ESL742 – Home Assignment

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1 Problem framing and context

A 100 MW grid-connected solar photovoltaic (PV) power plant is proposed in Palghar district (Maharashtra), with an expected capacity utilisation factor (CUF) of 0.20. The project appraisal report claims that the plant can deliver electricity at a levelized cost of electricity (LCOE) of Rs.3/kWh.

The Government has requested an independent review of this appraisal. The specific assignment is to:

1. Identify a set of all possible feasible economic parameters – capital cost (C_0), annual monetary benefits (B_j), annual monetary costs (C_j), useful life (n), discount rate (d), and salvage value (S) – that can deliver LCOE = Rs.3/kWh for the given 100 MW, CUF 0.20 plant in Palghar.

2. Prepare a table where only one parameter at a time is varied while all others are held constant, and list all combinations that match LCOE = Rs.3/kWh.

3. For each combination, provide explicit justification in the last column stating whether the parameter set is **"IDEAL"** or **"NOT APPROPRIATE"** for Palghar.

4. Finally, select the best set of parameters among the feasible combinations and identify the most robust alternatives with reasons.

Palghar is located on the Konkan coastal belt and receives high solar resource. Global Solar Atlas data for coastal Maharashtra shows annual global horizontal irradiance (GHI) of approximately 1,750–1,900 kWh/m^2/yr, consistent with CUF values of 0.19–0.21 for fixed-tilt ground-mounted PV. This supports the assignment CUF of 0.20. Indian regulatory practice typically adopts a 25–year project life for utility–scale solar tariff determination and normative O&M benchmarks of Rs.6–8 lakh/MW-year. Tariff bids in Maharashtra in 2023–24 cluster around Rs.2.9–Rs.3.1/kWh, confirming that the target LCOE of Rs.3/kWh is commercially realistic rather than theoretical.

2 LCOE formulation and energy output

For a project with:

- C_0 : upfront capital cost (Rs.)

- C_j : annual operating cost in year j (Rs./year)
- B_j : annual benefit or revenue in year j (Rs./year)
- S : salvage value at the end of year n (Rs.)
- d : real discount rate
- E_j : electrical energy generated in year j (kWh/year)

the real-term LCOE is defined as:

$$\text{LCOE} = \frac{C_0 + \displaystyle\sum_{j=1}^{n} \frac{C_j}{(1+d)^j} - \frac{S}{(1+d)^n}}{\displaystyle\sum_{j=1}^{n} \frac{E_j}{(1+d)^j}}$$

For this assignment:

$$E = 100 \times 0.20 \times 8760 = 175.2 \text{ GWh/year} = 175.2 \times 10^6 \text{ kWh/year}$$

and $E_j = E$ for all years. The appraisal objective is therefore:

$$\text{LCOE target} = \text{Rs.}3/\text{kWh}$$

Our task is to identify parameter combinations (C_0, C_j, B_j, n, d, S) that satisfy this equation and evaluate whether each combination is realistic for Palghar.

3 Base–case parameter set for Palghar

3.1 Selection of baseline parameters

A realistic base-case parameter set reflecting regulatory norms and market conditions is selected as follows:

- Useful life: $n = 25$ years (CERC norms)
- Real discount rate: $d = 6\%$ (close to estimated 5.9% real post-tax WACC for solar in India)
- Fixed O&M cost: Rs.8 lakh/MW-year = Rs.8 crore/year for 100 MW
- Salvage fraction: $s = S/C_0 = 15\%$
- Tariff benefit: $B_j = 3 \times E =$ Rs.52.56 crore/year

3.2 Solving for capital cost C_0

Imposing LCOE = Rs.3/kWh with C_j = Rs.8 crore/year, $d = 6\%$, $n = 25$, $s = 0.15$, and $E = 175.2 \times 10^6$ kWh/year, we solve the LCOE expression for C_0. Using a numerical solver (Python/Sympy, Appendix A), we obtain:

$$C_0 \approx \text{Rs.590.3 crore} \quad (\approx \text{Rs.5.9 crore/MW})$$

$$S = 0.15C_0 \approx \text{Rs.88.5 crore}$$

This parameter set exactly reproduces the target LCOE within rounding tolerance and serves as the reference feasible case for Palghar.

Since the tariff is fixed at Rs.3/kWh, the annual monetary benefit is $B_j = \text{LCOE} \times E_j = 3 \times E$, so B_j = Rs.52.56 crore/year.

4 Generating the feasible parameter set: one–at–a–time variation

To construct the required set of feasible economic parameter combinations (C_0, B_j, C_j, n, d, S) that deliver LCOE = Rs.3/kWh, the technical conditions are held constant (100 MW capacity, CUF = 0.20, constant annual energy output $E = 175.2 \times 10^6$ kWh/year, and no performance degradation). Annual monetary benefit is also fixed at B_j = Rs.52.56 crore/year, corresponding to a tariff of Rs.3/kWh.

Starting from the base case, exactly one economic parameter (d, n, s, or C_j) is varied at a time while solving for the capital cost C_0 such that the resulting LCOE remains equal to Rs.3/kWh. This procedure isolates the independent influence of each economic driver and reflects realistic tariff-based bidding behaviour in which developers adjust EPC costs, finance structures or O&M strategies in response to changing market or site conditions.

Each scenario is computed using the full discounted-cashflow LCOE expression, and all values are presented in real (inflation-adjusted) terms. This ensures internally consistent comparison of economic feasibility without assuming subsidy support or nominal escalation. Across all cases, the calculated LCOE matches Rs.3.00/kWh within a 0.001 tolerance, confirming that every listed combination represents a valid feasible solution under the stated constraints.

4.1 Summary table of scenarios

Notation:

C_0: initial capital cost (Rs. crore)

B_j: annual benefits (Rs. crore/year)

C_j: annual O&M cost (Rs. crore/year)

n: project life (years)

d: real discount rate (%)

S: salvage value (Rs. crore) at year n

$s = S/C_0$: salvage fraction

In all cases, exactly one of d, n, s or C_j is varied relative to the base case, and C_0 is recomputed such that $B_j = 52.56$ crore/year is held constant.

Case	Main parameter varied	C_0 (Rs. crore)	B_j (Rs. cr/yr)	C_j (Rs. cr/yr)	n (yr)	d (%)	s	S (Rs. crore)	LCOE (Rs./kWh)	Remarks for Palghar
0	Base case	590.3	52.56	8	25	6.0	0.15	88.5	3.00	**IDEAL**: Technically and financially consistent with Indian norms and Palghar context.
1	Lower discount rate	737.6	52.56	8	25	4.0	0.15	110.6	3.00	**NOT APPROPRIATE**: Requires exceptionally concessional capital; 4% real WACC is unrealistic relative to market structure [3].
2	Higher discount rate	486.3	52.56	8	25	8.0	0.15	72.9	3.00	**NOT APPROPRIATE**: Implies expensive capital; CAPEX must fall to Rs.4.9 cr/MW, infeasible for coastal PV [3].
3	Shorter life	536.2	52.56	8	20	6.0	0.15	80.4	3.00	**NOT APPROPRIATE**: Contradicts tariff norms and prematurely retires assets with remaining productive life [2].
4	Longer life	629.8	52.56	8	30	6.0	0.15	94.5	3.00	**NOT APPROPRIATE**: Unrealistic assumption of constant O&M despite coastal degradation [5].

Case	Main parameter varied	C_0 (Rs. crore)	B_j (Rs. cr/yr)	C_j (Rs. cr/yr)	n (yr)	d (%)	s	S (Rs. crore)	LCOE (Rs./kWh)	Remarks for Palghar
5	No salvage	569.6	52.56	8	25	6.0	0.0	0.0	3.00	**NOT APPROPRIATE**: Ignores realistic end-of-life recovery and land value; overly pessimistic [5].
6	Lower salvage (10%)	583.2	52.56	8	25	6.0	0.10	58.3	3.00	**IDEAL**: Conservative planning assumption suitable for leased land or volatile scrap markets.
7	Lower O&M	616.7	52.56	6	25	6.0	0.15	92.5	3.00	**NOT APPROPRIATE**: Unrealistically low coastal maintenance assumptions; risks performance loss [2].
8	Higher O&M	563.8	52.56	10	25	6.0	0.15	84.6	3.00	**IDEAL**: Realistic coastal O&M requirements; CAPEX optimisation compensates [3].

Table 1: Scenario combinations that produce LCOE = Rs.3/kWh for a 100 MW solar plant in Palghar

5 Interpretation of Results

The parameter variations show how each economic variable influences the feasibility of achieving an LCOE of Rs.3/kWh. Since only one parameter is changed at a time, its individual impact can be clearly assessed for realism in the context of Palghar.

5.1 Influence of discount rate (d)

The discount rate has the strongest effect on feasible CAPEX. With a lower rate of 4% (Case 1), the allowable CAPEX rises to Rs.737.6 crore, achievable only with concessional or sovereign-backed financing. At 8% (Case 2), CAPEX must fall to Rs.486.3 crore, below practical EPC benchmarks for coastal PV. Both assumptions therefore distort realistic economics.

Interpretation: A 6% real discount rate (Cases 0, 6 and 8) aligns with typical financing conditions; Cases 1 and 2 are **NOT APPROPRIATE**.

5.2 Influence of useful life (n)

A 20–year life (Case 3) forces early asset retirement despite productive residual life. A 30–year life (Case 4) assumes constant O&M costs, unrealistic under coastal corrosion and component replacement needs. Regulatory norms and degradation behaviour justify a 25–year lifetime.

Interpretation: A 25–year life (Case 0) is the only realistic value; Cases 3 and 4 are **NOT APPROPRIATE**.

5.3 Influence of salvage value (S)

Case 5 assumes no salvage, ignoring material recovery and land reuse value. Case 6 (10%) is a conservative assumption appropriate for leased land or weak scrap markets, while Case 0 (15%) reflects typical recycling conditions.

Interpretation: Salvage fractions of 10–15% are realistic. Case 6 is **IDEAL** and Case 0 is reasonable; Case 5 is **NOT APPROPRIATE**.

5.4 Influence of O&M cost (C_j)

Case 7 underestimates O&M at Rs.6 crore/year, ignoring higher cleaning and corrosion costs in coastal environments. Case 8, with Rs.10 crore/year, represents realistic operating conditions while still permitting feasible CAPEX.

Interpretation: Case 8 is operationally robust and **IDEAL**; Case 7 is **NOT APPROPRIATE**.

6 Best Parameter Sets and Policy Recommendation

Based on technical, environmental and financial realism, the following configurations are suitable for Palghar while maintaining LCOE = Rs.3/kWh:

- **Case 0 (Base Case)** — **IDEAL**. Balanced financing, realistic O&M, regulatorily consistent lifetime.
- **Case 6 (Conservative Salvage Case)** — **IDEAL**. Suitable for risk-averse planning and leased land execution.
- **Case 8 (High–O&M Coastal Case)** — **IDEAL**. Reflects realistic coastal environmental stress and maintenance.

All other scenarios rely on unrealistic financing terms, lifetime assumptions or O&M estimates and are therefore **NOT APPROPRIATE** for Palghar.

7 Final Remarks

The evaluation demonstrates that while multiple parameter combinations can mathematically achieve LCOE = Rs.3/kWh, only a limited set is realistic under Palghar's financial and operational conditions. Case 0 is recommended as the primary feasible configuration, with Cases 6 and 8 serving as robust alternatives for conservative planning and coastal reliability. These findings provide a defensible basis for government appraisal, tariff setting and competitive bid preparation.

Executive Summary

A 100 MW grid-connected solar PV plant is proposed in Palghar district with CUF = 0.20, and the project appraisal claims an LCOE of Rs.3/kWh. The Government has requested an independent evaluation to determine the economic feasibility of this claim and to identify combinations of project parameters (C_0, B_j, C_j, n, d, S) that can realistically achieve it.

A base-case scenario using $n = 25$ years, $d = 6\%$, $C_j =$ Rs.8 crore/year, and salvage fraction $s = 15\%$ yields the required capital cost $C_0 \approx$ Rs.590.3 crore. One-parameter-at-a-time variation then identifies a feasible solution space maintaining the target LCOE. Three realistic configurations emerge: Base Case (Case 0), Conservative Salvage (Case 6), and High-O&M Coastal (Case 8), all judged **IDEAL**, while all other combinations are **NOT APPROPRIATE**. Case 0 is recommended as the most defensible configuration.

Appendix A — Python Solver Code

```
import sympy as sp

def solve_lcoe(LCOE=None, C0=None, Cj=None, Bj=None, n=None, d=None, s=
    None, E=None):

    params = {"LCOE": LCOE, "C0": C0, "Cj": Cj, "Bj": Bj, "n": n, "d":
        d, "s": s, "E": E}
    missing = [k for k, v in params.items() if v is None]
    if len(missing) != 1:
        raise ValueError("Only one unknown parameter allowed.")

    x = sp.symbols(missing[0], real=True)
    for key in params:
        if params[key] is None:
            params[key] = x

    LCOE, C0, Cj, Bj, n, d, s, E = [params[k] for k in ["LCOE","C0","Cj
        ","Bj","n","d","s","E"]]

    S = s * C0
    PV_E = sp.summation(E / (1 + d)**t, (t, 1, n))
    PV_C = sp.summation(Cj / (1 + d)**t, (t, 1, n))
    PV_S = S / (1 + d)**n

    LCOE_expr = (C0 + PV_C - PV_S) / PV_E
    eq = sp.Eq(LCOE, LCOE_expr)

    sol = sp.solve(eq, x)
    print("Unknown:", missing[0])
    print("Value:", sol)
    return sol

res = solve_lcoe(
    LCOE=3.0,
    C0=None,
    Cj=8e7,
    Bj=52.56e7,
    n=25,
    d=0.06,
    s=0.15,
    E=175.2e6
)

print(res)
```

References

[1] World Bank. *Global Solar Atlas*. World Bank (2024).

[2] Central Electricity Regulatory Commission (CERC). *Norms for Renewable Energy Tariff*. CERC (2023).

[3] International Renewable Energy Agency (IRENA). *Renewable Energy Finance Outlook*. IRENA (2024).

[4] Reserve Bank of India (RBI). *Monetary Policy Report*. RBI (2023).

[5] National Renewable Energy Laboratory (NREL). *PV End-of-Life and Materials Recovery*. NREL (2022).

[6] Prayas Energy Group. *Analysis of Renewable Tariffs in Maharashtra*. Prayas (2024).