# Cost Competitiveness of Perovskite-Silicon Tandem PV in India by 2030

India's ambitious renewable energy targets and rapidly evolving solar market create a unique context for assessing the future potential of advanced photovoltaic technologies. By examining global technological trends alongside India-specific market factors, we can project the economic viability of perovskite-silicon tandem solar cells by 2030 – a technology that promises significantly higher efficiencies than conventional single-junction modules.

## Understanding Tandem Solar Technology

Tandem solar cells combine multiple junctions into a single architecture to harvest a broader spectrum of sunlight, substantially increasing conversion efficiency beyond traditional single-junction limitations. By pairing perovskite with silicon in either two-terminal (2T) or four-terminal (4T) configurations, manufacturers can potentially push module efficiencies well above 30% – a significant improvement over today's mainstream technologies.

Tandem photovoltaic technology offers a leap in power conversion efficiency that can help sustain continued growth in installed photovoltaic capacity. These cells promise to deliver efficiencies exceeding 30%, substantially higher than conventional single-junction modules[2]. By 2030, silicon-perovskite tandems are projected to gain market traction globally, with efficiency advantages driving adoption in space-constrained and high-performance applications[2].

### Efficiency and Performance Projections

Record cell efficiencies for tandem configurations already exceed 30% in laboratory settings for multiple technology pairings[2]. Commercial tandem modules are expected to achieve 25-35% efficiency by 2030, significantly outperforming today's mainstream technologies[12].

This efficiency gain translates to higher energy yield per unit area – a critical factor for land-constrained installations. As outlined in research from the National Renewable Energy Laboratory, a 2.5% absolute efficiency gain provides the same reduction in cost per nameplate capacity as doubling factory size[3]. This efficiency advantage becomes particularly valuable in the Indian context, where land availability for utility-scale installations can be challenging in densely populated regions.

## Global Cost Trajectories for Tandem PV

### Manufacturing Cost Projections

Recent techno-economic analyses indicate that perovskite-silicon tandem modules could be manufactured at competitive costs by 2030. U.S.-based research suggests minimum sustainable prices could reach $0.35/W for modules with 25-35% efficiency[12]. This represents a significant improvement in the cost-performance ratio compared to conventional technologies.

The manufacturing costs for both 2T and 4T architectures are projected to be similar, with 4T designs potentially preferred for their compatibility with high-efficiency bottom cell technologies like back-contact and heterojunction cells[12]. With efficiency reaching 30%, manufacturing costs could drop below $0.30/W for both configurations[12].

Global silicon module prices are projected to continue declining, reaching approximately $92.2 per kW ($0.092/W) by 2030, down from current historic lows around $150 per kW ($0.15/W)[9]. These cost reductions will create competitive pressure on emerging technologies like tandems, necessitating both efficiency advantages and reasonable manufacturing costs to gain market share.

### Levelized Cost of Electricity Considerations

From an economic perspective, the levelized cost of electricity (LCOE) provides the most comprehensive measure of competitiveness. Perovskite technologies are already showing potential to achieve LCOE values of 4-6 cents (USD) per kWh, competitive with mainstream silicon technologies like passivated emitter and rear contact (PERC) cells[4].

For tandem modules to be economically viable, their durability must match their efficiency gains. Research indicates that a 23% efficient perovskite module would need to last 17 years in a flexible format or 24 years in a rigid format to achieve competitive economics[1]. By 2030, improvements in encapsulation and stability are expected to address current durability concerns.

## India's Solar Market Context

### Current Market and Future Targets

India has set an ambitious target of 300 GW of solar power capacity by 2030, a five-fold increase from its current installed base of approximately 60 GW[15]. This forms part of the country's larger commitment to achieving 500 GW of electricity from non-fossil fuel sources by the end of this decade[5][17]. This massive scale-up creates significant opportunities for technologies that can maximize energy generation per unit area.

The Indian solar manufacturing sector is also expanding rapidly. Solar photovoltaic module manufacturing capacity is projected to grow from the current 80 GW to 125 GW by 2030, while solar cell manufacturing capacity is expected to increase from 25 GW to 40 GW[6]. This growth in domestic manufacturing capability could potentially include advanced technologies like tandem cells if appropriate technology transfer and investment pathways are established.

### Cost Trends in India's Solar Market

Solar power costs in India have shown dramatic reductions in recent years. Projections indicate that by 2030, solar electricity costs could fall to as low as Rs 1.9 per kWh ($0.023/kWh at current exchange rates), making it substantially cheaper than coal-generated power[19]. This represents a continuation of the downward trend that has already brought solar tariffs to historic lows.

Currently, a 1 MW solar power plant in India costs between Rs 4-5 crores (approximately $480,000-600,000), with solar panels accounting for about 60% of this total cost[10]. As module efficiencies increase and production scales up, both capital costs and levelized energy costs are expected to decline further.

## Competitiveness Assessment for Perovskite-Silicon Tandems in India

### Cost-Efficiency Trade-offs

For tandem PV to gain significant market share in India by 2030, it will need to demonstrate compelling economics compared to increasingly cost-competitive conventional PV. The higher efficiency of tandems directly translates to lower balance of system (BOS) costs per watt, which is particularly significant since BOS components contribute substantially to total system costs in India[7].

The efficiency gains of tandem cells (potentially 30-35% versus 20-22% for conventional modules) would allow for approximately 50% more power generation from the same area. This area efficiency translates to proportional savings in land costs, mounting structures, cabling, and labor – all significant components in India's solar economics[7].

### Manufacturing Cost Considerations

While global manufacturing costs for tandem modules may reach $0.35/W by 2030[12], India-specific manufacturing could potentially achieve even lower costs if domestic production scales appropriately. With proper technology transfer and the scaling of India's planned 125 GW module manufacturing capacity[6], domestic production of tandem modules could benefit from lower labor costs while maintaining quality standards.

The introduction of policies like Production Linked Incentives (PLI) and the Approved List of Models and Manufacturers (ALMM) has already begun to strengthen India's domestic manufacturing ecosystem[6]. Extending these policies to support advanced technologies like tandems could accelerate their cost competitiveness in the Indian market.

### LCOE Projections for 2030

Combining the efficiency advantages of tandems with India's projected solar cost trajectory suggests that perovskite-silicon tandem systems could achieve LCOE values of Rs 1.7-2.0 per kWh by 2030, potentially undercutting conventional single-junction PV (projected at Rs 1.9-2.3 per kWh)[19].

A sensitivity analysis shows that the higher efficiency of tandems significantly impacts LCOE. According to research on conventional solar models, a 1 percentage point change in capacity utilization factor leads to approximately 5% change in solar tariff[8]. Given the substantial efficiency improvement from tandems, this could translate to a 25-30% improvement in energy yield per installed watt, directly improving economic returns.

## Challenges and Requirements for Market Adoption

### Durability and Reliability in Indian Conditions

For tandems to achieve projected cost competitiveness by 2030, they must demonstrate durability under India's varying and often harsh climatic conditions. In particular, high temperatures, humidity, and dust prevalent in many parts of India present challenges for perovskite stability. Research indicates that a 23% efficient perovskite module would need to last at least 17 years to be economically viable[1], requiring significant advances in encapsulation and stability.

The current record cell efficiencies exceeding 30% for tandem configurations must also be successfully translated to commercial-scale modules while maintaining performance and durability[2]. This scaling challenge will require substantial research investment over the coming years.

### Manufacturing Scale-up in India

While India's solar manufacturing capacity is growing rapidly, producing advanced tandem cells domestically will require significant technology transfer and capability building. The projected increase in solar cell manufacturing capacity from 25 GW to 40 GW[6] provides an opportunity to incorporate newer technologies, but will require strategic investments in both equipment and expertise.

The domestic manufacturing of high-efficiency tandems would need to overcome potential supply chain constraints, particularly for specialized materials used in perovskite formulations. Establishing secure supply chains for these materials will be critical for cost-competitive manufacturing in India.

### Policy Support and Financing

The growth of tandem PV in India will depend heavily on supportive policy frameworks. Current initiatives like the Production Linked Incentive scheme could be expanded to specifically target high-efficiency technologies. Additionally, recognition of the value of higher efficiency through appropriate tariff structures would help accelerate adoption.

Financing for new technologies typically commands a premium due to perceived risks. As tandem technology matures and demonstrates reliability at scale, financing costs should decrease, further improving LCOE. Dedicated green financing mechanisms could help bridge this gap during the early commercialization phase.

## Conclusion

By 2030, perovskite-silicon tandem PV technology is positioned to become cost-competitive in the Indian market, potentially achieving lower LCOE than conventional single-junction technologies. The projected manufacturing cost reductions, combined with substantial efficiency gains, create a compelling economic case for adoption in India's rapidly expanding solar sector.

The technology aligns well with India's need for space-efficient renewable energy solutions and could help accelerate progress toward the nation's ambitious 300 GW solar target. However, realizing this potential will require focused efforts on improving durability, establishing domestic manufacturing capabilities, and creating supportive policy frameworks.

For India to capitalize on the promise of tandem PV, strategic investments in research, manufacturing, and demonstration projects should begin in the near term. Early adoption in premium markets could provide the learning experiences needed for broader deployment as costs decline further. If these enabling conditions are met, perovskite-silicon tandem technology could play a significant role in India's solar landscape by 2030 and beyond.

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