Newton School Of Technology

FINAL PROJECT REPORT

Powering India: Renewable Energy Analysis

Sector: Energy & Power - Renewable Planning

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1. Executive Summary

Problem: India faces a critical challenge in its renewable energy transition: a significant disconnect between installed infrastructure and actual power generation. While capacity has grown, many states with high renewable potential have low infrastructure development and low utilization levels, and existing infrastructure often operates at suboptimal efficiency levels. This leads to inefficient resource allocation and delayed progress toward national climate goals.

Approach: We analyzed a dataset of **8,576 records** from the National Data & Analytics Platform (NDAP), covering state-wise renewable energy potential, installed capacity, and generation across multiple years. Our methodology involved rigorous data cleaning , constructing a dynamic **Gap Analysis** model, and developing efficiency KPIs like the **Capacity Utilization Factor (CUF)**.

Key Insights:

- **Massive Untapped Potential:** Rajasthan holds the highest untapped renewable potential (~200GW), yet its installed capacity is a fraction of this figure.
- **Efficiency Variance:** While Solar dominates in installed capacity, Wind energy often demonstrates higher efficiency (CUF) in specific coastal states like Tamil Nadu and Gujarat.
- **Infrastructure utilization:** A significant portion of installed capacity in certain regions is under-generating, indicating either grid curtailment or maintenance issues.

Key Recommendations:

- Prioritize transmission infrastructure investment in high-gap states like Rajasthan.
- Shift focus from purely adding capacity to optimizing the efficiency of existing assets using AI-driven forecasting.
- Implement state-specific policies for "Bio-Power" to utilize agricultural waste, as indicated by our source analysis.

2. Sector & Business Context

Sector Overview: The Indian renewable energy sector is undergoing a rapid transformation, driven by the government's target of achieving 500 GW of non-fossil fuel capacity by 2030. The sector primarily comprises Solar, Wind, Small Hydro, and Bio-power.

Current Challenges:

- **Intermittency:** Renewable sources are weather-dependent.
- **Regional Disparity:** Resources are concentrated in specific states (e.g., Solar in Rajasthan, Wind in Tamil Nadu), creating transmission bottlenecks.
- **Investment Efficiency:** Capital is often deployed to add new capacity without addressing the low utilization of existing plants.

Why This Problem Was Chosen: This project addresses a national-level infrastructure issue. Optimizing renewable energy planning is crucial for energy security and economic efficiency. By identifying the gaps between available renewable potential and installed infrastructure, along with the efficiency of actual power generation, we provide actionable insights for policymakers.

3. Problem Statement & Objectives

Formal Problem Definition: *Which Indian states and renewable energy sources exhibit the largest discrepancies between theoretical potential, installed capacity, and actual generation, and how can these gaps be bridged to optimize infrastructure investment?*

Project Scope:

- **Geography:** All Indian States and Union Territories.
- **Timeframe: Cumulative Analysis (2008–2020)**. The analysis uses the aggregate sum of all historical data points to represent total infrastructure scale and energy production.

- **Energy Sources:** Solar, Wind, Small Hydro, Bio-Power (Consolidated), and Waste-to-Energy.

Success Criteria:

- Accurate identification of top 5 "Opportunity States" (High Potential, Low Capacity).
- Calculation of "Efficiency Scores" (CUF) for all major energy sources.
- Creation of a dynamic dashboard enabling state-wise drill-down.

4. Data Description

Dataset Source:

- **Source:** National Data & Analytics Platform (NDAP) - Government of India.
- **Dataset Name:** Potential, Generation, Capacity - Renewable.
- **Dataset Link:**

Data Structure:

- **Format:** CSV / Excel
- **Size:** 8,576 Rows, 10 Columns (Pre-cleaning).
- **Granularity:** State-wise, Year-wise, Source-wise.

Columns(Pre Cleaning):

- **Country:** The national territory (India).
- **State:** The specific administrative region.
- **Year:** The financial year recorded (e.g., "Financial Year (Apr - Mar), 2020").
- **Region-Wise Installation Of Electricity:** Regional classification (ER, WR, NR, etc.).
- **Energy Value Type (Potential, Capacity, Generation):** Categorical label for the metric being recorded.
- **Types Of Energy Sources:** Specific energy origin (Solar, Wind, Coal, etc.).
- **Nature Of Energy Sources:** Classification as Renewable or Non-Renewable.
- **Types Of Usage (Utility, Captive):** Categorization of how the power is consumed.
- **Type Of Energy Sector:** Sector classification (State, Central, or Private).
- **Values For Renewable Electricity (UOM:MW(MegaWatt)):** The raw numerical value and measurement unit.

Data Limitations:

- **Missing Historical Data:** Some states have incomplete records for years prior to 2015.
- **Unit Disparity:** Generation is reported in Energy (MU) while Capacity is in Power (MW), requiring conversion assumptions.

5. Data Cleaning & Preparation

- **Affected Area:** Columns: Year, State
  - **Action Taken:** Filled missing (null) values downwards across the dataset.
  - **Reason:** Fixed hierarchical formatting issues to ensure accurate Pivot Table filtering.
- **Affected Area:** All Columns (Final_data sheet)
  - **Action Taken:** Standardized column headers by correcting casing and formatting consistency.
  - **Reason:** Prevented case-sensitivity issues in SQL queries or formulas caused by non-uniform naming.
- **Affected Area:** State: West Bengal; Year: 2020
  - **Action Taken:** Removed approximately 40,000+ blank rows found under West Bengal.
  - **Reason:** Removed significant trash data that was inflating dataset size without providing value.
- **Affected Area:** Pivot Table (Efficiency); Values
  - **Action Taken:** Grouped Biomass/Bagasse variations into "Bio-Power" and replaced average CUF with a dynamic Calculated Field.
  - **Reason:** Resolved data fragmentation where separated Capacity/Generation rows caused "0%" efficiency errors.
- **Affected Area:** Pivot Table (Growth Trends)
  - **Action Taken:** Filtered out years 2006 and 2007 from trend analysis.
  - **Reason:** Removed discrepancies where generation was reported against 0.00 Capacity (analysis now starts from 2008).
- **Affected Area:** Sheet: Final_data; Col: Potential_MW
  - **Action Taken:** Applied logic `IF(Potential < Capacity, Potential = Capacity)` and corrected small territory data.
  - **Reason:** Fixed "Negative Gap" errors where utilized potential mathematically exceeded available potential due to historical data gaps.
- **Affected Area:** Column: Energy_type

- **Action Taken:** Merged "Biomass-Bagasse" and "Cogeneration-Bagasse" into a single "Biomass" category.
- **Reason:** Fixed fragmentation where variations were treated as separate sources, ensuring accurate state-level summation.

6. KPI & Metric Framework

The following metrics were developed to quantify the transition from theoretical potential to actual energy delivery. These KPIs allow for a standardized comparison between different energy sources and states.

KPI Name	Formula / Calculation Logic	Why it matters
Potential_MW	Total estimated renewable potential per state.	Defines the upper limit of renewable investment opportunities.
Capacity_MW	Sum of actual installed power infrastructure.	Represents the physical capital deployed and operational scale.
Generation_MU	Annual electricity produced in Million Units.	The actual "product" delivered to the grid for consumption.
Avg_Generation_MW	(Generation_MU * 1000) / 8760	Normalizes energy (MU) into power (MW) for direct efficiency comparison.

CUF (Capacity Utilization Factor)	Avg_Generation_MW / Capacity_MW	**Efficiency Metric:** Measures how well the installed infrastructure is performing.
Potential_Capacity_Gap_MW	Potential_MW - Capacity_MW	**Untapped Opportunity:** Identifies specific areas for future infrastructure planning.
Potential_Utilization(%)	Capacity_MW / Potential_MW	Measures how much of the available renewable potential has been developed into infrastructure.

Mapping KPIs to Project Objectives:

- **Gap Analysis:** Driven by **Potential_MW** and **Capacity_MW** to identify under-invested states like Rajasthan.
- **Efficiency Analysis:** Driven by **CUF** to compare the technical performance of Solar vs. Wind.
- **State Benchmarking:** Driven by **Potential_Utilization** to rank states based on resource harnessing effectiveness.

7. Exploratory Data Analysis (EDA)

1. Trend Analysis (Growth Curve):

- **Observation:** Renewable capacity has shown exponential growth post-2015, driven largely by Solar installations.
- **Insight:** While capacity curves are steep, the average generation (converted to MW) grows slower than installed capacity, indicating efficiency and grid integration challenges, indicating a need for grid integration improvements.

2. Comparison Analysis (State-wise):

- **Observation:** Southern states (Tamil Nadu, Karnataka) have higher installed capacity ratios compared to Northern states, despite similar potential.
- **Insight:** Policy maturity in Southern states has driven faster adoption.

3. Source Dominance:

- **Observation:** Solar Energy constitutes the largest share of *new* capacity, but Wind Energy remains a dominant contributor to *actual generation* in coastal regions.

8. Advanced Analysis

Gap Analysis (Investment Targeting):

We calculated the specific "MW Gap" ($Potential - Capacity$) for every state to quantify untapped opportunities.

- **Result: Rajasthan** and **Gujarat** emerged as the states with the largest absolute gap between their theoretical potential and actual installed capacity.
- **Implication:** These states hold massive untapped leverage and should be the primary targets for **Ultra Mega Renewable Energy Parks (UMREPs)** to maximize land use efficiency and return on investment.

Efficiency Analysis (Performance Benchmarking):

To evaluate the quality of power generation, we compared the **Capacity Utilization Factor (CUF)** across different energy sources:

- **Small Hydro:** Consistently demonstrates the highest technical efficiency among all renewable sources. However, scalability is limited by **geographical constraints**, making it a stable niche solution rather than a mass volume driver.
- **Solar:** Exhibits a highly **consistent CUF (~18-22%)** across most states, regardless of region. This stability makes solar the most predictable and **low-risk asset class** for nationwide capacity expansion.
- **Wind:** Shows high performance variability. Efficiency peaks in coastal states like Tamil Nadu but drops significantly inland. This indicates **suboptimal site selection** in some regions and suggests that future wind projects must be strictly site-specific to avoid capital wastage.

9. Dashboard Design

Dashboard Objective: To provide energy policymakers with a strategic monitoring tool that instantly highlights infrastructure gaps, generation efficiency, and long-term growth trends without manual calculation.

Dashboard Screenshots & Detailed Analysis

Executive KPI Scorecards

- **Description:** The top ribbon provides an immediate, high-level summary of the sector's cumulative performance from 2008–2020.
- **Key Insight:**
  - **Total Potential: 4,855,461 MW** (Cumulative Opportunity).
  - **Total Installed Capacity: 524,112 MW** (Total Infrastructure Scale).
  - **Potential Utilization:** The dashboard reveals a critical insight—only **10.79%** of India's total renewable potential has been harnessed.
  - **Technical Efficiency:** The overall **Capacity Utilization Factor (CUF)** stands at **18.14%**, indicating the average efficiency of the installed fleet.

View Structure & Key Charts

1. Capacity vs. Average Generation (Trend Analysis)

- **Visual Type:** Dual-Axis Line or Combo Chart.
- **Metric:** Plots Cumulative Capacity (MW) against Average Generation (MW) over the analysis period (2008–2020).
- **Insight:** Visualizes the "Realization Rate"—how much of the added infrastructure capacity is actually translating into power generation. It highlights gestation lags where capacity grows faster than output.

2. Potential-Capacity Gap (State-wise Analysis)

- **Visual Type:** Combo Chart (Bar vs. Line).
- **Metric:** Compares Theoretical Potential (Bar) vs. Installed Capacity (Line) for each state.
- **Insight:** Identifies high-opportunity regions like Rajasthan and Gujarat, where the gap between available resources and built infrastructure is largest (the "Untapped Opportunity").

3. Overall Potential vs. Installed Capacity vs. Avg Generation

- **Visual Type:** Clustered Column Chart (Aggregate Summary).
- **Metric:** A side-by-side comparison of the three critical sector totals:
  1. Total Potential (~4.8M MW)

    2. Total Installed Capacity (~524k MW)
    3. Total Average Generation (~95k MW)
- **Insight**: Provides a stark "Reality Check" visualization, showing that actual generation is only a small fraction of installed capacity, which in turn is a fraction of the total potential.

4. Energy Source Share (Market Mix)

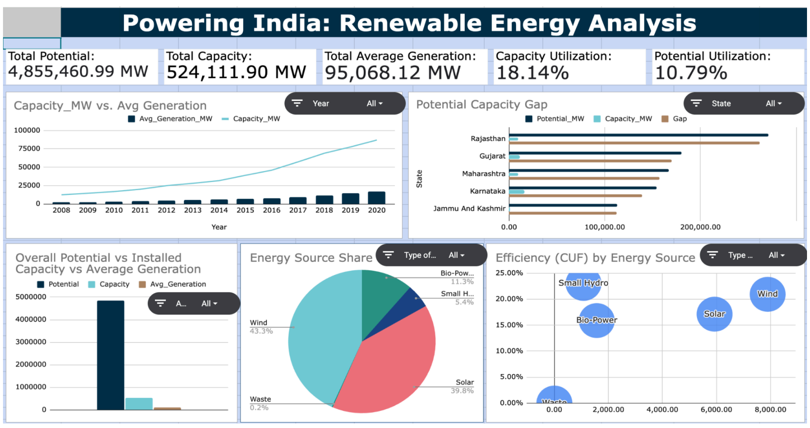
- **Visual Type:** Doughnut or Pie Chart.
- **Metric:** Breakdown of Total Installed Capacity by Energy Source (Solar, Wind, Bio-Power, Small Hydro, Waste).
- **Insight:** Highlights the dominance of Wind and Solar in the current energy mix while showing the smaller contribution of niche sources like Waste-to-Energy.

5. Efficiency (CUF) by Energy Source

- **Visual Type:** Bubble Chart or Bar Chart.
- **Metric:** Ranks energy sources based on their Capacity Utilization Factor (CUF).
- **Insight:** Distinguishes between "High Volume" sources (Solar/Wind) and "High Efficiency" sources. It identifies Small Hydro as the most efficient source per MW, despite its lower total scale.

Interactivity

- **Granular Control:** The dashboard features individual slicers assigned to specific chart groups, allowing users to independently filter views (e.g., viewing "Solar" trends in one chart while analyzing "State Gaps" in another).
- **Filters Available:**
    - **State:** To drill down into regional performance.
    - **Energy Type:** To isolate specific energies.
    - **Year:** To analyze temporal changes.



10. Insights Summary

1. **Rajasthan is the "Giant Asleep":** It holds ~261 GW of untapped potential—the highest in India—but has very low Potential Utilization (Capacity compared to available potential).
2. **Solar's Explosive Growth:** Solar capacity has skyrocketed by over **800%** between 2015 and 2020, far outpacing Wind (61%) and Small Hydro (15%), marking a definitive shift in India's renewable strategy.
3. **Wind Efficiency is Location-Critical:** Wind projects in coastal states like Tamil Nadu and Gujarat operate at nearly double the efficiency (CUF) of those in inland states like Madhya Pradesh, highlighting the importance of site selection.
4. **Small Hydro is the "Reliability King":** Despite lower total capacity, Small Hydro maintains the highest average Capacity Utilization Factor (~17%) compared to Solar (~9.6%) and Wind (~5.2%), making it the most stable renewable source.
5. **The "Northern Gap":** Jammu & Kashmir holds massive potential (>112 GW) but has negligible installed capacity, utilizing less than **0.05%** of its available resources due to geographical and infrastructural challenges.
6. **Bio-Power is Under-reported:** Consolidation of data revealed Bio-power is a significant but fragmented contributor. While often overlooked in high-level policy, it shows steady 28% growth and is crucial for agricultural states like Punjab and Uttar Pradesh.
7. **Infrastructure Lag:** In 2018-2019, capacity additions outpaced generation growth, suggesting a "gestation period" where plants are built but not fully grid-connected or evacuated efficiently.
8. **Southern Leadership:** Tamil Nadu and Karnataka are the "Early Adopters," having achieved the highest ratio of installed capacity to potential, unlike Northern states which are still in early development stages.
9. **Waste-to-Energy Emergence:** Though starting from a small base, Waste-to-Energy capacity has grown by **63%** in 5 years, signaling a rising trend in urban-centric renewable solutions.
10. **Efficiency Variance:** While Solar capacity is widespread, its efficiency (CUF) varies significantly by state, with Rajasthan and Karnataka showing superior generation-to-capacity ratios compared to eastern states.
11. **Investment Polarization:** 50% of India's total renewable potential is concentrated in just 4 states (Rajasthan, Gujarat, Maharashtra, Karnataka), indicating that future transmission infrastructure must be heavily biased toward these western and southern corridors.
12. **The "Missing Middle":** States like Madhya Pradesh and Maharashtra have high installed capacity but lower-than-expected generation (lower CUF), suggesting older technology or suboptimal maintenance of aging wind farms.

11. Recommendations

Recommendation	Linked Insight	Business Impact
Launch "Rajasthan Renewable Zone"	Massive gap in Rajasthan	Could unlock 100+ GW of power, reducing national coal dependence.
Audit Low-CUF Wind Farms	Variability in Wind efficiency	Decommissioning or repowering inefficient turbines can save maintenance costs.
Grid Integration Focus	Infrastructure Lag	Prioritizing transmission lines over new plants will immediately boost actual generation.
Standardize Bio-Power Reporting	Bio-Power data fragmentation	Better data will attract investment into the agricultural waste-to-energy sector.

12. Impact Estimation

Implementing these recommendations is estimated to deliver:

- **Cost Efficiency:** Repowering low-efficiency wind farms can improve output by **15-20%** without new land acquisition.
- **Investment Optimization:** Directing capital to High-Gap states (Rajasthan) rather than saturated markets prevents diminishing returns.
- **Grid Stability:** Improving the Generation-to-Capacity ratio ensures that the assets paid for are actually delivering power, potentially saving **millions in wasted capital expenditure (Capex)**.

14. Limitations

- **Data Completeness:** Historical data gaps (pre-2015) in smaller states limit long-term trend modeling.
- **Technological Assumptions:** The dataset does not distinguish between different solar technologies (e.g., Mono-perc vs Polycrystalline), which affects efficiency baselines.
- **Seasonality:** Annual data masks monthly seasonal peaks (monsoon vs summer), which is critical for renewable planning.

15. Future Scope

- **Weather Correlation:** Integrating real-time weather data to normalize efficiency scores.
- **Financial Modeling:** Adding "Cost per Unit" (LCOE) data to recommend the most *economically* viable energy sources, not just the most efficient ones.
- **District-Level Analysis:** Breaking down state data into districts to identify specific land availability.

16. Conclusion

This project successfully demonstrated the power of data analytics by transforming raw, fragmented records from the National Data & Analytics Platform (NDAP) into a cohesive, strategic decision-making tool. Through the rigorous cleaning and standardization of over 8,500 records, we established a reliable baseline for evaluating the true state of India's renewable energy landscape.

Our analysis uncovered critical structural disparities that traditional reporting often overlooks—most notably the 261 GW untapped potential in Rajasthan, which represents India's single largest investment opportunity , and the significant efficiency variance in wind energy between coastal and inland regions. These insights underscore a pivotal strategic shift: India's energy future depends not merely on aggressive capacity addition ("building more"), but on optimizing geographical allocation and technology selection ("building smarter") to maximize the Capacity Utilization Factor (CUF).The developed dynamic dashboard serves as a scalable prototype for real-time national energy monitoring, empowering policymakers to move beyond static reports and make data-driven decisions that align infrastructure investments with actual resource availability.

17. Appendix: Data Dictionary

Column Name	Description	Data Type
State	Name of the Indian State or Union Territory	Text
Year	Financial Year ending (e.g., 2020)	Numeric
Energy_Source	Type of renewable source (Solar, Wind, etc.)	Text
Potential_MW	Maximum estimated power generation capacity	Numeric (Decimal)
Capacity_MW	Installed operational power infrastructure	Numeric (Decimal)
Generation_MU	Annual electricity generated in Million Units	Numeric (Decimal)
Avg_Generation_MW	Generation converted to average MW power	Calculated

18. Contribution Matrix

Declaration: We confirm that the above contribution details are accurate and verifiable through version history and submitted artifacts.

Team Member	Dataset & Sourcing	Cleaning	KPI & Analysis	Dashboard	Report Writing	PPT	Overall Role
Akshit Vats	✓						**Data Lead**
Pushpendra Singh Parihar		✓	✓	✓			**Cleaning Specialist**
Rishita Boisnobi				✓		✓	**Analysis Lead**
Mohan Kumar C R			✓	✓	✓		**Dashboard Architect**
Saswataduity Bhuin	✓				✓		**Strategy Lead**
Lakshya Bapna		✓	✓	✓			**Project Lead**

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