Solar Power Integration in Bhutan: A Tariff-Based Competitiveness Analysis

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Received: 24 May 2026; Revised: 6 July 2026; Accepted: 8 August 2026; Published:13 August 2026

Abstract

This study examines the Feed-in Tariff (FIT) derived under the tariff determination methodology recently issued by the Electricity Regulatory Authority (ERA) of Bhutan, applying a cost-plus approach and Levelized Cost of Electricity (LCOE) analysis grounded in normative project parameters, including capital expenditure, Capacity Utilization Factor (CUF), operation and maintenance costs, and Weighted Average Cost of Capital (WACC). Financial viability was assessed through spreadsheet-based modelling tools designed to simulate realistic project economics. The analysis finds that a fair FIT for solar energy in Bhutan falls in the range of Nu. 4.34 to Nu. 5.82 per kWh, considerably higher than the cost of hydropower generation (Nu. 1.60 per kWh) and the prevailing subsidized retail electricity tariff (Nu. 2.66 per unit). This gap reveals a meaningful competitiveness challenge that makes solar projects financially unviable under the current tariff structure. The study argues that bridging this gap requires a well-designed FIT policy, supported by complementary metering mechanisms such as net billing or value-based compensation schemes. Such measures, if thoughtfully implemented, could enable the sustainable integration of solar energy into Bhutan's power sector while preserving its overall financial health.

Key Words: *Feed-in tariff, Levelized cost of electricity, Solar energy, Bhutan, Electricity Regulatory Authority, Renewable energy policy, Net billing*

1. INTRODUCTION

Bhutan is a small landlocked country in the Eastern Himalayas. It is bordered by India to its east, west and south, and the People's Republic of China to its north. With altitudes ranging from 100 to 7,500 meters over an area of 38,394 square kilometers, it has three distinct climatic zones of hot and humid southern belt, cool temperate central zone, and alpine northern region.

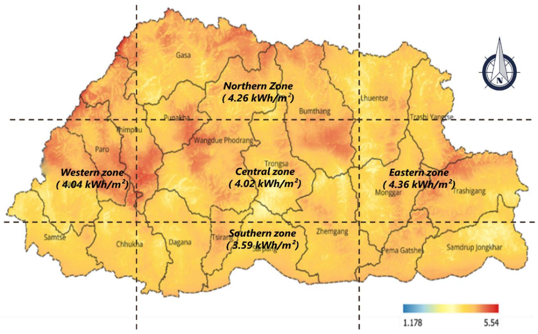

Fig. 1: *Global Horizontal Irradiation of Bhutan*

According to the National Solar Energy Roadmap (2025–40) (2025) Bhutan has solar potential of 12,000 MW and the global horizontal irradiation ranges from 3.59 kWh/m^2 in the southern zone to 4.36 kWh/m^2 in the eastern zone as shown in Figure 1. The geographical condition and landscape of Bhutan encourage the hydropower. However, it is a challenge in terms of solar and other sources of energy. The Royal Government of Bhutan (RGoB) has set an ambitious target to harness 5,000 MW of solar capacity by 2040, ensuring that at least 20% of our total generation capacity of 25,000 MW will come from Solar energy(National Energy Policy, 2025).

To support the ambition of the RGoB, the Electricity Regulatory Authority of Bhutan has published a tariff framework for Solar in December 2025 (TDR, 2025).

Tariff Framework for the Solar power plants were absent till December 2025 and the projects in operation before it was not compensated. This became the main issue and ERA issued a Net Metering tariff order as interim measure till the approval of Solar tariff framework.

This study aims to evaluate the financial viability and policy feasibility of solar photovoltaic energy in Bhutan by computing the Levelized Cost of Energy (LCOE) using normative project parameters, and determining a fair FIT range through spreadsheet-based financial modelling and sensitivity analysis. It assesses project-level economics, IRR, and payback period, under the current tariff structure, and analyses the tariff gap between the derived solar FIT, hydropower generation costs, and the prevailing subsidized retail electricity tariff. The study further evaluates complementary compensation mechanisms such as net billing and capital subsidy and tax incentives as policy instruments to bridge this competitiveness gap, and ultimately recommends a structured FIT policy framework that supports the sustainable integration of solar energy into Bhutan's power sector while safeguarding grid financial health and advancing the country's national energy targets and carbon neutrality commitments.

This study holds significant importance as it represents one of the first systematic attempts to derive a cost-reflective Feed-in Tariff for solar energy in Bhutan using a structured LCOE-based methodology anchored in the ERA's own tariff determination framework, thereby filling a critical policy gap that has long undermined investor confidence and impeded the growth of solar energy in the country. By quantifying the tariff gap between the derived solar FIT (Nu. 4.34–5.82/kWh), the cost of hydropower generation (Nu. 1.60/kWh), and the prevailing subsidized retail tariff (Nu. 2.66/kWh), the study provides regulators, policymakers, and energy planners with an evidence-based foundation upon which to design a fair and financially sustainable compensation mechanism for solar energy producers. At a time when Bhutan has set an ambitious target of 5,000 MW of solar capacity by 2040 and is actively seeking to diversify beyond its hydropower-dependent electricity generation, the findings of this paper are particularly timely, offering actionable policy recommendations, including net billing and value-based compensation schemes, that can support the sustainable integration of solar energy into the national grid without compromising the overall financial health of the power sector or the affordability of electricity for consumers.

The remainder of the paper is structured as follows: Section 2 reviews relevant literature on FIT design, LCOE methodologies, and the regulatory context in Bhutan; Section 3 describes the methodology and model parameters; Section 4 presents the results and sensitivity analysis; and Section 5 concludes with policy recommendations.

2. LITERATURE REVIEW

2.1 Feed-in-Tariffs as a Renewable Energy Policy Instrument

Among the policy instruments used to stimulate the adoption of renewable energy systems is the FIT. The Australian Energy Regulator (Australian Energy Regulator, 2019), FIT is described as the rate that customers are paid for exporting electricity back into the electrical network from their distributed energy systems, usually comprising solar power systems but can include wind turbines and hydro-powered energy generation systems; it should be noted that the customers cannot negotiate FIT rates with electricity providers (Regulated Feed-In Tariff Rate Determination for the Period from 1 July 2022 to 30 June 2025, 2022). FIT is a policy instrument through which the purchase price and periods for the electricity produced by each distributed energy system type are determined, and emphasize their importance in offsetting the initial cost of installation of the renewable energy system(Mekonnen et al., 2025).

The deployment of FITs and feed-in premiums has been widespread worldwide as instruments to facilitate the uptake of renewable energy technologies. According to the report of Global Status Report 2025 (REN21, 2025a), policies such as feed-in tariff, net metering, and net billing attracted continuous policy interest in 2024, having 116 policies operational in 93 countries. Among those were 44 countries with feed-in tariff policies, 61 countries with net metering policies, and 11 countries with net billing policies. Twenty-three countries operated feed-in tariffs alongside other incentives, with 19 utilizing feed-in tariff along with net metering and four, namely France, Greece, Moldova, and Poland, implementing feed-in tariff together with net billing policies. The widespread deployment of FITs around the globe is indicative of the importance of FITs as an important instrument for incentivizing the use of renewable energy in markets where solar and wind technologies fail to be competitive against incumbent energy.

An important consideration in the design of efficient FIT programs is that the feed-in tariff should be set at a realistic value taking into account the real cost of generation using a particular technology such that investors can get a decent return on their capital while still being financially sustainable for the government or public utility paying out the tariff. FIT programs normally have a duration period of 10 to 20 years where renewable energy firms sell electricity at a

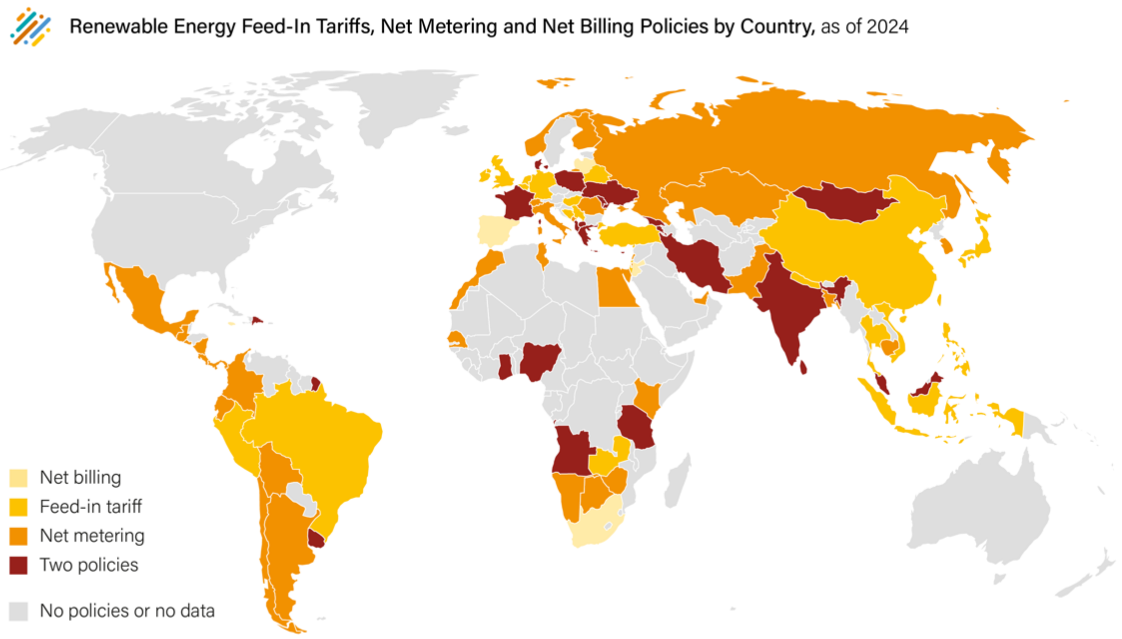

Fig. 2*: Energy FITs, Net Metering and Net Billing Policies by Country, as of 2024(REN21, 2025a)*

higher price than the market price with the support of government subsidy programs (Xu & Wang, 2025). It is evident that the price of electricity purchased through FIT programs is calculated based on the cost of producing renewable electricity plus a reasonable profit; hence, LCOE provides the necessary methodology for FIT programs.

Feed-in tariff policies differ not only in their tariff levels but fundamentally in how their remuneration is structured. Couture and Gagnon (2010) provide the foundational taxonomy of FIT design, distinguishing between market-independent models, in which a fixed price is guaranteed to renewable energy developers regardless of prevailing electricity market prices, and market-dependent models, in which a premium is added above the spot market price. Their analysis of seven distinct remuneration structures demonstrated that market-independent, fixed-price FITs consistently create greater investment security and lower-cost renewable energy deployment than market-dependent alternatives, primarily because they offer more predictable revenue streams over the project lifetime, lower the cost of capital for investors, and broaden participation to include smaller and community-based investors who cannot absorb the revenue volatility inherent in premium-based models. Critically, the authors argue that in the most successful jurisdictions, FIT payment levels are determined as closely as possible in relation to the specific generation costs of each technology(Couture & Gagnon, 2010), a cost-plus principle that directly underpins ERA's Tariff Determination Regulation 2025 and the LCOE-based methodology adopted in this study.

Their finding that ensuring FIT payments are adequate to recover project costs over the project lifetime while allowing a reasonable rate of return remains the central challenge of FIT policy design is of direct relevance to Bhutan, where the derived FIT (Nu. 4.34–5.82/kWh) significantly exceeds both the hydropower generation cost and the prevailing subsidized retail tariff, making the choice of remuneration structure and guarantee duration critical policy decisions.

2.2 Global Growth of Solar PV and the Role of Supportive Policies

It has become clear in recent years that the fast-paced increase in global solar photovoltaic capacity has been closely related to the existence of supportive policy frameworks such as feed-in tariffs and other forms of payment for energy produced. As reported by (REN21, 2025b), in 2023-2024 alone, there has been a remarkable increase in the capacity of installed solar PV of 37%. Following the crossing of the 1TW capacity threshold in 2022, less than two years have passed before reaching more than 2TW of installed solar PV capacity globally by 2024, with 60% of global additions and 47% of total capacity coming from China.

The example of China in this case is especially significant. Under the Chinese FIT program, the feed-in tariff of new energy electricity is explicitly defined by the government, while power companies are obliged to buy all the power produced by eligible new energy providers at the tariff equal to the production cost per unit of renewable energy plus a profit margin (Xu & Wang, 2025). Such a system contributed to an impressive number of installations in both solar and wind projects, turning China into the market leader when it comes to solar PV. Nevertheless, China has shown how costly it can be to maintain open-ended FIT programs.

On the contrary, though Spain is one of the first countries to invest in Solar power plant(Herrera, 2024), there is the case of Spain that provides a cautionary story. According to (Dufo-López & Bernal-Agustín, 2015), the use of PV generators in Spain was stimulated using FITs starting from 2004; however, when the government abruptly withdrew all subsidy support from renewable energy in 2012, the solar industry came to a standstill. Such an example underscores the need for policy continuity and certainty as well as regulatory stability in order to guarantee investment in solar energy, especially in developing solar markets like that of Bhutan.

A comparative review of solar PV incentive mechanisms across thirteen countries, including Germany, Spain, France, the United States, China, India, Canada, Brazil, Mexico, Malaysia, the United Arab Emirates, and Sub-Saharan Africa by Kılıç and Kekezoğlu identified the Feed-in Tariff as the most widely adopted policy instrument globally, supplemented in leading markets by portfolio standards, tax exemptions, categorized incentive systems, and tendering mechanisms. The review found that countries achieving their installed capacity targets earliest were those that diversified their incentive portfolios notably China, which implemented virtually all available incentive models simultaneously, while nations relying on a single mechanism, or those applying excessively short FIT guarantee periods, consistently underperformed against their targets (Kılıç & Kekezoğlu, 2022). Critically, the study demonstrated that the duration of the FIT purchase guarantee is at least as important as the tariff value itself, with leading countries applying periods of 20 to 25 years compared to shorter durations in less successful markets, and that incentives calibrated specifically for rooftop and micro-generation facilities below 100 kW produced measurably stronger distributed solar uptake. These findings carry direct relevance for Bhutan, where the derived FIT range of Nu. 4.34 to Nu. 5.82 per kWh must be considered alongside guarantee duration, categorization by project scale, and complementary metering mechanisms if the country's 5,000 MW solar target by 2040 is to be achieved.

A comprehensive review of global solar energy policy across Europe, North America, Asia, and Australia established that FIT, Renewable Portfolio Standards (RPS), and direct financial incentives are the most widely deployed and effective policy instruments for solar energy development(Solangi et al., 2011). Their analysis found that FIT and RPS policies provide significant motivation for investment in renewable energy technologies and that no single policy instrument is universally superior rather, the most successful countries combine multiple mechanisms tailored to their economic conditions, energy market structure, and renewable resource endowment. The review also documented the range of financial incentive instruments accompanying FITs in leading markets, including tax exemptions, low-interest loans, capital subsidies, and net metering, noting that these complementary measures are critical for making FIT-supported solar projects financially viable in jurisdictions where the retail electricity price does not yet reflect the cost of solar generation.

This multi-instrument framework is directly relevant to Bhutan, where the tariff gap analysis in this study shows that a FIT alone, set at Nu. 4.34–5.82/kWh is insufficient to drive solar deployment without accompanying capital subsidies, concessional financing, and an appropriate metering scheme.

2.3 Regional Experiences: South Asia and the Himalayan Context

In South Asia, there are various countries which have similar geographic and developmental conditions to Bhutan and have been able to make great progress with regards to the application of solar energy. Nepal, being one such nation which has similar geographic and socioeconomic attributes as Bhutan, has made tremendous progress with respect to solar energy adoption.

Within the Himalayan regional context, the study performing comprehensive review of energy policy evolution in a comparable economy, evaluating four decades of Nepal's renewable energy policy through a five-dimensional energy security framework covering availability, accessibility, affordability, acceptability, and accommodation(Bhattarai et al., 2024). Their review found that Nepal's successive energy plans have been disproportionately focused on hydropower development, and that solar, wind, and hybrid technologies have been treated as secondary policy targets despite significant resource potential, a pattern that parallels Bhutan's own energy policy trajectory.

Critically, the study demonstrated that two-thirds of the untapped global hydropower potential lies in the Himalayas, and that the policy lessons and financing models applicable to Nepal have direct relevance to its neighboring countries given the common socioeconomic, physiographic, and institutional settings across the region. For Bhutan, the implication is that Nepal's experience, including its gradual shift from subsidy-based to credit-based renewable energy support mechanisms, and its recent move toward competitive tendering for utility-scale solar, offers a practical policy roadmap for the phased reduction of FIT support over time as the solar market matures.

Nepal has made considerable progress with respect to adopting solar energy. As a result, Nepal is among the most electrified nations in the world with electrification levels of 99% in urban regions and 95% in rural settings due to the integration of grid-connected solar power along with off-grid solar energy, aided by policies like the Renewable Energy Subsidy Policy (Bhandari et al., 2025).

2.4 Net Metering and Net Billing as Complementary Mechanisms

Apart from FITs, net metering and net billing can be seen as emerging policy tools that help address distributed solar energy generators as a way of providing incentives to these systems. Net metering, also known as net energy metering (NEM), can be defined as the use of policies in many regions that promote the usage of renewable energy as part of the strategy that encourages the creation of a clean power source within the residential, commercial, and industrial sector of electricity consumers located behind the meter, often referred to as behind-the-meter generation(“The Role of Net Metering in the Evolving Electricity System,” 2023).

Net billing, which is related but different from net metering, pays out distributed generators on a predetermined export tariff rate basis instead of the full retail tariff rate, hence more appropriately capturing the worth of energy produced to be fed back to the grid. According to (REN21, 2025a), as of 2024, net billing schemes had been adopted in 11 countries. There is a continued increase in the use of such policy tools as policymakers attempt to find a way of balancing the needs of solar producers against those of non-solar ratepayers. It is clear that there is need for differentiation of net metering and net billing schemes as the case of Bhutan illustrates, especially where there is heavy subsidization of the retail electricity tariff.

2.5 LCOE as the Methodological Foundation for FIT Determination

LCOE is the globally accepted measure of assessing the economic competitiveness of electricity generation technologies and, hence, provides a very natural choice for FIT determination based on cost considerations. LCOE refers to the cost of production of electricity using a particular technology throughout its lifetime, taking into account capital investment, operational costs, financing costs, as well as time value of money, expressed through a tariff that would make the project break-even at net present value. Bhutan's own ERA follows this practice explicitly as it states in its TDR (2025) that the levelized cost over 25 years will form the basis for tariff of the solar power project in Bhutan**.** The role of ERA is explained in details in the following section.

2.6 Role of ERA

The ERA's role has grown in strategic importance as Bhutan embarks on an ambitious energy diversification agenda, transitioning from an almost exclusively hydropower-dependent electricity system toward a more diversified generation portfolio that incorporates solar photovoltaic, wind, and other alternative renewable energy sources. In this context, the ERA's tariff-setting function has emerged as a particularly critical lever, since the financial viability of any new renewable energy technology in Bhutan is fundamentally determined by the compensation framework that the ERA establishes for electricity generated from that technology and fed into the national grid.

The Act also mandates ERA to approve tariff for generation not regulated by PPAs (Electricity Act of Bhutan, 2001). The ERA's approach to tariff determination is grounded in a cost-plus regulatory framework, which is the most widely adopted methodology for electricity tariff setting in developing economies with regulated utility sectors. Under the cost-plus approach, the ERA determines the allowable revenue that a regulated entity, such as a generator, transmission company, or distribution licensee, is permitted to recover from its customers based on a systematic assessment of the prudent and efficient costs incurred in providing the regulated service, plus a reasonable return on the capital invested. This approach is designed to ensure that tariffs are both cost-reflective and investment-enabling, while protecting consumers from excessive pricing.

2.7 Current Retail Tariff and Cross Subsidy Challenges

Over the year, there has been rise in the domestic electricity tariff due to various factors. Although small, the rise has been steady, and an extrapolation of the tariff gives an average annual increase of 1.8% (Dukpa, 2023). According to the Tariff Review Report of BPC, the current unsubsidized cost for the supply is as provided in Table 1:

Table 1: *Unsubsidized Tariff for Tariff Period 2022-25 (source: (BPC Tariff Review Report 2022 to 2025, 2022))*

Consumer Category	Nu/kWh
Wheeling	0.23
High Voltage (HV)	2.5
Medium Voltage (MV)	3.71
Low Voltage (LV)	4.85

Based on annual subsidy allocation of Nu 365.67 million to the LV consumers and application of uniform tariff of Nu 2.66/kWh approved by the Royal Government of Bhutan. The HV consumers were cross subsidizing MV and LV consumers.

The approved structure is as provided in Table 2:

Table 2: *Approved Tariff Structure for Tariff Period 2022-25 (source: (BPC Tariff Review Report 2022 to 2025, 2022))*

Tariff Structure	Unit	2022-25
	Low Voltage (LV)	
LV Block I (Rural) 0-100kWh	Nu/kWh	0
LV Block I (High landers) 0-200kWh	Nu/kWh	0
LV Block I (Others) 0-100kWh	Nu/kWh	1.28
LV Block II (All) >100kWh	Nu/kWh	2.66
	Medium Voltage (MV)	
Energy Charge	Nu/kWh	1.6
Demand Charge	Nu/kVA/Month	170
	High Voltage (HV)	
Energy Charge	Nu/kWh	1.6
Demand Charge	Nu/kVA/Month	496
Wheeling	Nu/kWh	0.23

As shown in Tables 1 and 2, the unsubsidized cost of supply for Low Voltage consumers (Nu. 4.85/kWh) is substantially higher than the approved retail tariff of Nu. 2.66/kWh, a gap that is bridged by government subsidy and cross-subsidization from High Voltage consumers. The tariff gap referred to throughout this study is the difference between the cost-reflective solar FIT (Nu. 4.34–5.82/kWh) and this prevailing subsidized retail tariff, which renders solar investments financially unviable without additional compensation. As a result of this structural gap and the absence of a systematic solar compensation scheme, the following methodology was developed to derive evidence-based recommendations suited to Bhutan's conditions.

3. METHODOLOGY

The methodology in Figure 3. provides a brief overview of the procedure of the study.

3.1 Tariff Methodology

(TDR, 2025), provides ERA's tariff determination methodology, as expressed in its most recently issued guidelines, is structured around the following core components:

- Capital Cost Benchmark: The ERA recognizes the capital expenditure (CAPEX) incurred in the construction and commissioning of a generation or network asset as the starting point for tariff determination. CAPEX includes all costs associated with equipment procurement, civil and electrical works, project development, and financing during construction. The ERA evaluates whether the CAPEX claimed by a licensee or proposed by a developer is prudent and reasonable, benchmarking it against comparable projects and international cost data where Bhutan-specific data is limited. For Solar, the benchmark capital cost published in the TDR are provided in the table below:

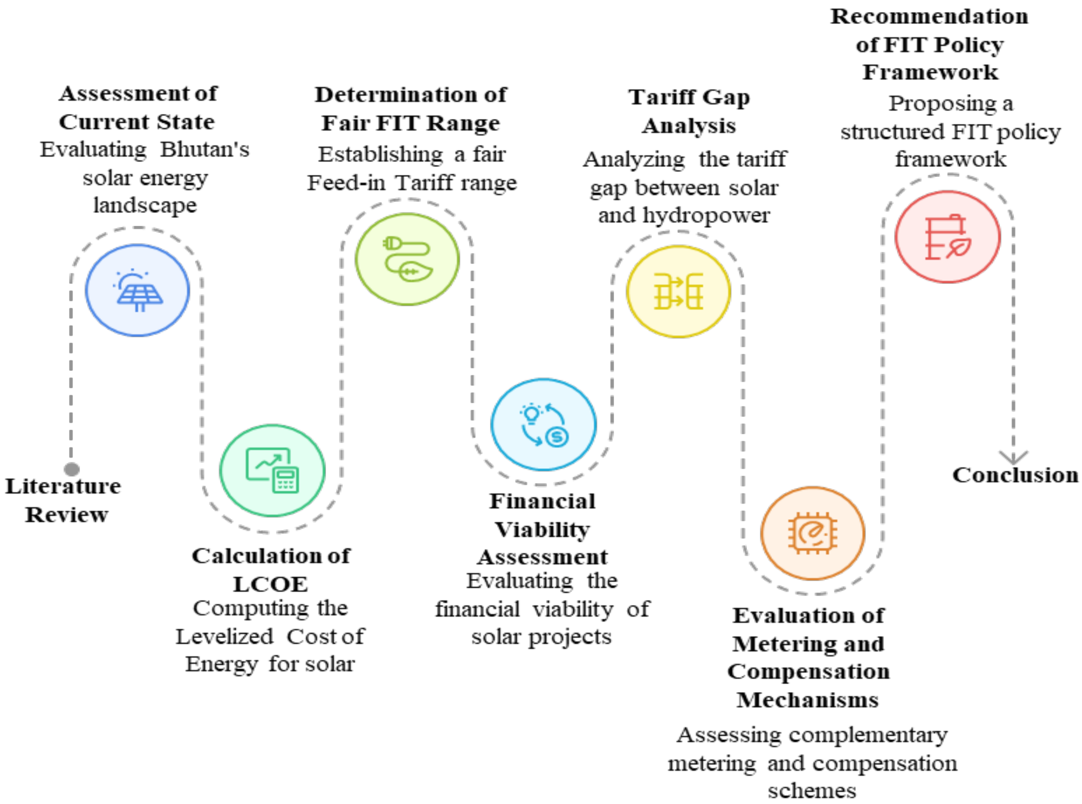

Fig. 3: *Methodology Flow Diagram*

Table 3*: Capital Cost Benchmark for different Categories of Solar Power Plants*

Type of Solar Power Plant	Category	Capacity (kWp)	Capital Cost (Nu/kW)
Rooftop Solar Power Plant	1A	<30	Up to 50,000
	1B	31 till 1000	Up to 47,500
Ground-mounted solar power plant	2	0 till 3000	Up to 47,500
Utility Scale Power Plant	3A	3001 till 10,000	Up to 45,000
	3B	10,001 till 50,000	Up to 42,500
	3C	Above 50,000	Up to 40,000

- Operational Cost Allowance. Annual Operation and Maintenance (O&M) costs are assessed and included in the tariff as a recurring cost component. For solar PV systems, O&M costs typically include panel cleaning, inverter maintenance, monitoring system costs, insurance, and land lease payments. The ERA's methodology requires that O&M cost to be less than 1.5%.
- Depreciation and Asset Life: The ERA's methodology incorporates both straight-line and accelerated depreciation over the useful economic life of the asset, which for solar PV systems is typically assumed to be 25 years, consistent with international practice and the warranty periods of major solar module manufacturers.
- Weighted Average Cost of Capital (WACC): The ERA applies a WACC to determine the fair return on capital that an investor in a regulated electricity asset is entitled to earn. The WACC reflects the blended cost of equity and debt financing, weighted by their respective proportions in the project's capital structure.
- Levelized Cost of Electricity (LCOE) as the Tariff Basis. Building on the cost components described above, the ERA's methodology effectively converges on an

LCOE-based tariff determination approach, in which the tariff is set at a level that allows the developer to recover all capital and operating costs over the project lifetime, earn the allowed return on capital, and break even on a net present value basis over the project's economic life. This approach aligns with international best practice in FIT design, where the tariff is set to reflect the true cost of generation from a given technology rather than the market price of electricity, which in Bhutan's case is artificially suppressed by decades of hydropower-based cross-subsidization.

- Capacity Utilization Factor (CUF): The CUF measures the ratio of actual energy generated by a solar PV system over a given period to the maximum energy it could theoretically generate if operating at full capacity for the entire period. In Bhutan, the CUF for solar PV is benchmarked as minimum of 15% for rooftop solar projects and minimum of 17% for the ground mounted solar power projects. The ERA's tariff methodology requires that the CUF assumption used in tariff calculations be based on site-specific solar resource assessments and reflect realistic generation expectations rather than optimistic projections. The Equation 1 is used for calculating CUF is as provided below:

$$CUF\ (\%) = \frac{Annual\ Generation\ (kWh)}{Capacity\ (kW)\ X\ 8760} X\ 100 \quad (1)$$

CUF is the efficiency of the plant in layman term and the impact of it is explain in result. But the it has to be noted that ERA's cost-plus tariff framework sits within a retail tariff structure that is heavily subsidized, meaning there is an inherent conflict between cost-reflective solar compensation and existing electricity prices.

3.2 LCOE Model

Using the provisions from the (TDR, 2025) an Excel-based model was developed for tariff computation. Category 1A (rooftop solar below 30 kWp) is excluded from the main LCOE modelling as ERA has already published a fixed tariff of Nu. 5.77/kWh for this category (TDR, 2025) and it automatically fall under prosumer category. The LCOE model covering a 25-year project life was used, consistent with the project life specified in National Energy Policy 2025 and the standard economic life of solar PV systems assumed by major module manufacturers. As per the NEP 2025, gearing ratio of minimum 70% has to be maintained for all kinds for solar power projects.

The WACC is determined using Equation 2 (the standard pre-tax WACC formula, where the tax shield is applied to the cost of debt):

$$WACC = \frac{[COE \times (1 - Gearing)]}{1 - Tax} + (COD \times Gearing), \quad (2)$$

Where, COE is Cost of Equity, COD is Cost of Debt and Gearing ratio is the percentage of debt in capital cost. Tax here refers to the income tax that has to be paid by the developer however as per the (Fiscal Incentives Act of Bhutan, 2021), for a solar developer there is tax holiday of 10 years. For the remaining years, the developer is liable to pay tax rate of 22%.

The economic feasibility of solar PV projects is most commonly evaluated using the LCOE, which benchmarks the per-unit cost of generation by discounting all lifetime costs against all lifetime energy output. Branker, Pathak, and Pearce conducted a foundational review of LCOE methodology for solar PV, identifying a widespread lack of clarity in the reporting of assumptions, particularly regarding discount rates, system lifetime, degradation rates, and financing terms, that produces widely varying and often contradictory results across studies. Their analysis demonstrated that LCOE is highly sensitive to the choice of discount rate and financing structure, that system lifetimes for crystalline silicon panels frequently exceed the commonly assumed 20–25 years, and that degradation rates of 0.2%–0.5% per annum are more realistic than the 1% often used in policy analyses. Critically, the paper noted that a Feed-in Tariff removes the price risk for renewable energy producers but does not eliminate financing risk, and that LCOE estimates intended to inform policy mandates must be accompanied by explicit sensitivity analysis across variable ranges(Branker et al., 2011).

The present study adopts these methodological standards by anchoring LCOE parameters to ERA's TDR 2025 benchmarks, applying a degradation rate of 0.5% per annum, and conducting a one-at-a-time sensitivity analysis across the five parameters most subject to uncertainty in the Bhutanese context. The LCOE is computed using Equation 3 below:

$$LCOE = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}} \quad (3)$$

Where, 'C_t' is the net cost required for the operation of the plant, 't' ranges from 0 to 25 years (useful life of the project), 'E_t' is the energy generated in given year adjusted with degradation and auxiliary losses and '$(1+r)^t$' is the discount factor which is equivalent to project WACC.

3.3 Key Input Parameters

The model input parameters are derived from the published TDR benchmarks of ERA and cross-validated against regional and international practices where Bhutan-specific data are not available. The Cost of Debt (COD) of 9.45% maximum lending rate approved by the ERA as per the TDR 2025. Couture and Gagnon (2010) note that fixed-price FITs without inflation adjustment cause the real value of developer revenues to erode over time (Couture & Gagnon, 2010), a risk particularly salient in Bhutan given an average inflation rate of 3.46% over the tariff review period. The inflation rate of 3.46% is the three-year average consumer price inflation of non-food items for Bhutan used in ERA's tariff reviews. For the simulation the key parameters common for all categories are provided in Table 4 and category-specific parameters in Table 5 below:

***Table 4**: Parameters Common for All Categories (Source: ERA TDR 2025)*

Parameter	Value
COD	9.45%
COE	16%
Interest on Working Capital	9.23%
Operation and maintenance cost	1.5% of Capital cost
Arrears	40 days
Gearing Ratio	70%
Tax	0% for first 10 years and 22% thereafter
Depreciation	Accelerated depreciation with 10% salvage value
Inflation	3.46%
Inventories	15% of O&M Cost
Project Life	25 years

***Table 5**: Category Specific Parameters (Source: ERA TDR 2025)*

Category	Capital Cost (Nu/kW)	CUF (%)	Auxiliary loss (%)
1A	50,000	15	0
1B	47,500	15	0
2	47,500	17	0.5
3A	45,000	17	0.5
3B	42,500	17	0.5
3C	40,000	17	0.5

Given the uncertainty inherent in key financial and technical parameters — particularly the cost of equity (due to Bhutan's nascent capital markets), CUF (due to the significant topographic variability across Bhutan's three climatic zones), and capital cost (due to limited Bhutan-specific procurement data) — a sensitivity analysis was conducted to assess the robustness of the derived tariff to variations in key assumptions.

3.4 Sensitivity Analysis

For the sensitivity analysis, parameters used are cost of equity, gearing ratio, operation and maintenance cost, capital cost and capacity utilization factor. Impact on tariff with respect to change in the aforementioned parameters are discussed in Section 4 of this paper. Each parameter was varied over a defined range, COE between 13% and 16%, capital cost ±5% of the benchmark, and CUF ±2 percentage points, while all other parameters were held constant at base case values, to isolate individual effects on the computed tariff. Furthermore, financial viability assessments were also conducted for this analysis, Internal Rate of Return was calculated for each scenario. The results and discussions are provided in the next section.

4. RESULTS AND DISCUSSION

The results that have been obtained and analyzed in this section come from the application of the LCOE-based financial model which was established on the base of the (TDR, 2025) published by the ERA. This model was applied to five categories of solar energy plants (excluding Category 1A, which is addressed separately below) established in Bhutan's regulations. The analysis proceeded in four steps: (1) LCOE values were computed for each project category and used as the cost-reflective basis for the Feed-in Tariff; (2) a sensitivity analysis was conducted to assess how changes in key input parameters affect the derived tariff; (3) the financial viability of each category was evaluated using the Internal Rate of Return (IRR) and payback period; and (4) the tariff gap between the derived solar FIT and prevailing electricity prices was analysed, and complementary policy instruments were assessed to bridge that gap.

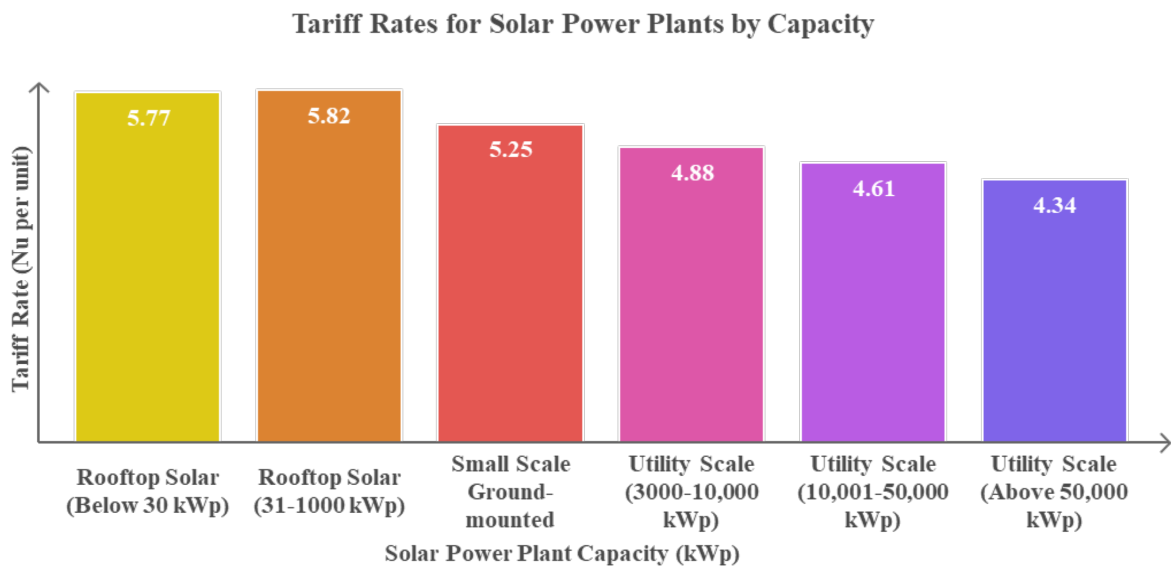

Fig. 4: *Tariff Rates for Each Category*

4.1 Levelized Cost of Energy (Base Tariff)

In order to achieve the Base Tariff for each category, the LCOE-based financial model was employed across all five categories of solar power plants (Category 1A excluded, as noted above). The tariff obtained for all the categories is provided in the Fig. 4.

According to the ERA, rooftop solar below 30 kWp need not have to apply for license and is considered as deemed exemption(Licensing Regulation for Solar Power Plant, 2024) and the tariff of Nu 5.77 per unit is published and no changes would be considered. Using these tariffs as base tariff, sensitivity analysis was conducted.

4.2 Sensitivity Analysis Results

In order to establish the validity of the proposed LCOE-based tariff and understand which parameters has the greatest effect on the economic viability of solar energy projects in Bhutan, a sensitivity analysis was performed through varying five critical input parameters; Cost of Equity, Operation & Maintenance Cost, Capital Cost, and Capacity Utilization Factor, while maintaining the other parameters constant at base case values.

The sensitivity analysis revealed that tariff outcomes are most sensitive to changes in the Cost of Equity, Capital Cost, and CUF. The significance of these findings is amplified by Bhutan-specific conditions: financing costs carry higher uncertainty due to the country's nascent capital markets, and CUF estimates are less certain due to significant topographic variability across Bhutan's climatic zones.

4.2.1 Cost of Equity (COE)

Cost of equity is the compensation an investor expects for the risks taken when investing in a company's equity (Kenton, 2024). The TDR 2025 provides a provision of approving COE of 13% - 16% for solar power plants (TDR, 2025). As per the in the Tariff Review Report of 200 kW Ground Mounted Solar Project at Tamzhing, COE of 16% has been approved due to its efficient nature of the project (ERA, 2025b). Whereas, for as per Tariff Review Report of 22.38 MWp Sephu Solar, COE of 13.66% was approved(ERA, 2025a). The variation of COE and its impact on tariff is displayed in the Fig. 5:

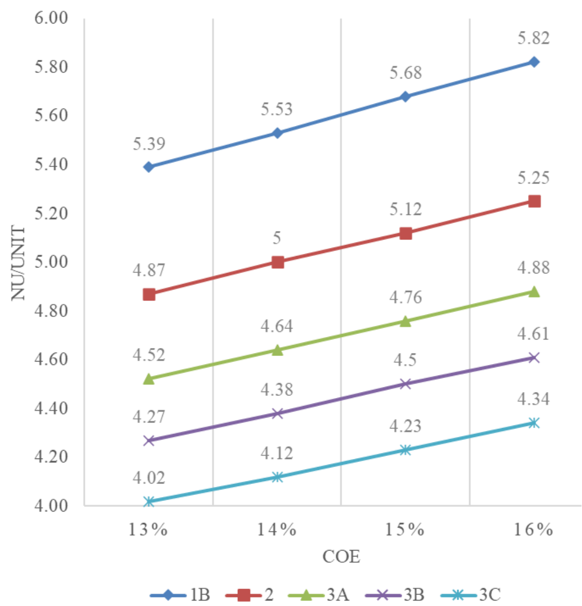

Fig. 5: *Variation of Tariff with Change to COE*

As shown in Figure 5, a clear proportional relationship was observed between COE and the computed solar tariff: for every 1% increase in COE, the solar tariff rose by an average of 2.5% across all project types. This finding underscores the importance of the cost of equity as a primary driver of solar project economics in Bhutan, particularly given the country's nascent capital markets and the currently applicable COE of 16%. Reducing the COE through targeted financial instruments, such as green bonds, blended finance, or risk-sharing guarantees, could meaningfully reduce the tariff burden without compromising investor returns.

4.2.2 Operation and Maintenance Cost

The operation and maintenance (O&M) costs of utility-scale solar PV plants have declined in the last decade, driven by module efficiency improvements that have reduced the surface area required for every MW of capacity (Renewable Energy Agency, 2023).

As per TDR 2025, the operation and maintenance cost shall include all recurrent expenditures incurred in the day-to-day operation of a solar PV project over its operational lifetime. These include, but are not limited to, salaries and wages of operational and technical personnel, transportation expenses, insurance of assets, routine and preventive maintenance of panels, inverters, and balance-of-system components, office materials and administrative expenses, rentals, and consumables.

Under standard accounting practices, all such recurring costs are treated as operational expenditures and are recovered annually through the tariff over the project's 25-year economic life. In line with the ERA's TDR 2025, the aggregate O&M cost is benchmarked at 1.5% of the capital cost per annum, escalated annually by the applicable inflation rate of 3.46% (average consumer inflation rate for past 3 years for non-food items), ensuring that the real value of the O&M allowance is preserved throughout the project lifetime. For the analysis, the O&M allowance has been increased and reduced by 0.5%.

As shown in Figure 6, the sensitivity analysis revealed that a 0.5% increase in the O&M cost allowance results in an average increase in the tariff rate of about 4.20%, indicating a proportional relationship between the O&M cost and the computed solar tariff rate. This finding has a significant regulatory implication in the sense that since according to ERA's TDR 2025, the O&M cost benchmark is capped at 1.5% of capital cost per year, any developer whose actual recurrent costs are above the cap is unable to recover their excess expenditure from the tariff; hence, they have to bear the cost of any additional expense above the benchmark by up to 4.20% of the applicable tariff for every extra 0.5% of O&M expenses above the benchmark level.

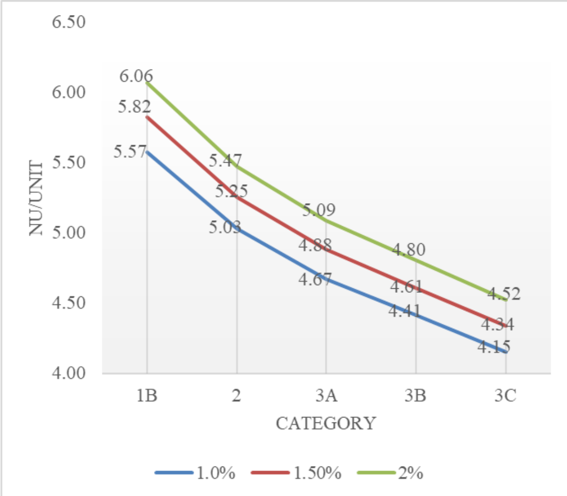

***Fig 6**: Variation of Tariff with O&M Cost*

4.2.3 Capital Cost

The cost of capital (CoC) for renewable power generation technologies is a very important driver of total costs. CoC is a major determinant of the cost of electricity from renewable power generation technologies (Anatolitis et al., 2023).

In this sensitivity analysis, two capital cost cases have been considered, wherein a developer who exceeds the capital cost benchmark by 5% and a developer who attains a capital cost 5% lower than the benchmark is taken into account, thereby proving that capital cost is linearly related to the tariff rate.

As shown in Figure 7, for a developer who exceeds the capital cost benchmark by 5%, an average of 4.94% of financial losses incurred are not compensated through the tariff.

This confirms that capital cost control is critical for financial viability under the ERA's cost-plus framework. Developers who can procure equipment and execute construction at or below the benchmark capital cost directly benefit from the full solar tariff allowance.

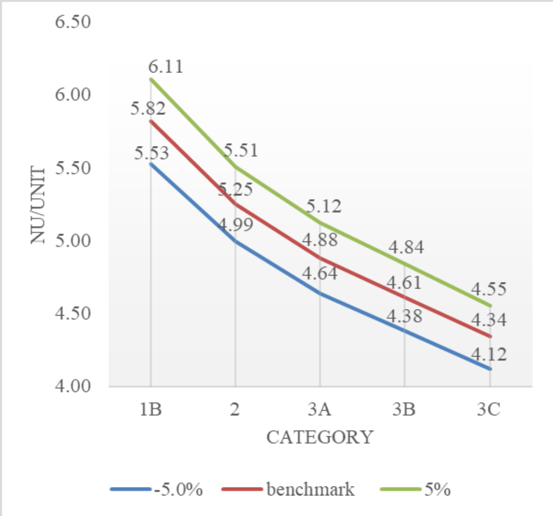

***Fig. 7:** Variation of Tariff with Capital Cost*

4.2.4 Capacity Utilization Factor

States in India having geographic and climatic similarities with Bhutan, especially Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh that have similar terrain, altitudes, and cloudiness pattern features, have a standard solar PV CUF between 14%-19% due to lesser levels of solar radiation and a higher monsoon season period in the Himalayan region. In other words, the Central Electricity Regulatory Commission (CERC), and respective state-level electricity regulatory authorities in these hill states have considered a CUF benchmark of 14%-19% for tariff calculations, which is quite similar to the CUF benchmark of 15% and 17%, respectively, set by ERA for roof-top and ground-mounted solar PV installations in Bhutan.

In this sensitivity analysis, the variation of the CUF is performed separately for rooftop category and ground-mounted category.

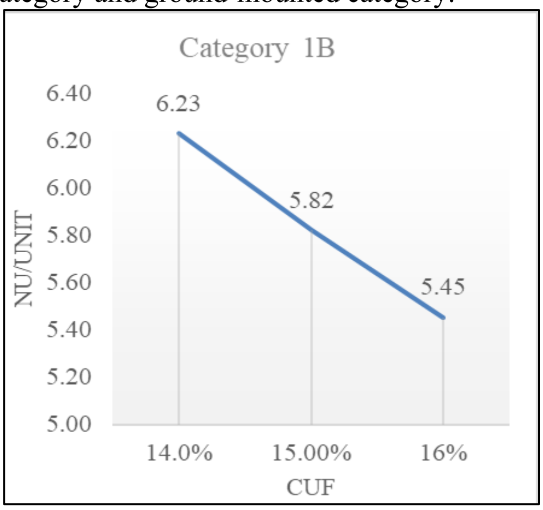

***Fig. 8:** Variation of Tariff with CUF for Rooftop Solar*

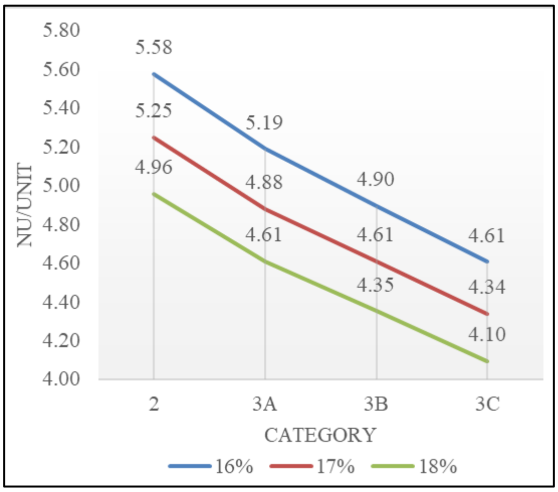

***Fig. 9:** Variation of Tariff with CUF for Ground-mounted Solar Projects*

As shown in Figures 8 and 9, CUF was found to have an important inverse relationship with the solar tariff: higher actual CUF reduces the required tariff since more energy is generated from the same capital investment. However, developers are advised to declare their realistic actual CUF, as any energy injected beyond the declared quantum will be compensated only at the average power purchase price of generation (TDR, 2025) which will be much lower than the solar tariff determined by the Authority. The financial viability of solar power plants is also assessed in the next section.

4.3 Tariff Gap and Financial Viability Analysis

Bhutan is hydropower dominant in terms of electricity and solar is newly encouraged source of energy to diversify the energy source. The difference between hydropower tariff and solar tariff is significant the difference between the tariffs is shown in the figure below:

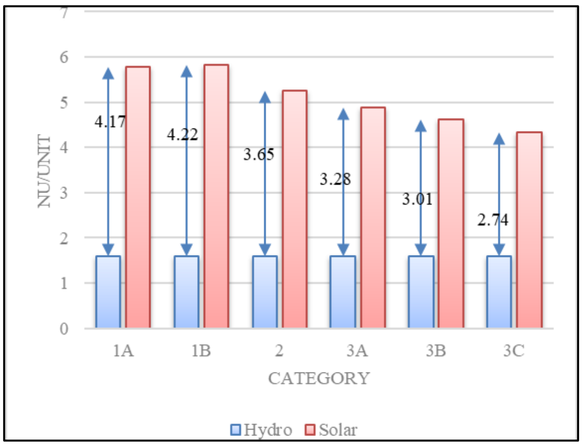

***Fig. 10:** Difference between Hydropower and Solar Tariff*

The gap in the tariff needs to be bridged in order to encourage the developers to invest in solar. Therefore, subsidy injections and incentives in different approaches are recommended.

Some of the parameters to be triggered to arrive at the reasonable tariff for category 3C is provided in the figure below:

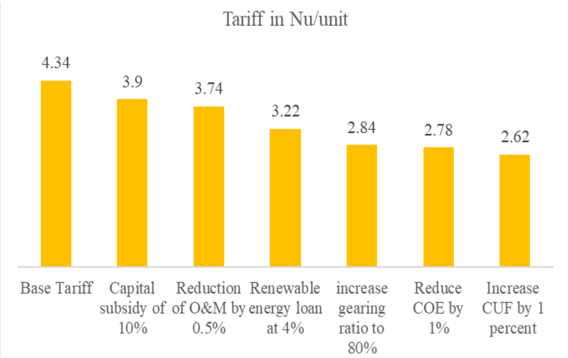

Fig. 11: *Variation of Parameters to Mitigate the Tariff Gap*

Since capital cost has been recognized as one of the important parameters in the determination of solar tariff, capital subsidy is one of the options to be considered by the policymakers. Under the PM Surya Ghar Muft Bijli Yojana, capital subsidy on the solar panels of up to Rs. 78,000 in non-hilly areas and at Rs. 85,800 in hilly areas for systems with a capacity of 3 kW has been implemented in India (Bhatt, 2023). Likewise, in Bhutanese context, if capital cost of 10% is subsidized by the RGOB, the tariff reduces for Nu 4.34 per unit to Nu 3.9 per unit.

The second parameter varied was O&M cost, if the developer could achieve an efficient O&M cost of 1% of the capital cost the tariff further reduced to Nu 3.74 per unit.

Green Finance Taxonomy of Bhutan, generations from solar power plants and considered as green (MOF, 2024). With this initiation of incentives such as lower interest rate loans are recommended. If interest rate of 4%, which is at par with the Economic Stimulus Program (ESP) loan is provided to the solar developers the tariff again reduces to Nu 3.22 per unit.

If the project majorly debt financed and the gearing is increased to 80%, the tariff reduces to Nu 2.84 per unit. Furthermore, with reduction of the expected return by 1% and increasing the efficiency of the plant by 1% the realizable tariff of Nu 2.62 per unit which is almost equivalent to the retail tariff can be achieved.

Net billing and net metering schemes serve as financial incentives for solar energy adoption in various countries; however, in the context of Bhutan, net metering is not a viable mechanism. The prevailing subsidized retail tariff of Nu. 2.66/kWh falls significantly below the LCOE of solar PV, which ranges from Nu. 4.34/kWh for Category 3C to Nu. 5.82/kWh for Category 1B, making full net metering financially unsustainable for the utility. Consequently, gross metering is the recommended metering scheme, wherein energy injected into the grid and energy drawn from the grid are compensated at differentiated rates. For prosumers, entities that both consume and generate solar energy, a net billing scheme is recommended, supplemented by additional compensation for surplus energy exported to the grid.

Notwithstanding the above recommendations, the financial viability of base tariffs was assessed. The IRR for each category was also determined and compared, the IRR arrived was equivalent to its WACC and the average payback period was observed to be average of 7.1 years for all the categories. The average payback period of 7.1 years across all Bhutanese categories is notably shorter than the 11.3–15.6 years reported for Ethiopian solar PV under comparable developing-country conditions (Mekonnen et al., 2025), reflecting the difference in capital cost benchmarks and the higher CUF values applicable in Bhutan's sub-tropical Himalayan zones. However, both studies confirm the central finding that cost-reflective FIT rates in developing countries with heavily subsidized retail tariffs will exceed the prevailing electricity price, and that bridging instruments, including capital subsidies and concessional financing are essential complements to FIT policy rather than optional additions. The detailed observation is provided in the Table below:

Table 6: *IRR and Payback Period*

Category	IRR	Payback period (Years)
1A	11.18%	8
1B	12.23%	7
2	12.23%	7
3A	12.23%	7
3B	12.23%	7
3C	12.23%	7

4.4 Model Validation Against Actual ERA Approvals

The LCOE-based model adopted in this study can be validated against ERA's published tariff review report of 200kW Tamzhing Solar Power Project in Bhutan, which was determined under the TDR 2025 framework that underpins this study's methodology.

The Tariff Review Report for the 200-kW Ground-Mounted Solar Project at Tamzhing, a small-scale project for which ERA approved a COE of 16%, the upper bound of the ERA permitted range and identical to the base case COE assumption used across all categories in this model. The O&M rate and project life parameters approved for Tamzhing are also consistent with this study's assumptions. The Tamzhing approval therefore provides direct empirical support for the model's base case parameter set.

With all the results and discussions explained, the conclusion is provided in following sections.

5. CONCLUSION

This study derived a cost-reflective Feed-in Tariff for solar photovoltaic energy in Bhutan using an LCOE-based financial model anchored in ERA’s Tariff Determination Regulation 2025. The computed FIT ranges from Nu. 4.34/kWh for the largest utility-scale category (Category 3C) to Nu. 5.82/kWh for medium-scale rooftop installations (Category 1B), which is considerably higher than both the cost of hydropower generation (Nu. 1.60/kWh) and the prevailing subsidized retail electricity tariff (Nu. 2.66/kWh).

Bridging this tariff gap requires a combination of targeted policy interventions. Specifically, ERA should establish a differentiated FIT structure with Nu. 4.34/kWh for Category 3C and Nu. 5.82/kWh for Category 1B.

The Royal Government should consider:

1. A capital subsidy of at least 10% for the first 100 MW of solar capacity,
2. Concessional financing at rates comparable to the Economic Stimulus Program (approximately 4%), and
3. A gross metering scheme in which energy injected into the grid and energy drawn from the grid are compensated at differentiated rates.
4. For prosumers, a net billing scheme supplemented by export compensation at the average power purchase price is recommended.

These measures, applied in combination, can reduce the effective tariff to levels near Nu. 2.62/kWh, which is financially sustainable and consistent with Bhutan’s goal of 5,000 MW of solar capacity by 2040.

This study has several limitations that should be acknowledged. The model relies on normative parameters drawn from ERA’s TDR 2025 rather than actual project cost data, as Bhutan’s solar market remains nascent. Grid integration costs, transmission losses, and land acquisition costs were not included in the LCOE computation. Furthermore, Bhutan-specific solar resource data with high spatial resolution remains limited, introducing uncertainty in CUF assumptions.

Future research should track actual IRR outcomes following FIT implementation, conduct a comparative analysis as real projects mature and cost data becomes available, and apply Monte Carlo simulation to more rigorously quantify parameter uncertainty. Post-implementation monitoring of FIT effectiveness and its impact on grid financial health will also be critical for evidence-based policy refinement.

6. ACKNOWLEDGEMENT

We would like to show our sincere gratitude to the College of Science and Technology and for this opportunity and support. The Authors would also like to acknowledge Electricity Regulatory Authority for the support.

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