

Review

Solar Energy Adoption in Nepal's Industrial Sector

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Abstract: Nepal's industrial sector suffers from high energy consumption, high operating costs and unreliable grid supply, and industrial solar photovoltaics are developing as an alternative to diesel backup power generation. This study investigates the status, drivers and challenges for industrial solar uptake in Nepal by using publicly available sources, academic research publications, conference proceedings and international case studies. The solar capacity installed in Nepal has grown from 50 MW in 2019 to over 117 MW in 2024, with a further 27 grid-connected projects of 154.74 MW under development. Our illustrative techno-economic study found a system levelized cost of energy of approximately NPR 9.71/kWh for industrial rooftop solar, compared to approximately NPR 30/kWh for comparable capacity diesel generation, with typical installation costs ranging from NPR 85,000.00–100,000.00 per kWp. Industrial solar can replace diesel generation and reduce annual energy expenditures by 40–60%. Sensitivity analysis indicates that a 20% reduction in panel costs or a 10% increase in power tariffs can reduce payback periods by 1–1.5 years. Detailed Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis identifies high upfront capital expenditures, legacy grid infrastructure, regulatory inconsistencies and institutional fragmentation as the major impediments. There are opportunities for international climate finance, smart-grid development and job creation. As Nepal-specific diesel-related CO₂ reductions cannot yet be quantified reliably, an illustrative sensitivity analysis using internationally documented emission factors is therefore presented. These results show that targeted policy interventions, financial innovation and institutional coordination can be used to accelerate industrial solar adoption in Nepal.

Keywords: Solar Energy; Industrial Sector in Nepal; Renewable Energy; Solar Policy; Barriers to Solar Implementation

1. Introduction

Reliable, affordable and sustainable energy is essential for industrial productivity, competitiveness and long-term economic growth. The worldwide electrical industry is rapidly switching to renewable energy [1]. In 2024, the world's electricity production exceeded 30,850 TWh, and the contribution of renewable energy was approximately 32% of the total production, although fossil fuels remained the main source of energy [1]. The worldwide renewable energy capacity reached over 4,448 GW by the end of 2024, with a historic rise of 585 GW, corresponding to an annual growth rate of 15.1%. The solar energy represented the majority of the renewable capacity with a capacity of over 1,865 GW [2]. The rapid growth of the world's renewable energy capacity is an indication of the global trend

toward low-carbon and sustainable energy systems and provides a significant basis for evaluating the opportunities for industrial solar deployment in countries like Nepal [3–5].

Industries use solar energy to diversify their energy sources, reduce dependence on the national grid, lower operational costs, and reduce greenhouse gas emissions [3,5], although grid-connected photovoltaic (PV) systems must also be integrated without compromising distribution-grid reliability [6]. However, industrial solar energy adoption in Nepal remains limited and uneven due to financial, technical, organizational, infrastructural, and policy-related barriers. Previous studies have investigated solar energy adoption in urban, rural, and remote communities in Nepal. This paper, however, focuses specifically on industrial enterprises, their energy requirements, and the factors influencing their decisions to adopt solar energy.

This study assesses the status of industrial solar adoption, its principal drivers, anticipated benefits and the financial, technical, institutional, and environmental barriers to the use of solar energy in the industrial sector in Nepal. The industrial sector of Nepal (manufacturing, mining and quarrying, electricity, and construction) contributes about 13–14% of national gross-domestic product (GDP) and is a major growth engine for jobs and infrastructure [7]. Solar PV has emerged as a potential option to address the rising energy demand of Nepal because it is scalable, can serve both grid-connected and off-grid purposes, and can be deployed close to the industrial installations in Nepal. Nepal's solar energy capacity has been growing steadily over the previous five years, with the total installed capacity more than doubled from roughly 50 megawatt (MW) in 2019 to over 117 MW in 2024 [2,8,9].

Figure 1 shows Nepal's historical solar energy capacity growth over policy-oriented targeted capacity from 2019 to 2024. Installed capacity grows moderately from ~50 MW in 2019 to ~117 MW in 2024 while targeted capacity increases much more steeply from 200 MW in 2019 to 800 MW by 2024. The wide gap underscores Nepal's ambitious targets to expand its solar power and the urgent need to speed up implementation to meet future energy needs. It also shows that the country is heading forward positively toward the utilization of solar power as a renewable energy source.

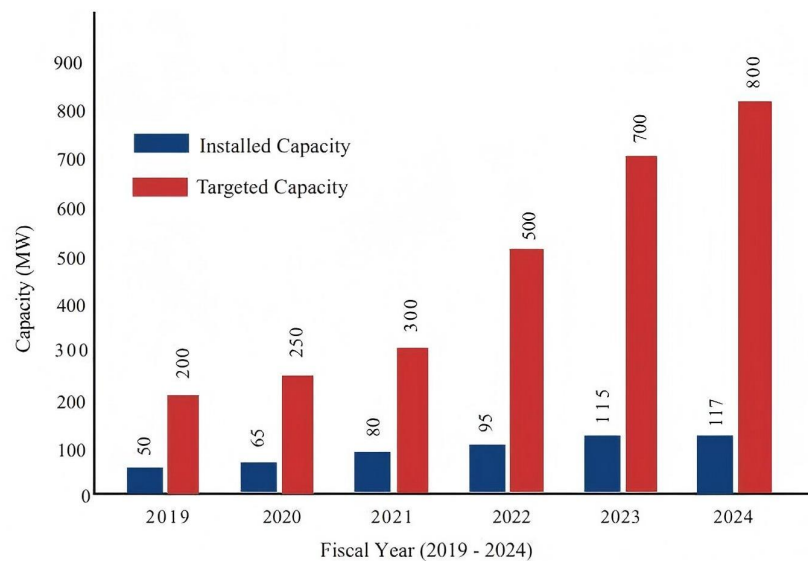


Figure 1. Nepal's solar energy capacity growth each year: Installed (blue bar) vs. Targeted (red bar) capacity. The targeted capacity represents planning ambition of solar power.

The 25 MW Nuwakot Solar Power Station is one of Nepal's largest solar power plants and one of the major installations contributing to this growth. Likewise, the Mithila Solar PV Stations have a combined capacity of 20 MW and supports the national grid. Also, the 8.5 MW capacity, Butwal Solar PV Project is helping to enhance electricity supply in the Rupandehi District in western Nepal [10]. In fiscal year 2024/25, Nepal's grid-connected solar capacity had risen to 141.94 MW. Of this total, independent power producers accounted for 116.94 MW, while the Nepal Electricity Authority operated the remaining 25 MW [11]. Based on the recent expansion trend, national installed solar capacity may reach approximately 160–170 MW by the end of 2026.

In addition to the historical trend for capacity, Nepal also has a substantial grid-connected project pipeline [11]. The 2024 call for proposals by the Nepal Electricity Authority allowed a maximum cumulative allocation of 800 MW across specified substations, while subsequent award notices identified several projects and award capacities over commissioned capacities. Note that these figures relate to capacity procured or awarded, not generation commissioned. Implementation will, however, be subject to financing, land acquisition, construction schedules, transmission availability, and timely grid connection. Nepal's broader solar-resource potential is large [12, 13], however, industrial uptake depends on supportive regulation, suitable financing, PV-system performance, and compatibility with industrial load profiles [3, 5, 14]. Household-level adoption is outside the scope of this review and has been examined elsewhere [3].

This review provides a Nepal-specific assessment of industrial solar adoption by combining techno-economic analysis, institutional, policy dimension, the Industrial Solar Competitiveness Framework (ISCF) methodology and Industrial Solar Adoption Index (ISAI), and SWOT and policy-based evaluation to offer feasible approaches for speeding up industrial PV implementation. The framework and the index are conceptual propositions rather than validated forecasting instruments.

The remainder of the review is organized as follows. Section 2 examines the relevant literature. Sections 3 and 4 present the theoretical framework and methodology. Sections 5 and 6 present the energy landscape of Nepal and the current status of industrial solar adoption and Section 7 describes the financial feasibility and techno-economic performance. Section 8 addresses socioeconomic impacts, and Section 9 major adoption challenges. Section 10 reviews international best practices. Sections 11–13 present the SWOT findings, policy implications and strategic recommendations and Section 14 concludes the review.

2. Literature Review

Global assessment documents highlight the growing deployment of solar technologies and their use for sustainable development [15–17]. The worldwide installed solar photovoltaic (PV) capacity increased from 40,334 MW in 2010 to 709,674 MW in 2020 and has continued to expand thereafter. The growth was fueled by falling module and balance of system costs, technology learning, manufacturing scale and policy support. These global trends are relevant to Nepal, but international cost and deployment outcomes cannot be transferred directly without accounting for local financing, tariffs, grid conditions, and industrial demand profiles.

Solar PV also contributes to employment, emissions reduction, and energy-access objectives. International evidence identifies solar PV as the largest renewable-energy employment category, although national employment effects depend on the extent of local installation, operation, maintenance, manufacturing, and service activity [14, 18, 19]. For Nepal, the results suggest possible socioeconomic benefits rather than a precise estimate of jobs created by industrial solar deployment. Furthermore, we have categorized applications of solar energy into two main technologies: photovoltaics and concentrated solar power (CSP) and highlight PV's dominant position in both urban and rural electrification, water desalination, heating and zero-energy buildings.

The use of renewable energy in developing countries indicates the promise and challenge of solar energy in changing industrial sectors. The global movement toward renewable energy has led to more studies on the role of solar power in enabling sustainable development. In developed economies such as the United States and Germany, the industrial sector has been encouraged to adopt solar power through significant financial incentives, policy mandates, and falling prices of solar panels [20]. The German Renewable Energy Sources Act (EEG) and India's National Solar Mission provide good examples of government-supported solar expansion that allowed industrial deployment [21].

Research in Nepal has focused on rural household electrification with solar home systems (SHS) [22, 23]. Bhandari and Stadler state that although SHS programs have improved the living standards in rural areas, solar applications for commercial and industrial use are still few [22]. Mainali and Silveira identify the problem of financing off-grid solar projects in Nepal as high upfront costs and the absence of institutional credit lines [23]. Bhattarai provided a snapshot of Nepalese energy policy over four decades, referring to fragmentation between renewable energy goals and irregular application [12]. Similarly, Adhikari et al. mention weak enforcement of policies, absence of private sector involvement, and technical barriers in the application of solar energy for non-residential uses [14].

Previous studies focused on Nepal provide important evidence regarding household electrification, off-grid

finance, national renewable energy policy, and general adoption barriers. However, they fail to jointly assess industrial load profiles, project economics, grid-integration conditions, and firm-level adoption readiness. **Table 1** highlights this distinction. The present review, therefore, addresses a more specific gap: the interaction of technical, economic, institutional, and policy factors in the decision-making processes of manufacturing, agro-processing, and other commercial and industrial electricity users. No primary field surveys, interviews, or site-visit datasets were used; instead, the analysis is based on published evidence and clearly specified illustrative calculations.

Table 1. Comparison of Nepal focused-studies and research gap addressed in this review.

Study	Method and Coverage	Principal Contribution	Limitation Relative to This Review
Bhandari and Stadler [22]	Technical and economic assessment of solar electrification in Nepal	Established the relevance of PV for electrification	Primarily household and rural systems and no industrial adoption framework yet
Mainali and Silveira [23]	Country case on financing off-grid rural electrification	Identified capital and institutional financing barriers	Does not examine grid-connected industrial loads or firm-level investment performance
Adhikari et al. [14]	Systematic review of renewable-energy technologies in Nepal	Synthesized national technology, policy, and implementation barriers	Broad multi-technology scope; limited industrial PV-specific analysis
Bhandari et al. [3]	Review of solar potential, financial viability, and adoption barriers	Connected Nepal's solar resource with financial and policy constraints	Does not integrate industrial load matching, grid conditions, and a sector-specific adoption index

Figure 2 summarizes the principal drivers and limitations identified in the reviewed literature: solar-resource availability, industrial electricity demand, governance and infrastructure, financial support, and technical barriers. The emphasis on governance and infrastructure suggests that the mere presence of resource potential is not enough for adoption. But policy implementation, grid procedures, technical capacity and access to finance are some of the key factors that will determine whether this potential can be translated into operational projects [14,24–26]. The diagram offers a clear and policy-oriented visualization which is useful for decision-making and research.

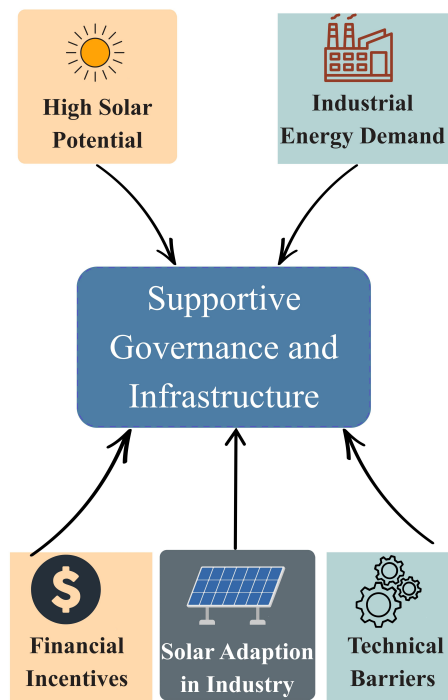


Figure 2. Principal drivers and constraints affecting the adoption of solar energy in the industrial sectors in Nepal. The diagram illustrates thematic relationships instead of statistically estimated causal effects.

Figure 3 describes the common steps involved in developing an industrial solar energy project: from feasibility study to financing, procurement, installation and commissioning. Each of these stages is a key milestone in the

successful deployment. The linear visual flow also emphasizes the importance of planning and coordination at each of the stages. Stakeholders ranging from industries to investors and regulators may utilize this framework to predict bottlenecks and optimize the project execution. The workflow is consistent with the planning and implementation guidance provided for commercial and industrial grid-connected PV systems in Nepal [27]. Commissioning and grid connection also depend on local grid readiness, including the smart-grid capabilities reviewed for Nepal [28].

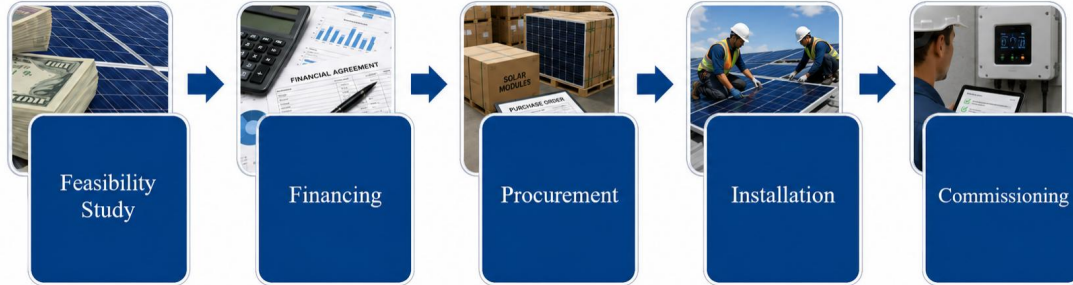


Figure 3. Simplified development stages identified for developing an industrial solar energy project: feasibility study, financing, procurement, installation, and commissioning based on AEPC-GIZ implementation guidance.

Note: The AEPC-GIZ partnership is the cooperation between the Alternative Energy Promotion Centre (AEPC) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The partnership is focused on the support of regional development and the promotion of international cooperation projects.

3. Theoretical Framework for Industrial Solar Energy Adoption

Industrial solar adoption is different from household solar adoption as the decision to invest is influenced by the financial return, production reliability, energy security, operational continuity and long-term competitiveness [29]. The proposed Industrial Solar Competitiveness Framework (ISCF) combines three established perspectives: technology-organization-environment reasoning, which recognizes technical readiness, organizational capacity, and external policy conditions [30]; diffusion-of-innovation reasoning, which emphasizes relative advantage, compatibility, complexity, and observability; and conventional capital-investment appraisal based on costs, savings, risk, and expected return. Within this combined perspective, adoption becomes more likely when the expected economic and operational benefits of solar exceed perceived financial, technical, and institutional risks.

The preliminary operationalization of the Industrial Solar Adoption Index (ISAI) is as follows: $ISAI = \alpha EC + \beta ES + \gamma TR + \delta PS + \epsilon GS$ where $\alpha + \beta + \gamma + \delta + \epsilon = 1$. Here, EC denotes Economic competitiveness and is quantified as $EC = \frac{C_g - C_s}{C_g}$; energy security is represented by ES , defined as $ES = 1 - \frac{P_o}{P_t}$; technological readiness is indicated by TR , expressed as $TR = \frac{I_a}{I_m}$; policy support is referred to as PS , articulated as $PS = \frac{S_i}{C_i}$; and grid stability improvement is denoted by GS , where it is defined as $GS = 1 - \frac{E_g}{E_t}$. In this context, C_g is the cost of grid electricity, C_s is the levelized cost of solar energy, P_o is the annual production deficit caused by power outages, P_t is the total annual production value, I_a is the compatible infrastructure that is already in place, I_m is the infrastructure that is needed for full integration, S_i is the economic value of incentives received, C_i is the total cost of installation, E_g is the amount of electricity imported from the grid each year after solar deployment, and E_t is the total annual electricity demand.

A threshold particular to the sector, referred to as theta, θ may be delineated so that $ISAI \geq \theta$ reflects an empirically assessed state conducive to adoption. At this stage, the ISAI is a nascent theoretical proposal instead of a confirmed forecasting model. Prior to application, all components need to be adjusted to a consistent 0–1 range, accompanied by specific protocols for negative values, outliers, and missing information. This review has not estimated the weights and threshold; calibration is needed using observed industrial adoption decisions, firm-level surveys, or expert-elicitation data. Sensitivity analysis should consider different weighting frameworks and correlation analysis should consider the potential for double counting between economic competitiveness, energy security and grid dependency. Therefore, this analysis does not use the ISAI to rank sectors, firms, or locations or regions. Unlike household-oriented adoption models reported earlier [3], the proposed framework emphasizes operational performance, energy resilience, production continuity, industrial competitiveness, and policy support.

4. Methodology

The present study adopted a qualitative integrative-review design to synthesize the academic literature, official reports, policy documents, and relevant technical evidence on industrial solar adoption in Nepal. The core literature window was initially set for 2005–2025 and was extended through August 2026 to capture recently published sources already in the final manuscript. The review did not include any surveys, interviews, stakeholder consultations, site visits or other primary field research.

Academic sources covered Scopus, Web of Science, ScienceDirect and Google Scholar, while gray literature was collected from the official portals of the Alternative Energy Promotion Center (AEPC), Ministry of Energy, Water Resources and Irrigation (MoEWRI), Nepal Electricity Authority (NEA), the World Bank, UNDP and Green Climate Fund (GCF), the International Renewable Energy Agency, IRENA and related government portals. The core Boolean structure was: (“solar energy” OR “solar PV” OR photovoltaic) AND (industry OR industrial OR manufacturing OR “agro-processing”) AND Nepal AND (adoption OR finance OR policy OR barrier OR grid). Database search syntax was adjusted as needed for each platform. Eligible records include English-language journal articles, conference papers, government reports, policy documents, and institutional technical reports. Some records were excluded if they were duplicates, not directly relevant to Nepal or similar industrial contexts, had no traceable evidence, or were focused on household systems without transferable policy or financing implications.

After the removal of duplicate titles and sources, 42 candidate records were assessed for the central theme. Twenty were retained because of their relevance, methodological clarity, traceability of data and comprehensive coverage of the topic; 22 were rejected due to limited relevance to industry, duplication of evidence, lack of detailed sources or an emphasis on domestic aspects.

The reference list is extensive, comprising a total of 63 sources. Additionally, 39 other documents are utilized solely for background statistics, theoretical frameworks, technical context, policy comparisons, or calculation assumptions and are not incorporated into the 20 primary thematic studies. All other documentation not falling within these two categories was excluded from this assessment. The information was organized into a matrix that included solar resources, adoption patterns, financial frameworks, regulatory aspects, technological constraints, institutional conditions, and recorded outcomes.

The extracted evidence was synthesized thematically to identify recurrent findings, disagreements, and evidence gaps. Stronger sources were more likely to be primary or official, have a clear reference year and system boundary, and provide a traceable method or data set. SWOT factors were extracted from the thematic matrix and retained only if supported by the reviewed evidence; no numerical priorities were assigned, as no stakeholder weighting exercise was conducted. The authors collaborated on coding, but no formal statistic was calculated for inter-coder reliability. Therefore, the SWOT analysis and policy recommendations should be viewed as structured qualitative syntheses rather than causal or statistically weighted findings.

4.1. Scope and Limitations

This subsection summarizes the key assumptions underlying the analysis, the limitations of the underlying evidence base, and the resulting uncertainties in the review’s findings. The evidence base is limited by inconsistent reporting of installed, operating, awarded and proposed solar capacity; limited public reporting of industrial system sizes and operating performance; and variation in financial assumptions across studies. The scenario analysis is based on illustrative transparent assumptions rather than audited firm-level cash flows is discussed in the later section (see Section 7). The review therefore supports evidence-informed interpretation and hypothesis development but does not establish causal effects, nationally representative adoption rates or validated firm-level predictions.

4.2. Photovoltaic Energy-Yield and Temperature-Dependent Performance Modelling

The instantaneous DC power output of a PV array can be estimated from a temperature-corrected irradiance model [31]:

$$E_{PV} = P_{STC} [1 + \beta_p T_{cell} - T_{STC}] \left(\frac{H_t}{H_{STC}} \right) \quad (1)$$

where P_{STC} is the rated module power output at Standard Test Conditions (STC: 1,000 W/m² irradiance, 25 °C cell temperature, AM1.5 spectrum), β_p is the power-temperature coefficient of the module (%/°C; typically −0.35%

to $-0.45\%/^{\circ}\text{C}$ for crystalline-silicon modules), T_{cell} and T_{STC} are the cell operating temperature and the standard test conditions (STC) reference temperature (25°C), and H_t and H_{STC} are the incident and STC solar irradiance (W/m^2), respectively. Because module temperature is rarely measured directly at the industrial sites considered in this review, the following empirical ambient-temperature-to-cell-temperature relationship was used [31]:

$$T_{cell} = T_{\infty} + 7.8 \times 10^{-2} \times H_t \quad (2)$$

where T_{∞} is the ambient air temperature ($^{\circ}\text{C}$) and H_t is the incident irradiance (W/m^2). This relationship provides an order-of-magnitude estimate of operating cell temperature and is intended for illustrative sensitivity analysis rather than as a substitute for measured module temperature.

Applying Equations (1) and (2) to representative hot, high-irradiance daytime conditions in Nepal's Terai industrial belt (ambient temperature $T_{\infty} \approx 30^{\circ}\text{C}$ and incident irradiance $H_t \approx 700 \text{ W}/\text{m}^2$, broadly consistent with the representative Terai solar-radiation data reported in Section 9 gives an estimated cell operating temperature of $T_{cell} \approx 30 + (0.078 \times 700) \approx 84.6^{\circ}\text{C}$. Using a representative crystalline-silicon coefficient of $\beta_p = -0.40\%/^{\circ}\text{C}$ the temperature-related derating factor $[1 + \beta_p (T_{cell} - T_{STC})] \approx [1 - 0.0040 \times 59.6] \approx 0.76$, i.e., an approximate 24% reduction in instantaneous DC output relative to the STC nameplate rating under these hot-weather, high-irradiance conditions, before soiling, inverter, wiring, and mismatch losses are considered.

This component-level estimate is directionally, and in order of magnitude, consistent with the aggregate performance ratio ($\text{PR} = 0.80$) adopted for the location-specific yield estimates since typical PR values of 0.75–0.82 implicitly embed thermal derating together with soiling, inverter, and other system losses. Equations (1) and (2) make the temperature-related loss mechanism explicit and quantifiable rather than folding it into a single aggregate PR assumption. However, because hourly irradiance and module-temperature datasets specific to the industrial sites considered are not publicly available, the worked example above should be read as an illustrative sensitivity case rather than a site-validated energy-yield simulation, consistent with the limitations discussed in Section 4.1. Site-specific, temperature- and irradiance-resolved yield modelling using measured meteorological and module-temperature data is identified as a priority direction for future industrial PV studies in Nepal.

5. Energy Landscape in Nepal

Nepal's energy economy has historically depended on indigenous biomass and imported fossil fuels [3,8]. The Water and Energy Commission Secretariat (WECS) synopsis report [32] provides important historical baseline. However, its energy shares and hydropower-development values refer to earlier reporting years and are not treated here as current 2025–2026 statistics. The enduring structural issue is that industrial electricity demand is growing while reliability, network capacity, and geographic access remain uneven, encouraging some facilities to maintain diesel backup or consider on-site renewable generation [33]. Traditional biomass sources such as firewood, agricultural residue and animal dung still dominate the energy mix of Nepal, accounting for more than two-thirds of the total energy consumption in recent national energy balances [34]. This continued reliance on solid biomass is associated with deforestation, indoor air pollution and lower productivity, especially in rural households. By contrast, electricity still accounts for less than 3% of the country's total final energy demand. On the supply side, Nepal's theoretical hydropower potential is still estimated to be in the order of 83,000 MW, of which some 40,000–43,000 MW is considered economically and technically viable. By contrast, by 2025 only some 3,400–3,600 MW had been installed, which meant that much of the potential capacity had not been exploited [11]. Meanwhile, industrial energy demand is growing rapidly, and many industrial park zones lack reliable grid connectivity and consistent power supply. Consequently, industries are heavily dependent on diesel generators, which are inefficient and environmentally harmful [33].

Industrial electricity tariffs vary by voltage level, demand category, time of use, and applicable NEA schedules; the NPR 10–14/kWh range used later is therefore an illustrative avoided-cost range rather than a universal tariff [35]. Most regions receive approximately 4.5–5.5 kWh/m²/day of average solar radiation, supporting technical potential for PV deployment [36,37]. However, publicly available sources do not yet provide a complete national census of industrial PV capacity, ownership, operating status, and annual generation. This data limitation prevents a defensible estimate of total industrial solar penetration [7]. The gap between possible and current use of renewable energy emphasizes the need for revolutionary policy, investment and technology paradigms [38].

6. Current State of Solar Energy in Industry

Industrial solar adoption remains limited relative to Nepal's resource potential, but official programmes document a growing set of commercial and industrial rooftop projects [33]. Most of the solar technology applications in the industry are in the form of small-scale rooftop systems for captive use. According to AEPC, about 12.6 MW of rooftop solar capacity had been promoted in the commercial and industrial sectors by 2025 [39].

Figure 4 shows the distribution of solar energy use by sector reported earlier but it does not show a complete picture of energy distribution in Nepal. Available evidence shows applications across manufacturing, food and beverage processing, telecommunications, health facilities, and other commercial and public loads, but it does not support a nationally representative percentage distribution by sector. **Figure 4** should therefore be read an indicative illustration of reported application rather than as a nationally representative sector distribution.

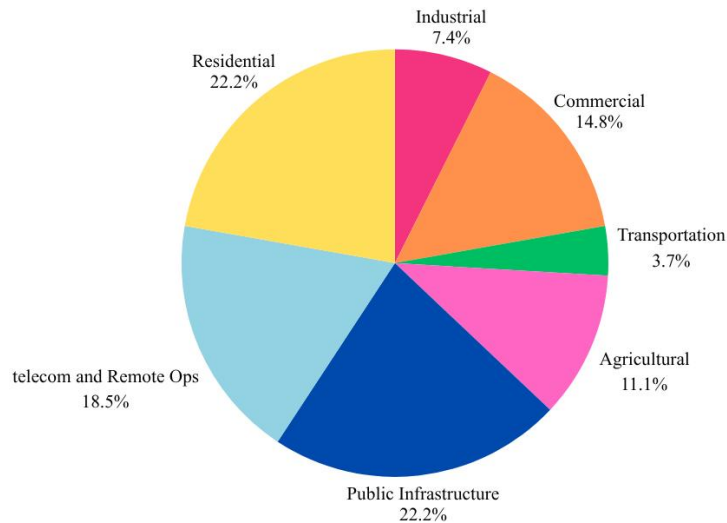


Figure 4. Solar energy deployment is expanding in various industrial sectors in Nepal: sector-wise distribution of solar energy.

Table 2 distinguishes verified industrial cases from broader commercial or programme-level examples and should not be interpreted as a complete national inventory [7,40] and presents some examples of organizations using solar power in different industrial and commercial sectors in Nepal along with the locations and major uses [40]. Installed and approved capacities are reported separately; the table is illustrative only. The policy environment supports renewable energy broadly and now includes specific mechanisms for commercial and industrial rooftop PV. Alternative Energy Promotion Centre's (AEPC's) current C&I programs provide time-limited interest support and generation-based incentives under defined eligibility conditions [40,41]. Nevertheless, project bankability still depends on transparent interconnection procedures, metering rules, export compensation, credit terms, and the predictability of program funding. These emerging mechanisms should therefore be described as developing support rather than as evidence of a fully mature industrial solar market. The verified examples in **Table 2** also demonstrate technical feasibility across different load types, however their small number and mixed operational status do not establish a national adoption rate or average project performance. They instead illustrate the need for a public registry reporting system size, commissioning date, ownership model, annual generation, self-consumption, and operational status. Such data would allow future studies to evaluate realized cost savings, reliability benefits, and sector-specific adoption patterns.

Table 2. Exemplary commercial and industrial solar deployment in Nepal.

Organization or Portfolio	Classification	Location	Capacity/Status	Evidence and Application
Yeti Carpet Industries	Industrial: carpet manufacturing	Birgunj, Parsa	316.6 kWp installed	Grid-connected rooftop PV reported by AEPC [40]

Table 2. Cont.

Organization or Portfolio	Classification	Location	Capacity/Status	Evidence and Application
Hama Iron and Steel Industries	Industrial: iron and steel	Simara, Bara	633.6 kWp installed	Grid-connected rooftop PV reported by AEPC [40]
Nepal Telecom, Chhauni	Commercial/public telecommunications	Kathmandu	100 kWp case-study system	Performance analysis of a grid-tied rooftop plant [42]
Sustainable Energy Challenge Fund (SECF)-supported portfolio	Mixed C&I and public-service portfolio	Multiple locations	>5 MW approved across 14 projects	Approved portfolio includes food, beverage, pharmaceutical, steel, footwear, hospitality, and health facilities [41]

7. Financial Feasibility

Economic feasibility is one of the drivers for solar in the industrial sector of Nepal. The average cost of installing an industrial solar PV facility, depending on location and technical specifications will range from NPR 85,000 to 100,000 per kWp. This means that to install a 100 kWp facility in a medium-sized factory an initial investment of about NPR 9–10 million is required.

Industrial solar projects are eligible for government subsidies of only 5–10% of the total capital investment. This is compared to household systems, which are allowed up to 30%. However, the long-term savings they deliver still make investment in solar power economically viable. For example, industries replacing diesel generators (costing NPR 25–35/kWh) with solar (literature-reported cost NPR 10–12/kWh) can reduce their annual energy cost by 40–60%.

Figure 5 reveals that Nepal still finds diesel the most expensive source of power whereas hydro and biomass are amongst the cheapest sources. Alternative financing models like Power Purchase Agreements (PPA), third-party leasing and energy service company (LESCO) models are largely untested in Nepal so far but have the potential to take adoption levels much higher if introduced with proper regulatory support. A sensitivity analysis reveals that a 20% reduction in the cost of panels or a 10% increase in energy tariffs would lead to a 1–1.5-year reduction in payback period. For comparison, literature-reported industrial solar electricity costs are around NPR 10–12/kWh, although the actual levelized cost depends on system assumptions, funding conditions, and the degree of on-site solar utilization.

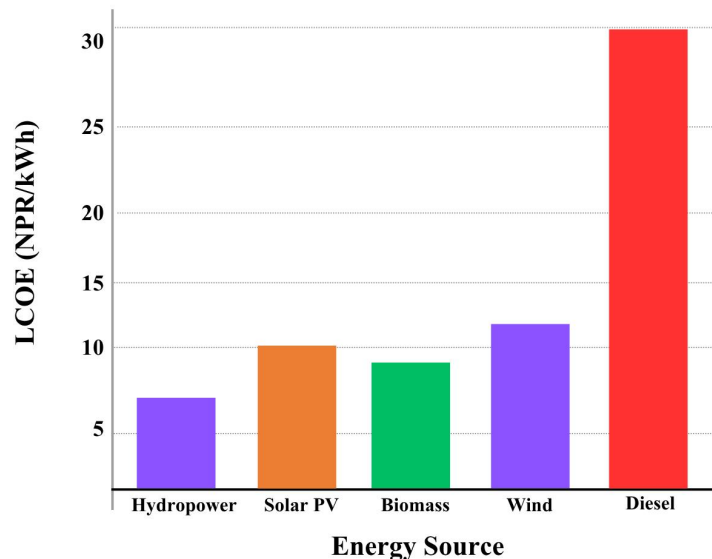


Figure 5. Comparison of Levelized Cost of Energy (LCOE) for major sources in Nepal.

7.1. Scenario-Based Techno-Economic Assessment

To extend the financial feasibility assessment beyond simple cost and payback comparisons, an illustrative discounted-cash-flow analysis was conducted for a representative 100-kWp industrial rooftop solar PV sys-

tem [42,43]. The base capital investment was taken as NPR 9.5 million, consistent with the NPR 9–10 million range reported above. An annual PV yield of approximately 150,000 kWh was assumed, consistent with Nepal's favorable solar resource of approximately 4.5–5.5 kWh/m²/day.

This analysis used in the illustrative assumptions are summarized in **Table 3**: a 20-year project life, annual PV degradation of 0.5%, annual operation and maintenance expenditure equal to 1.5% of the initial capital cost, and a real discount rate of 12%. The avoided industrial electricity tariff was set at NPR 12/kWh for the base case, within the NPR 10–14/kWh range reported for industrial consumers [37]. Because industrial net-metering and feed-in arrangements remain uncertain, surplus electricity exported to the grid was assigned no monetary value in the base case. Three representative industrial load profiles were therefore evaluated according to the degree of coincidence between PV generation and on-site electricity demand: a single-shift/light-manufacturing profile with 70% self-consumption, a daytime-intensive manufacturing profile with 90% self-consumption, and a continuous-process profile with 98% self-consumption. These profiles are illustrative scenarios rather than measured load data and are intended to demonstrate the sensitivity of investment performance to load-generation matching.

Table 3. Assumptions used in the illustrative 100-kWp industrial PV analysis. Monetary values are nominal 2023 NPR; the system boundary includes PV capital and stated operation and maintenance costs but excludes land, taxes, debt-service structure, battery storage, salvage value, and export revenue. O&M = operation and maintenance.

Parameter (s)	Base-Case Assumption
PV System Size	100 kWp
Initial investment	NPR 9.5 million
Annual PV generation (Year 1)	150,000 kWh
Project lifetime	20 years
Annual PV degradation	0.5%
Annual O&M cost	1.5% of initial investment
Discount Rate	12%
Avoided electricity tariff NPR	12/kWh (base case)
Export Value	NPR 0/kWh (conservative base case)

The financial indicators were evaluated using the following relationships: $LCOE = [I_0 + \Sigma(C_t/(1+r)^t)]/[\Sigma(E_t/(1+r)^t)]$; $NPV = -I_0 + \Sigma[(B_t - C_t)/(1+r)^t]$ and IRR = the discount rate at which $NPV = 0$ and discounted payback period = the first year in which cumulative discounted net cash flow becomes non-negative. Here, I_0 is the initial investment, C_t is annual operating and maintenance cost, E_t is annual PV electricity generation, B_t is the monetary benefit from self-consumed solar electricity, and r is the discount rate. Under the conservative zero-export-value assumption, the economic benefit depends directly on the fraction of PV generation consumed by the industrial facility.

The system-level LCOE (LCOE) is approximately NPR 9.71/kWh when all generated electricity is included. As shown in **Table 4**, the higher effective utilized-energy LCOE values for the 70% and 90% cases arise because, under the conservative assumption adopted here, electricity not consumed on site receives no export compensation.

Table 4. Illustrative techno-economic performance under different industrial load profiles.

Industrial Load Profile	Solar Self-Consumption	Effective Utilized-Energy LCOE (NPR/kWh)	NPV (NPR Million)	IRR (%)	Discounted Payback
Single-shift/light manufacturing	70%	13.88	-1.43	9.48	>20 years
Daytime-intensive manufacturing	90%	10.79	+1.18	13.99	13.85 years
Continuous-process industry	98%	9.91	+2.22	15.69	11.19 years

The results demonstrate that industrial load profile is a critical determinant of solar investment performance. Under the single-shift profile with 70% self-consumption, the project yields an NPV of approximately -NPR 1.43 million and an IRR of 9.48%, below the assumed 12% discount rate; consequently, the discounted investment is not recovered within the 20-year project life. In contrast, the daytime-intensive profile with 90% self-consumption produces a positive NPV of approximately NPR 1.18 million, an IRR of 13.99%, and a discounted payback period of approximately 13.85 years. For the continuous-process profile, in which approximately 98% of PV electricity is consumed on site, the NPV increases to approximately NPR 2.22 million, the IRR to 15.69%, and the discounted payback period decreases to approximately 11.19 years. These results indicate that the economic attractiveness of

industrial PV in Nepal depends not only on installed cost but also strongly on the temporal matching of industrial demand with solar generation.

The sensitivity of the daytime-intensive case to the avoided electricity tariff is reported in **Table 5**. The tariff sensitivity analysis further shows that project viability is strongly influenced by the value of displaced grid electricity. For the 90% self-consumption case, increasing the avoided tariff from NPR 10/kWh to NPR 14/kWh changes the NPV from approximately –NPR 0.78 million to +NPR 3.14 million and raises the IRR from 10.65% to 17.16%. At NPR 14/kWh, the discounted payback period decreases to approximately 9.66 years.

Table 5. Tariff sensitivity for the daytime-intensive (90% self-consumption) case.

Avoided Electricity Tariff (NPR/kWh)	NPV (NPR Million)	IRR (%)	Discounted Payback
10	–0.78	10.65	>20 years
12	+1.18	13.99	13.85 years
14	+3.14	17.16	9.66 years

Therefore, industries with high daytime electricity consumption and higher avoided electricity costs are expected to present the strongest economic case for solar PV deployment. These results should be interpreted as scenario-based estimates rather than field-measured project returns, but they provide a more rigorous quantitative basis for comparing industrial solar adoption conditions in Nepal.

7.2. Environmental Cost-Adjusted Economic Analysis (Carbon-Adjusted LCOE and Payback)

The environmental-cost-adjusted levelized cost of energy and simple payback time were calculated as:

$$LCOE_{env} = \frac{CRF \times I_o + C_{O\&M} - C_{CO_2}}{E_t} \quad (3)$$

$$PBTM = \frac{I_o}{Income} \quad (4)$$

where $CRF = r(1 + r)^n / [(1 + r)^n - 1]$ is the capital recovery factor, I_o is the initial capital investment, $C_{O\&M}$ is the annual operation and maintenance cost, E_t is the annual utilized (self-consumed) electricity, and Income is the annual net monetary benefit of the system, including any environmental-cost credit. The environmental damage cost avoided by displacing diesel-based backup generation, C_{CO_2} was estimated as:

$$C_{CO_2} = \delta \times EF_{CO_2} \times E_t \times SCC_{CO_2} \quad (5)$$

where δ is the assumed share of self-consumed solar electricity that displaces diesel-generator backup output rather than hydropower-based grid electricity, EF_{CO_2} is the CO₂ emission factor of diesel-generator electricity (kg CO₂/kWh), and SCC_{CO_2} is the social cost of carbon (USD/tCO₂), converted to NPR at an assumed exchange rate of NPR 135/USD.

Because Nepal-specific, verified diesel-displacement volumes and industrial emission factors remain unavailable (Section 4.1), the parameters in Equation (5) were populated using internationally documented reference values rather than left unquantified. A CO₂ emission factor of $EF_{CO_2} = 1.0$ kg CO₂/kWh was adopted for the base case, corresponding to the United Nations Framework Convention on Climate Change (UNFCCC) and Clean Development Mechanism (CDM) TOOL33 default emission factor for 35–135 kW diesel-generator systems operating at low (25%) load factor, which is a representative of intermittently used backup sets (the corresponding TOOL33 default at 50–100% load is 0.8 kg CO₂/kWh) [44]; a sensitivity range of 0.8–1.3 kg CO₂/kWh, reflecting smaller and less efficient generator sets, was also examined.

Note that continuous-process load profile (98% self-consumption; effective utilized energy comes out to be approximately 147,000 kWh in Year 1 under the base-case parameters $\delta = 100\%$, $EF_{CO_2} = 1.0$ kg CO₂/kWh, $SCC_{CO_2} = USD 70/tCO_2$ gives an estimated avoided-emissions credit of approximately 147 tCO₂/year, equivalent to an environmental-cost credit of approximately NPR 9.45/kWh and an annual monetary value of approximately NPR 1.39 million. A social cost of carbon of $SCC_{CO_2} = USD 70/tCO_2$ was adopted for the base case and within the range of carbon prices documented internationally by the World Bank [45]; a sensitivity range of USD 50–100/tCO₂

was also examined. Because Nepal's grid electricity is predominantly hydropower-based (Section 8), the diesel-displacement share δ was varied from 20% (a grid-connected facility using diesel only occasionally, e.g., during outages) to 100% (an upper-bound case in which self-consumed solar output is assumed to fully displace diesel-backup generation) to reflect this uncertainty explicitly, rather than assuming a single value.

Table 6 reports the resulting environmental-cost-adjusted LCOE for the continuous-process case, together with a one-at-a-time sensitivity analysis across the diesel-displacement share, emission factor, and social cost of carbon. For the continuous-process case, the annual net monetary benefit (Income in Equation (4)) excluding any carbon credit is approximately NPR 1.62 million/year (avoided electricity cost of NPR 12/kWh $\times$ 147,000 kWh, less annual O&M of NPR 142,500), giving a simple payback time of PBTM = NPR 9.5 million/NPR 1.62 million/year $\approx$ 5.9 years. Including the base-case environmental-cost credit (NPR 1.39 million/year) raises the annual net benefit to approximately NPR 3.01 million/year and shortens the simple payback time to PBTM $\approx$ 3.2 years. These payback estimates are shorter than the discounted payback periods reported in **Table 4** because PBTM, as defined in Equation (4), is undiscounted and therefore does not account for the time value of money; it is reported here alongside the discounted payback period while retaining the more conservative discounted measure as the primary decision metric.

Table 6. Environmental cost-adjusted LCOE for the continuous-process load profile (base effective utilized-energy LCOE = NPR 9.91/kWh), with one-at-a-time sensitivity to the diesel-displacement share (δ), diesel emission factor (EF_{CO_2}) and social cost of carbon (SCC_{CO_2}).

Parameter Varied	Value	Avoided CO ₂ (tCO ₂ /year)	Environmental Credit (NPR/kWh)	CO ₂ -Adjusted LCOE (NPR/kWh)
Base case	$\Delta = 100\%$, EF = 1.0, SCC = \$70/t	147.0	9.45	0.46
Diesel-displacement share (δ)	20%	29.4	1.89	8.02
Diesel-displacement share (δ)	50%	73.5	4.73	5.18
Emission factor (EF_{CO_2})	0.8 kg/kWh	117.6	7.56	2.35
Emission factor (EF_{CO_2})	1.3 kg/kWh	191.1	12.29	-2.38
Social cost of carbon (SCC_{CO_2})	USD 50/t	147.0	6.75	3.16
Social cost of carbon (SCC_{CO_2})	USD 100/t	147.0	13.50	-3.59

These results indicate that, under assumptions consistent with internationally documented emission factors and carbon prices, explicitly valuing avoided diesel-generator emissions can substantially improve the apparent economics of industrial solar PV in Nepal, and that this improvement is highly sensitive to the assumed diesel-displacement share, emission factor, and social cost of carbon. The wide range spanned by **Table 6** including cases in which the environmental-cost credit exceeds the underlying financial LCOE, illustrates why a single national carbon-adjusted LCOE estimate would be premature without verified, Nepal-specific data on diesel-generator use by industrial facilities, generator-set emission factors, and an explicitly chosen social cost of carbon. Consistent with Section 4.1, this environmental cost-adjusted analysis is presented as a transparent, literature-parameterized illustration of the requested methodology rather than a validated national estimate, and the underlying assumptions (δ , EF_{CO_2} , SCC_{CO_2}) are stated explicitly in **Table 6** so that they can be revised as better local data become available.

7.3. PV-Only versus PV-Plus-Battery Storage

Battery energy storage is not necessarily required for all industrial solar PV applications. For industries with substantial daytime electricity demand that closely coincides with solar generation, a PV-only configuration can provide high direct self-consumption while avoiding the additional capital cost associated with battery storage. In contrast, PV-plus-BESS systems may provide additional value where peak shaving, backup power, load shifting, increased self-consumption, or grid-support services are required. However, battery deployment also introduces additional capital cost, efficiency losses, replacement requirements, and greater operational complexity. Therefore, the economic justification for BESS is site-specific and depends on the industrial load profile, tariff structure, reliability requirements, and the value assigned to energy flexibility and backup services. **Table 7** summarizes the qualitative trade-offs between the PV-only and combined PV and battery energy storage system (BESS) configurations.

Table 7. Comparison (qualitative) of PV-only and PV-plus-battery energy storage system (BESS). The preferred configuration depends on load profile, reliability requirements, tariff structure, and the value of flexibility.

Configuration	Principal Benefits	Main Limitations
PV-only	Lower capital cost; suitable for industries with high daytime demand; simpler operation	Limited ability to shift excess solar generation or provide backup
PV + BESS	Peak shaving, backup power, load shifting, higher self-consumption and potential grid support	Higher capital cost, storage losses, battery degradation/replacement and greater complexity

8. Socioeconomic Impacts

Industrial solar deployment can provide socioeconomic benefits beyond direct savings on electricity costs. Replacing routine diesel generation can reduce local air pollution, noise and exposure to imported fuel prices. On-site generation can increase operational resilience. The scale of these benefits is site-specific and depends on the amount of diesel displaced, system performance, and the carbon intensity of the electricity replaced.

Solar deployment can also create employment in system design, installation, electrical work, operation, maintenance, energy auditing, and project finance. International evidence identifies solar PV as a major renewable-energy employer [18,19], but no verified Nepal-specific coefficient was found to support the estimate of 15–20 jobs per 100 kWp. This review therefore treats employment creation as a plausible opportunity requiring project-level labour data rather than as a quantified national outcome.

Potential distributional benefits include more reliable electricity for labour-intensive enterprises, cold storage, and agro-processing facilities. Such improvements may reduce production interruptions and post-harvest losses, but resulting changes in wages, food security, or business income depend on ownership, labour practices, market access, and how energy savings are allocated.

Women and vulnerable groups may benefit from better working conditions, technical training and participation in solar service enterprises. However, these results are not automatic and require inclusive program design. In addition, Nepal's climate commitments and access to climate finance can be boosted by emission reductions, if project-level generation and avoided-emissions calculations are transparently documented.

Displacing diesel-based backup generation with industrial solar also reduces direct on-site CO₂ emissions from fuel combustion; see an example from Libya [46]. This benefit is particularly relevant in Nepal, where grid electricity is predominantly hydropower-based. Consequently, the largest near-term emissions-reduction opportunity from industrial solar lies specifically in displacing diesel generation (see **Figure 5**), rather than displacing grid electricity. Quantifying this reduction at a national scale would require verified diesel-displacement volumes and standard emission factors for Nepal's industrial sector, which are not yet consistently reported in public sources (see Section 4.1).

A first, transparent quantification of this opportunity is now provided in Section 7.2: under internationally documented reference parameters (a diesel-generator emission factor of 1.0 kg CO₂/kWh and a social cost of carbon of USD 70/tCO₂), the illustrative continuous-process scenario avoids approximately 147 tCO₂/year for a representative 100 kWp system, with a sensitivity range of roughly 30–190 tCO₂/year depending on the assumed diesel-displacement share and emission factor (**Table 6**).

9. Challenges to Adoption

Industrial PV can introduce distribution-system requirements including voltage-rise control, reverse power flow, reactive-power management, protection coordination, metering, and hosting-capacity assessment. These are established engineering considerations for distributed generation [47,48], but their severity must be evaluated for the relevant feeder rather than assumed uniformly across Nepal's grid. Appropriate inverter controls, interconnection studies, protection settings, and grid-code compliance are therefore essential for larger installations.

The main issue is the control of load variability, particularly in the hours of maximum solar production, as there is a lack of smart metering systems and energy storage connected to the grid, which reduces the capacity to efficiently take in and redistribute excess electricity. Besides, the structural design of industrial buildings in Nepal is also challenging. Many factories and warehouses were built without consideration for high-capacity rooftop solar installations, and are often limited by physical constraints, such as weak roof integrity, limited surface area or shading from nearby structures. These constraints significantly reduce the feasibility and effectiveness of large-

scale solar panel installation in industrial zones. Solar energy's technical potential in Nepal's industrial sector will remain untapped without major upgrades in grid modernization and infrastructural adaptation.

Another main challenge is the financial barrier of the high initial capital investment required for the installation of solar systems. The high cost of purchasing and installing photovoltaic (PV) systems, inverters, battery storage units and other related infrastructure is a major economic challenge, particularly for small and medium-sized enterprises (SMEs) with limited cash flow [49].

Dedicated solar-financing mechanisms are emerging, including AEPC-supported interest and generation-based incentives [41], but access remains limited by program windows, eligibility requirements, lender risk perceptions, collateral requirements, and the absence of standardized project-performance data. Broader use of concessional loans, performance-linked support, leasing, and RESCO models could reduce upfront burdens if contractual and credit risks are allocated transparently [23,50].

Furthermore, the lack of formal Power Purchase Agreements (PPAs) for industrial producers significantly undermines investor confidence. Industries are often reluctant to commit to solar infrastructure over the long term without legal agreements that guarantee a fixed tariff for surplus electricity sold to the grid. These problems are made worse by the limited availability of government subsidies that are targeted specifically at deploying solar at industrial scale.

Support for residential and public systems has historically been more visible than support for industrial installations, although current C&I programmes indicate a shift toward targeted assistance [40]. Future fiscal measures should therefore be evaluated against their actual availability, duration, eligibility, and budget rather than described as wholly absent. Predictable depreciation, import-duty, financing, and generation-support rules could improve investment confidence, particularly for small and medium-sized enterprises.

Similarly, a significant barrier exists to smooth implementation of solar energy projects in industrial sector in Nepal. The regulatory environment is characterized by procedural uncertainties, uneven enforcement and lack of fixed time frames, resulting in delayed in project approvals and higher transaction costs. Such bureaucratic delays often discourage private sector participation and foreign investment as stakeholders are unsure about permitting, licensing and compliance procedures [51]. In addition, the lack of transparency and accountability in institutions makes it difficult to navigate through administrative requirements, preventing industries from launching or scaling solar initiatives.

A major barrier is frequent changes in energy policy direction with changes in political leadership. Such volatility is not conducive to policy continuity and creates a risk-averse environment for long-term investment as no stakeholder is certain that measures or incentives will be in place over a sustained period. This regulatory uncertainty is especially harmful to those industries that are contemplating investing in solar infrastructure over several years.

MoEWRI, NEA, and AEPC have distinct but interdependent responsibilities for energy policy, grid operation, project support, and renewable-energy implementation. Coordination can become difficult when programmatic approval, financing, and grid-connection processes are handled separately [8,14,52]. A clearly documented division of responsibilities and a common project-tracking mechanism would reduce duplication and improve accountability without assuming that a new institution is necessarily required.

Another challenge in Nepal is environmental constraints, where the monsoon can lead to a drastic reduction in solar output and much lower system efficiency during the monsoon season. The generation of energy is also affected by the accumulation of dust on the panels, shading from nearby buildings or foliage and occasional fog in the Terai region. Also, the limited availability of low-cost battery storage technology makes it difficult to use energy when there is no daylight.

Figure 6 compares the average daily solar radiation received in five major cities of Nepal, namely Kathmandu, Pokhara, Biratnagar, Nepalgunj and Dhangadhi. Note that solar radiation is in kilowatt-hours per square meter per day ($\text{kWh/m}^2/\text{day}$), which indicates the solar energy available for photovoltaic (PV) power generation. Nepalgunj has the highest average solar radiation among the selected cities, with approximately $5.5 \text{ kWh/m}^2/\text{day}$, followed by Dhangadhi ($5.4 \text{ kWh/m}^2/\text{day}$) and Biratnagar ($5.3 \text{ kWh/m}^2/\text{day}$). Pokhara has the lowest average solar radiation of about $4.8 \text{ kWh/m}^2/\text{day}$, and Kathmandu has a moderate amount of solar radiation of about $5.1 \text{ kWh/m}^2/\text{day}$.

The seasonal variation of solar resource in Nepal is significant with relatively more solar resource in the dry and pre-monsoon period and less solar resource in the monsoon period due to the increased cloud cover and rainfall during this period. Therefore, the PV generation in Nepal will vary over the year with less PV generation in the

months with less solar irradiation. This variation of solar resources should be considered when estimating the annual generation, system size, and industrial energy reliability.

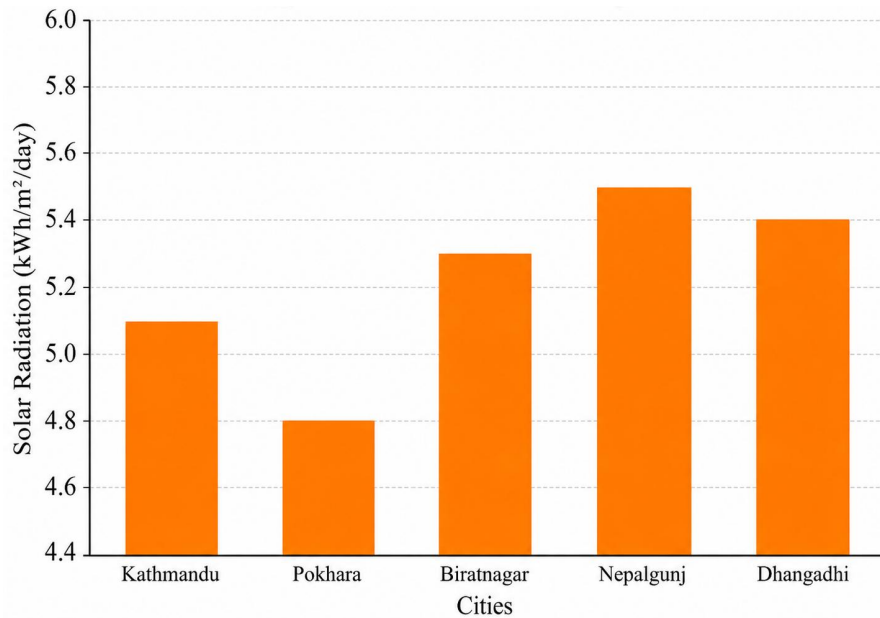


Figure 6. Average daily solar radiation across major cities in Nepal.

From this figure all five cities are generally subjected to high levels of solar irradiance, ranging from 4.8 to 5.5 kWh/m² /day. This means Nepal has good solar energy resources in different topographical locations. The western Terai region, especially Nepalgunj and Dhangadhi, has the highest potential for large-scale solar photovoltaic application. These results bring out the possibility of large-scale enhancement of solar energy production and facilitating its industrial and commercial utilization throughout Nepal [36]. The geographic diversity of Nepal results in regional variation in solar radiation. Seasonal variations can also affect the reliability and efficiency of solar energy generation.

Using the average daily solar-radiation values reported for representative locations and an illustrative photovoltaic performance ratio of 0.80, the estimated annual specific yield ranges from approximately 1,489 to 1,606 kWh/kWp/year, corresponding to capacity factors of about 17.0–18.3% (see **Table 8**). These values are indicative estimates rather than site-measured performance and are intended to provide a comparative indication of location-dependent industrial PV generation potential.

Table 8. Annual specific yield and capacity factor for representative industrial sites in Nepal.

Location	Average Solar Radiation (kWh/m ² /day)	Estimated Specific Yield (kWh/kWp/Year)	Estimated Capacity Factor
Kathmandu	5.1	≈1,489	≈17.0%
Biratnagar	5.3	≈1,548	≈17.7%
Nepalgunj	5.5	≈1,606	≈18.3%
Dhangadhi	5.4	≈1,577	≈18.0%

Note: Specific yield was approximated as average daily solar radiation × 365 × 0.80, and capacity factor was calculated as specific yield/8,760. The performance ratio of 0.80 is an exemplary model assumption.

10. Best Global Practices

Global solar deployment has expanded rapidly as technology costs declined and policy, financing, and procurement mechanisms matured [2,53]. For comparison, global installed solar capacity reached approximately 1,865 GW at the end of 2024 [2,54]. A clear increase in global commitment to clean energy is supported by declining solar technology costs, favorable government policies, and rising demand for sustainable power solutions. This

trend underscores solar PV's leading role in the global energy transition toward a low-carbon future. The growth of global installed solar capacity over 2016–2025 is shown in **Figure 7**.

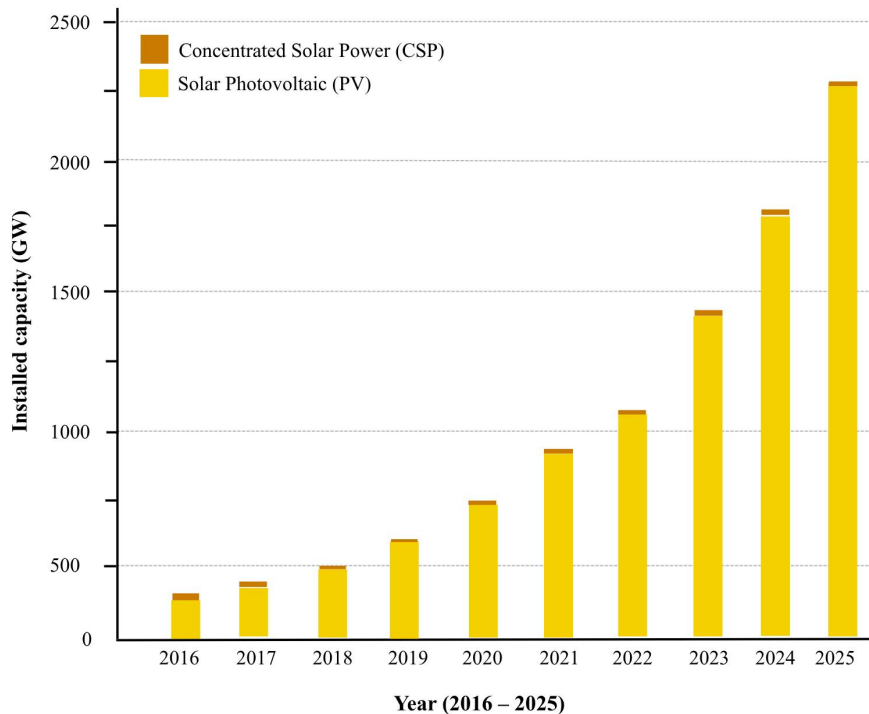


Figure 7. Global installed solar capacity (GW) from 2016 to 2025, showing cumulative capacity growth by technology, with solar photovoltaic contributing the dominant share and concentrated solar power (CSP) representing a comparatively smaller portion of total installed capacity.

Figure 7 depicts the growth in global installed solar capacity from 2016 to 2025, highlighting an impressive and consistent upward trend. Total installed capacity increased from approximately 298 GW in 2016 to approximately 2,392 GW (≈ 2.39 TW) by the end of 2025, driven predominantly by solar photovoltaic systems, which accounted for about 2,383 GW [55]. Global solar capacity therefore already exceeded 1 TW (1,000,000 MW) in 2022, and a record of about 511 GW was added in 2025 [55].

Figure 8 shows the global distribution of solar energy usage in the industrial sector. China is the largest contributor (20%), followed by India (15%) and the USA (13%). These three countries are the major contributors. Germany accounts for 12%, followed by moderate shares for UAE, Australia, Japan and Chile. Overall, the distribution underscores the dominant impact of Asia, especially China and India—on the adoption of solar energy for the industry globally. However, there are also significant contributions from North America, Europe, the Middle East, Africa and other parts of the world. These cross-country differences are closely linked to the policy, financial and regulatory structures that have underpinned solar deployment in leading markets. These shares are indicative only and are not measured market statistics; for comparison, the International Renewable Energy Agency (IRENA) data show that China alone accounted for about half of global installed solar capacity at the end of 2025 [55].

International experience shows that sustained deployment depends less on a single subsidy than on a coordinated package of market access, predictable regulation, finance, grid procedures, and industrial capability [20,21,53,56–58]. Germany illustrates long-term market formation through feed-in and auction mechanisms; India combines national missions, state programmes, net-metering rules, and concessional or capital-support instruments; China combines large-scale procurement with domestic manufacturing and supply-chain policy; and the United States uses tax incentives, state-level standards, and corporate procurement. These mechanisms are not directly transferable, but they provide design principles relevant to Nepal. **Table 9** summarizes these approaches and their relevance to Nepal.

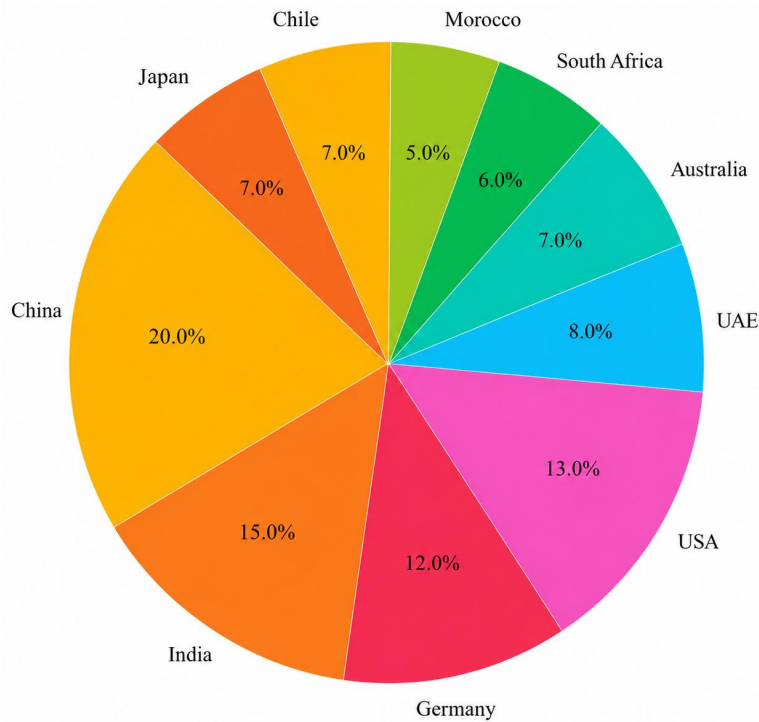


Figure 8. Approximate country-wise distribution of global industrial solar power usage, with China accounting for the largest share, followed by India, the USA, and Germany.

Note: These percentages are an illustrative/approximate distribution compiled by the authors.

Table 9. Structured comparison of selected international solar-policy approaches and their relevance to industrial deployment in Nepal [20,21,53,56–58].

Country	Principal Policy Instrument	Financing or Market Mechanism	Implementation Evidence	Potential Relevance to Nepal
Germany	Long-term renewable-energy legislation; auctions/feed-in arrangements	Policy-backed revenue certainty and development finance	Mature distributed and utility-scale market	Stable rules, transparent tariffs, and predictable grid access
India	National mission plus state-level implementation	Concessional finance, subsidies, net metering, and competitive procurement	Large and diverse rooftop and utility-scale deployment	Industrial-cluster programs and state/province implementation
China	National targets, procurement, and manufacturing policy	State-linked finance and large-scale supply chains	Rapid capacity and domestic manufacturing expansion	Procurement scale, standards, and local technical capability
United States	Federal tax incentives and state standards	Tax credits, power-purchase agreements, and corporate procurement	Strong corporate and distributed-generation markets	Bankable contracts and third-party ownership models

11. SWOT Analysis and Discussion

The SWOT analysis synthesizes factors extracted from the thematic evidence matrix rather than from a stakeholder survey. A factor was categorized as a strength or weakness when it primarily reflected Nepal's current internal conditions and as an opportunity or threat when it arose mainly from external technological, financial, environmental, or political conditions [36].

Table 10 links each category to supporting references. No numerical ranking is assigned because stakeholder weights and inter-coder reliability statistics were not available.

Table 10. Evidence-linked SWOT synthesis for industrial solar adoption in Nepal.

Category	Evidence-Supported Factors
Strengths	High solar resources; modular deployment; compatibility with daytime industrial loads; potential diesel displacement [3,7,33,36].
Weaknesses	High upfront cost; limited public project data; uneven grid and institutional readiness; limited standardized finance [14,23,38,49,50,59].

Table 10. Cont.

Category	Evidence-Supported Factors
Opportunities	C&I support programmes; climate finance; RESCO/PPA models; storage and smart-grid development; skills and service markets [5,7,41,60].
Threats	Policy discontinuity; currency and imported-equipment exposure; monsoon and soiling effects; end-of-life waste risks [14,50,61,62].

Nepal's principal internal strengths are its generally favorable solar resource, the modularity of PV systems, and the potential match between daylight generation and many industrial operating schedules [3,36]. Public and private interest in renewable energy is also increasing, while documented C&I projects show that rooftop deployment is technically feasible across several load types [7,40,42].

Those strengths are tempered by internal weaknesses. The upfront investment is still high for small and medium-sized enterprises, and the project economics worsen when daytime self-consumption is low. Public data on installed industrial capacity, operating performance, export arrangements and realized savings are still incomplete, and financing, permitting and interconnection procedures are not yet standardized across all project types [23,24].

Grid integration is not uniformly constrained, but larger distributed systems may require feeder-specific hosting-capacity assessment, protection review, voltage regulation, and metering upgrades [47,48]. Similarly, institutional responsibilities are established but interdependent; clearer service timelines and data sharing would reduce procedural uncertainty [14,60].

External opportunities include international climate finance, C&I rooftop-support programs, third-party ownership, RESCO and PPA structures, declining technology costs, and advances in storage and smart-grid control [5,14,28]. These mechanisms can increase bankability and energy flexibility, in particular when combined with auditable project data and standardized contracts [5].

Industrial solar also offers opportunities for local engineering, installation, maintenance, energy auditing, and project-finance services [50]. The extent of domestic job creation will depend on training, local procurement, project volume, and whether higher-value technical and managerial activities are retained within Nepal.

The main external threats are policy discontinuity, approval delays, foreign-exchange exposure, dependence on imported modules and inverters, and international supply-chain disruption [14,63]. These factors can affect capital cost, replacement availability, and investor confidence even when the underlying solar resource is favourable [63].

Environmental conditions also introduce risk. Monsoon cloud cover, dust accumulation, shading, and temperature can reduce output relative to simplified annual-yield estimates [62]. Operations and maintenance planning should therefore include cleaning, performance monitoring, drainage, structural review, and seasonal generation assessment [62].

Improper disposal of solar-related waste such as spent batteries can also pose new environmental risks in the absence of proper environmental management practices. These external concerns bring to the fore the importance of formulating a robust and adaptable energy policy, which considers such risks and ensures their mitigation, while encouraging the long-term industrial adoption of solar energy in Nepal.

Overall, the literature supports cautious optimism rather than a deterministic conclusion. Nepal possesses favorable resource and demand conditions, but realized industrial benefits depend on firm-level load matching, financing, grid compatibility, implementation quality, and policy continuity. These relationships are evidence-informed interpretations and should not be treated as causal estimates.

12. Policy Implications

Policy should address the barriers specifically identified in the evidence: initial funding, unclear project information, load-generation imbalances, grid-connection rules, institutional cooperation and technical expertise. The current policies and the AEPC's initiatives provide a basis, but their industrial relevance should be assessed with transparent indicators such as program adoption, installed capacity, annual output and repayment or performance data [7,40].

12.1. Financial and Technical Enablers for Industrial Solar Development

Financial assistance ought to focus on viable commercial and industrial initiatives that possess verified load profiles and technical schematics. Concessional financing, credit assurances, performance-based assistance, RESCO

frameworks, and uniform power purchase agreements can alleviate investment obstacles, whereas grid enhancement, intelligent metering, justified storage solutions, and established interconnection protocols can facilitate increased distributed generation.

12.2. Institutional Coordination and Governance Harmonization

Enhancing institutional coordination could be achieved via an inter-agency industrial-solar working group integrated within the current energy governance framework, rather than presuming the necessity for a new permanent entity. It would harmonize AEPC programme assistance, NEA interconnection protocols, government policies, financial institution requirements, technical specifications and public project documentation.

13. Strategic Considerations and Recommendations

For projects that cannot consume all PV generation on site, a stable and transparent net-metering or export compensation framework is important. However, the financial analysis shows direct self-consumption as the biggest value driver in the short term. So, incentives or financing approvals should be preceded by industrial energy audits, interval-load measurements, and properly sized systems. Grid upgrades and storage should be allocated to proven feeder or reliability needs, not applied across the board. Awareness, technical training and demonstration projects can overcome information and implementation barriers; public-private collaboration can enhance local design, installation, monitoring, and maintenance capability.

Table 11 translates these recommendations into a minimum implementation framework linking each action to the barrier it addresses, the responsible institutions, an indicative time-frame and a measurable indicator. The time horizons proposed are policy-planning suggestions, not forecasts of completion.

Table 11. Evidence-linked implementation framework for industrial solar adoption in Nepal.

Recommended Action	Barrier and Evidence	Lead Responsibility	Indicative Horizon	Performance Indicator
Standardize C&I finance and contracts	Upfront cost and limited bankability [23,50]	AEPC/CREF, banks, MoF	1–2 years	Loan volume; financed MW; default rate
Publish interconnection and export rules	Procedural and revenue uncertainty [11,24,35]	NEA and MoEWRI	1–2 years	Approval time; connected MW; rejected applications
Require load-based project appraisal	Self-consumption drives NPV and IRR (Tables 4 and 5)	Lenders, ESCOs, industries	Immediate	Projects with interval-load studies; realized self-consumption
Create a public C&I project registry	Incomplete capacity and performance data	AEPC with NEA	Within 1 year	Projects reporting capacity, status, generation, and ownership
Coordinate skills and quality assurance	Technical and O&M capability gaps [14,50]	AEPC, CTEVT, universities, industry	1–3 years	Certified personnel; inspected systems; performance-compliance rate

14. Conclusions

Nepal has good solar resources and a growing need for reliable, lower-carbon industrial electricity, but the reviewed evidence does not support a single national adoption rate, universal payback period or causal claim about industrial outcomes. Commercial and industrial programmes and documented rooftop projects provided practical pathways for deployment, and national solar installations continued to increase significantly through 2024. The illustrative financial assessment demonstrates that project viability is highly sensitive to daytime self-consumption, the value of displaced electricity, capital cost and financing assumptions. High upfront investment, incomplete project data, feeder-specific grid requirements, procedural uncertainty, and limited standardized finance remain important constraints. The ISCF and ISAI organize these factors conceptually but require firm-level data, normalization, weight calibration, sensitivity analysis, and validation before quantitative use. Near-term progress is therefore most likely through load-matched project design, transparent C&I data, standardized financing and contracts, predictable interconnection rules, targeted technical capacity building, and coordination among existing institutions.

The environmental cost-adjusted analysis introduced in Section 7.2 further shows that explicitly valuing avoided diesel-generator emissions, using internationally documented emission factors and carbon prices, can materially improve the apparent economics of industrial solar PV, but that this improvement is highly sensitive to the assumed diesel-displacement share, emission factor, and social cost of carbon; verified Nepal-specific data on these parameters remain a priority for future work.

Author Contributions

S.B. created the first draft, oversaw policy analysis and contextual integration, and contributed to the financial and institutional structure. D.N. did the literature search and helped to draft the article. C.R. oversaw the technical material and guided the final synthesis of the work. All authors contributed to the article's idea, design, literature review, and preparation, and the final version was reviewed and approved.

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No new data were generated or analyzed in this study. All information used in this review was obtained from publicly available sources cited in the manuscript.

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The authors declare no conflicts of interest regarding the publication of this article.

AI Use Statement

During revision, the authors used ChatGPT 5.0 to assist with grammar and language editing. The authors independently checked the scientific content, calculations, citations, and conclusions and accept full responsibility for the final manuscript.

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