Nuclear, Hydro, or Solar?

A Multi-Criterion Decision Analysis of India's Clean Electricity Sources

Shaunak Joshi

AllStation Laboratory

6 May 2026

Introduction

Energy (electricity and heat) is the single largest emitting sector in India. In 2023, India's energy sector emitted about 1.55 billion tons of greenhouse gases, approximately 44% of country's total emissions [1]. This is mainly because most of India's energy is generated using coal [2]. In order to curb these emissions, India has set goals in clean energy—such as having 500GW non fossil-fuel (NFF) energy capacity by 2030 (read more in ASL2). This is being achieved mainly through the construction and usage of nuclear, hydro, and solar energy, with a tiny share going to wind.

But what exactly to build? Nuclear, hydro, and solar energy each have distinctive pros and cons. External factors such as geography, resource availability, accessibility, cost, etc. alongside internal factors such as levelised cost of electricity, lifecycle emissions, land use, etc. influence the decision of what to construct and where. Nuclear may have the most benefits in one state or city and solar might have a massive advantage in another. External factors are quite contextual, but internal factors are fairly consistent. This technical paper aims to evaluate which NFF source is the best overall, based on a few major criteria.

Clarifications

This paper will utilise multi-criterion decision analysis (MCDA) to evaluate nuclear, hydro, and solar power plants. MCDA has been utilised for sustainable energy planning by Demirtas (2013) [3], proving it to be a useful tool in environmental studies. Demirtas put forward 12 criterion four fields to evaluate energy projects: technology, economics, environment, and social. For the sake of parsimony, this paper will utilise four criterion across four fields: technology, economics, environment (social is neglected, as evaluating the highly complex Indian social context is out of the scope of this paper). So what are these criteria?

1. **Technology $\subset$ Capacity Factor (%):** this is the ratio of actual produced electricity with respect to installed capacity over a certain period of time (usually a year or 8760 hours). A solar farm may have a capacity factor of 20% because the sun does not shine at night, it gets cloudy sometimes, and more (see ASL2 for more information).

2. **Economics $\subset$ Levelised cost of energy (LCOE; \$/MWh):** this is the average lifecycle cost per unit of electricity produced for a power plant [4]. LCOE includes the costs of

manufacturing, construction, operation, and decommissioning. This is a unique criterion, allowing for comparison of different technologies, each having different properties and costs, in one quantity.

3. **Environment $\subset$ Lifecycle CO_2 Emissions (gCO_2/kWh):** this measures the lifecycle emissions of power plants, including again manufacturing, construction, operation, and decommissioning. The 'lifecycle' part must be especially stressed, as plants emit differently depending on their stage of life.

4. **Environment $\subset$ Water Consumption (l/MWh):** this quantity captures how much freshwater is consumed (i.e. evaporated and permanently removed from the landscape; not used and returned) by a power plant per unit of electricity generated. As a water-stressed country in many regions, this figure is important in the Indian context.

Land Use per GW, indicating how much land is required to install a power plant per GW was also considered as a criterion, however due to a lack of useable data, this criterion has been removed.

Process

This paper will implement MCDA in two distinct steps: Analytical Hierarchy Process (AHP), followed by Weighted-Sum Average (WSA). Put simply, AHP is a system that assigns a 'weight' to each criterion based on how important it is (on a scale of 1 to 9) compared to every other criterion. The judgements are noted in the form of a comparison matrix, which is normalised and checked for consistency, finally providing each criterion's weight. WSM is the simplest and most widely-used MCDA method, utilising the weights to calculate a weighted average; adding the product of each criterion's weight with the score received by the plant in that criterion. It is important to note the limitations of this approach—many other criterion of judgement (as used by Demirtas) are not considered. India is a very diverse country in every manner possible, hence actual feasibility of a power plant is almost entirely dependent on regional context. This model simply aims to rank power plants for better knowledge and planning.

Empirical data that conveniently states the magnitude and hierarchy of importance of each criterion unfortunately does not exist. In its stead, this paper utilises what data is available to decide on a direction instead of a route. Therefore, pairwise judgements are made on the basis of India's policy goals when the information is available, and on the author's judgement when not. See Appendix A for the comparison matrix and explanation of judgements.

Next comes the table of data to be used for scoring. This data will be normalised (numerically adjusted into a common scale) and used in the WSM. This data has been derived from existing literature (an estimate is used for hydropower land use as a clear answer is unavailable). It is important to note our aforementioned limitation of diversity, which does affect data availability and hence certain leeway or error must be granted to the numbers listed below. CO_2 emission numbers are derived from globally harmonised median estimates as per IPCC AR5 [5], and India-specific figures may differ due to the coal-heavy grid utilised for manufacturing and construction. A fun fact of note is that coal emits 820 gCO_2/kWh as compared to the tiny figures of the solar, hydro, and nuclear.

Table 1: Raw data for WSM scoring

Criterion	Unit	Solar	Hydro	Nuclear
Capacity Factor	%	20 [6]	50 [7]	80 [8]
CO_2 Emissions	gCO_2/kWh	48	24	12
LCOE	$/MWh	56 [9]	68 [10]	140 [11]
Water Consumption	L/MWh	23 [12]	80,000 [13]	2,120 [14]

For the sake of rigour, this paper also conducts a simple sensitivity analysis, envisioning three different scenarios aside from the base case. These scenarios modify weights to prioritise one criterion over another: grid-first case (capacity factor gets majority priority), climate-first case (emissions importance is strengthened), and cost-first case (LCOE is prioritised). See Appendix A for the assumed weights.

Results

After implementing the comparison matrix in Python (see Appendix B for AHP code and results), we receive the weights:

Table 2: AHP-derived criterion weights

Criterion	Weight (%)
Capacity Factor	48.2
CO_2 Emissions	27.2
LCOE	15.8
Water Consumption	8.8

Utilising the above weights as well as the sensitivity analysis cases in WSM MCDA (again in Python, see Appendix C for WSM code and results), we get the following results:

Table 3: WSM scores across all scenarios

Scenario	**Solar**	**Hydro**	**Nuclear**	**Winner**
Base Case (AHP weights)	0.2458	0.5574	0.8402	Nuclear
Grid-First	0.2500	0.5119	0.7974	Nuclear
Climate-First	0.2500	0.5619	0.7974	Nuclear
Cost-First	0.5000	0.5762	0.4974	Hydro

Insights

A majority-winner across categories is clearly nuclear, by at least 0.2 in every winning scenario. The nuclear energy share as of 2026 is low (∼2%) [2]. The current nuclear capacity (8180 MW) is planned to triple by 2032 (22480 MW), acknowledging its benefits [15]. A goal of 1,00,000 MW nuclear capacity by 2070 is also suggested for India [15]. With the strong capacity factor of nuclear, it becomes a natural choice for regions where grid reliability is struggling. The significantly lower lifecycle emissions of nuclear also contribute to its win—the importance of lifecycle emissions is stressed here; negligible fuel processing contribute to the low figure of nuclear emissions. This result is also consistent with the global scientific consensus.

Hydropower has several strengths, however it can have varying environmental and social impact, which tends to be the biggest challenge. A 2023 announcement by the Government of India stated that India has currently developed 29% of its hydropower potential, with another 10% under construction (42104.6 MW out of 145320 MW, 15023.5 MW under construction), implying that the benefits of Hydropower are well-understood [16]. While solar power places third in every scenario, its cost-efficiency and negligible water use make it a practical option for renewable energy generation everywhere, especially on a private scale. The negligible water use primarily keeps solar relevant in this MCDA, making it well-suited for water-stressed regions. These advantages are reflected in real life, with solar power making up 33% of renewable generation in India, second only to hydro [2].

As the winner changes for Grid-First, this paper concludes that the results are certainly sensitive to scenarios. This strengthens the idea that careful consideration of context and selection of overarching goals is required to plan power plants.

Conclusion

The MCDA declares nuclear as a clear winner. Hydro and solar become advantageous depending on the context. Sensitivity to scenarios reaffirms the idea that a careful and broad understanding is required before investing in a power plant for a region's wellbeing. Hydro winning in the cost-first scenario is a direct reflection of its lower LCOE combined with other advantages. In time of peak financial stress, resources could be diverted towards hydropower instead of halting or slowing renewable energy growth. It is important to recall the need of the environmental hour being clean energy. With its goals and development in the renewable energy sector (as well as significant progress), India is certainly working its way towards being more environmentally friendly. A natural direction to aid this progress would be public awareness campaigns and for the citizens to advocate for renewable energy (and install the same when possible), pushing the country to a stronger position regarding the environment and energy.

References

1. Ritchie, H. & Rosado, P. (2025). CO_2 and Greenhouse Gas Emissions. *Our World in Data*. https://ourworldindata.org/profile/co2/india

2. IEA. (2026). India. *International Energy Agency*. https://www.iea.org/countries/india

3. Demirtas, O. (2013, December). Evaluating the Best Renewable Energy Technology For Sustainable Energy Planning. *International Journal of Energy Economics and Policy*, 2(4), pp. 23–33.

4. DOE. Levelised Cost of Energy. *U.S. Department of Energy, Office of Indian Energy*. https://www.energy.gov/documents/lcoepdf

5. Holappa, L. (2020). Lifecycle greenhouse gas emissions from electricity generation: IPCC AR5 estimates. Values drawn from IPCC AR5 Technical Summary, Table TS.2.

6. Mohan, A. (2017, November). Whose land is it anyway? Energy futures & land use in India. *Energy Policy*, 110, pp. 257–262. https://doi.org/10.1016/j.enpol.2017.08.025

7. IRENA. (2023). Hydropower. *International Renewable Energy Agency*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA_Changing_role_of_hydropower_2023.pdf

8. NPCIL. (2026). NPCIL Nuclear Power Plants Details and Installed Capacity. *Nuclear Power Corporation of India Limited*. https://www.npcil.nic.in/content/302_1_AllPlants.aspx

9. Rangelova, K. et al. (2026, April 7). Ember Energy. https://ember-energy.org/latest-insights/battery-storage-is-now-cheap-enough-to-unleash-indias-full-solar

10. Majumdar, S. et al. (2023, March). Hydro Power. *ICRA Ltd.*

11. Singh, A. et al. (2018, March). Levelised Cost of Electricity for Nuclear Power Using Light Water Reactor Technology in India. *SSRN Electronic Journal*, 55(10), pp. 55–64. https://doi.org/10.2139/ssrn.3440443

12. Supe, H. et al. (2024, January 15). Assessment of the solar energy–agriculture–water nexus in the expanding solar energy industry of India: An initiative for sustainable resource management. *Heliyon*, 10(1). https://doi.org/10.1016/j.heliyon.2023.e23125

13. Bakken, T. H. et al. (2013, October 15). Water consumption from hydropower plants – review of published estimates and an assessment of the concept. *Hydrology and Earth System Sciences*, 17, pp. 3983–4000. https://doi.org/10.5194/hessd-10-8071-2013

14. Membracon. (2022, August 30). Nuclear power and water consumption. *Smart Water Magazine*. https://smartwatermagazine.com/news/membracon/nuclear-power-and-water-c

15. PIB Delhi. (2024, July 25). India's Installed Nuclear Power Capacity to Triple by 2031-32: Union Minister Dr. Jitendra Singh. *Press Information Bureau*. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2037046&reg=3&lang=2

16. PIB Delhi. (2023, 21 March). Utilization of Hydro Power Potential - 42104.6 MW (29%) out of 145320 MW developed and 15023.5 MW (10.3%) is under construction. *Press Information Bureau*. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1909276&reg=3&lang=2

17. CEA. (2024, October). National Electricity Plan. *Government of India, Ministry of Power, Central Electricity Authority*. https://powermin.gov.in/sites/default/files/uploads/National_Electricity_Plan_Volume_II_Transmission.pdf

18. PIB Delhi. (2026, March 25). Cabinet approves India's Nationally Determined Contribution (2031-2035) to be communicated to the United Nations Framework Convention on Climate Change. *Press Information Bureau*. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2245209&reg=3&lang=1

19. MoEFCC. (2022). India's long-term low-carbon development strategy. *Ministry of Environment, Forest and Climate Change, Government of India*. https://unfccc.int/sites/default/files/resource/India_LTLEDS.pdf

20. IEA. (2021). India Energy Outlook 2021. *International Energy Agency*. https://iea.blob.core.windows.net/assets/1de6d91e-e23f-4e02-b1fb-51fdd6283b22/India_Energy_Outlook_2021.pdf

21. MoF. (2025). Economic Survey 2025-26: Environment and Climate Change. *Government of India, Ministry of Finance*. https://www.indiabudget.gov.in/economicsurvey/doc/eschapter/echap10.pdf

22. WRI. (2026). Aqueduct Water Risk Atlas. *World Resources Institute*. https://www.wri.org/applications/aqueduct/water-risk-atlas

23. NISE. (2025, September). Solar PV Potential of India. *National Institute of Solar Energy, Ministry of New and Renewable Energy, Government of India*. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2025/09/1759223689.pdf

Appendix A: Comparison Matrix and Sensitivity Weights

Disclaimer: AI tools were used to assist in formulating the mathematical structure of the AHP and WSM models and in generating the initial Python code for calculations. All assumptions, parameter choices, interpretation of results, and written analysis are of the author's. AI was used as a computational aid, not for generating any essay content.

1. As per India's Central Electricity Authority [17], dispatchability and capacity factor is the foremost concern of clean energy power plants. Hence this matrix prioritises capacity factor over any other criterion.

2. In accordance with India's updated Nationally Determined Contribution under the Paris Agreement [18], the Ministry of Environment, Forests, and Climate Change has declared emissions as an important goal of the country's energy transition [19]. Therefore, this matrix considers emissions as its second priority.

3. India's economic survey [21] agrees with the Indian Energy Outlook provided by the International Energy Association [20] in the conclusion that cost and finance is a major constraint for all energy projects in India. Thus this matrix ranks LCOE/affordability third.

4. The Water Risk Atlas of the World Resources Institute [22] lists the majority of India at high and extremely high water risk. As an Indian citizen, the author recognises the enormous limitation of water in the country. Therefore water consumption is ranked fourth.

The CEA [17] discusses land use in the national electricity plan without considering it as a major constraint (although it certainly is a challenge). Hence, if one wishes to consider land use as a criterion, this paper recommends it be awarded lowest priority.

Pairwise Comparison Matrix:

Criterion	Capacity Factor	CO_2	LCOE	Water
Capacity Factor	1	2	3	5
CO_2	1/2	1	2	3
LCOE	1/3	1/2	1	2
Water	1/5	1/3	1/2	1

Sensitivity Analysis Weight Scenarios:

Scenario	Capacity Factor	CO_2	LCOE	Water
Base Case (AHP)	0.4824	0.2718	0.1575	0.0883
Grid-First	0.50	0.20	0.15	0.10
Climate-First	0.20	0.50	0.15	0.10
Cost-First	0.20	0.20	0.40	0.10

Appendix B: AHP Code and Results

```
import numpy as np

criteria = ["Capacity Factor", "CO2 Emissions", "LCOE", "Water Consumption"]

matrix = np.array([
    [1,     2,     3,     5  ],
    [1/2,   1,     2,     3  ],
    [1/3,   1/2,   1,     2  ],
    [1/5,   1/3,   1/2,   1  ],
])

n = len(criteria)

# Step 1: Column sums
col_sums = matrix.sum(axis=0)

# Step 2: Normalised matrix
norm_matrix = matrix / col_sums

# Step 3: Weight vector (row averages)
weights = norm_matrix.mean(axis=1)

# Step 4: Consistency check
weighted_sum = matrix @ weights
lambda_values = weighted_sum / weights
lambda_max    = lambda_values.mean()
CI = (lambda_max - n) / (n - 1)
RI = 0.90   # Random Index for n=4 (Saaty, 1980)
CR = CI / RI
```

Results:

Step 1 — Column sums: Capacity Factor: 2.0333 | CO_2: 3.8333 | LCOE: 6.5000 | Water: 11.0000

Step 2 — Normalised matrix:

	CF	**CO_2**	**LCOE**	**Water**
Capacity Factor	0.4918	0.5217	0.4615	0.4545
CO_2 Emissions	0.2459	0.2609	0.3077	0.2727
LCOE	0.1639	0.1304	0.1538	0.1818
Water Consumption	0.0984	0.0870	0.0769	0.0909

Step 3 — Weight vector (row averages):

Criterion	**Weight**
Capacity Factor	0.4824 (48.2%)
CO_2 Emissions	0.2718 (27.2%)
LCOE	0.1575 (15.8%)
Water Consumption	0.0883 (8.8%)
Sum	1.0000

Step 4 — Consistency check:

Parameter	**Value**
λ_{max}	4.0145
Consistency Index (CI)	0.0048
Random Index (RI), $n = 4$	0.90
Consistency Ratio (CR)	0.0054
Verdict	CR $= 0.0054 < 0.10$ — matrix is consistent

Appendix C: WSM Code and Results

```
import numpy as np

criteria     = ["Capacity Factor", "CO2 Emissions", "LCOE", "Water
Consumption"]
technologies = ["Solar", "Hydro", "Nuclear"]

# Raw data: rows = technologies, cols = criteria
raw_data = np.array([
    [20,   48,    56,    23    ],   # Solar
    [50,   24,    68,    80000 ],   # Hydro
    [80,   12,    140,   2120  ],   # Nuclear
])

# Direction: True = higher is better, False = lower is better
higher_is_better = [True, False, False, False]

# AHP weights from Appendix B
weights = np.array([0.4824, 0.2718, 0.1575, 0.0883])

# Sensitivity scenarios: [CF, CO2, LCOE, Water]
scenarios = {
    "Base Case (AHP)" : np.array([0.4824, 0.2718, 0.1575, 0.0883]),
    "Grid-First"      : np.array([0.50,   0.20,   0.15,   0.10  ]),
    "Climate-First"   : np.array([0.20,   0.50,   0.15,   0.10  ]),
    "Cost-First"      : np.array([0.20,   0.20,   0.40,   0.10  ]),
}

# Normalise to 0-1 scale
norm_data = np.zeros_like(raw_data, dtype=float)
for j in range(len(criteria)):
```

```
    col = raw_data[:, j].astype(float)
    col_min, col_max = col.min(), col.max()
    if higher_is_better[j]:
        norm_data[:, j] = (col - col_min) / (col_max - col_min)
    else:
        norm_data[:, j] = (col_max - col) / (col_max - col_min)

# WSM scores
for name, w in scenarios.items():
    scores = norm_data @ w
    winner = technologies[np.argmax(scores)]
```

Results:

Step 2 — Normalised scores (0 = worst, 1 = best):

Criterion	Direction	Solar	Hydro	Nuclear
Capacity Factor	Higher is better	0.0000	0.5000	1.0000
CO_2 Emissions	Lower is better	0.0000	0.6667	1.0000
LCOE	Lower is better	1.0000	0.8571	0.0000
Water Consumption	Lower is better	1.0000	0.0000	0.9738

Step 3 — WSM final scores and winners:

Scenario	Solar	Hydro	Nuclear	Winner
Base Case (AHP weights)	0.2458	0.5574	0.8402	Nuclear
Grid-First	0.2500	0.5119	0.7974	Nuclear
Climate-First	0.2500	0.5619	0.7974	Nuclear
Cost-First	0.5000	0.5762	0.4974	Hydro