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RENEWABLE CAPACITY AND ELECTRICITY SUPPLY DEFICITS IN INDIA'S INTERCONNECTED POWER GRID

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Abstract:

This analysis examines whether renewable electricity capacity is associated with supply adequacy in India, addressing the international challenge of aligning renewable expansion with electricity demand. It uses 11 national annual observations from the financial year beginning in April 2010 through the financial year ending in March 2021. Separate Pearson correlations assess the relationships between solar, wind and small hydropower capacity and the annual electricity supply deficit. An exploratory analysis compares annual changes. The level correlations are negative for solar, wind and small hydropower, at −0.774, −0.935 and −0.938 respectively. The annual change correlations are weaker and imprecise, with direction changes for solar and small hydropower. These results qualify the interpretation of accumulated capacity as an indicator of supply adequacy. Installed capacity represents potential generation, while its contribution to meeting demand depends on electricity availability and system operation. The analysis does not identify causal effects or the separate contribution of each technology. For electricity planners, the findings support assessing electricity delivered and unmet demand alongside capacity expansion.

Key Words: Electricity Supply Deficit; India; Pearson Correlation; Renewable Capacity; Supply Adequacy

1. Introduction:

Expanding renewable electricity capacity creates an opportunity to meet demand, but installed capacity alone does not show whether electricity is available when and where it is needed. This distinction matters for electricity planners who must assess both investment in generation and the adequacy of supply. In interconnected systems, the contribution of renewable capacity depends on resource availability, transmission and the flexibility of other generation sources (Heptonstall & Gross, 2021; Martinot, 2016).

The relationship is particularly relevant to India, where electricity demand and the composition of generation have changed alongside investment in renewable energy. Lu et al. (2020) modelled an integrated Indian electricity system and showed that solar and wind could contribute substantially to future electricity supply under specified investment and operating conditions. Their analysis considered generation, transmission and storage together, demonstrating why the contribution of renewable capacity must be understood within the wider system. The modelled potential, however, does not establish how historical changes in installed capacity were associated with observed electricity supply deficits.

Solar, wind and small hydropower capacity may each contribute to supply adequacy, but their potential output depends on different resources. Solar generation varies with sunlight, wind generation depends on wind conditions, and small hydropower depends on water availability and plant operation. Where generation coincides with unmet demand and can be delivered through the grid, additional capacity may contribute to a lower deficit. Where output is unavailable or cannot be used, the contribution may be smaller than installed capacity alone suggests. Research on small hydropower in India also identifies financial and institutional constraints that can influence project development and operation (Khan, 2015).

The timing of renewable output further complicates the relationship between capacity and supply adequacy. In a modelled Indian electricity system, Gulagi et al. (2020) found that wind generation and transmission could complement solar generation during the monsoon. This result illustrates a possible system mechanism rather than an observed effect of historical capacity additions on national deficits. More broadly, Collins et al. (2017) show that limited temporal resolution can obscure the variation needed to assess how electricity systems accommodate variable generation. Annual capacity and deficit data therefore provide a useful aggregate perspective, but they cannot directly measure generation during shortage periods or the mechanisms that connect capacity to supply.

The reviewed evidence establishes the importance of renewable resources and system flexibility, but it does not resolve the relationship examined here: whether national annual levels of solar, wind and small hydropower capacity were associated with India's reported electricity supply deficit over the selected period, and whether the pattern is similar when annual changes are examined. This question concerns observed association rather than the simulated contribution of renewable generation under assumed operating conditions. It also directs attention to a measurement distinction between capacity at the end of a financial year and a deficit accumulated over that year.

This study aims to examine the associations between renewable electricity capacity and the national electricity supply deficit in India. The research question asks how solar, wind and small hydropower capacity relate to the annual deficit, and whether the observed relationships differ when changes between years are considered. The analysis examines each capacity measure separately against the reported deficit percentage. It uses 11 national annual observations covering the financial year beginning in April 2010 through the financial year ending in March 2021, with Pearson correlations in levels and an exploratory comparison of annual changes.

The findings show negative correlations between each capacity measure and the deficit in levels. The annual change correlations are weaker and imprecise, and the estimates for solar and small hydropower change direction. This contrast qualifies an interpretation based on capacity levels alone: renewable expansion occurred alongside a declining deficit, but the available evidence does not establish the separate contribution of each technology. Shared trends, the small sample and the mismatch between end of year capacity and the annual outcome limit inference. The analysis does not test a causal pathway or a moderating relationship.

The contribution is therefore a bounded empirical comparison of accumulated capacity and annual changes in an interconnected electricity system. It informs a wider discussion about the evidence required to connect renewable investment with supply adequacy, without assuming that results from one national series transfer directly to other systems. For planning, the analysis supports examining the electricity available to meet demand alongside installed capacity. Its relevance to other settings depends on their resource profiles, network conditions and methods of measuring electricity deficits.

2. Theory, Conceptual Framework and Hypotheses Development:

Electricity supply adequacy provides the theoretical foundation for this analysis. An interconnected grid must match electricity requirements with available supply across locations and time. Additional generation capacity can expand the resources available to meet demand, but its contribution depends on resource availability, network access and system operation. Lu et al. in 2020 modelled the Indian power system as an integrated network in which generation, transmission and operational flexibility jointly determine how renewable electricity can serve demand. Their results establish the potential for integration under modelled conditions, rather than an observed relationship between installed capacity and historical supply deficits.

Renewable electricity generation capacity refers to the installed capacity of solar, wind and small hydropower plants. This analysis measures each dimension in megawatts at the end of the financial year. The outcome is the annual electricity supply deficit, expressed as a percentage of electricity requirement. Greater capacity can increase potential supply, while rising demand, resource variability and network constraints can weaken that contribution. Heptonstall and Gross in 2021 show that the system effects of variable renewable energy depend on demand, technology and the availability of flexible operation. Installed capacity is therefore a measure of potential output, rather than electricity delivered.

The framework proposes three separate associations between observed capacity measures and the observed supply deficit. These relationships are theoretical expectations. Capacity is recorded at the end of each financial year, whereas the deficit covers the full year. The analysis therefore treats the hypotheses as exploratory associations between annual measures.

Solar capacity represents the installed potential to convert solar radiation into electricity. Its contribution to supply adequacy arises when electricity generated during daylight is available to meet demand. Higher solar capacity can increase potential generation and reduce the annual supply deficit when the resulting electricity reaches consumers.

The contribution is constrained by the timing of sunlight and variations in weather. Capacity added at the end of a year may also have supplied electricity for only part of that year. Gandhi et al. in 2020 identify technical limits to photovoltaic integration, while Al Shetwi et al. in 2020 explain that integration depends on requirements for stability and power quality. These findings support a conditional mechanism rather than an automatic reduction in deficits.

The expected association is negative because additional solar capacity expands potential supply. The annual data can test this association but cannot determine how much solar electricity was delivered during periods of shortage.

H1: Higher solar capacity is associated with a lower electricity supply deficit in India.

Wind capacity represents the installed potential to generate electricity from wind. Its contribution differs from solar capacity because wind output depends on wind conditions and may occur at different times from solar generation. When wind generation is available during periods of unmet demand, greater capacity can contribute to a lower annual deficit.

The relationship depends on the location and timing of wind resources and on the ability of the grid to use the electricity generated. Gulagi et al. in 2020 modelled the Indian grid and found that wind could complement solar generation during the monsoon in their simulated system. This result supports the proposed mechanism, but it does not establish the historical association in the present dataset.

Wind and solar output can also vary together under some conditions, and higher installed capacity does not guarantee supply when demand is unmet. Weschenfelder et al. in 2020 show that the extent of

complementarity depends on location and assessment method. The analysis therefore expects a negative association while allowing for a weaker or inconclusive result.

H2: Higher wind capacity is associated with a lower electricity supply deficit in India.

Small hydropower capacity represents the installed generating potential of small hydropower plants. Its proposed contribution to supply adequacy depends on water availability and the ability of plants to deliver electricity to the grid. When operating plants provide additional electricity during periods of unmet demand, greater capacity can contribute to a lower annual deficit.

Unlike solar and wind capacity, small hydropower capacity relies directly on water resources and plant conditions. Installed capacity may therefore increase without a proportional increase in electricity supplied. Khan in 2015 identifies financial and institutional constraints affecting small hydropower development in India. These constraints support the relevance of capacity while limiting claims about its realised contribution to supply.

The expected association is negative because greater small hydropower capacity expands potential supply. The annual dataset does not measure water availability, plant output or the timing of generation. It can therefore assess the association but cannot isolate the mechanism.

H3: Higher small hydropower capacity is associated with a lower electricity supply deficit in India.

The dataset contains 11 national annual observations. The three capacity measures and the deficit may share time trends, while other changes in the electricity system may affect the observed relationships. The hypotheses can be examined as exploratory associations, but the small sample and timing of the measures limit the precision and interpretation of any test. A positive, negative or inconclusive result remains possible for each hypothesis.

3. Data:

This section establishes the provenance and coverage of the national annual dataset. It defines the study variables and identifies the information available for examining renewable electricity capacity and supply deficits in India.

3.1 Data Sources, Population, and Sample Construction:

The dataset draws on historical electricity statistics published by the Central Electricity Authority of India. Solar, wind and small hydropower capacity were extracted from Chart 8B of the source report. Electricity requirement, availability and the energy deficit percentage were extracted from Table 8.

The unit of analysis is the national electricity system in one financial year. The dataset forms an annual time series covering the financial year beginning in April 2010 through the financial year ending in March 2021. The capacity measures are stocks recorded at the end of each financial year. Electricity requirement and availability are annual energy flows, while the deficit is an annual percentage.

The target population comprises national annual observations on the selected renewable capacity measures and electricity supply deficit within the study period. The accessible sampling frame consists of the corresponding observations in the workbook. All 11 available financial years were retained. The workbook does not record the number of source records reviewed before selection or when the eligibility rules were established.

Sample Construction Stage	National Units	Annual Observations	Rule or Status
Available frame in workbook	1	11	Financial years within the study period
Exclusions from workbook	0	0	No exclusion recorded in the workbook
Retained dataset	1	11	All workbook observations retained

The national annual series provides a common basis for examining associations between renewable capacity and the supply deficit. It does not provide regional or plant level variation. An integrated model of the Indian electricity system indicates that renewable supply depends on the interaction of generation, transmission and operational flexibility (Lu et al., 2020).

3.2 Data Integration, Cleaning, and Quality Assurance:

The workbook aligns capacity and electricity supply statistics by financial year. Each year appears once, and all six numeric fields contain values for all 11 observations. The workbook does not document a separate merge procedure, unmatched records, source conflicts or changes made during extraction.

Capacity values refer to the end of the financial year, while electricity supply measures refer to the full financial year. Capacity added late in a year may therefore have contributed electricity for only part of the period covered by the deficit. This timing difference matters because the contribution of installed renewable capacity depends on actual resource availability and system operation (Heptonstall & Gross, 2021).

The workbook retains the published values. It does not document interpolation, imputation, outlier removal or adjustment for inflation. The published deficit percentage is retained as the outcome and is not recalculated from the displayed requirement and availability values. Displayed source figures may differ slightly from calculations based on rounded values.

The workbook does not identify the extraction date, a version identifier or a licence. The report is a later compilation of historical observations and should not be represented as information available to decision makers at the end of each financial year.

3.3 Variable Measurement, Construction, and Validation:

The analysis uses three observed measures of installed capacity and one observed measure of electricity supply deficit. The capacity measures describe the potential output of each technology. They do not directly measure electricity generated or delivered. Technical and operational constraints can affect the contribution of installed capacity to electricity supply (Al Shetwi et al., 2020; Gandhi et al., 2020).

Variable	Analytical Role	Definition and Source Location	Unit and Frequency
Solar capacity	Predictor for H1	Installed solar generation capacity at financial year end, Chart 8B	Megawatts, annual
Wind capacity	Predictor for H2	Installed wind generation capacity at financial year end, Chart 8B	Megawatts, annual
Small hydropower capacity	Predictor for H3	Installed small hydropower capacity at financial year end, Chart 8B	Megawatts, annual
Electricity supply deficit	Outcome	Published annual energy deficit as a percentage of electricity requirement, Table 8	Percentage, annual
Electricity requirement	Supporting source measure	Annual electricity requirement, Table 8	Gigawatt hours, annual
Electricity availability	Supporting source measure	Annual electricity available, Table 8	Gigawatt hours, annual

The analysis uses the published deficit percentage without constructing an index or applying a transformation. Requirement and availability are retained as supporting measures rather than additional predictors. Each listed variable has 11 available values. No missing value treatment was required within the supplied workbook.

Measure	Valid Observations	Mean	SD	Median	Minimum	Maximum
Solar capacity, megawatts	11	13,875.74	14,739.04	6,762.85	32.39	40,085.37
Wind capacity, megawatts	11	27,114.09	9,170.62	26,777.40	12,806.54	39,247.05
Small hydropower capacity, megawatts	11	4,093.45	591.15	4,273.47	2,913.00	4,786.81
Electricity supply deficit, percentage	11	3.49	3.50	2.11	0.38	8.73

The descriptive statistics were calculated from the workbook. They describe the observed series and do not establish the direction or significance of any hypothesis. The source measures are observed national statistics rather than indicators of a latent construct.

3.4 Analytical Framework, Identification, and Reproducibility:

The intended analysis is associational. It concerns the relationship between each renewable capacity measure and the national electricity supply deficit across financial years. The theoretical expectation is that higher capacity may be associated with a lower deficit when additional generation is available to meet demand.

The workbook contains no implemented regression specification, estimator, inference procedure or robustness results. A final model and its estimation sample therefore cannot be reported as completed. The capacity measures increased over the period, while the supply deficit also changed. Common trends, omitted changes in the electricity system and the small number of observations may make associations difficult to interpret.

The end of year capacity measures do not precede the full annual outcome with which they are matched. This timing prevents the data from establishing that capacity additions caused changes in the same year's deficit. Wind and solar generation may complement each other under particular resource conditions, but the workbook does not measure that interaction. Such complementarity has been identified in a modelled Indian electricity system (Gulagi et al., 2020).

The workbook preserves the annual values, variable definitions and source locations needed to reproduce the descriptive statistics. It does not include construction code, a dated extraction log or an estimation script. Any later model choices, sample changes and statistical results must be documented as implemented.

4. Methods:

4.1 Research Design and Identification:

The analysis uses an observational time series to examine the relationship between renewable electricity capacity and the national electricity supply deficit in India. The unit of analysis is one financial year. The empirical analysis comprises 11 annual observations covering the financial year beginning in April 2010 through the financial year ending in March 2021.

The analysis estimates separate, unadjusted associations between each capacity measure and the deficit. Variation across years provides the basis for comparison. The estimates describe whether higher

capacity values tended to occur in years with higher or lower deficits. They do not identify the effect of a capacity addition on the deficit.

Common time trends, changes in electricity demand and other developments in the power system provide competing explanations for the observed associations. Capacity is measured at financial year end, while the deficit covers the full year. The design therefore does not establish that capacity observed at year end preceded the deficit or caused its change. Serial dependence can also affect correlation inference in time series data (Afyouni et al., 2019).

4.2 Association Measures and Inference:

The primary analysis calculates a separate Pearson correlation between each renewable capacity measure and the annual electricity supply deficit:

$$r_j = \frac{\sum_{t=1}^{n}(x_{jt} - \bar{x}_j)(y_t - \bar{y})}{\sqrt{\sum_{t=1}^{n}(x_{jt} - \bar{x}_j)^2}\sqrt{\sum_{t=1}^{n}(y_t - \bar{y})^2}}$$

In Equation 1, r_j is the sample correlation for capacity measure j, x_{jt} is installed capacity for measure jin financial year t; y_t is the electricity supply deficit percentage; $\bar{x}_j$ and $\bar{y}$ are their sample means; and nis the number of paired annual observations. The index jidentifies solar, wind or small hydropower capacity. Negative values indicate that higher capacity tended to occur in years with lower deficits.

For each correlation, the analysis reports a two-sided p value for the null hypothesis of zero population correlation and a 95% confidence interval using the Fisher transformation. The conventional p values assume independent, normally distributed paired observations under the null. The confidence intervals rely on an approximate sampling distribution and may be inaccurate when observations are dependent or distributions depart from the assumptions (Afyouni et al., 2019; Bishara & Hittner, 2017). They are therefore interpreted as indicative rather than conclusive.

Each hypothesis specifies an expected negative association. The analysis considers the direction and uncertainty of the level correlation alongside the exploratory annual change comparison. It does not interpret a p value alone as evidence of causation or a non-significant result as proof that an association is absent.

4.3 Sample and Measurement Alignment:

As documented in the sample construction table and variable dictionary, the dataset contains one national observation for each financial year. The level analysis uses all 11 paired observations for each capacity measure and the deficit. There are no missing values among these variables in the supplied workbook.

The predictors are installed solar, wind and small hydropower capacity, measured in megawatts at financial year end. The outcome is the published annual energy deficit as a percentage of electricity requirement. No index, interaction or adjusted capacity measure is constructed. The separate correlations do not control for the other capacity measures, demand or changes in the electricity system.

The timing and meaning of the measures limit interpretation. Installed capacity describes potential generation, whereas the deficit reflects an annual supply shortfall. A capacity addition near year end may have operated for only part of the year. The national series also does not identify regional differences or electricity delivered during shortage periods.

4.4 Data Processing, Sensitivity, and Reproducibility:

The analysis reads the numeric observations from the workbook, retains their chronological order and calculates descriptive statistics and the three level correlations. The standard deviation reported for each measure is the sample standard deviation. No observations were deleted for missingness, and no imputation, interpolation, weighting or outlier adjustment was applied. An exploratory sensitivity analysis calculates consecutive annual changes for each capacity measure and the deficit:

$$\Delta x_{jt} = x_{jt} - x_{j,t-1}, \qquad \Delta y_t = y_t - y_{t-1}$$

In Equation 2, Δx_{jt} is the change in installed capacity for measure \(j\) between consecutive financial year ends, and $\Delta y_t$is the change in the annual deficit in percentage points. Pearson correlations are then calculated between each pair of change series using Equation 1. Differencing leaves 10 paired changes because the first observed year has no preceding observation in the dataset.

The annual change analysis was exploratory and was not documented as prespecified. It assesses whether the direction and magnitude of the level associations are similar when consecutive changes are compared. Differencing does not by itself establish stationarity, remove serial dependence or resolve confounding. The level and change estimates also use different numbers of observations.

Calculations were performed in Python 3.12.14 using NumPy 2.3.5, SciPy 1.17.0 and openpyxl 3.1.5. SciPy was used for Pearson correlations, two-sided p values and Fisher transformation confidence intervals. The supplied workbook provides the input values and variable definitions; an estimation script is not included in the workbook.

5. Findings:

The analysis examines the associations between renewable electricity capacity and the national electricity supply deficit in India. It assesses the three hypotheses using annual observations and

examines whether the associations persist in annual changes. The results describe exploratory relationships and do not establish causation.

The dataset contains 11 national annual observations covering the financial year beginning in April 2010 through the financial year ending in March 2021. Solar, wind and small hydropower capacities are measured in megawatts at financial year end. The electricity supply deficit is measured as a percentage of annual electricity requirement. All four variables have complete observations in the workbook.

Variable	Observations	Mean	SD	Median	Minimum	Maximum
Solar capacity, megawatts	11	13,875.74	14,739.04	6,762.85	32.39	40,085.37
Wind capacity, megawatts	11	27,114.09	9,170.62	26,777.40	12,806.54	39,247.05
Small hydropower capacity, megawatts	11	4,093.45	591.15	4,273.47	2,913.00	4,786.81
Electricity supply deficit, percentage	11	3.49	3.50	2.11	0.38	8.73

The national electricity supply deficit declined from 8.50% in the first observation to 0.38% in the last, a difference of 8.12 percentage points. Over the same period, all three installed capacity measures increased. These simultaneous changes motivate the association analysis but do not establish that renewable capacity caused the decline in the deficit. Installed capacity measures potential output, while actual contributions depend on resource availability and system operation (Heptonstall & Gross, 2021).

The main analysis uses separate Pearson correlations between each capacity measure and the deficit. A negative coefficient indicates that years with higher capacity tended to have lower deficits. The confidence intervals and p values rely on conventional assumptions, including independent observations. Those assumptions may not hold for an annual time series, so the reported uncertainty is indicative rather than conclusive.

Hypothesis	Capacity Measure	Observations	Pearson Correlation	95% Confidence Interval	p Value
H1	Solar	11	−0.774	−0.938 to −0.324	0.005
H2	Wind	11	−0.935	−0.983 to −0.762	Less than 0.001
H3	Small hydropower	11	−0.938	−0.984 to −0.773	Less than 0.001

Solar capacity has a negative correlation with the supply deficit. The coefficient indicates that years with higher installed solar capacity tended to have lower reported deficits. This pattern is consistent with the direction of H1. It does not identify how much electricity solar plants delivered during periods of shortage. Solar output varies with resource conditions, and the system contribution of installed capacity depends on integration constraints (Gandhi et al., 2020).

Wind capacity also has a negative correlation with the supply deficit. The direction is consistent with H2, although the estimate combines all changes occurring over the observation period. Modelling of the Indian electricity system suggests that wind can complement solar generation under particular seasonal conditions, but the annual capacity data do not measure that mechanism (Gulagi et al., 2020).

Small hydropower capacity has a negative correlation with the deficit, consistent with the direction of H3. The result does not distinguish the contribution of small hydropower from other developments in the electricity system. Installed capacity alone does not capture water availability, plant operation or electricity delivered. Financial and institutional conditions can also affect small hydropower development (Khan, 2015).

An exploratory sensitivity analysis examines annual changes in each capacity measure and annual changes in the deficit. It uses 10 paired changes because the first observation has no preceding year in the dataset. Differencing reduces the influence of common levels over time, but it does not remove every time series or identification concern.

Capacity Measure	Observations	Correlation of Annual Changes	95% Confidence Interval	p Value
Solar	10	0.348	−0.361 to 0.802	0.324
Wind	10	−0.279	−0.773 to 0.425	0.435
Small hydropower	10	0.108	−0.559 to 0.691	0.766

The annual change correlations are weaker than the correlations in levels. The solar and small hydropower coefficients change direction, while the wind coefficient remains negative. All three confidence intervals include both negative and positive values. The sensitivity analysis therefore does not provide precise evidence of the direction of the relationship between annual capacity additions and annual deficit changes. Non-significance does not establish that an association is absent.

The level correlations are consistent with H1, H2 and H3, but the sensitivity analysis does not confirm a stable relationship across specifications. Each hypothesis remains inconclusive as an explanation of changes in the supply deficit. The evidence is consistent with renewable capacity expansion occurring alongside a declining national deficit, while leaving the separate contribution of each technology unresolved. This distinction aligns with research showing that renewable integration depends on the

broader configuration of generation, transmission and system flexibility (Al Shetwi et al., 2020; Lu et al., 2020).

6. Discussion:

Expanding renewable capacity and reducing electricity deficits occurred together, but their relationship changes when the analysis moves from levels to annual changes. The level correlations are negative for solar, wind and small hydropower capacity, with the strongest coefficients observed for wind and small hydropower. The annual change correlations are weaker and imprecise, and two change direction. This contrast is the central contribution of the analysis: it shows that the apparent strength of a national association depends on whether the comparison concerns accumulated capacity or changes between years. The results do not establish which technology contributed most to deficit reduction. Differences in correlation magnitudes cannot be interpreted as differences in causal effects.

The distinction between capacity and delivered electricity is central to interpreting these findings. Installed capacity represents potential output, while electricity supply depends on when resources are available and whether generation can reach demand. Hirth (2013) demonstrates that the value of variable renewable generation depends on its production profile and the electricity system in which it operates. The present analysis adds an empirical caution to that system perspective: a strong correlation between accumulated capacity and a declining deficit does not reveal the contribution of generation during shortage periods. The annual data do not identify a transmission mechanism, so the observed associations cannot be attributed to generation timing, network performance or any other pathway.

The difference between the level and annual change results also limits conclusions about the three hypotheses. All three level correlations follow the expected negative direction, but the annual change estimates do not provide precise evidence of a consistent direction. This does not prove that capacity additions have no relationship with supply adequacy. Instead, it indicates that the available observations cannot separate that relationship from other developments occurring over time. Research on Indian electricity distribution identifies demand projections and procurement costs as factors affecting electricity sector outcomes (Das & Srikanth, 2020). These factors illustrate why a national capacity series alone cannot isolate the contribution of each renewable technology.

The international relevance lies in the risk of treating aggregate capacity as a sufficient measure of supply adequacy. Experience from electricity systems in Germany, Denmark and California highlights the role of operational flexibility in integrating variable generation (Martinot, 2016). The Indian results address a different outcome and do not establish whether its system performed better or worse than those systems. They nevertheless reinforce a broader analytical distinction: capacity expansion and the ability to meet demand are related questions that require different evidence. Reviews of energy system models also show that limited temporal resolution can obscure variation relevant to balancing supply and demand (Collins et al., 2017).

For electricity planners, the results support monitoring supply adequacy alongside capacity expansion rather than using installed megawatts as a standalone indicator of deficit reduction. The analysis does not establish a basis for prioritising one of the three technologies over another. Future research can examine the relationship more precisely by matching generation and demand at shorter intervals and across regions, while documenting the timing of capacity additions. Such evidence would help assess whether the association observed in annual national levels persists when the timing and location of electricity supply are taken into account.

7. Conclusion and Implications:

A transition to renewable electricity requires more than expanding installed capacity: it also requires evidence that supply can meet demand. This analysis shows that the three capacity measures were associated with a lower national supply deficit in the annual data, but the associations became weaker and less precise when changes between years were examined. The contribution is the distinction between these two patterns. It cautions against interpreting a relationship between accumulated capacity and a declining deficit as evidence that additional capacity caused the decline. For electricity planners, the practical implication is to assess investment alongside measures of electricity delivered and unmet demand. Grid operators can strengthen routine monitoring by recording when new plants begin operation and when shortages occur. Policymakers can use this information to evaluate whether investment is translating into supply that reaches consumers. The distinction is relevant to other countries seeking to expand renewable generation while maintaining reliable electricity, although its application depends on local system conditions.

The evidence is limited by the short national annual series, the timing difference between capacity and deficit measures, and the absence of generation data for shortage periods. Future research can use regional and higher frequency observations to examine whether the associations persist when supply and demand are matched more closely. Comparisons across electricity systems could assess how far the findings transfer, while richer operational data could support tests of the mechanisms through which additional generation contributes to supply adequacy.

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