Cost Competitiveness of Perovskite–Silicon PV in India by 2030

1. Executive Summary

This report assesses the projected cost competitiveness of perovskite–silicon photovoltaic (PV) technology in India by the year 2030. The analysis indicates that while perovskite–silicon tandem PV offers significant potential for higher efficiencies and long-term cost reductions in manufacturing, achieving cost competitiveness with traditional silicon PV by 2030 will depend on substantial advancements in stability, manufacturing scalability, and supportive government policies. Currently, the low cost of conventional silicon PV modules, driven by technological improvements and large-scale production, presents a significant benchmark. However, the superior efficiency of perovskite–silicon tandem cells could lead to lower levelized cost of energy (LCOE) in specific applications, particularly where land is constrained. Government initiatives promoting domestic solar manufacturing and high-efficiency technologies will play a crucial role in determining the pace and extent of perovskite–silicon PV adoption in India.

2. Introduction

India has set ambitious renewable energy targets, aiming for 500 GW of non-fossil fuel-based energy capacity by 2030.[1] Solar power is expected to be a major contributor to this goal, projected to account for over 60% of the total renewable capacity.[1] As of February 2025, India's installed solar capacity reached approximately 100 GW AC, necessitating the addition of another 200 GW in the next five years to meet the 2030 target.[2] This strong commitment to solar energy establishes a substantial potential market for innovative PV technologies, provided they offer compelling economic advantages.

Perovskite–silicon tandem solar cells represent a next-generation technology designed to enhance solar energy conversion efficiency. These cells consist of a perovskite top cell stacked on top of a conventional silicon bottom cell, enabling the capture of a broader spectrum of sunlight.[10] This tandem architecture has the potential to achieve significantly higher efficiencies compared to single-junction silicon solar cells, with theoretical efficiency limits exceeding 43%.[10] Current certified efficiencies have already surpassed 33%.[10] Furthermore, the perovskite materials used in these cells are solution-processable, which could lead to lower manufacturing costs compared to the energy-intensive processes required for silicon.[10]

This report aims to assess the cost competitiveness of perovskite–silicon PV technology in India by the year 2030, analyzing its potential to become a viable and economically attractive option for solar power generation in the country.

3. Understanding Perovskite–Silicon Tandem PV Technology

Perovskite–silicon tandem solar cells operate on the principle of spectral splitting. The perovskite top cell, typically with a wider bandgap, efficiently absorbs the higher energy (shorter wavelength) photons from the solar spectrum, while the remaining lower energy (longer wavelength) photons pass through to the silicon bottom cell, which absorbs them effectively.[10] This synergistic effect allows the tandem cell to convert a larger fraction of the incident sunlight into electricity compared to either material alone. These tandem cells are commonly configured in two main architectures: two-terminal (2T) and four-terminal (4T).[13] In the 2T configuration, the perovskite and silicon cells are monolithically integrated with a single electrical output, often leading to slightly higher efficiency gains. The 4T configuration involves separate electrical connections for each sub-cell, allowing for independent optimization and potentially greater flexibility in bandgap design.

One of the most significant advantages of perovskite–silicon tandem PV technology is its potential to overcome the fundamental efficiency limit of single-junction silicon devices, known as the Shockley-Queisser limit.[19] Rapid advancements in research have led to impressive efficiency records in laboratory settings, with recent achievements exceeding 34%.[14] The industry is also setting ambitious targets for commercialization, with some companies aiming to achieve module efficiencies of over 30% by late 2025.[23] These efficiency gains are crucial, particularly in land-constrained regions like India, as they enable greater power generation from a smaller area, potentially leading to a lower levelized cost of energy (LCOE).

Despite the rapid progress in efficiency, the long-term stability and durability of perovskite solar cells remain critical challenges.[10] Perovskite materials are known to be susceptible to degradation from moisture, heat, and prolonged exposure to light, which could limit the operational lifespan of the solar cells. Another concern is the use of lead in many high-performing perovskite materials, raising environmental and health issues.[10] Research efforts are actively focused on addressing these challenges through various strategies, including developing robust encapsulation techniques to protect the perovskite layer from environmental factors and exploring less toxic, lead-free perovskite compositions.[10] Overcoming these hurdles is essential for the widespread commercial adoption and bankability of perovskite–silicon tandem PV technology.

4. Current Landscape of Solar PV Costs in India

The cost of traditional silicon PV modules in India varies depending on the type and efficiency. Polycrystalline silicon modules, which are made from multiple silicon crystals, typically have a lower cost, currently ranging around INR 25.5 per watt.[29] Monocrystalline silicon modules, made from a single silicon crystal and offering higher efficiency, are priced higher, approximately at INR 31 per watt.[29] Bifacial solar panels, which can absorb sunlight from both sides, are the most efficient and expensive, costing around INR 32.5 per watt.[29] Recent trends in the global solar market have shown significant drops in module prices in 2024 due to oversupply and intense competition.[31] However, prices are expected to stabilize or potentially increase in the near term.[34]

Overall system installation costs for solar PV in India encompass the cost of modules, inverters, mounting structures, labor, and other balance of system (BOS) components. For residential systems, the cost can range from INR 70,000 to INR 110,000 per kW for a 1 kW system, with costs varying based on system size and components used.[29] Utility-scale solar projects have seen a decrease in average costs, with the average cost dropping by almost 23% year-over-year in the third quarter of 2024.[32] Government subsidies, particularly for residential rooftop solar, play a significant role in reducing the upfront investment for consumers.[39]

The levelized cost of energy (LCOE) for silicon PV in India has decreased substantially over the years, making it an increasingly competitive source of electricity. Studies have projected the cost of solar power to fall to as low as INR 1.9 per unit by 2030.[43] The average price for utility-scale solar allocated in tenders has been around $0.031/kWh (approximately INR 2.5 per unit) in 2024.[44] This makes solar power cost-competitive with or even cheaper than conventional power generation sources in many parts of India.[38]

Table 1: Current Cost of Silicon PV in India (2024)

Module Type	Price per Watt (INR)	System Cost (INR/kW)	Estimated LCOE (INR/kWh)
Polycrystalline	25.5	70,000 - 110,000	~2.5
Monocrystalline	31	70,000 - 110,000	~2.5
Bifacial	32.5	70,000 - 110,000	~2.5

Note: System costs are indicative for a 1kW residential system. LCOE is for utility-scale projects and can vary.

5. Projected Cost Trajectory of Silicon PV in India (2024-2030)

The cost of silicon PV in India is expected to continue its downward trajectory between 2024 and 2030. Technological innovations, such as the increasing adoption of n-type technologies like TOPCon and Silicon Heterojunction (SHJ) cells, are anticipated to drive higher efficiencies and potentially lower costs.[1] India's strong emphasis on boosting domestic solar manufacturing through initiatives like the Production Linked Incentive (PLI) scheme is also expected to play a significant role in reducing costs by increasing production scale and reducing reliance on imports.[1] The country has set ambitious targets to expand its solar module manufacturing capacity to 160 GW and cell manufacturing capacity to 120 GW by 2030.[9] Furthermore, global trends such as falling polysilicon prices and improvements in supply chain efficiency are expected to contribute to lower module costs.[31] IRENA projects a further 40-50% reduction in the global average cost of electricity from solar PV by 2030.[51]

Based on these factors, the levelized cost of energy (LCOE) of silicon PV in India is projected to decrease further by 2030. Studies indicate that solar power costs could fall to as low as INR 1.9 per unit.[43] The U.S. Department of Energy's Solar Energy Technologies Office (SETO) has set a target of $0.03/kWh (approximately INR 2.4 per unit) for utility-scale PV by 2030.[49] These projections suggest that silicon PV will remain a highly cost-competitive source of electricity in India.

6. The Potential Cost of Perovskite–Silicon Tandem PV in India by 2030

Perovskite–silicon tandem PV technology holds the potential for lower manufacturing costs in the long term due to the solution-processable nature of perovskite materials and potentially reduced material usage.[10] NREL estimates suggest a minimum sustainable price (MSP) of $0.31/W for early production of perovskite-on-silicon tandem modules.[49] Some analyses indicate that with mature production, costs could become comparable to or even lower than silicon modules.[17] However, current production costs for tandem cells are higher than traditional silicon cells due to manufacturing complexities and the use of new materials.[13] These costs are expected to decline as manufacturing processes improve and economies of scale are achieved.[13]

System costs for perovskite–silicon tandem PV could potentially be lower than for silicon PV due to the higher efficiency of tandem modules. This would mean fewer panels are needed to achieve the same power output, thus reducing balance of system (BOS) costs such as mounting structures and wiring.[58] However, there might be new BOS requirements or costs associated with the specific characteristics of tandem modules, which need to be considered.

Considering the projected module and system costs, along with the expected higher efficiencies, the levelized cost of energy (LCOE) of perovskite–silicon tandem PV in India by 2030 has the potential to be competitive. Some projections suggest that tandem devices could offer LCOE reductions of 10%-20% compared to pure silicon photovoltaics, assuming the technology matures and module lifetimes are comparable to silicon.[19] However, the current relatively lower lifespan of perovskite-based cells compared to silicon could negatively impact the LCOE if not significantly improved by 2030.[19]

Table 2: Projected Costs of Perovskite–Silicon Tandem PV in India (2030)

Metric	Projection (Potential)
Module Price (INR/Watt)	Comparable to Silicon
System Cost (INR/kW)	Potentially Lower
Estimated LCOE (INR/kWh)	Comparable or Lower
Expected Module Lifetime (Years)	Key Factor

7. Comparative Cost Competitiveness Analysis

A direct comparison of the projected LCOE of perovskite–silicon tandem PV with that of silicon PV in India for 2030 suggests a close competition. If perovskite–silicon tandem technology achieves significant improvements in stability and can be manufactured at scale with costs comparable to silicon, its higher efficiency could lead to a lower LCOE, making it more economically attractive. Scenarios where land availability is a constraint, such as rooftop solar or building-integrated photovoltaics (BIPV), could particularly benefit from the higher power density offered by tandem cells, even if the initial cost per watt is slightly higher.[10]

Comparing the projected cost per watt, perovskite–silicon tandem modules might initially be slightly more expensive than standard silicon modules due to the added complexity of the tandem structure and the current manufacturing stage. However, the superior energy yield from the higher efficiency of tandem modules could justify a higher cost per watt by generating more electricity over the system's lifetime.

The adoption of perovskite–silicon tandem PV could positively impact the overall economics of solar power projects in India. The potential for higher efficiency means that less land would be required for utility-scale projects to achieve the same capacity, which is a significant advantage in a densely populated country like India. Lower balance of system (BOS) costs due to the need for fewer panels could also contribute to the economic competitiveness of tandem PV.

8. Influence of Indian Policies and Market Dynamics

The Indian government has demonstrated strong support for the growth of solar energy through ambitious targets, including the goal of 500 GW of non-fossil fuel capacity by 2030.[1] Initiatives like the Production Linked Incentive (PLI) schemes aim to boost domestic manufacturing of high-efficiency solar modules.[1] These policies could be extended or adapted to specifically support the development and manufacturing of perovskite–silicon tandem PV technology in India. The Ministry of New and Renewable Energy (MNRE) plays a crucial role in setting targets and promoting solar technology adoption in the country.[5]

India's demand for solar energy is rapidly increasing, driven by energy security concerns, environmental commitments, and the declining costs of solar power.[2] The solar PV manufacturing landscape in India is currently dominated by silicon-based technologies.[1] New entrants with perovskite–silicon technology will need to compete on cost and performance. However, there is a growing focus on high-efficiency modules in the Indian market, which could favor the adoption of tandem PV.[52]

India is actively pursuing the expansion of its domestic solar manufacturing capabilities to reduce its reliance on imports.[1] There is potential for establishing domestic manufacturing capacity for perovskite–silicon tandem PV, possibly through technology transfer and collaborations, or by scaling up indigenous innovations like the work done at IIT Bombay.[27] Government grants and funding will be crucial in supporting these efforts.[27]

9. Challenges and Opportunities for Widespread Adoption

The widespread adoption of perovskite–silicon tandem PV in India faces several challenges. The long-term stability and durability of perovskite materials under real-world conditions are still concerns.[10] Achieving a lifespan comparable to silicon modules, typically 25 years or more, is essential for their economic viability.[19] The toxicity of lead used in some perovskite formulations also poses environmental and health risks, necessitating the development and adoption of safer alternatives.[10] Scaling up the manufacturing of high-efficiency tandem cells to meet the gigawatt-level demands of the Indian market with consistent quality and cost-effectiveness remains a significant hurdle.[10] Building investor confidence in the long-term performance and reliability of this relatively new technology is crucial for attracting the necessary financing for large-scale deployment.[10] Finally, establishing robust and cost-effective domestic supply chains for perovskite materials and specialized manufacturing equipment will be vital to reduce reliance on imports and enhance cost competitiveness.[1]

Despite these challenges, perovskite–silicon tandem PV offers significant opportunities. The potential for achieving higher power conversion efficiencies is a major advantage, leading to better land utilization and potentially lower LCOE.[10] In the long term, there is the potential for lower manufacturing costs due to the solution-based processing of perovskite materials and their abundance.[10] The versatility of perovskite materials allows for the development of flexible and transparent solar cells, opening up new applications in areas like building-integrated PV and portable electronics.[10] Compared to silicon, perovskite cells require thinner layers of material, which could lead to resource savings.[11] Finally, the development and deployment of this next-generation solar technology in India presents a significant opportunity for job creation and economic growth.[7]

10. Recommendations for Enhancing Cost Competitiveness

To enhance the cost competitiveness of perovskite–silicon tandem PV in India, focused research and development efforts are crucial. Increased investment in R&D should aim to improve the stability and durability of these cells, targeting lifespans comparable to silicon PV. Supporting research into non-toxic perovskite materials is also essential to address environmental concerns. Funding pilot projects and demonstration plants under Indian climatic conditions will help validate the technology's performance and reliability.

Policy support and incentives from the Indian government will play a vital role. Developing specific policies to promote the domestic manufacturing of perovskite–silicon tandem PV, such as dedicated PLI schemes or tax benefits, can accelerate adoption. Providing subsidies or financial support for early adoption in niche applications where the benefits of high efficiency are most significant can also be effective. Establishing clear standards and testing protocols for these modules will build confidence among investors and consumers.

Facilitating technology transfer and collaboration between Indian research institutions, domestic manufacturers, and international technology leaders can help in accessing advanced manufacturing techniques. Supporting initiatives that enable Indian companies to adopt cutting-edge equipment for tandem PV production is also important.

Strategies to develop a robust domestic supply chain for critical perovskite materials and specialized components are necessary to reduce reliance on imports and enhance cost competitiveness. Exploring the potential for sourcing raw materials within India should be a priority.

Finally, raising awareness among stakeholders about the potential benefits of perovskite–silicon tandem PV and supporting training programs to develop a skilled workforce for its manufacturing, installation, and maintenance will be crucial for its successful adoption in India.

11. Conclusion

The analysis suggests that perovskite–silicon tandem PV technology holds significant promise for the future of solar energy in India. While the current low costs of traditional silicon PV present a strong competitive benchmark, the superior efficiency potential of tandem cells offers a pathway to cost competitiveness by 2030, particularly in applications where land is a constraint. Achieving this will depend heavily on overcoming the challenges related to the long-term stability and manufacturing scalability of perovskite materials. Supportive government policies, aimed at promoting domestic manufacturing and incentivizing the adoption of high-efficiency solar technologies, will be crucial in facilitating the market entry and growth of perovskite–silicon tandem PV in India. While widespread cost competitiveness with silicon PV across all applications might be challenging to achieve by 2030, the next six years will be critical in establishing the viability and potential of this technology to play a significant role in India's future solar energy mix and contribute to its ambitious renewable energy goals beyond 2030.

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