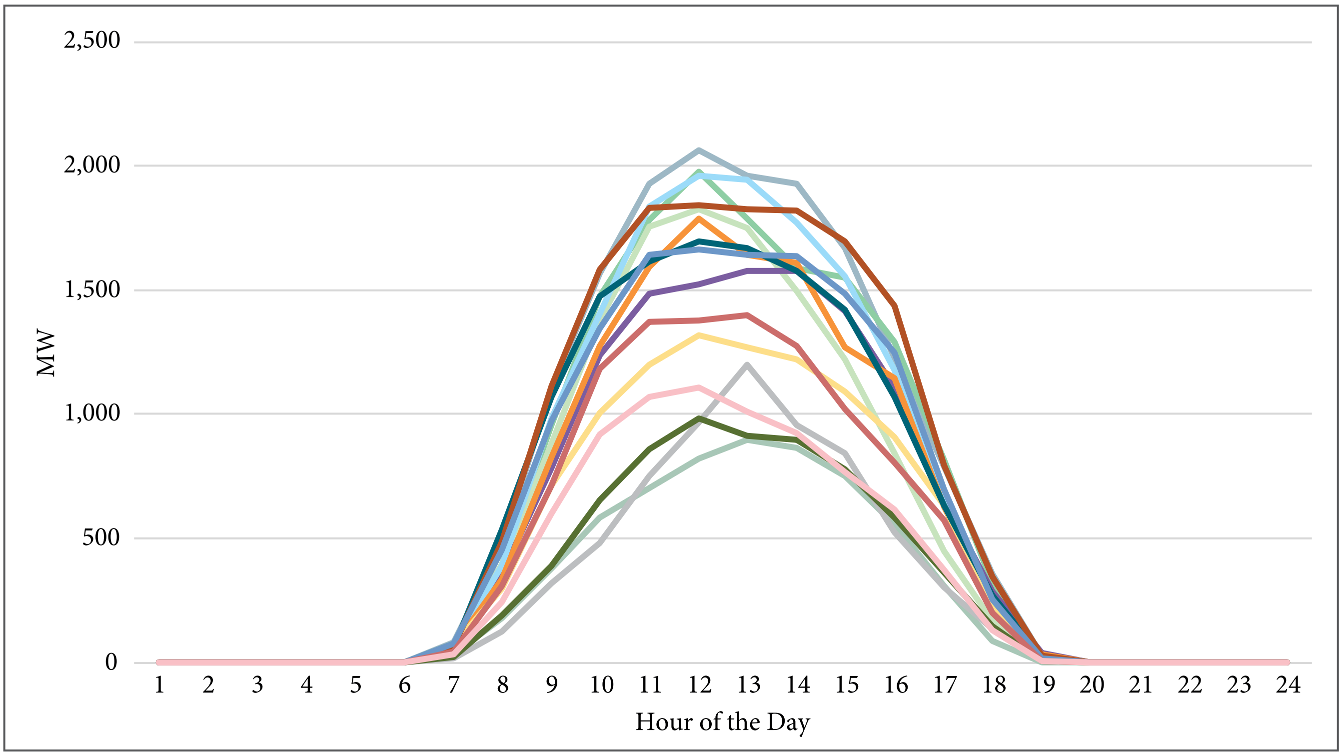
3.2 Use of Capacity Credits Not Appropriate for RE

As discussed above, using PRM as a measure of resource adequacy relies on using capacity credits. The framework for RA established by the MoP gives three methods to calculate the capacity credit for RE:

- Use the average of the historical contribution during peak load hours.
- Use the average of the historical contribution during peak net load hours.
- Use the expected load carrying capability (ELCC). ELCC is estimated as the additional load the system can add after the generator under test is added to the system and the system returns to the earlier reliability level.

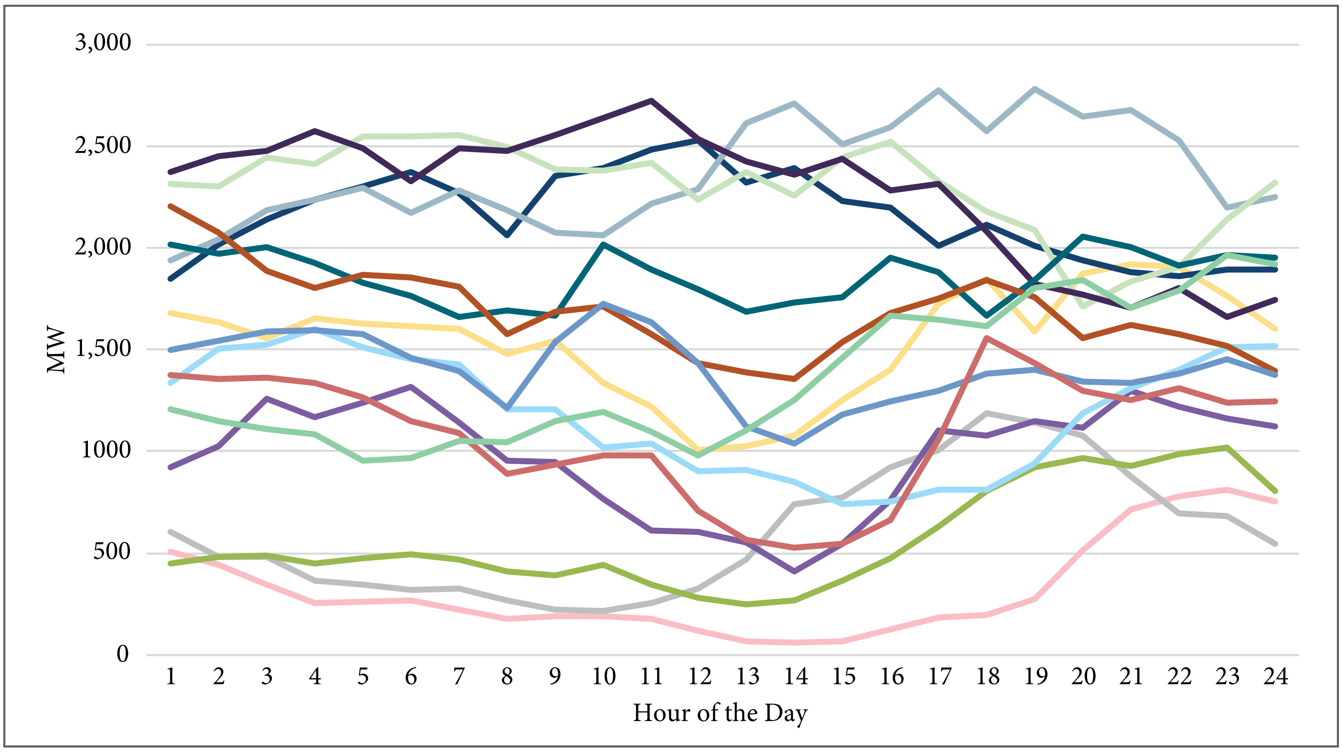
Figures 2 and 3 show the hourly solar and wind energy generation for 15 consecutive days in September 2023 (September 1–15, 2023) for the State of Maharashtra. There is considerable variability in solar and wind over these 15 days. Solar generation varies by more than 2:1, and wind varies by more than 2.5:1. The waveshape for solar generation remains roughly the same; for wind, there is a significant variation in the pattern of wind generation over the 15 days. Averaging wind and solar generation profiles for capacity credit calculations fails to capture their variability and thus undermines accurate resource adequacy assessments.

Figure 2: Hourly Solar Generation in Maharashtra Over First 15 Consecutive Days in September 2023



Source: MSLDC. (2024). Maharashtra State Load Despatch Centre website. https://mahasldc.in/home.php/daily-reports/

Figure 3: Hourly Wind Generation in Maharashtra Over First 15 Consecutive Days in September 2023



Source: MSLDC. (2024). Maharashtra State Load Despatch Centre website. https://mahasldc.in/home.php/daily-reports/

3.3 LOLH is a Better Metric Than LOLP

The framework established by the MoP uses LOLP to assess the PRM required to ensure resource adequacy. The MoP Guidelines state that LOLP is a 'Measure of the probability that a system's load may exceed the generation and firm contracts available to meet that load in a year'. The CEA uses an LOLP of 0.2% over a year, and we expect that an LOLP of 0.2% will continue to be used to assess resource adequacy.

LOLP is not a very intuitive measure, and it can sometimes be challenging to grasp what an LOLP of 0.2% means for assessing the grid's reliability. Furthermore, when assessing reliability and LOLP, some planners consider the peak load hour for each day, which results in 365 computations. In contrast, some consider each hour in the year, which results in 8,760 computations, which can sometimes be confusing (Kueck et al., 2004).

Since maximum vulnerability in RE-rich systems doesn't always coincide with peak load, an hourly metric is more suitable. Loss of Load Hours (LOLH) is one such metric. LOLH is defined as the 'Average number of hours per year with loss of load due to system demand exceeding available generating capacity' and is given in hours per year (NARUC, 2023). The Guidelines also recommend modelling on an hourly chronological resolution (Annexure E of the Guidelines), so giving shortfalls in hours would be consistent with the modelling. The European Network of Transmission System Operators for Electricity (ENTSO-E) uses a similar index but with a different name: Loss of Load Expectation (LOLE), which is expressed in hours per year[1] (ENTSO-E, 2020).

3.4 Need for Multiple Metrics

LOLP, and even LOLH, give the expected number of days or hours in a year when there will be a generation shortfall. However, neither LOLP nor LOLH gives information about the depth or duration of individual outages, nor does it give any information about the frequency of outages. NENS, the other metric recommended for use in the MoP framework, gives information about the total amount of unserved energy over the year but does not give information about individual outages.

The information about the depth, duration, and frequency of outages is vital because these features affect the distress they cause to electricity consumers. For example, a single ten-hour outage will cause more distress than ten one-hour outages spaced over many days. Having the additional information about individual outages is likely more important when working with a RE-rich power system than when working with a fossil-fuel-based system. Dent et al. (2023) show that, in the UK, adding more wind to the resource mix leads to longer but fewer shortfalls for the same level of EENS. While we do not know definitively if this result can be generalised for other RE resources, such as solar, or for other geographies, we think that it is plausible that it can be. RE-generating plants are, in general, likely to be more reliable because of their modularity; however, shortfalls, when they occur due to cloudy days or lack of wind, are likely to be longer. So even though the LOLP (or LOLH) for a year may be the same for two cases, one would cause much more distress if the outages were of much longer duration than the other. Therefore, rather than having just two metrics for reliability (LOLP/LOLH and NENS), it would be better to also use the following metrics with limits on their value for an acceptable level of RA:

- Loss of load events, LOLEv (frequency of shortfalls);
- Duration of any single shortfall;
- Depth of any single shortfall (MW).

As ESIG (2024) mentions, we expect one of these multiple metrics to be binding at any time, and the others are likely to be redundant; however, the binding constraint could change as the resource mix or load pattern changes.

As we discuss later in this paper, probabilistic modelling and analysis should be used to assess RA for RE-rich systems. When that is done, the values for any metrics (LOLP/LOLH, etc.) represent average or expected values. They do not provide information on the probability distribution of the shortfalls. It is crucial to consider the distribution of shortfalls because two systems may have the same average value of these metrics but could have very different risk profiles (ESIG, 2021). The importance of this will be further highlighted in our later discussion of high-impact, low-probability events.

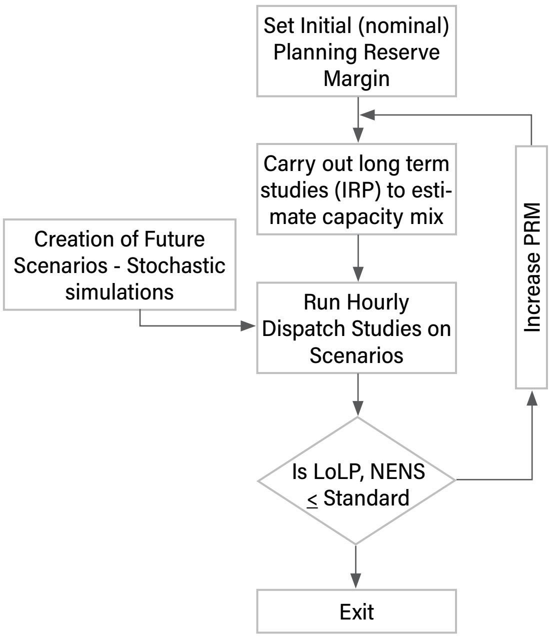
[1] This should not be confused with LOLE used by many states in the US with units of days/year and was mentioned in Section 2 of this paper (NARUC, 2023).

3.5 Improving the Approach for Handling Uncertainty and Managing Risk

Approach Used in the MoP's Framework

The MoP's approach to addressing and managing risk is detailed in Annexure B of the Guidelines, 'Determination of LOLP/NENS, Optimal Planning Reserve Margin (PRM) and Resource Adequacy Targets', and is shown schematically in Figure 4. The framework manages risk by creating a deterministic draft capacity expansion plan and then testing it against various future scenarios, including variations in demand, hydro conditions, plant outages, and RE generation. The PRM is increased to ensure that LOLP and NENS stay within prescribed limits for all the scenarios.

Figure 4: Approach to Handling Uncertainty in MoP's Framework



Source: Guidelines for Resource Adequacy Planning Framework for India, Annexure B.

We think this approach of finding an optimal plan and then subjecting it to various uncertainties may not lead to the least-cost plan. This approach may have worked earlier when generation was mainly based on fossil fuels. At that time, energy was expensive, and ensuring reliability had almost no additional cost. This was because thermal plants that were running could provide reliability services at almost no additional cost. With increased contribution by RE in the generation mix, that will change. In this changed scenario, energy will be inexpensive, but ensuring the grid's reliability will be expensive. Therefore, a plan that is the lowest cost before being subjected to uncertainties could become much more expensive and thus no longer optimal after it has to ensure reliability in the face of various uncertainties. In the following sub-section, we describe an alternative approach that we think would result in a resource adequacy plan with lower, and possibly much lower, costs.

Best Practice for Risk Management[2]

Instead of having just one draft plan that is then subjected to stochastic simulations, as shown in Figure 4, we suggest the discoms develop a few alternate plans, subject them to stochastic simulation, and select the plan that performs the best under uncertainties.

Utilities use three main techniques to address uncertainty and manage risk: scenario planning, sensitivity analysis, and probabilistic analysis.[3] We describe each of them in the following paragraphs.

Scenario Planning

Scenario planning is used to create alternative plans or portfolios of resources. It starts with developing plausible and internally consistent futures (Hirst, 1992). These futures are developed by first understanding forces that would move the world in different directions and then mapping out a handful of possible alternative futures—each accompanied by a narrative that describes that future (Borison, 2014). Usually, each future has an underlying theme: for example, a clean energy scenario would have a high penetration of energy efficiency and RE, while a nuclear energy scenario would have a high penetration of nuclear power. Resource portfolios are then developed to satisfy the electricity requirements in each future. Because the assumptions are different for different scenarios (futures), the resource plan in each scenario will be different.

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[2] This section draws significantly from the earlier joint work of one of the authors: Singh, D., & Swain, A. (2018, July). *Fixated on Megawatts: Urgent Need to Improve Power Procurement and Resource Planning by Distribution Companies in India*. Centre for Energy, Environment & Resources, New Delhi.

[3] Singh & Swain (2018) discuss one additional technique—Options Analysis. It deals with addressing uncertainties that are evolving and how to implement and manage a preferred plan in an adaptive way. Because we are discussing how to select a preferred plan, we do not discuss options analysis here.

The most significant advantage of scenario planning is that it helps identify uncertainties. It broadens the planners' horizons by drawing attention to what could happen in the future—both good and bad. It also facilitates understanding the impact of an alternative future on a plan developed for another future. Further, scenario planning involves brainstorming with many people, so it tends to be inclusive and participatory (Borison, 2014).

Sensitivity Analysis

Sensitivity analysis is carried out to understand how changes in key assumptions will likely affect the Present Value of Required Revenues[4] (PVRR). It answers 'what if' questions. Typically, a single assumption (load growth or fuel price, etc.) is varied over a plausible range from low to high. Sometimes, a cluster of assumptions is varied. Sensitivity analysis helps identify uncertainties with the most significant impact; the impact of such variables can be studied in more depth later.

One of the shortcomings of sensitivity analysis is that it lacks analytic rigour. The basis for selecting a variable's specific 'high' or 'low' level is not well defined, sometimes arbitrarily put as +10% and -10% from the base case value. It can be made more rigorous by defining 'high' and 'low' values—at, say, the 90th and 10th percentile, respectively, of the variable's value (Borison, 2014). Another shortcoming of sensitivity analysis is that it ignores correlations and interactions between variables.

Probabilistic Analysis

Probabilistic analysis overcomes the shortcomings of sensitivity analysis and provides information that can be used to rank alternative plans. Probabilities are assigned to different values of critical variables, and the PVRR and any other significant outputs are calculated for each combination of variables. The results are obtained either using decision trees or Monte Carlo simulation. The results for each plan give the expected value and probability distribution for critical outcomes, such as PVRR and electricity prices (Hirst, 1992).

Probabilistic analysis provides insights into a plan's performance under uncertainty, facilitating more effective comparisons between different plans. For example, Plan A may have a slightly higher expected PVRR value than Plan B. However, the variation in the PVRR of Plan B may be much higher, meaning that, under some conditions, it could perform much worse than Plan A. Under these circumstances, one may choose Plan A despite its slightly higher costs. Probabilistic analysis can be more challenging because it requires data on the probability distribution for the critical variables to be modelled.

Pulling it All Together – Best Practice

Each of the three analytical techniques discussed so far has advantages and disadvantages. Fortunately, best practice does not require selecting one or the other technique. Instead, as proposed by Borison (2014), these techniques can be woven into a logical progression, as shown in Figure 5. The following paragraphs elaborate on this view of best practice.

Scenario analysis should be used first to frame the analysis. It facilitates a consensus on the objectives, a comprehensive understanding of the uncertainties to be faced, and the possible alternatives. Because it is a creative and participatory exercise, it facilitates an expansive approach necessary for good framing of the problem. Scenario analysis should produce various alternative plans as outputs.

The next step should be sensitivity analysis. Sensitivity analysis identifies the most critical uncertainties and highlights the more important issues. It also eliminates alternative plans that are likely to perform poorly under uncertainty. With its focus on rigorous computational analysis, sensitivity analysis narrows the focus after the expansion in scenario analysis.

Next, probabilistic analysis compares alternatives across a range of futures. It identifies the preferred plan that best balances value and risk. The results from the probabilistic analysis will tell us how each of the plans performs on the reliability metrics: LOLP/LOLH, NENS, LOLEv, and maximum depth and duration of generation shortfalls. The results from probabilistic analysis can be used to ensure that the preferred plan meets the limits set on the reliability metrics.

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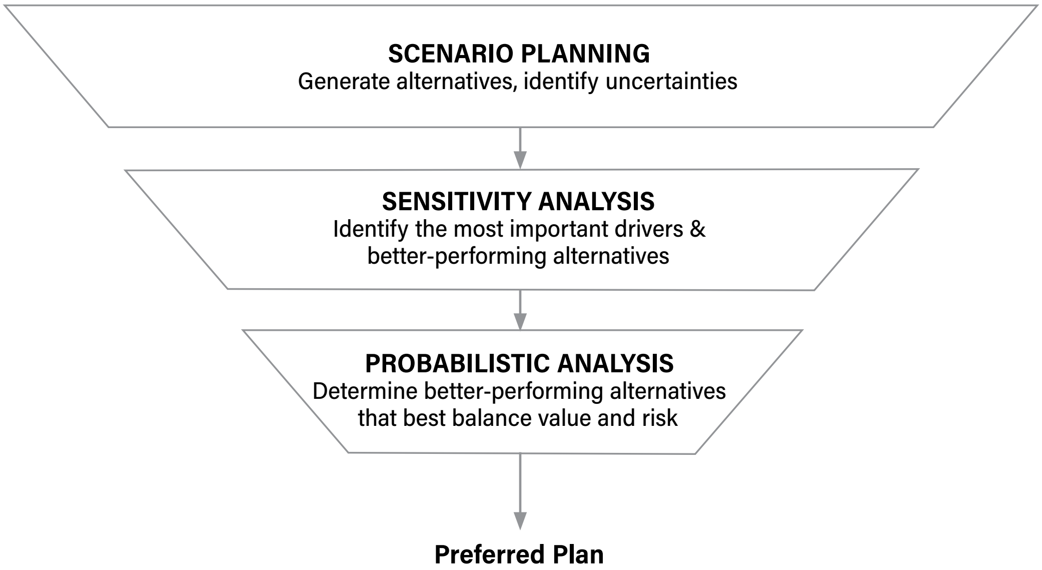
[4] Present Value of Required Revenues (PVRR) is a measure of the total system costs of any resource plan over the planning horizon. It is also often used in resource planning to compare the costs of two plans.

Figure 5: Best Practice for Addressing Uncertainty and Managing Risk



Source: Adapted from Borison, A. (2014). Electric Power Resource Planning Under Uncertainty: Critical Review and Best Practices. White Paper. Berkeley Research Group, California, USA.

One of the major differences between the best practice outlined above and the recommended approach in the MoP Guidelines, as shown in Figure 4, is that the Guidelines create scenarios to subject only one plan (the draft plan) to various uncertainties. Therefore, the final plan using the Guidelines' approach may meet reliability requirements but is the least costly under baseline conditions only and possibly more expensive under other conditions. In contrast, the best practice outlined above leads to a plan that not only meets the reliability requirement but also provides the best value under the uncertainties that are likely to be faced by the system. It best balances value and risk. Because power purchase costs comprise 70–80% of the cost consumers pay for electricity, the portfolio of generating assets and power purchase contracts that a discom uses to provide electricity must be the portfolio that provides the best value. In addition, while the Guidelines list the variables that must be considered, they say very little about how the scenarios will be constructed. The construction of scenarios is important in ensuring the RA plan covers all relevant uncertainties.

3.6 Addressing High-Impact, Low-Probability Events

With greater contribution from RE, the power system is becoming more weather-dependent. When extreme weather patterns occur over a wide area, we can experience correlated generation shortfalls, resulting in significant vulnerability to demand exceeding supply. For example, a dust storm over most parts of Rajasthan would lead to a sharp drop in solar generation. Multiple stresses co-occurring on the power system would result in even greater vulnerability (ESIG, 2024). For example, the system would be under great stress if a heat wave that drives up demand (due to cooling requirements), dust storms, and dry hydro reservoirs coincided over a significantly long period.

Dust storms in India, particularly in the Indo-Gangetic Plains before monsoon season, along with extreme weather events, exemplify high-impact, low-probability events. For example, in the month of May 2018, there were 'three major back-to-back dust storms' followed by heavy rainfall that caused great damage over a large part of north India (Sarkar et al., 2019). Such weather events can have a severe impact on solar-based power generation. Climate change is expected to further increase the frequency and severity of such events (Aggarwal, 2018), highlighting the need to consider them in RA planning.

These may be low-probability events, but they must be considered because large generation shortfalls under these conditions would cause extreme distress and significant economic losses. Furthermore, while these occurrences may have been rare in the past, their frequency is likely to rise sharply due to climate change. Therefore, the effects of such events must be accounted for in the reliability assessment.

Given that such events have a low probability of occurrence, they are unlikely to affect aggregate metrics such as LOLE or NENS. ESIG (2024) suggests that one way to account for such events is to conduct deterministic stress testing for the combination of conditions that could lead to such an event. For example, a specific scenario could be created with a heat wave over a wide region, multi-day low RE generation due to dust storms, and dry hydro reservoirs. It is possible that the power system cannot maintain reliable operation under these stress conditions, even though the aggregate reliability metrics are within acceptable limits. In that case, adding more generating capacity of the same type may not help (ESIG, 2024). Because these are low-probability events, it would make sense to consider generating resources that have low capital costs. The variable costs for these generating plants would not be of much concern because they would be used rarely. One possible alternative could be open-cycle combustion turbines running on biodiesel. Another alternative could be deferment of retirements of older fossil-fuel generating units. These are simply possible alternatives that could be considered; the optimal portfolio should be arrived at by modelling.

The creation of these scenarios for stress testing can be tricky. As ESIG (2024) cautions, 'planners should avoid creating implausible doomsday scenarios' and 'instead, focus on credible, albeit rare, weather events or other stressors.' Thus, planners have to walk a thin line between covering credible rare events while avoiding implausible scenarios.

As a proxy for high-impact, low-probability events, in developing the National Electricity Plan, the CEA assesses the adequacy of the proposed portfolio of generating resources on a few 'critical days' (CEA, 2023). Some of these critical days are: peak demand day; minimum solar generation day; minimum variable RE (wind and solar) generation day; and others. This approach is a step in the right direction. However, it does not cover several potential high-impact, low-probability events where multiple stressors occur at the same time. As the frequency of extreme weather events increases, the frequency of such events caused by multiple stressors occurring simultaneously will also increase and should be addressed in the RA Framework based on the suggestions in this section.

3.7 Demand Forecast

Annexure E of the Guidelines, titled 'Methodology of Preparation of Resource Adequacy Plan', says that data on the actual demand met by the discom for the last five years should be collected, and then 'the hourly demand profile for the distribution licensee shall be projected over the planning horizon, based on the forecasted values of annual energy requirement and peak demand trajectory'. The guidelines allow flexibility in the projection method: 'trend method, time series, econometric methods or any state-of-the-art methods.'

The Guidelines seem to recommend a top-down approach to demand forecasting and suggest that the demand profile be based on the historical pattern of the previous five years. As discussed earlier, the future demand profile may differ significantly from the past due to changing weather patterns, a greater frequency of extreme weather events, and newer loads, such as EV chargers. We suggest using bottom-up or end-use-based forecasts because they lead to a much better understanding of the drivers of demand. Because of this better understanding, it will be easier to modify the load forecast when circumstances change. For example, suppose ambient temperatures turn out to be higher than projected. In that case, we will know which components of the load are temperature-dependent and change those to get a revised forecast that is more accurate than the original one.

End-use models require data which is best collected through load research. Load research refers to the 'systematic collection and analysis' of consumers' use of electricity segregated by time-of-day, season, and socio-economic factors (Elkarmi, 2008). A significant component of load research involves the continuous measurement of electricity for each end-use for representative samples of consumers over extended periods. As Singh & Swain (2018) point out, there has been very limited load research carried out in India, and even the studies that have been done have significant shortcomings.

3.8 Re-Evaluation of Economic Justification for RA Criteria

As ESIG (2021) shows, the relationship between reliability and system costs is highly non-linear. A slight tightening of reliability criteria can lead to a proportionately much higher cost increase. Conversely, a slight loosening of reliability criteria can lead to a proportionately much larger cost reduction. Because we have suggested the use of multiple criteria to ensure reliability, and particularly because we are suggesting limits on the depth and duration of individual outages, it is possible that the annual limit on LOLP, LOLH, or NENS could be relaxed.

Another issue to consider when setting reliability criteria is the level of outages caused by factors other than shortfalls in bulk power generation. Consumers also experience outages due to failures in the distribution network and do not differentiate between different sources of outages (ESIG, 2021). ESIG (2021) cites the example of the outages experienced by consumers in Australia due to various causes. Only 0.3% of the outages (in GWh) were due to generation shortfalls, and the bulk of the lost load was due to failures on the distribution network. We do not have equivalent data for India, but we think the situation will not be very different. The main lesson from this example is that we should be watchful and ensure that we do not overspend on grid adequacy and underspend on the reliability of the distribution network.

3.9 Other Issues

Use of Historical Data—The Future Will Be Different from the Past

We alluded to this issue earlier, but it is worth reiterating. The Guidelines recommend that historical data be used to generate the hourly generation profiles for RE and, to some extent, demand. Given the change in weather patterns and the frequency of extreme weather events, the future could be very different from the past. Therefore, electricity planners must collaborate with climatologists to develop more realistic projections so that better forecasts for RE generation and electricity demand can be established.

Share of Long-Term Contracts

The Guidelines (Section 3.6) suggest the share of long-term contracts should be 75–80% of the total Resource Adequacy Requirement (RAR), medium-term contracts should be 10–20%, and the remaining can be met through short-term contracts. It is not clear why any such share amounts should be specified. The share of long-term, medium-term, and short-term contracts should be an outcome of the portfolio optimisation by the discoms. Therefore, for discoms to develop a least-cost portfolio, it would be better to leave it to the discretion of the discom, subject to the approval of the respective SERC. When there is excess capacity, it may be more cost-effective to have a slightly lower share of long-term contracts, while when the market is tight and prices are high, it may be better to have a greater share of contracts. The discoms should be given the freedom to make the most economical choice.

The Awkward Relationship Between Renewable Purchase Obligations (RPOs) and Resource Planning

In resource planning, ideally, the discom should be able to pick the resources for its supply portfolio to minimise overall costs. RPOs specify the minimum amount of energy that must come from each technology. Thus, there is an inconsistency between resource planning and RPOs. This is particularly difficult in India because there is a separate RPO for each of the following resources: wind, hydro, distributed RE, and other RE. Singh (2021a) suggests that the target could be set in terms of grams of CO2-eq per kWh of electricity sold by a discom, as one way of giving discoms the flexibility to choose an optimal resource mix. Alternatively, the target could be set in the percentage of energy sold that should come from non-fossil fuel resources. However, this is a bigger policy issue beyond the scope of this paper, so we will not discuss it further in this paper.

Transmission Planning and Integration Between States

Section 3.6 of the Guidelines says that each discom shall contract capacities to meet its contribution to the national peak. Section 3.7 says that each discom shall undertake a resource adequacy plan to meet its peak. Because many discoms will not have a peak at the same time as the national peak, it is unclear how the difference will be made up. The country will likely have excess capacity if each discom meets its peak requirement. The Guidelines are silent on this issue.

The difference between the contribution of a discom to the national peak and its peak demand draws attention to a broader issue. The current Guidelines focus solely on ensuring adequate capacity addition for peak demand at the national level. By treating each state as a closed system, the Guidelines make it harder for the state discoms to leverage regional differences in demand and resource endowments to mutual advantage. Leveraging such differences to advantage requires a sound transmission system that facilitates quick and smooth power transfer. A well-designed transmission system can avoid the addition of generation capacity in some instances. The current Guidelines do not seem to facilitate this. The extent and manner in which inter- and intra-state transmission planning is included is unclear. Unless urgent steps are taken to address the transmission planning issue, the capacity addition at the state level will likely be sub-optimal and may tend toward excess.

4. Process-Related and Institutional Issues in the Framework

4.1 Require All Load Serving Entities to Comply with RA Guidelines

The present framework puts the onus of state-level RA planning on the discoms. A discom faces penalties if it fails to demonstrate the capacity tie-up recommended by the Guidelines. It is worrisome that the discoms are responsible for planning for the entire state demand when sales migration is at record levels and is expected to increase further as renewable energy and storage prices decrease rapidly. Opportunistic switching by open-access consumers—using partial or short-term access to move between the market and the discom—increases the risk of stranded capacity. A fairer approach would require all load serving entities (LSEs) to comply with the RA Guidelines. This necessitates modifying open access provisions so that open access is seen as a mechanism to exercise choice of supplier on a long-term basis and not for short-term gaming to minimise a customer's costs. Singh (2017) and Singh and Tongia (2021b) provide a detailed discussion of this issue and the necessary open access reforms.

The present long- and medium-term open access-related regulations require the entity seeking such open access to demonstrate firm tie-up of capacity that would be sufficient to meet its demand at all times. Such consumers also need to provide a detailed demand supply forecast and hourly schedules on a day-ahead basis. These existing regulations can be suitably modified to ensure that all such consumers are required to demonstrate firm tie-up of capacity consistent with the RA framework.

4.2 Good Long-Term Resource Planning Requires Time

Annexure F of the Guidelines provides the RA framework's implementation timeline and gives discoms two months to prepare the Long-Term Distribution Licensee Resource Adequacy Plan (LT-DRAP). We think that this is too short. Developing good Integrated Resource Plans (IRPs) takes time. Preparing a good load forecast, gathering all essential data on the existing generating stations and any new ones being contemplated, developing alternative and internally consistent futures and the associated alternate plans, and evaluating them to select a plan that best balances value and risk all take time. In the US, whenever IRPs have been required, they are usually required every two years.

Conventional wisdom seems to imply that the purpose of planning is to develop plans, and once a plan is developed, the planner's job is done. But that is not so; the value of planning extends beyond merely developing plans. Circumstances change, and consequently, plans have to be modified. As Dwight Eisenhower, Supreme Commander of the Allied Forces in World War II, is reported to have said that his war experience taught him that 'plans are worthless, but planning is everything' (Contreras, Ceberio, & Kreinovich, 2017). Planning provides insights by broadening the planner's understanding of plausible scenarios and the instruments for change available and facilitating the planner's ability to respond to changing circumstances. Rigorous computation helps even if plans change because it would be difficult to reproduce the detailed computation and rigour at short notice (Contreras et al., 2017). In that sense, planning helps the planner develop a strategy for dealing with changing circumstances. Therefore, it is important that discoms have a reasonable amount of time to carry out comprehensive and effective resource planning.

5. Conclusions and Recommendations

The framework for RA recommended in the Guidelines—based on LOLP, PRM, and NENS—was designed for power systems driven by fossil fuels. Two recent major reliability failures in the US, where many states use a very similar framework, have led to a rethinking of this framework, and that has led to the development of several significant modifications. In India, at the national level, the contribution from variable RE in generation is still low (12.6% in FY 2022–23), and that from thermal plants is high (74.6%) (CEA, 2024); therefore, the MoP framework could possibly continue to be adequate for ensuring RA now. However, even presently, not all states have a supply mix similar to the national level, and the contribution from RE is quite significantly higher for some states, such as Karnataka. In the future, as the contribution from RE in the generation mix increases rapidly, it will be important to make changes to the RA framework to ensure that it is appropriate for a RE-rich power system.

We recognise that some of the proposed changes may be challenging to implement and, therefore, we recommend a gradual transition to the modified framework. However, it is important that these changes are not ignored because doing so could lead to decreased reliability and increased costs that consumers will have to pay for electricity service. Power procurement costs constitute 70–80% of the costs of electricity that consumers pay, and effective resource planning can help significantly reduce those costs. If some of our recommended changes are ignored for a long time, some of the practices from the 'older' framework may become entrenched in the planning processes and may be difficult to change later.

Power system reliability is paramount for planners, but ensuring it cost-effectively is crucial. Given that power procurement (generation and power purchases) comprises 70–80% of consumer electricity costs, achieving Resource Adequacy (RA) at the lowest possible cost is essential. The following recommendations detail measures to both enhance reliability and improve its cost-effectiveness.

5.1 Measures to Enhance Reliability

- **Use Better Metrics for RA**
    - LOLP is not a very intuitive metric. We recommend that Loss of Load Hours (LOLH) be used instead. LOLH gives the expected number of hours in a year when a generation shortfall could occur. Because planning will also be done for all hours of the year, LOLH will be more appropriate to use as the metric for RA.
    - The depth (in MW) and duration of individual generation shortfalls, and the frequency of shortfalls, are important because they are measures of consumer distress due to shortfalls. Therefore, we recommend that instead of a single metric, such as LOLP, or even LOLH, that gives only the aggregate duration of shortfalls over the year, the following metrics, along with the probability distribution of these metrics over the year, also be assessed:
        1. Duration of individual shortfalls;
        2. Depth of individual shortfalls (MW);
        3. LOLEv (frequency of shortfalls).
- **Exercise Caution in the Use of PRM and Capacity Credits**
    - In a RE-rich power system, maximum vulnerability may not be at the time of peak load. Therefore, relying only on the use of PRM to ensure resource adequacy for a RE-rich system would not be appropriate. The recommendation in the MoP framework to use hourly chronological modelling mitigates this concern to some extent.
    - Capacity credits are not good proxies for the contribution of RE to RA. Given the wide variability of generation from RE, capacity credits are not an accurate representation of RE's contribution to RA.
- **Address High-Impact, Low-Probability Events**
    - We recommend that, in addition to an assessment of the reliability metrics discussed earlier, there be deterministic stress-testing for a few potential high-impact, low-probability events.
- **Avoid Reliance on Historical Data Alone**
    - Given the change in weather patterns and the increasing frequency of extreme weather events, the future could be very different from the past. Therefore, reliance on historical data alone for hourly generation profiles for RE and demand for electricity could lead to erroneous results.
    - We recommend that power sector planners collaborate with climatologists to develop more realistic projections of future weather patterns so that better forecasts for RE generation and electricity demand are developed.

5.2 Measures to Ensure Cost-Effectiveness of RA Measures

- **Evaluate a Few Alternate Plans to Get the Best Balance of Value and Risk**
    - Instead of developing just a single plan and subjecting it to various uncertainties, evaluate a few alternate plans so that the preferred plan is the one that best balances value and risk.
        - A plan that has a slightly higher expected (mean) overall cost may be preferable to another plan that has a lower expected (mean) overall cost but has much higher volatility in costs.
- **Re-evaluate the Economic Justification for RA Criteria**
    - A slight loosening of reliability criteria can lead to a proportionately much larger reduction in overall costs.
    - Consumers are indifferent to the cause of any outage. Therefore, compare outages, on an energy (GWh) basis, due to bulk supply shortfalls versus those due to faults on the distribution network. Such an assessment will ensure that we are not overspending on avoiding bulk system shortfalls and underspending on upgrading the distribution network.
- **Allow Time and Training for Effective Long-Term Resource Planning**
    - There is a great need for training personnel at discoms and SERCs on the principles and practice of long-term resource planning. Schemes should be developed to provide such training.
    - Preparing a long-term resource plan, even by experts, requires time. Allowing only two months to do such an exercise, as given in the Guidelines, is extremely short for it to be meaningful and comprehensive. The timeline allowed in the US is usually two years. We suggest that, instead of requiring a long-term resource plan from a load serving entity every year, it should be required every two years. The short- and medium-term plans can continue to be required yearly, as given in the Guidelines, and these short- and medium-term plans can be used for updating the long-term plans.
- **Need to Modify the Institutional Framework for RA Planning**
    - The current framework puts the onus for planning on the discoms alone. However, with the ongoing and expected consumer migration, this may not be the best option. Instead, opportunistic switching between discom and market should be discouraged by promoting long-term open access, and each LSE should be made responsible for its RA planning.
    - The review of resource plans of discoms and other LSEs by the respective SERCs should be carried out in a holistic manner for the entire state to ensure that any synergies between discoms and other LSEs are taken advantage of to ensure the delivery of electricity at the lowest cost for the entire state.

References

Aggarwal, M. (2018, May 14). Climate change could be intensifying dust storms in India, experts say. Mongabay. https://news.mongabay.com/2018/05/climate-change-could-be-intensifying-dust-storms-in-india-experts-say/

Borison, A. (2014). *Electric Power Resource Planning Under Uncertainty: Critical Review and Best Practices.* White Paper. Berkeley Research Group, California, USA.

Carvallo, J.P., Zhang, N., Leibowicz, B.D., Carr, T., Baik, S., Larsen, P.H. (2023, June). *A Guide for Improved Resource Adequacy Assessments in Evolving Power Systems—Institutional and Technical Dimensions.* Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

CEA. (2024, May). *All India Electricity Statistics—General Review 2024.* Central Electricity Authority, Ministry of Power, Government of India.

CEA. (2023, May). National Electricity Plan (Volume I), Generation, Central Electricity Authority, Ministry of Power, Government of India.

Contreras, A.F.G, Ceberio, M., Kreinovich, V. (2017, November). Plans Are Worthless but Planning is Everything: A Theoretical Explanation of Eisenhower's Observation. *Departmental Technical Reports (CS). 1102.* University of Texas at El Paso, USA. https://scholarworks.utep.edu/cs_techrep/1102.

Dent, C.J., Sanchez, N., Shevni, A., Smith, J.Q., Wilson, A.L., Yu, X. (2023, September 12). *Resource Adequacy and Capacity Procurement: Metrics and Decision Support Analysis.*

Elkarmi, F. (2008). Load research as a tool in electric power system planning, operation, and control—The case of Jordan. Elsevier Energy Policy 36 (2008) 1757-1763. https://doi.org/10.1016/j.enpol.2008.01.033

ENTSO-E. (2020). *Mid-term Adequacy Forecast, Appendix 2, Methodology, 2020 Edition*. European Network of Transmission System Operators for Electricity.

ESIG. (2021). *Redefining Resource Adequacy for Modern Power Systems.* A Report of the Redefining Resource Adequacy Task Force. Reston, VA, USA.

ESIG. (2024). *New Resource Adequacy Criteria for the Energy Transition—Modernizing Reliability Requirements*. Reston, VA, USA. https://www.esig.energy/new-resource-adequacy-criteria/

Hirst, E. (1992). *A Good Integrated Resource Plan: Guidelines for Electric Utilities and Regulators*. Oak Ridge National Laboratory, Tennessee, USA.

Kueck, J.D., Kirby, B.J., Overholt, P.N., Markel, L.C. (2004). *Power Quality Blog, Part 4 Loss of Load Probability: A Historical Perspective*. Measurement Practices for Reliability and Power Quality: A Toolkit of Reliability Measurement Practices, 2004.

Micheli, L., Almonacid, F., Bessa, J.G., Fernandez-Solas, A., Fernandez, E.F. (2024). *The Impact of Extreme Dust Storms on the National Photovoltaic Energy Supply. Sustainable Energy Technologies and Assessments, 62 (2024), 103607.*

MSLDC. (2024). Maharashtra State Load Despatch Centre website. https://mahasldc.in/home.php/daily-reports/, accessed on August 7, 2024.

NARUC. (2023, November). *Resource Adequacy for State Regulators: Current Practices and Emerging Reforms.* National Association of Regulatory Utility Commissioners, Washington, DC, USA.

Newman, A. (2021, September 2). *43 Die as Deadliest Storm Since Sandy Devastates the Northeast*. New York Times. Retrieved from https://www.nytimes.com/2021/09/02/nyregion/ida-flooding-nyc.html?nl=todaysheadlines&emc=edit_th_20210903.

PIB. (2023, Dec 06). *Coal Import for blending at 6% till March 2024, to ensure uninterrupted power supply across the country: Power and New & Renewable Energy Minister.* Retrieved from https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1983084

Prayas. (2019, Jul 31). *Come September: Can coal-based power plants sing a happier tune?* Retrieved from https://energy.prayaspune.org/our-work/webinar/come-september-can-coal-based-power-plants-sing-a-happier-tune

Sarkar, S.; Chauhan, A., Kumar, R., and Singh, R.P. (2019). Impact of Deadly Dust Storms (May 2018) on Air Quality, Meteorological, and Atmospheric Parameters Over the Northern Parts of India. *GeoHealth*, 3, 67-80. https://doi.org/10.1029/2018GH000170.

Singh, D. (2017). *Newer Challenges for Open Access in Electricity: Need for Refinements in the Regulations*, Brookings India IMPACT Series No. 042017-02.

Singh, D. (2021a, October). *Long-Term Goal-Setting and Planning for Decarbonising the Indian Power Sector—Need for a Coordinated Approach*. Centre for Social and Economic Progress, New Delhi.

Singh, D., & Swain, A. (2018, July). *Fixated on Megawatts: Urgent Need to Improve Power Procurement and Resource Planning by Distribution Companies in India*. Centre for Energy, Environment & Resources, New Delhi.

Singh, D.; Tongia, R. (2021b). *Reforming Electricity Distribution in India: Understanding Delicensing and Retail Competition* (CSEP Discussion Note 7). New Delhi. Centre for Social and Economic Progress.

The Hindu. (2022, Jun 05). Railways cancelled almost 9,000 train services this year, over 1,900 due to coal movement. Retrieved from https://www.thehindu.com/news/national/railways-cancelled-almost-9000-train-services-this-year-over-1900-due-to-coal-movement-rti/article65497266.ece

University of Texas at Austin. (2021, July). *The Timeline and Events of the February 2021 Texas Electric Grid Blackouts.* Energy Institute, The University of Texas at Austin, USA.

Varadhan, S. and Yap, C. (2024, April 2). India hydropower output records steepest fall in nearly four decades. Reuters. https://www.reuters.com/business/energy/india-hydropower-output-records-steepest-fall-nearly-four-decades-2024-04-01/#:~:text=Hydro

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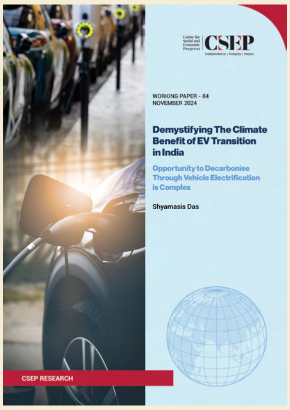
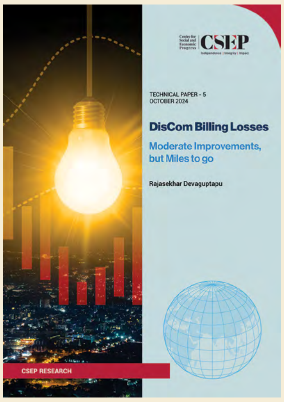
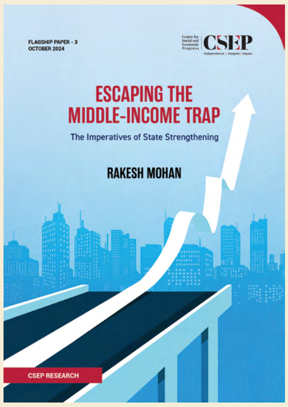
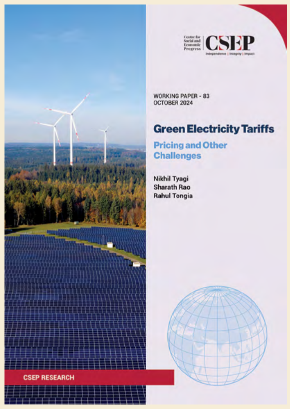
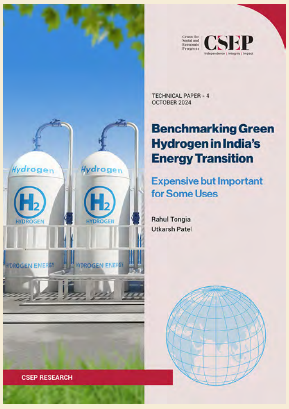
Other publications

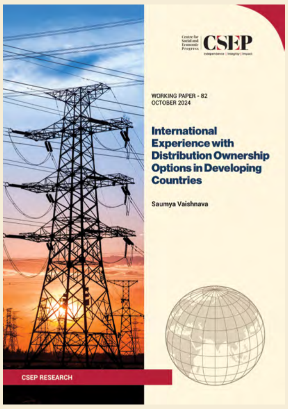


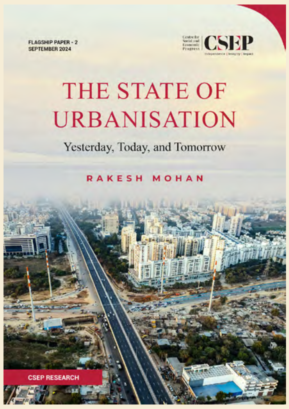


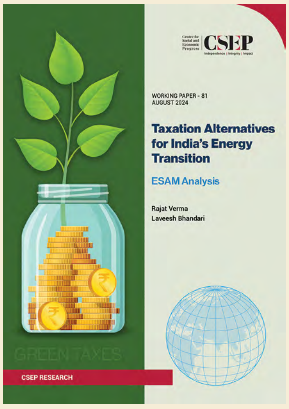


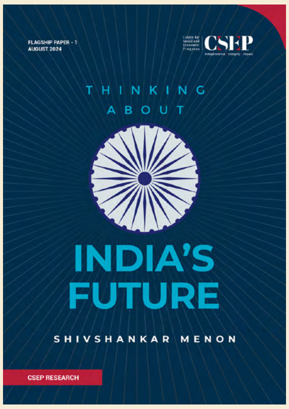


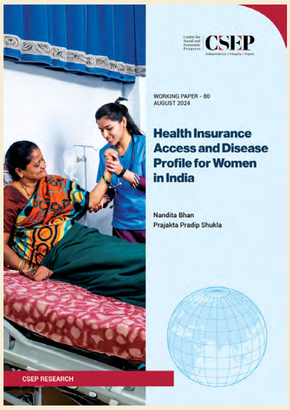


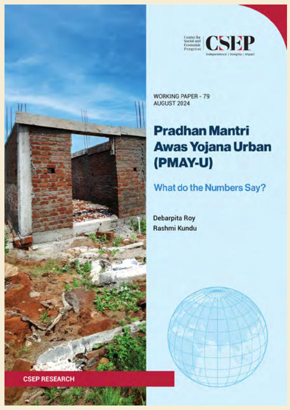


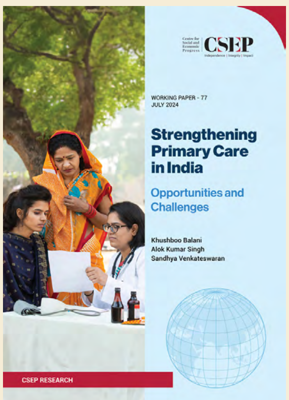


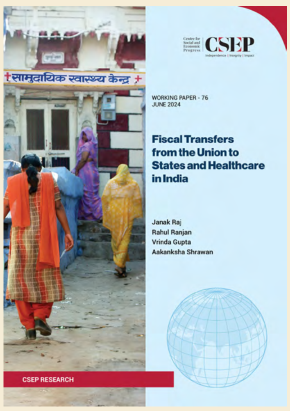


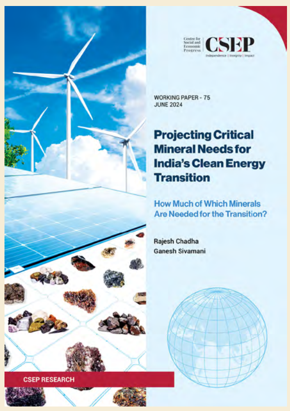












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