Advanced Passivated Contact (TOPCon) Technology

Tiger Neo 3.0 Commercial White Paper

TOPCon

JinKO Solar

JinkoSolar Co., Ltd.

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01 | Introduction

1.1 Trends in the PV Industry

The essence of the energy revolution is an economic revolution. As the global energy system accelerates its transition toward low-carbon and carbon-neutral development, the binary opposition between "clean" and "non-clean" is being replaced by more practical competitive dimensions. The core question for the photovoltaic (PV) industry is which technology can break through the boundaries of energy accessibility and redefine the coordinates of energy economics with a lower levelized cost of energy (LCOE).

Currently, the PV industry is undergoing a strategic shift from "subsidy-driven" to "technology-driven". As Passivated Emitter and Rear Cell (PERC) efficiency approaches theoretical limits, N-type technologies represented by TOPCon are opening a new round of generational leapfrog development in the PV industry with their higher efficiency ceilings, better temperature coefficients, and lower degradation rates. Behind this technological revolution lies a fundamental upgrade in the competitive logic of the PV industry: from simply pursuing a reduction in the cost per watt of modules to optimizing the cost per kilowatt-hour of energy over the entire life cycle through a system-level approach.

In terms of cost competitiveness, the global PV supply chain has formed a new pattern of multi-centered, regionalized development. Leading companies have achieved breakthroughs in process technology, such as silicon wafer thinning and reduced silver paste consumption, through technological innovation. Combined with global manufacturing capacity and localized supply chain construction, they have significantly enhanced technological penetration efficiency and cost control resilience. TOPCon products, represented by JinkoSolar's Tiger Neo 3.0, leveraging vertical integration advantages and intelligent manufacturing systems, are redefining the scalability cost boundaries of N-type technology.

In terms of LCOE competitiveness, the direction of technological iteration has shifted from a single-driver focus on cost reduction to a dual-driver approach combining cost reduction and efficiency improvement. TOPCon technology, featuring a mass production efficiency exceeding 25.8%, a bifaciality coefficient over 85%, and an annual degradation rate below 1%, enables power plant systems to increase electricity generation by approximately 3%–5% over their entire lifecycle. This means that even if the initial investment in modules is slightly higher, the increased power generation and reduced operational costs can significantly offset the cost per kilowatt-hour, creating a more favorable internal rate of return (IRR) model for investors.

This trend is reshaping the underlying logic of global energy investment decisions: as PV power plants evolve from "cost-sensitive" assets to "value-creating" assets, the criteria for technology selection will inevitably shift toward maximizing the value over the entire lifecycle. This white paper will delve into how TOPCon technology builds new competitive advantages in cost per kilowatt-hour through efficiency improvements, power generation gains, and system adaptability breakthroughs, and illustrate the commercial value paradigm created by JinkoSolar's Tiger Neo 3.0 in global energy applications. In this round of industry transformation led by N-type technology, technological innovators are writing the next value growth equation for the era of grid-parity PVs.

1.2 Industrial Background of TOPCon Technology

In the wave of clean energy, PV cell technology, as the core driving force of energy transformation, has undergone multiple innovations from monocrystalline silicon to polycrystalline silicon, PERC, TOPCon, and tandem technology. These technological advancements have not only significantly improved PV conversion efficiency but also drastically reduced the cost of PV power generation, making it gradually become the mainstream energy form globally.

Monocrystalline silicon cells, with their high-purity crystals and excellent PV performance, first laid the foundation for the PV industry. However, the high production costs limited its large-scale application, prompting the industry to shift its focus to the research, development, and promotion of polycrystalline silicon cells. Polycrystalline silicon cells dominated the global PV market for a certain period by reducing material costs. Although their PV conversion efficiency was slightly lower than that of monocrystalline silicon, their lower manufacturing costs enabled them to rapidly gain widespread adoption, laying a solid foundation for the large-scale development of the PV industry.

With the emergence of PERC technology, PV cell efficiency has reached a new level. PERC technology enhances efficiency by adding a passivation layer and localized metal contacts on the back of the cell, effectively reducing the recombination loss of photogenerated carriers while improving back reflection efficiency. This technological innovation marked the beginning of the high-efficiency cell era, with efficiency improvements of approximately 0.5%–1% compared to traditional aluminum back-field cells. The widespread adoption of PERC cells further reduced the cost of PV power generation, enhancing its competitiveness on a global scale.

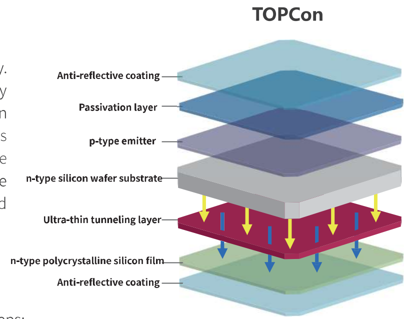
Subsequently, TOPCon technology, with its unique tunnel oxide layer and doped polycrystalline silicon layer design, achieved more efficient carrier transport and surface passivation. Compared to PERC, TOPCon technology demonstrates significant advantages in terms of open-circuit voltage and fill factor, with efficiency improvements of up to 0.5%–1%. Additionally, TOPCon cells exhibit better temperature coefficients and bifacial power generation performance, enabling superior performance under high-temperature environments and complex lighting conditions. This technology fundamentally transforms the basic structure and operating principles of cells, opening new possibilities for further improvements in PV cell efficiency. During the same period, Back Contact (BC) emerged as a complementary process-level innovation, offering new optimization strategies within the existing TOPCon technology framework. By relocating the front electrode to the back side, BC reduces shading area, thereby improving cell aesthetics and increasing efficiency. The ongoing development of BC will drive deeper technical iterations of TOPCon technology.

With the advent of the tandem cell era, PV cell technology has entered a new phase of development. By combining the complementary properties of materials with different bandgaps, tandem structures can fully utilize different wavelength bands of sunlight, theoretically enabling PV conversion efficiency to exceed 30%. This breakthrough design not only expands the application scenarios of PV cells but also points the way forward for the development of ultra-high-efficiency cells in the future.

In summary, with its unique structural design and excellent performance, TOPCon technology has quickly gained widespread recognition in the global market since its launch. With a market share exceeding 70% that is still growing rapidly, it has become a key force in promoting the PV industry toward higher efficiency.

02 | TOPCon Technology Overview

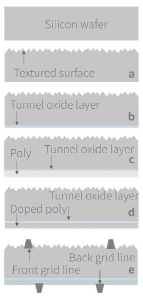
2.1. TOPCon Technology Principles



TOPCon (Tunnel Oxide Passivated Contact) is an advanced PV cell technology. Its core lies in the formation of an ultra-thin silicon oxide layer (approximately 1–2 nm thick) combined with a doped polycrystalline silicon layer on the silicon wafer surface, enabling selective carrier transport and surface passivation. This structure allows a small number of charge carriers to pass through the oxide layer via the quantum tunneling effect while blocking the majority of charge carriers, thereby significantly reducing surface recombination rates and improving open-circuit voltage and PV conversion efficiency.

2.2. TOPCon Cell Fabrication Process

The fabrication process of TOPCon cells primarily includes the following key steps:



a. Cleaning and texturing: The silicon wafer surface is cleaned, and a pyramid structure is formed to reduce reflection and improve light absorption efficiency.

b. Tunneling oxide layer preparation: A thin layer of ultra-thin silicon oxide is grown on the back of the silicon wafer using thermal oxidation or plasma-enhanced chemical vapor deposition (PECVD) technology.

c. Polysilicon Layer Deposition: A doped amorphous silicon film is deposited on the oxide layer using low-pressure chemical vapor deposition (LPCVD) or PECVD methods, followed by annealing to crystallize it into polysilicon.

d. Phosphorus Diffusion and Activation: Phosphorus is injected or diffused at high temperatures to optimize doping effects and activate passivation properties.

e. Metallization process: Metallization is performed in the front and back electrode regions using screen printing or laser sintering technology to form low-resistance ohmic contacts.

The pyramid structure formed by the texturing process effectively reduces light reflectance, allowing more photons to enter the silicon wafer and be absorbed, thereby increasing the number of photogenerated carriers. Electrically, the core of the TOPCon cell lies in its unique tunnel oxide layer and polycrystalline silicon layer structure. The ultra-thin tunnel oxide layer provides excellent surface passivation, reducing carrier recombination losses at the interface, while the polycrystalline silicon layer serves as an efficient carrier transport channel, further improving carrier collection efficiency. This combination enables TOPCon cells to perform exceptionally well in terms of open-circuit voltage and fill factor, ultimately achieving higher PV conversion efficiency.

2.3.Advantages of TOPCon Technology

2.3.1 Advantages of TOPCon over PERC Technology

Compared to the previous-generation PERC technology, TOPCon demonstrates significant advantages in multiple aspects. First, in terms of efficiency, TOPCon achieves an approximately 1% to 2% higher PV conversion efficiency than PERC cells by introducing a tunneling oxide layer and a polycrystalline silicon layer structure, which significantly improves surface passivation quality and carrier transport efficiency. Second, TOPCon has a higher bifaciality coefficient, typically exceeding 80%, meaning it can capture more reflected light from the rear side, further increasing power generation. Additionally, TOPCon exhibits lower light-induced degradation (LID) and potential-induced degradation (PID), which not only improves the long-term stability of the cells but also enhances investors' confidence in the profitability of power plants.

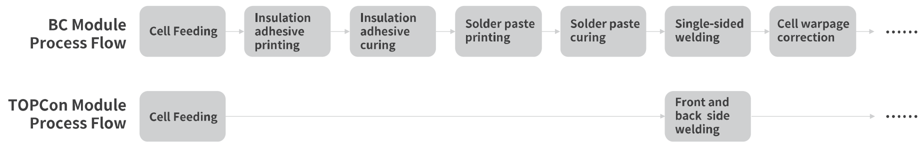
Furthermore, TOPCon has a lower temperature coefficient, resulting in smaller power losses at high temperatures compared to PERC. This characteristic is particularly important for PV systems installed in hot regions, as a lower temperature coefficient means that TOPCon can maintain higher output power even under high-temperature conditions, thereby improving the overall system's power generation performance and economic efficiency. In summary, based on the further development of PERC technology, TOPCon demonstrates significant technical advantages in terms of high efficiency, high bifaciality, low degradation, and low temperature coefficient, bringing new growth momentum and development directions to the PV industry.

2.3.2 Advantages of TOPCon over BC Technology

The advantages of TOPCon over BC products primarily lie in three aspects: manufacturing process, cost, and reliability.
TOPCon achieves lower manufacturing costs than BC by simplifying the manufacturing process and reducing production line investment, resulting in a cost reduction of 0.08–0.1 CNY/W. TOPCon cells retain metal grid lines (busbars and fingers) on the front side, while the back side achieves passivation contact through a tunneling oxide layer and doped polysilicon layer. This symmetrical structure provides superior mechanical strength compared to BC modules. TOPCon cells adopt a front-back contact structure, retaining the diffusion junction on the front side. The presence of the diffusion junction enhances the cell surface's resistance to ultraviolet radiation and slows down the degradation rate of the passivation layer. In BC cells, lateral carrier transport leads to localized resistance heating, which can easily form hot spots at high temperatures (hot spot temperature >100 ° C), accelerating the aging of encapsulation materials (such as EVA yellowing). Through empirical testing, TOPCon modules exhibit a UV60 degradation of 1.23%, while BC modules show a UV60 degradation of 2.20%.

2.3.2.1 Process Flow

TOPCon only needs to coat the ribbon with flux, and then weld the cells into strings through infrared heating. BC cells need to undergo an additional cell printing process (insulating glue printing and solder paste printing) before string welding. The printing yield (missed prints, incomplete prints) affects the string welding process (string return 2%–4%), and the fragment rate is 0.1–0.2% higher than TOPCon.
TOPCon has a busbar spacing of 8–11 mm, with the welded strips distributed on both sides of the cell, offering advantages in current carrying capacity and stress symmetry distribution. The process is simpler, with a yield rate >99.7%. BC cells are single-sided welded, but due to different thermal expansion coefficients between the welded strips and the silicon substrate, the cells may warp after welding, leading to easy breakage during lamination. Printing issues like missed or incomplete prints can cause short-circuit defects, which reduces the overall yield to 99%–99.5%.



2.3.2.2 Cost

a. Investment: Initial investment for new TOPCon production capacity is 22.4–23.8 million USD/GW, and capacity can be rapidly scaled up by upgrading existing PERC production lines (conversion cost approximately 4.2–7.0 million USD/GW). Initial investment for new BC production capacity is 35–42 million USD/GW.

b. Costs: TOPCon modules are 1.1-1.4 USD/W cheaper than BC modules, primarily due to advantages in non-silicon material costs, yield rates, and equipment depreciation. BC modules still require large-scale production and technological breakthroughs to reduce costs.

BC Post-Welding Structural Diagram

TOPCon Post-Welding Structural Diagram

2.3.2.3 Reliability

a.Mechanical strength： TOPCon modules are superior to BC modules in terms of load performance (such as mechanical strength and resistance to hidden cracks). TOPCon cells retain metal grids (busbars and fingers) on the front side and achieve passivation contact on the back side through a tunnel oxide layer and a doped polycrystalline silicon layer. This structure is relatively symmetrical, and the electrodes are distributed on both the front and back sides, resulting in a more uniform overall stress distribution, dispersing stress caused by mechanical loads (such as wind pressure and snow load), and reducing the risk of local stress concentration. TOPCon cell electrodes are formed via screen printing, requiring fewer laser grooving or etching steps compared to BC, with a mature process that causes minimal damage to the silicon wafer, thereby enhancing the structural stability of the silicon wafer.

b.UV Degradation Resistance： TOPCon modules exhibit superior UV degradation resistance compared to BC modules. (Empirical data: TOPCon modules UV60 degradation 1.23%, BC modules UV60 degradation 2.20%).

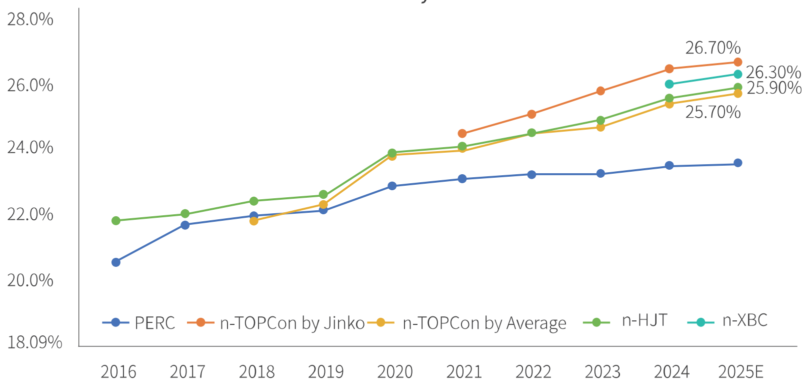
03 | Core Advantages of TOPCon Modules

3.1 High-Efficiency of TOPCon Cells

TOPCon cell efficiency has surged from 25.1% in 2022 to 25.8% in 2023 and 26.5% in 2024. JinkoSolar, leveraging its deep technical expertise and strong R&D capabilities, continues to break through mass-production efficiency limits. These figures not only validate technological progress but also demonstrate JinkoSolar's leading position in the PV industry, with mass-production efficiency consistently exceeding the industry average.

It is expected that JinkoSolar's mass-production efficiency will reach 26.7%–27% in 2025, further consolidating its leadership.
By 2026, crystalline silicon cell technology will approach the physical efficiency limit of its materials. Under this background, JinkoSolar is actively exploring the integration of TOPCon and perovskite technologies to form tandem cells. This innovative solution theoretically achieves an efficiency of 34.22% (a record achieved by JinkoSolar), opening up new directions for PV technology development. JinkoSolar's early planning and in-depth research on TOPCon-perovskite tandem technology highlight its forward-looking approach to technological innovation and the high extensibility of TOPCon technology.

The development trend of China solar cell mass production conversion efficiency from 2016 to 2025



*CPIA's "China Photovoltaic Industry Development Roadmap 2024-2025" Company Annual Reports

3.2 High bifaciality of TOPCon Module

TOPCon modules also far outperform BC technology modules in terms of overall power and efficiency. Based on the current test method for bifacial modules, the simplified formula is: Front Power + (Front Power * Bifaciality Coefficient * Rear Irradiance). The mainstream bifaciality coefficient of TOPCon modules is over 85%, while that of BC modules is over 75%.

The specific differences are shown in the following table:

 Water Albedo：2～5%	TOPCon Overall Power	=670+670*85%*5%	=698.5w	TOPCon Higher 3.4w
	BC Overall Power	=670+670*75%*5%	=695.1w	
 Grass Albedo：10～20%	TOPCon Overall Power	=670+670*85%*6%	=704.2w	TOPCon Higher 4w
	BC Overall Power	=670+670*75%*6%	=700.2w	
 Sand Albedo：22～25%	TOPCon Overall Power	=670+670*85%*8%	=715.6w	TOPCon Higher 5.4w
	BC Overall Power	=670+670*75%*8%	=710.2w	
 Cement Albedo：30～33%	TOPCon Overall Power	=670+670*85%*10%	=727.0w	TOPCon Higher 6.7w
	BC Overall Power	=670+670*75%*10%	=720.3w	
 White-paint Albedo：80～85%	TOPCon Overall Power	=670+670*85%*15%	=755.4w	TOPCon Higher 10w
	BC Overall Power	=670+670*75%*15%	=745.4w	

In summary, with the same module size, due to the higher bifaciality alone, TOPCon modules can deliver a higher overall power across all application scenarios, which is approximately 1% higher than that of BC modules on average.

03 | Core Advantages of TOPCon Modules

3.3 Low-irradiance performance of TOPCon Module

TOPCon has better low-irradiance performance than BC because its cell structure can reduce the leakage current path. It adopts a tunnel oxide layer structure that can effectively reduce energy loss and improve low-light conversion efficiency.

Type	Irradiation (W/m²)	Pmpp	Uoc	Isc	FF	Low irradiance Performance
TOPCon	1000	610.2	53.35	13.86	82.53%	96.77%
	200	118.1	50.70	3.00	77.72%	
BC-Company A	1000	650.0	53.62	14.84	81.67%	94.28%
	200	122.6	51.02	3.14	76.49%	
BC-Company B	1000	627.1	53.33	14.63	80.66%	94.51%
	200	118.5	50.49	3.12	75.55%	

According to the test method of IEC 61215-2:2021, it is calculated that the TOPCon module generates 2.26% - 2.49% more power compared to BC under low irradiation conditions. This also means that the TOPCon module can make full use of morning and evening sunlight, increase power generation during high-electricity-price periods, and maximize revenue.

3.4 Better UVID performance of TOPCon Module

The manufacturing process of the TOPCon cell incorporates an optimized passivation layer design, which includes increasing the thickness and uniformity of the AlO film and adjusting the refractive index of SiNx. The process also strengthens control of thin-film deposition, such as standardizing monitoring methods for the thickness and uniformity of AlO thin films and increasing the detection frequency.

Synchronously, ultraviolet monitoring of PV cells is increased; for example, the UV monitoring frequency for modules is tripled. Meanwhile, TOPCon modules adopt superior encapsulating materials. Therefore, the product exhibits superior performance in the UVID test, with lower degradation rates compared to other technologies in areas with high ultraviolet radiation (such as Yunnan, Qinghai, coastal areas, the Middle East and Africa, etc.).

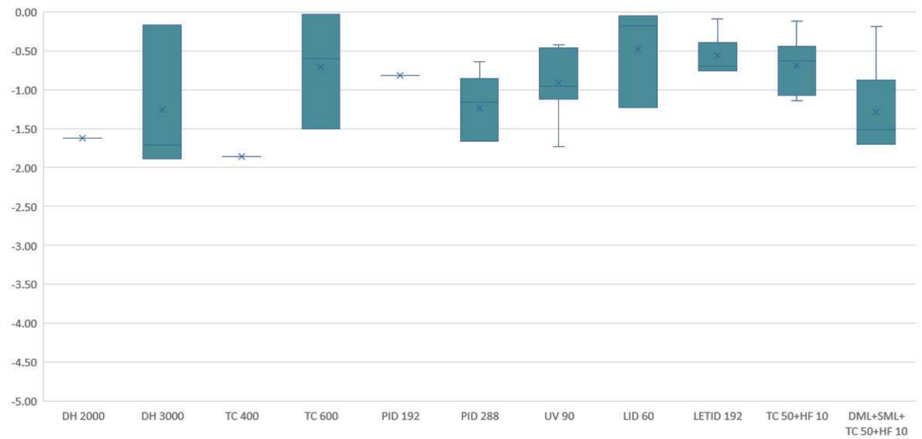
After the UV test, all types of modules will show similar UVID phenomena, but the TOPCon technology modules have the best degradation rate, which is much lower than the degradation values of other technologies.

04 | Reliability and Application

4.1 3x IEC Reliability Testing

The 3x IEC Reliability Testing for PV modules is an enhanced testing methodology designed to validate long-term reliability and durability under extreme environmental conditions. Based on International Electrotechnical Commission (IEC) standards (e.g., IEC 61215, IEC 61730), it intensifies testing by increasing severity levels or repetition cycles (typically 3 times the IEC standard requirements). This simulates module performance in harsher environments, ensuring high reliability in real-world applications. Test data from the authoritative third-party institution TÜV NORD provides laboratory validation for the stable power generation performance and safety reliability of JinkoSolar's TOPCon technology modules throughout their lifecycle. The test data is shown below:

Power Degradation (%) Before & After 3x IEC Reliability test



Overall, the 3x IEC Reliability Testing represents the PV industry's pursuit of higher product quality standards, holding significant importance, especially in extreme environment applications. JinkoSolar's high success rate in passing the 3x IEC test series provides strong evidence of its product quality and reliability, further enhancing its competitiveness and influence in the global PV market.

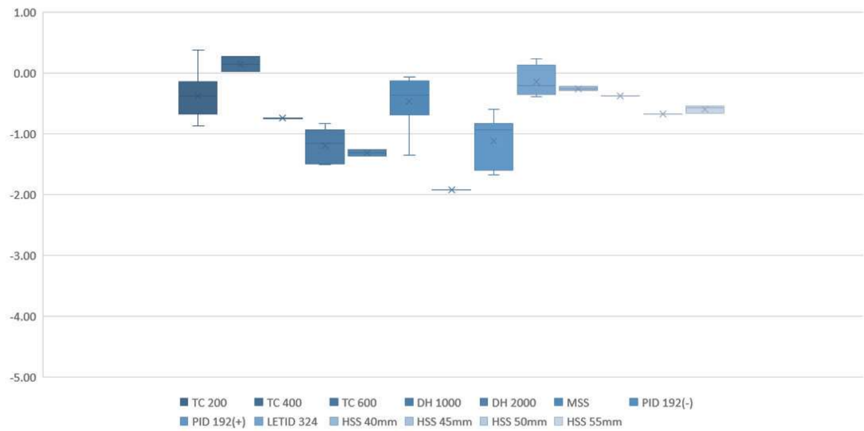
4.2 PQP Testing

PQP Testing is a comprehensive and rigorous PV module quality certification designed to ensure modules maintain outstanding reliability under diverse environmental conditions. It encompasses intensified reliability tests including TC (Thermal Cycling), DH (Damp Heat), MSS (Mechanical Load Sequence), PID (Potential Induced Degradation), LID+LETID (Light Induced Degradation + Light and Elevated Temperature Induced Degradation), PAN (Performance at Nominal conditions), and UV Aging Test.

JinkoSolar earned the "Top Performer" accolade in Kiwa PVEL's 2025 PV Module Reliability Scorecard report. 2025 marks the eleventh year Kiwa PVEL has published this report, which aims to recognize leading module manufacturers excelling in their Product Qualification Program (PQP) testing. JinkoSolar is one of the few manufacturers globally to achieve the "Top Performer" honor in all eleven consecutive reports, validating the superior performance of JinkoSolar TOPCon modules in delivering high levels of reliability and power generation capability even under harsh climatic conditions.

TOP PERFORMER 2025 kiwa PV MODULE RELIABILITY SCORECARD

Power Degradation (%) Before & After PQP test



In the Renewable Energy Test Center (RETC) 2025 "PV Module Index (PVMI)" report, JinkoSolar was awarded the "High Achiever" distinction for the sixth consecutive year. The "High Achiever" award recognizes manufacturers demonstrating outstanding performance across the three dimensions of reliability, performance, and quality, representing the program's highest honor. This program provides assurance to project owners, insurers, investors, and engineers, ensuring mass-produced PV modules perform reliably in commercial operations.

2025 PV Module Index Report RETC part of the VDE GROUP OVERALL HIGHEST ACHIEVER

4.3 Module Application Across All Scenarios

JinkoSolar is committed to exploring new application scenarios for PV modules to meet evolving industry and societal demands. As application scenarios diversify to include deserts, Gobi regions, barren lands, coal mining subsidence areas, saline-alkali tidal flats, mountainous terrain, and offshore environments, JinkoSolar has developed a comprehensive All-Scenario PV Solution that balances high efficiency with reliability.

4.3.1 "Three Advantaged" Modules

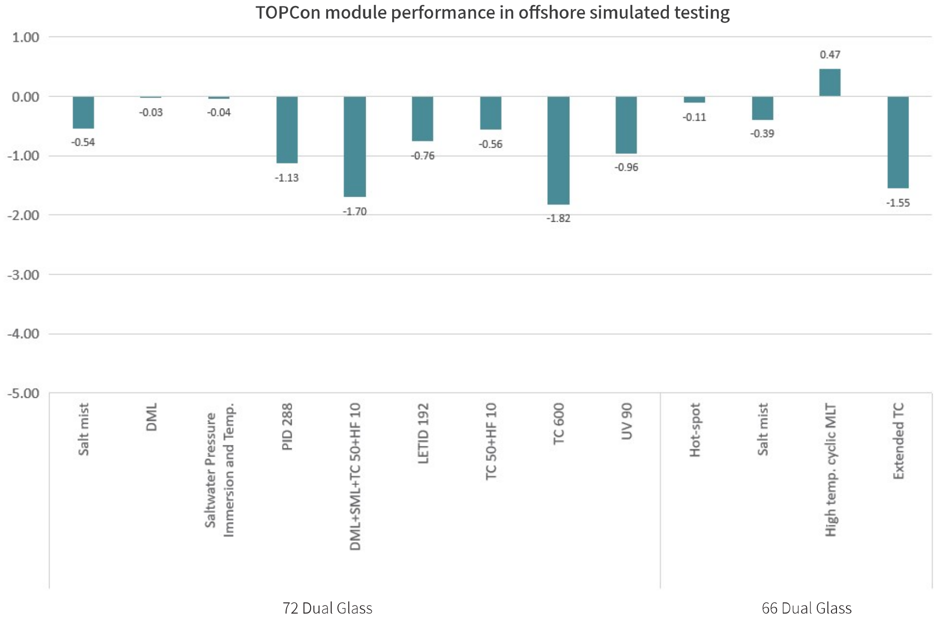
JinkoSolar's "Three Advantaged" modules are designed for extreme weather scenarios such as hail and hurricanes, featuring "High Hail Resistance, High Wind Load Resistance, and High Fire Rating" performance. This product has successfully passed:

55mm Hail Impact Test by authoritative third-party institutions TÜV SUD and RETC.
Maximum Static Load Test of 4000 Pa (standard installation) / 5400 Pa (special installation) on the rear side.
Achieves IEC Fire Class A and UL Fire Type 30 ratings.

04 | Reliability and Application

4.3.2 Offshore Modules

JinkoSolar's Offshore modules are designed for the specific marine environment characterized by the "Three Highs and Two Strengths" (High Temperature, High Humidity, High Salt Mist, Strong Wind, and Strong Waves). Utilizing AA20 High-Strength Frames, Double-Layer Coated Glass, and Double-Sided POE Encapsulation technology, these modules effectively block moisture ingress and resist salt mist corrosion, having passed rigorous third-party testing.



JinkoSolar has successfully transitioned offshore PV projects from concept to reality, facilitating the successful deployment of numerous marine projects. Notably, China's first far-sea floating PV project – the CIMC Offshore Semi-Submersible Floating PV Demonstration Platform – has undergone 1.5 years of reliability validation. This project conducted comprehensive performance tests on modules, including power degradation, EL, insulation, and static mechanical load. Results demonstrate the exceptional performance of JinkoSolar's offshore PV modules, which not only passed all tests but also exhibited outstanding mechanical load resistance. Electrically, they showed significantly lower degradation rates; compared to conventional modules, JinkoSolar's N-type TOPCon offshore modules reduced degradation by nearly 20%, thereby meeting the high reliability and stability demands of offshore PV projects.

Marine Environment Characteristic	Test Item Targeting Marine Environment	Test Method Targeting Marine Environment	Conventional Test Method	Test Purpose	Test Standard
Strong Corrosivity	Alternating Salt Spray Test	PH=3.5，5%NaCl	No salt spray test	Evaluate reliability under high salt mist	IEC 60068 - 2-52 Test Method 8
	PID Test	PH=3.5，96h*3cycle	PH=7, 96h*3cycle	Evaluate salt mist corrosion of materials/ components & PID performance	IEC TS 62804 - 1:2015, method a
High Temperature	High-Temperature Test	-40 - 110 °C*392cycle	40 - 85 °C 200cycle	Evaluate performance with seawater cooling and frequent temperature changes	IEC 62892
	Hot Spot Test	Level 2: 70°C after salt spray (uncleaned)	50°C (no salt spray)	Evaluate hot spot performance post-salt spray without cleaning	IEC 61215-2
High Humidity	Damp Heat + UV Test	UV 180W/m² & DH applied simultaneously for 1000h	DH 1000h	More rigorous assessment of moisture resistance (combined UV & DH)	IEC 61215-2
Strong UV Radiation			UV 15W/m²		IEC TR 63279
High Wind Load	Dynamic Mechanical Load Test	±1000Pa*1000cycle	No dynamic load test	Evaluate mechanical performance & power degradation under high winds	IEC 61215-2 IEC TS 62782
	Wind Tunnel Test	60m/s*10mins	No Wind Tunnel Test	Evaluate overall wind resistance of modules mounted on floats/piles	DIN 1055-4

4.3.3 Anti-Dust Modules

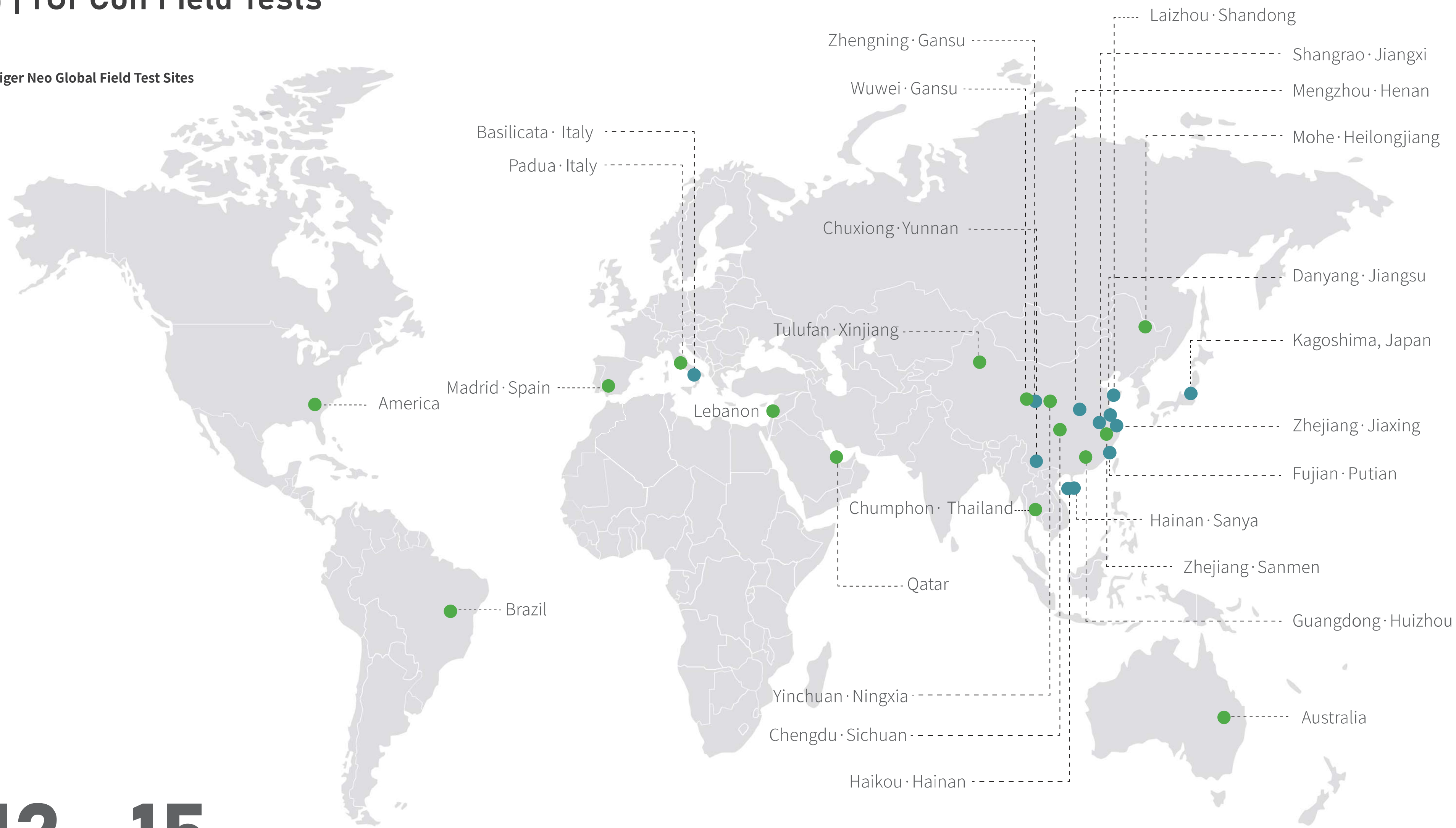
JinkoSolar's Anti-Dust modules target commercial & industrial (C&I) and residential rooftop applications characterized by low roof pitch, significant dust accumulation, low cleaning frequency, high cleaning difficulty, yet requiring high power generation efficiency. The module frame features an innovative design where the short sides lack an 'A' surface, making the frame flush with the glass surface. This innovation allows rainwater to flow naturally and smoothly off the frame, significantly reducing dust retention and accumulation on the front surface. This translates to an increase in power generation efficiency by over 3% on average and reduced long-term O&M costs. Additionally, the module has passed impact tests with hailstones up to 45mm and static load tests up to 6000/-3000 Pa (Jinko installation method), which ensures the module's reliability.

4.3.4 "Desert" Modules

JinkoSolar is currently developing "Desert Modules" specifically engineered for the challenging desert environment characterized by High UV Radiation, High Mechanical Loads, Large Temperature Fluctuations, and Abundant Sand/Dust. These modules will feature high temperature resistance, sand/dust resistance, UV resistance, and high reliability, enabling optimal adaptation to harsh desert conditions, ensuring long-term stable operation, and reducing maintenance costs. Simultaneously, they will possess ultra-high conversion efficiency to maximize sunlight-to-electricity conversion under the intense desert irradiance, significantly boosting energy yield.

05 | TOPCon Field Tests

5.1 Tiger Neo Global Field Test Sites



12 In Operation **15** Planning

Ground: Grassland	Ground: Barren land	Ground: Concrete	C&I: Corrugated Metal Roofing	C&I: Concrete Roofing	Residential Rooftop	Desert	Shallow Water	Offshore
Brazil	Australia	America	Zhejiang · Jiaxing	Zhengning · Gansu	Danyang · Jiangsu	Wuwei · Gansu	Zhejiang · Sanmen	Fujian · Putian
Hainan · Sanya	Yinchuan · Ningxia	Kagoshima, Japan	Shangrao · Jiangxi	Guangdong · Huizhou	Laizhou · Shandong	Qatar		
Basilicata · Italy	Mengzhou · Henan	Madrid · Spain	Chuxiong · Yunnan	Haikou · Hainan		Lebanon		
	Mohe · Heilongjiang			Chengdu · Sichuan		Tulufan · Xinjiang		
	Chumphon · Thailand							
	Padua · Italy							

*The field tests above involve JinkoSolar TOPCon modules and BC modules, covering third-party testing sites and client field test sites

鉴衡认证
CHINA GENERAL CERTIFICATION

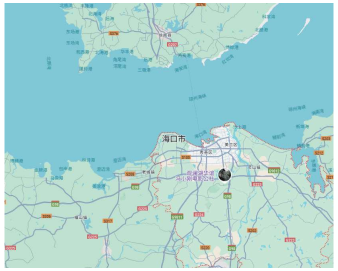
Haikou, Hainan Outdoor Field Test

TOPCon Demonstrates 5.11% Higher Energy Yield Gain Compared to N-type BC Modules

Project Location: Haikou, Hainan Province, China (19°31’ 32” N, 110°07’ 22” E)

Site Selection: Haikou is located in the northern part of Hainan Island, situated on the northern edge of the tropical zone. It features a tropical monsoon climate with no harsh winters or scorching summers. The climate is warm and pleasant year-round with evergreen conditions. The area has long annual sunshine hours and high solar radiation, with an average annual total irradiance of 2043.8 kWh/m², average annual temperature of 25.2°C, average wind speed of 2.9 m/s, and relative humidity of 89.3% RH.

Project Overview: This field test involved Jinko’ s N-type TOPCon modules with an average bifaciality of 83.0% and another manufacturer’ s N-type BC modules with an average bifaciality of 68.7%. Each type had 10 modules installed. All were mounted on fixed racks (≈20° tilt) on a rooftop, with the lowest edge of the modules 0.5 meters above the concrete surface. Each module was equipped with high-precision sensors to monitor real-time power output and ensure accurate and reliable test results.

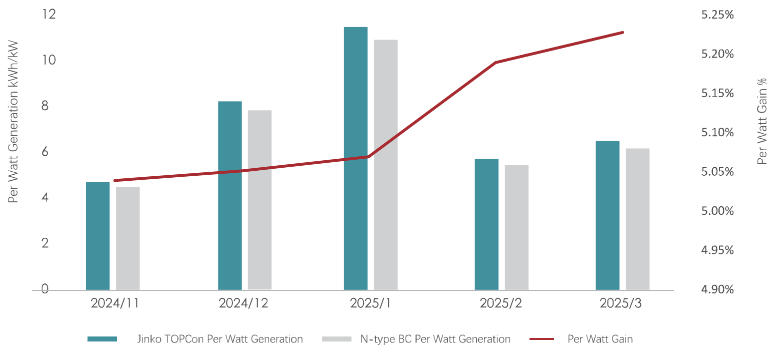


	Jinko N-type TOPCon Module	BC Module
Technology	TOPCon	BC
Specification	2278X1134X30mm	
Quantity	10 pcs	10 pcs
Power	575	575
Installation Scenario	Rooftop Mounting	
Installation height	0.5m	
Starting Time	2024-11-14	

Test Results: The report compares the energy yield and thermal performance of Jinko’ s N-type TOPCon modules and N-type BC modules over a one-quarter test period from November 15, 2024, to March 31, 2025. Key insights include:

1.The data shows that Jinko’ s TOPCon modules outperformed N-type BC modules in terms of energy yield, achieving a 5.11% higher yield.

2.The performance ratio (PR) of Jinko’ s TOPCon modules reached 95.48%, while the PR of the BC modules was 90.89%. The significantly higher PR indicates that Jinko’ s TOPCon modules experienced lower overall system losses—including losses due to temperature, wiring, and dust—resulting in better system efficiency during actual operation.



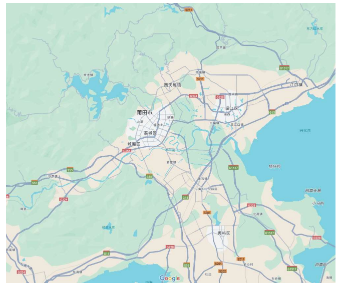
Mengzhou, Henan Outdoor Field Test

Monthly Energy Yield Gain of up to 4.71% for TOPCon Compared to P-type BC Modules

Project Location: Mengzhou City, Henan Province (34°50’ N, 112°33’ E)

Site Selection: This project was conducted as part of an owner’ s actual power generation project, meaning the results reflect the actual performance of the modules in use. Mengzhou, Henan, has a warm temperate continental monsoon climate, with hot and rainy seasons overlapping. The test period covered the winter season, during which the low solar altitude placed particular emphasis on evaluating the modules’ bifacial performance.

Project Overview: The two types of modules used in this field test were 575W N-type TOPCon modules and 575Wp P-type BC modules from another manufacturer. Each type included 18 modules. They were installed on fixed mounting racks at a tilt angle of 35° . All modules were equipped with high-precision sensors to monitor real-time energy yield data and ensure the accuracy and reliability of the test results.

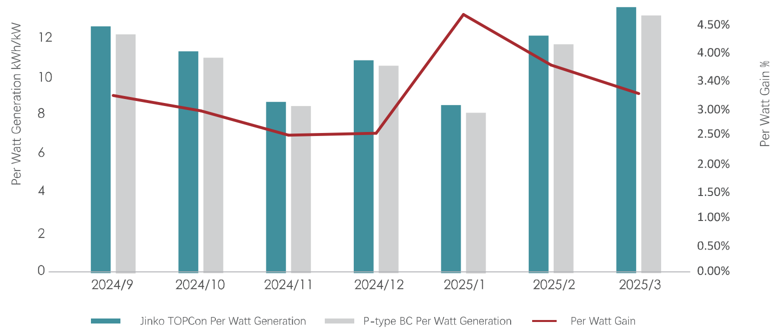


	Jinko N-type TOPCon Module	BC Module
Technology	TOPCon	BC
Specification	2278X1134X30mm	
Quantity	18 pcs	18 pcs
Power	575	575
Installation Scenario	Ground Mounted	
Installation height	1.5m	
Starting Time	2024-8-14	

Test Results: An analysis of performance data from September 2024 to March 2025 showed that JinkoSolar’ s TOPCon modules demonstrated excellent energy yield capability, producing an average per-watt yield 3.27% higher than that of the P-type BC modules. Notably, in January—when sunlight conditions were weaker—TOPCon modules, with a bifaciality exceeding 80%, effectively utilized ground-reflected light to further improve efficiency. During this period, their per-watt energy yield was 4.71% higher than that of the P-type BC modules, fully demonstrating the advantage of high bifaciality.

Throughout the test period, the operating temperature of TOPCon modules remained consistently lower than that of P-type BC modules. The P-type BC’ s rear-contact design tends to trap heat on the back surface, causing the module temperature to rise and reducing power output efficiency. This issue may be even more pronounced in bifacial P-type BC modules, as both sides are glass-covered. Combined with the rear-contact design, this leads to greater heat accumulation, further increasing the risk of reduced efficiency and accelerated module aging.

The bifaciality of TOPCon modules ranges from 75% to 85%, significantly higher than the 55% to 65% of P-type BC modules. In Mengzhou, this difference is particularly important, as the sandy ground with high reflectivity can effectively bounce extra light onto the module’ s rear surface. A higher bifaciality allows the module to capture more of this reflected light, significantly enhancing overall power generation.



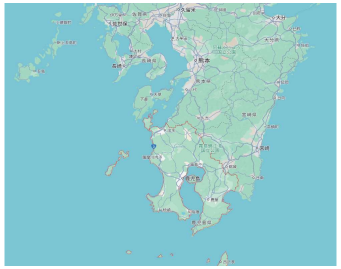
Kagoshima, Japan Outdoor Field Test

TOPCon Achieves 7.1% Long-Term Energy Yield Gain Over N-type BC Modules

Project Location: Kagoshima, Japan (32°3′57″N, 130°19′53″E)

Site Selection: Kagoshima’ s coastal location and subtropical marine climate—with high humidity, salt exposure, and seasonal variation—makes it an ideal site to test solar module durability, corrosion resistance, and performance in challenging conditions. It also provides valuable data for nearshore and offshore PV applications.

Project Overview: The field test installed two types of modules: N-type TOPCon and N-type BC. Two modules from each manufacturer were mounted on fixed racks 1.2 meters above the ground at a tilt angle of 32°. Initial power was measured using a transient simulator (SAT method), without spectral correction in the results. DC power output of each module was collected using a high-precision CR1000X data acquisition system, with a sampling interval of one minute. In parallel, irradiance on module surfaces, backsheet temperature, ambient temperature and humidity, and atmospheric pressure were also recorded every minute.



Technology	Size(mm)	Type
N-type TOPCon	2278x1134x30	Bifacial
N-type BC	2278x1134x30	Monofacial

Test Results: Between October 2024 and March 2025, comprehensive performance tests were conducted on the two module types. Results showed that TOPCon modules delivered a six-month normalized energy yield of 495.36 kWh/kW, while N-type BC modules yielded 462.54 kWh/kW. This translates to an average long-term per-watt energy yield gain of 7.1% for TOPCon. Key insights include:

1. From October to December 2024, Kagoshima experienced frequent rainy and cloudy days, with few sunny days. Under these low-irradiance conditions, TOPCon modules demonstrated superior low-light performance. For example, during a 15-day cloudy period from October 15 to 29, the average daily per-watt gain reached 9.13%.

2. In sunny conditions, TOPCon’ s high bifaciality of up to 80%+ boosted energy yield. This benefit was particularly prominent in Kagoshima, where gravel surfaces with high albedo helped reflect more light onto the module backsides. Higher bifaciality allows TOPCon modules to capture more reflected light, significantly increasing generation.

3. Located 2km away from the coast, the test site exposed modules to high humidity and salt mist. This made reliability critical. The test confirmed TOPCon’ s excellent durability and stability in nearshore and offshore environments, maintaining high output and extending system lifespan even under harsh conditions.

Laizhou, Shandong Ourdoor Field Test

Up tp 4.77% Monthly Yield Gain of TOPCon Over P-Type BC

Project Location: Laizhou, Shandong Province, China (34°50′ N, 112°33′ E)

Site Selection: Laizhou is a coastal city with abundant sunlight and a marine climate. This site was selected for pilot testing of PV modules under different environmental conditions. This case specifically evaluates the power generation performance of TOPCon versus P-type BC modules in a real residential solar power plant scenario.

Project Overview: This is a rooftop residential PV project located 2km away from the coastline in Laizhou, Shandong. Two types of modules were installed: Jinko’ s N-type TOPCon modules (rated at 575W) and P-type BC modules (ratedat 580W). The modules are south-facing, installed at a 20° tilt. Each type used 15 modules per string and shared the same model of inverter from the same manufacturer. The modules were installed approximately 10cm above the rooftop surface, with no shading at the test site.

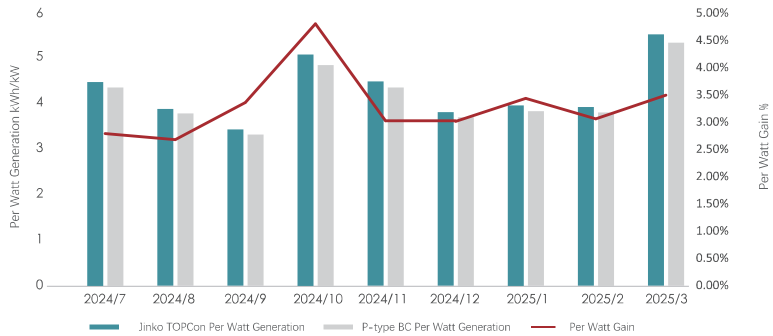
	Jinko N-type TOPCon Module	P-type BC Module
Technology	TOPCon	BC
Specification	2278X1134X30mm	
Quantity	15 pcs	15 pcs
Power	575	580
Installation Scenario	Rooftop Mounting	
Starting Time	2024-6-23	

Test Results: From July 2024 to March 2025, Jinko’ s N-type TOPCon modules achieved an average daily power output of 4.27 kWh/kW, compared to 4.13 kWh/kW for the P-type BC modules—an energy yield gain of 3.31%. Under low-light conditions, TOPCon modules showed even more pronounced advantages. Data from clear mornings and afternoons in October and November (7:00–9:00 AM and 3:00–5:00 PM) showed that TOPCon modules outperformed P-type BC modules by 8.29%. Key insights include:

1. During hot summer months (July–September) in Shandong, Jinko’ s TOPCon modules demonstrated superior heat dissipation, leading to significantly lower power degradation than P-type BC modules. This thermal stability allowed TOPCon to maintain higher efficiency and improve annual system output.

2. In low irradiance conditions, such as early morning and late afternoon (7:00–9:00 AM and 3:00–5:00 PM), TOPCon generated 8% more electricity than P-type BC. This shows TOPCon’ s excellent weak-light performance, delivering stable and higher energy yields even under cloudy or low-sunlight conditions.

3. Backed by multiple field studies and offshore PV projects, Jinko’ s TOPCon modules have proven their high durability and reliability in nearshore and marine environments. Even under harsh conditions like high humidity and salt mist, TOPCon maintains strong performance and significantly extends system lifespan.



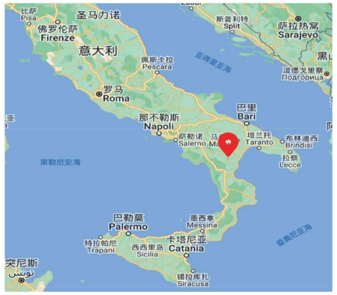
Italy Outdoor Field Test

Tiger Neo Delivers 2.04% Higher Average Energy Yield over TBC Modules

Project Location: Basilicata region, Southern Italy (40.42°N, 16.16°E)

Site Selection: This region features both a Mediterranean climate and typical environmental conditions of European PV power plants. It receives an average annual irradiance of 1800 kWh/m², with extreme summer temperatures exceeding 45°C and significant humidity fluctuations during winter. These conditions provide an effective environment to evaluate the long-term reliability of PV modules under combined stress factors such as high temperature, high humidity, and irradiance variability.

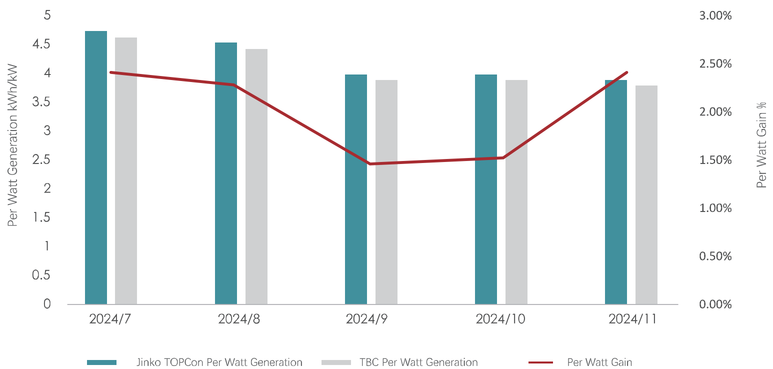
Project Overview: The European photovoltaic market accounts for 15–20% of global demand, ranking as the second-largest PV market in the world. This specific region in Southern Italy offers a mix of Mediterranean climate traits and standard European utility-scale PV conditions, making it well-suited for stress testing under variable irradiance and extreme weather. Each string in the comparative test group consisted of 16 bifacial modules. The installation angle was 33°, the ground surface was grass, and the distance between the bottom of the modules and the ground was 1 meter.



Technology	Power(W)	Size(mm)	Type
N-type TOPCon	605	2278x1134x30	Bifacial
TBC	610	2278x1134x30	Bifacial

Test Results: Data from the July to November 2024 test period show that the Tiger Neo 3.0 modules achieved an average daily energy output of 4.21 kWh/kW, while the TBC modules averaged 4.13 kWh/kW. This represents a power yield gain of 2.04%.

Month	Jinko TOPCon Per Watt Generation	TBC Per Watt Generation	Per Watt Gain
Jul	4.75	4.64	2.37%
Aug	4.52	4.42	2.26%
Sep	3.98	3.92	1.53%
Oct	3.94	3.88	1.55%
Nov	3.86	3.77	2.39%
Total	**4.21**	**4.13**	**2.04%**



Putian, Fujian Outdoor Field Test

TOPCon Achieves Monthly Energy Yield Gain of up to 2.65% Compared to P-type BC Modules

Project Location: Tidal flat area of Putian, Fujian Province (24°59' N, 118°27' E)

Site Selection: With the rapid global growth in PV installations, offshore photovoltaics have emerged as an innovative approach to energy utilization and resource development. Known for high energy yield and minimal land use, offshore PV offers an effective solution to increasingly limited land resources. However, for PV modules to operate reliably in marine environments, they must endure harsh conditions such as strong winds, extreme temperatures, seawater immersion, saltwater corrosion, and marine organism attachment.

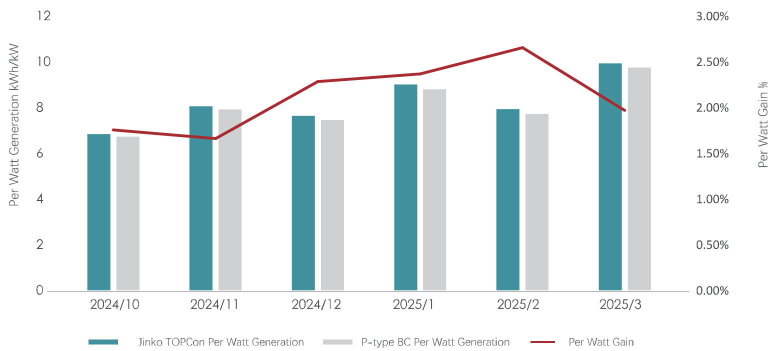
Project Overview: The tidal flat area of Putian features unique marine climate conditions, including tides, humidity, and salt mist, making it an ideal testing ground for evaluating PV module performance. This test deployed 26 Jinko N-type TOPCon bifacial modules and 26 P-type BC bifacial modules from another manufacturer. All modules were installed on fixed racks with a tilt angle of 20°, positioned about 5 meters above the ground and approximately 100 meters from the coastline.

Technology	Power(W)	Size(mm)	Type	Quantity
N-type TOPCon	575	2278x1134x30	Bifacial	26
P-type BC	580	2278x1134x30	Bifacial	26

Test Results: During the test period from October 2024 to March 2025, the Jinko N-type TOPCon modules generated a total of 492.81 kWh/kW, while the P-type BC modules produced 482.60 kWh/kW. The per-watt power yield gain for Jinko's TOPCon modules reached 2.12%. Notably, in February, which had only six sunny days, Jinko's TOPCon modules showed a significant advantage under limited sunlight, delivering a 2.65% higher energy yield per watt than P-type BC modules. Even under cloudy conditions throughout the rest of the period, TOPCon's average yield gain consistently remained above 2%. Key insights include:

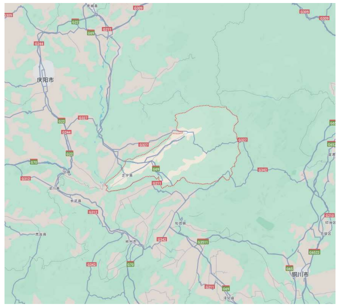
1.In offshore installation scenarios, intense solar radiation over the sea can raise module temperatures to 50°C, which can easily cause power degradation. Jinko's TOPCon modules, with excellent heat dissipation, operated at lower temperatures than P-type BC modules, significantly reducing heat-induced power loss.

2.In coastal-light environments, morning fog, evening twilight, or intermittent cloud cover often reduce irradiance. Under these conditions, weak-light performance becomes critical. TOPCon's advantage in low-light environments makes it particularly suitable for offshore applications. In cloudy or rainy conditions, its energy yield gain over P-type BC modules can exceed 2%.



Zhengning, Gansu Outdoor Field Test

TOPCon Achieves Monthly Maximum Energy Yield Gain of 2.06% Compared to P-type BC Modules



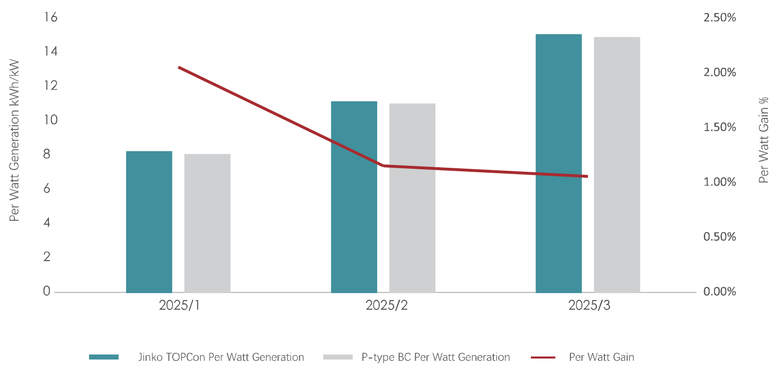
Project Location: Qingyang City, Gansu Province (35°14' 40" N, 107°57' 38" E)

Site Selection: Qingyang is located in the southern part of Gansu and features a temperate continental monsoon climate with humid and semi-humid characteristics. It has distinct seasons, with cold and dry winters, mild and humid summers, and fluctuating temperatures in spring and autumn. The average annual temperature is 8.7°C, average annual precipitation is 616 mm, and the average annual sunshine duration exceeds 2,400 hours. The establishment of this demonstration power plant provides valuable data for studying PV system performance in industrial and commercial applications in Northwest China.

Project Overview: This test compared TOPCon modules with BC modules produced by another manufacturer. All modules were installed on the rooftop of a local primary school to ensure the accuracy and consistency of measurements. The main goal was to assess and compare the real-world performance of both module types to offer efficient and reliable solar solutions for clients. Two types of modules were tested: Jinko's N-type TOPCon modules rated at 575W, and the other manufacturer's BC modules rated at 580W. Each module type consisted of 18 panels, mounted on fixed racks with a tilt angle of 20°. All modules were equipped with high-precision sensors to monitor power output in real time, ensuring the reliability and accuracy of the results.

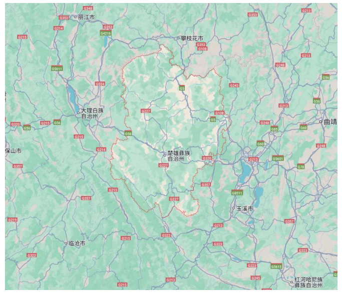
	Jinko N-type TOPCon Module	BC Module
Technology	TOPCon	BC
Specification	2278X1134X30mm	
Quantity	18 pcs	18 pcs
Power	575	575
Installation Scenario	Rooftop Mounting	
Starting Time	2024-12-24	

Test Results: From December 2024 to March 2025, several notable climatic and performance trends were observed. Taking February 2025 as an example, average daytime temperatures ranged between 2°C and 4°C, and the total irradiance for the month was recorded at 329.3 MJ/m². Due to shorter daylight hours and low solar elevation in winter, the PV modules operated under generally low irradiance conditions. Under these conditions, the per-watt energy yield of TOPCon modules was 1.33% higher than that of BC modules, demonstrating TOPCon's superior low-light response capability, which allowed it to maintain better performance in weak sunlight. Furthermore, due to the region's large temperature fluctuations between day and night and frequent wind and dust, the results reflect that TOPCon modules are more capable of delivering stable power output compared to same-size BC modules in complex climatic environments.



Chuxiong, Yunnan Outdoor Field Test

TOPCon Delivers Over 7.65% Higher Average Energy Yield Compared to N-type BC Modules



Project Location: Chuxiong City, Yunnan Province (25°2' N, 101°32' E)

Site Selection: Chuxiong in Yunnan Province is located in a subtropical monsoon climate zone. The test period spans both the dry and wet seasons, covering three representative weather patterns: continuous rainy days (15 average rainy days in November), mostly cloudy conditions (average 4.2 sunshine hours/day in December), and sunny periods (average 7.8 sunshine hours/day in January). With an annual average solar radiation of 5,800 MJ/m² and UV intensity over 30% higher than in lowland areas, this location provides valuable conditions for evaluating the comprehensive energy performance of different PV technologies, particularly in terms of low-light performance and UV-induced degradation.

Project Overview: Two types of modules were tested in this project: 610W N-type TOPCon modules and 610W N-type BC modules from another manufacturer. Each type consisted of 26 modules. The modules were installed on fixed ground-mounted racks elevated at 4.5 meters, with an effective clearance from the ground of 3.8 meters, and a tilt angle of 10°. The ground surface had an approximate reflectivity of 20%. All modules were equipped with high-precision sensors for real-time energy monitoring to ensure data accuracy and test reliability.

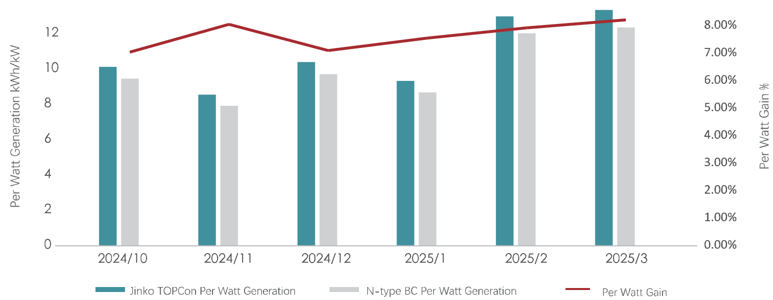
	Jinko N-type TOPCon Module	BC Module
Technology	TOPCon	BC
Specification	2278X1134X30mm	
Quantity	26 pcs	26pcs
Power	610	610
Installation Scenario	Rooftop Mounting	
Starting Time	2024-9-14	

Test Results: The results of the field study indicate that between October 2024 and March 2025, Jinko's N-type TOPCon modules demonstrated significantly better overall energy performance in Chuxiong compared to N-type BC modules, achieving an average yield gain of 7.65%. Thanks to their higher bifaciality, excellent low-light performance, and superior resistance to UV degradation, the TOPCon 3.0 modules delivered higher energy yield and more stable performance in real-world conditions. Key insights include:

1.The high bifaciality advantage of TOPCon was further validated in this field test as a key factor in improving energy yield for ground-mounted systems. Jinko's TOPCon dual-glass modules feature a bifaciality of up to 85%, compared to approximately 65% for BC modules—a 15% to 25% advantage. When installation height, tilt angle, and ground conditions are factored in, this contributes to an additional energy gain of about 3.28%.

2.TOPCon modules also performed exceptionally well under low-light conditions. On cloudy and rainy days, their daily energy yield was about 7% to 9% higher than BC modules. Particularly during the prolonged rainy period in November, the daily output of TOPCon consistently stayed at a higher level, exceeding BC modules by more than 9% on certain days.

3.In UVID90 kWh/m² testing (equivalent to 6 times the IEC61215 standard of UV15 kWh/m²), Jinko's TOPCon modules exhibited outstanding UV resistance, with degradation kept within 2%. This characteristic is particularly valuable for Yunnan, where UV radiation is significantly stronger than in lowland regions, providing solid assurance for the long-term efficiency and operational stability of solar plants under complex climate conditions.



TOPCon Modules Demonstrate 1.43% Power Generation Advantage Over BC Technology

Recently, the 2024 annual data results of China's National PV and Energy Storage Demonstration Platform (Daqing Base) have been released in Beijing. As China's first national PV energy storage demonstration experimental platform approved by the China's National Energy Administration, Daqing Base has become an authority in the industry due to its comprehensive testing of all module types across various installation environments, supported by extensive data collection. The project is constructed and operated by Huanghe Hydropower Development Co., Ltd., with 640 experimental schemes planned and arranged, with a scale of about 1.05 gigawatts. Since its launch in November 2021, this state-approved platform has completed three phases of development, scaling its total installed capacity to 500 MW (500,000 kW) and expanding its testing protocols to 389 distinct configurations, cementing its status as a global benchmark for PV technology evaluation.

The inverter in the PV module comparison area adopts an integrated inverter booster platform, the mounting adopts a fixed-ground mounting method, and the installation height is consistent from the ground, with the design spacing ensuring that it is not blocked from 9am to 3pm in winter. The layout is arranged in four rows horizontally. In the comparison area, except for the PV modules, the boundary conditions of the other equipment selection and design schemes are the same. According to the content of the comparative analysis, the real-time online test equipment in the module demonstration experiment comparison area, including a radiometer, an online IV tester, and a module backsheet temperature sensor are used to analyze the temperature, irradiation, degradation rate and other parameters of the module.

The findings highlight TOPCon's sustained dominance over mainstream technologies, with annual power generation gains of 2.02% over PERC and 1.43% over IBC (Interdigitated Back Contact), respectively. The gap in power generation between N-type TOPCon modules and PERC modules is increasing year by year, mainly due to the superior degradation characteristics of N-type modules compared to PERC modules.

Power generation of modules of different technology types in phase I

Type	Bifaciality Coefficient	Power Output				Power Gain			
		2022	2023	2024	Average	2022	2023	2024	Average
N-Type TOPCon	80%	182.33	173.85	163.18	173.12	1.79%	2.02%	2.28%	2.02%
N-Type IBC	58%	179.77	170.66	161.62	170.68	0.36%	0.15%	1.31%	0.59%
PERC	63%	179.13	170.40	159.54	169.69	--	--	--	--
N-Type HJT	84%	176.91	164.15	/	/	-1.24%	-3.67%	/	/

According to the 2024 meteorological environment measurement data of the Daqing Base, from 2022 to 2024, the three-year average rear side irradiation of the inclined surface account for 13.5% of total irradiation, and the proportion of backside irradiation on the inclined surface reach 12.87% in 2024, which shows the importance of the bifaciality coefficient of modules to the power generation gain. The surface condition throughout the year is listed as follows: snow from January to March, land from April, low grassland from May to June, high grassland from July to November, and snow from December. Comparative analysis of the proportion of irradiation on the rear side of the horizontal plane of different ground condition can draw the following conclusions:

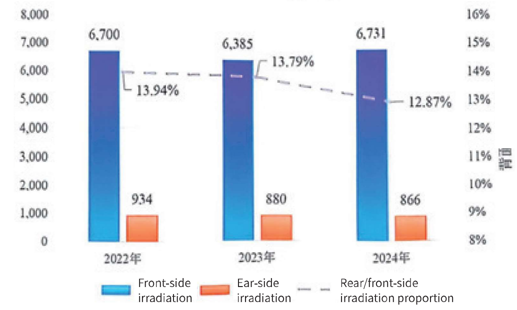
(1) From 2022 to 2024, the proportion of rear side irradiation in different ground conditions (except snow) are relatively consistent. When the ground surface is snow, the proportion of rear side irradiation in the horizontal plane varies greatly in each year.

(2) From 2022 to 2024, when the ground surface is snow, the proportion of irradiation from the rear side of the horizontal plane is relatively high. The proportion of irradiation from the rear side of the horizontal plane is between 20% and 40% for thin snow, while the irradiation on the rear side of the horizontal plane of snow is between 50% and 70%. The overall trend is determined by snow cover (full cover, incomplete cover) and snow thickness.

(3) When the ground condition is grassland or land surface, the difference in the proportion of irradiation on the rear side of the horizontal plane is not obvious, in which about 15% is for land and grassland, and about 10% is for high grassland.

According to the data form Daqing Base, TOPCon's bifacial power generation efficiency stands out as a primary advantage, achieving a bifaciality coefficient of 79.09%—significantly higher than PERC (69.72%) and IBC (58.89%). Compared with IBC and PERC modules, TOPCon modules have a significant advantage of 10-20% bifaciality coefficient, which allows TOPCon's module to display power generation advantages in a wide range of ground conditions. The higher the ground reflectivity, the more obvious the advantage. Analyzing the power generation characteristics of modules in different scenarios, TOPCon modules have a more significant advantage in power generation in scenarios with high reflectivity, especially in snow days, which is 6.55% higher than that of PERC modules.

Comparison chart of irradiation proportion on the rear side of the inclined surface (45°)



Module Type		IBC	PERC	TOPCon
Measured Bifaciality Coefficient		58%	70%	79%
Calculated Bifaciality Coefficient	Average	58.89%	69.72%	79.09%
	Median	60.49%	70.99%	80.12%

2. TOPCon has excellent low irradiance performance

The data shows that the power generation gain of different technology types of modules is quite different compared with PERC modules in different types of weather. The power generation gain of TOPCon modules is higher in cloudy, rainy and snowy conditions. Influenced by ambient temperature, the power generation gain of TOPCon modules relative to PERC is lower in sunny winter conditions.

Year	Sunny Days	Cloudy Days	Overcast Days	Snowy Days	Rainy Days			
					Days	Measured Rainfall (mm)	Average Rainfall (mm)	Accumulative Total
2022	97	165	34	19	50	144.8		365
2023	98	188	30	15	34	346.2	427.5	365
2024	97	166	39	12	52	250.6		366

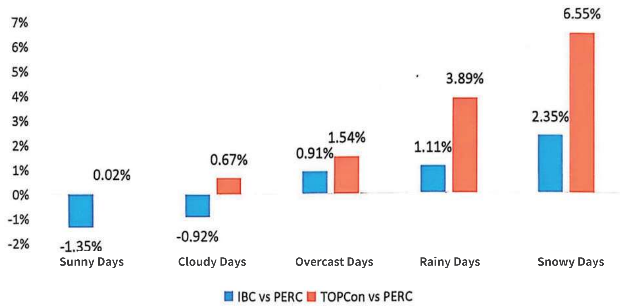
TOPCon Modules Demonstrate 1.43% Power Generation Advantage Over BC Technology

(1) From 2022 to 2024, the weather at the base was mainly cloudy, accounting for 47.3% of the annual weather, followed by sunny days (26.7%), rainy days (12.4%), overcast days (9.4%), and snow days (4.2%).

(2) In 2024, the base had the most cloudy days, with a total of 166 days, and the rest of the weather was 97 days of sunny days, 52 days of rainy days, 39 days of overcast days, and 12 days of snowy days.

(3) The number of sunny days in 2024 is basically the same as in 2022 and 2023. Cloudy days were one day longer than in 2022 and 22 days less than in 2023, while there were five and nine more overcast days than in 2022 and 2023, respectively. There were two more rainy days than in 2022 and 18 days in 2023. There were seven fewer snow days than in 2022 and three days less than in 2023.

Power Generation Difference under Different Weather Conditions of TOPCon, IBC, and PERC Modules



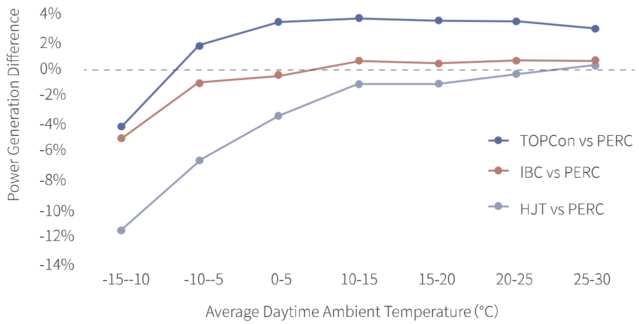
3. The stable performance of TOPCon in degradation

Long-term reliability further distinguishes TOPCon. A two-year tracking period revealed a minimal current degradation rate of 0.67%, outperforming HJT (2.21%), PERC (0.88%), and IBC (0.77%). Voltage stability remained consistent across all tested technologies except HJT from 2022-2023. The operating voltage of HJT modules showed a downward trend, and the operating voltages of IBC, PERC and TOPCon modules were basically unchanged.

The measured degradation rate of modules meets the manufacturer's commitment value, but some manufacturers have a significantly higher degradation rate. There are differences in the degradation rate of different manufacturers of the same technology, and the maximum difference is more than 2%. The efficiency of the modules in the second phase had improved, and the power generation is about 0.6% higher than that of the first phase.

Notably, TOPCon maintains its advantage over PERC even in cold temperate climates, where temperatures remain below 25° C for 68.09% of the year. Even at temperatures above -10 ° C, the technology demonstrates resilience, underscoring the importance of climate-specific research for optimizing solar solutions. When the ambient temperature is below 0 ° C, the power generation of TOPCon modules are better, which is 0.23% and 3.29% higher than that of PERC modules and IBC modules, respectively. When the ambient temperature is higher than 25 ° C, the power generation of high-efficiency modules with a lower temperature coefficient is significantly better, and the cumulative power generation per MWp of IBC and TOPCon modules is 5.67% and 4.15% higher than that of PERC modules, respectively.

Differences in Power generation of different technology types at different ambient temperatures

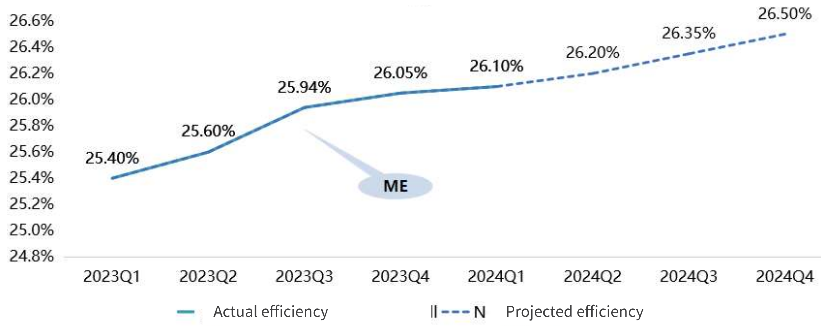


*The above content is excerpted from the report released by the National Photovoltaic and Energy Storage Testing and Experimental Platform in 2024

06 | Long-Term Outlook of TOPCon Technology

TOPCon cells still possess significant efficiency improvement potential. Through Double-Sided Poly-Si Structure Design, 20BB Technology, and Low-Temperature Cell Technology, high efficiency growth rates are expected to be maintained over the next 3-5 years.

2023-2024 Efficiency roadmap of Jinko N-Type cell

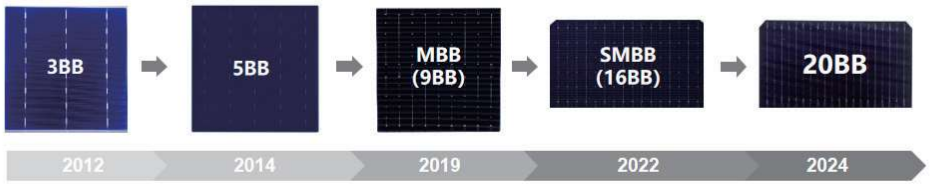


6.1 20BB Technology

20BB technology significantly reduces the shading area of front-side electrodes on TOPCon cells, increasing the effective light-receiving area. This enhances short-circuit current density and overall photoelectric conversion efficiency. Typically, this technology can boost cell efficiency by approximately 0.3%–0.5%.

Reliability Considerations:

Mechanical Strength: Reduced metal grid coverage area may impact electrode adhesion and the cell's mechanical performance under bending or thermal stress.



6.2 Low-Temperature Cell Technology

Low-temperature cell technology primarily refers to Low-Temperature Passivation Techniques. It utilizes low-temperature deposition processes to improve surface and bulk passivation levels in silicon wafers, enhancing open-circuit voltage (Voc) and fill factor (FF), with an expected efficiency gain of 0.2%.

Reliability Considerations:

Deposition Uniformity & Density: Achieving uniform and dense thin-film deposition under low-temperature conditions can be challenging, potentially affecting cell performance.

6.3 Tandem Cell Technology

TOPCon, serving as the crystalline silicon bottom cell combined with a perovskite top cell in a two-terminal tandem structure, efficiently utilizes different segments of the solar spectrum, significantly boosting photoelectric conversion efficiency. Theoretically, the efficiency limit of a dual-junction tandem cell can exceed the theoretical limit of current single-junction cells by over 10%.

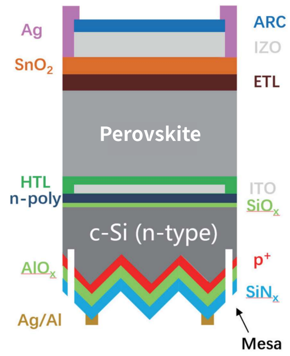
Reliability Considerations:

Interface Matching: Optical and electrical matching between the sub-cells is a key challenge. Any mismatch will result in efficiency loss.

Perovskite Stability: Tandem cells combine perovskite technology with TOPCon crystalline silicon cell technology. The stability of the perovskite cell needs further improvement against various environmental factors, including the effects of moisture, oxygen, light, and heat.

Currently, in the N-type monocrystalline silicon era, photovoltaic cells are gradually approaching the theoretical Shockley-Queisser (SQ) efficiency limit of 29.4%, while the theoretical efficiency for tandem cells can reach 43%.

Tandem cell products are expected to emerge after 2026.



Structure of JinkoSolar Perovskite /TOPCon Tandem cell

07 | Tiger Neo 3.0

7.1 Application Value of TOPCon

Driven by global energy transition and carbon neutrality goals, the economics of PV power generation have become a core industry consideration. The Levelized Cost of Electricity (LCOE) is a key indicator for measuring the life cycle economics of PV projects and directly determines the market competitiveness of solar energy. Based on the standards of the International Renewable Energy Agency (IRENA), this chapter systematically analyzes how TOPCon modules optimize project LCOE by reducing initial investment costs and increasing power generation. This chapter first explains the definition and core formula of LCOE, then details the impact mechanism of TOPCon technology on power plant construction costs, particularly in reducing Balance of System (BOS) costs. It further uses the PVsyst simulation software to quantitatively analyze the power generation gains of TOPCon over other technologies in four typical regions. Finally, it comprehensively evaluates the overall LCOE optimization effect of TOPCon modules to provide technical and economic references for PV power plant investment decisions.

7.1.1 Definition and Formula of LCOE

The LCOE is the "gold standard" for evaluating the lifecycle economics of PV projects. It is defined as the ratio of the present value of total project costs to the present value of total power generation. According to the standardized calculation method published by IRENA, the LCOE formula is expressed as:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

I_t: Investment cost in year t (including modules, inverters, racking systems, construction, etc.)

M_t: Operation and maintenance cost in year t

F_t: Fuel cost in year t (typically 0 for PV projects)

E_t: Power generation in year t

r: Discount rate

n: Project operation life

The core logic of this formula is that LCOE depends on two variables: total lifecycle cost (numerator) and total lifecycle power generation (denominator). Therefore, the essence of reducing LCOE is to "increase generation and reduce cost": either by lowering construction and O&M costs through technological innovation and economies of scale, or by increasing power output through improved module efficiency and system reliability.

In the iterative upgrading of PV cell technologies, N-type TOPCon has become a major key technical path for reducing LCOE, thanks to its high efficiency, high bifacial ratio, low degradation rate, excellent temperature coefficient, and long-term reliability.

7.1.2 Optimization Effect of TOPCon Modules on PV Plant Construction Costs

The initial construction cost of a PV power plant, which typically accounts for >70% of total lifecycle costs, is a decisive factor affecting LCOE. This cost can be broken down into module costs and Balance of System (BOS) costs. BOS costs cover all hardware and construction expenses except modules, mainly including mounting systems, cables, inverters, installation fees, O&M costs, indirect costs, etc..

Compared with BC technology modules, TOPCon modules can reduce the per watt BOS cost by up to ~2.39% under the same PV module size. This benefit stems from the high-efficiency TOPCon cell technology, optimal cell size and module type (such as 66pcs), superior efficiency advantages, and better adaptability to mounting systems (especially with tracker systems) and electrical systems (inverters). A comparison of investment costs between TOPCon and BC modules in typical global climatic and installation scenarios shows that TOPCon technology modules can save up to 0.667 UScents/W in BOS costs.

Scenario		High Altitude		High Temp&Humdity		High Temp&Irrdiation		Temperate Zone	
Project location	unit	Qinghai,CN		Hainan,CN		Saudi Arabia		Italy	
		Fixed 2P		Fixed 2P		Tracker 1P		Tracker 1P	
Project Info	Same Capacity 100MWp								
Module Type		TigerNeo3.0	BC	TigerNeo3.0	BC	TigerNeo3.0	BC	TigerNeo3.0	BC
Module Power	Wp	660	660	660	660	660	660	660	660
Module Price diff.	Same								
BOS diff.	UScents /Wp	-0.14	BSL	-0.118	BSL	-0.669	BSL	-0.553	BSL

7.1.3 Generation Gain Performance of TOPCon Modules in Typical Global Regions

Increasing power generation is another core path to reduce LCOE. TOPCon modules demonstrate significant power generation advantages in different global climate zones, thanks to their excellent power generation performance and long-term reliability. This section uses PVsyst-simulated power generation data to analyze the power generation performance of TOPCon modules in typical environments and installation methods, as shown below:

Scenario	High Altitude		High Temp&Humdity		High Temp&Irrdiation		Temperate Zone	
Project location	Qinghai,CN		Hainan,CN		Saudi Arabia		Italy	
Mounting system	Fixed 2P		Fixed 2P		Tracker 1P		Tracker 1P	
Project Info	Same Capacity 100MWp							
Module Type	TigerNeo3.0	BC	TigerNeo3.0	BC	TigerNeo3.0	BC	TigerNeo3.0	BC
1st year Generation Gain	+0.65%	BSL	+0.94%	BSL	+1.19%	BSL	+0.91%	BSL

07 | Tiger Neo 3.0

In different global climates and complex environmental types, TOPCon modules can improve per watt power generation by 0.65%-1.19% compared to BC modules, thanks to their high bifaciality, excellent low-irradiance performance, and strong reliability.

*Note: Assuming power generation comparison under the same capacity, as most market tenders are based on fixed capacity.

7.1.4 Comprehensive Optimization Effect of TOPCon Modules on Project LCOE

Reducing LCOE is the core goal of PV technology development, requiring synergistic optimization of cost structure and power generation performance. TOPCon modules provide significant economic improvements for PV projects through a dual mechanism of "cost reduction + yield enhancement". This section comprehensively quantifies the overall impact of TOPCon technology modules on project LCOE based on previous analyses and demonstrates their application effects in typical project cases with empirical power generation data, providing data support for investment decisions.

Scenario	High Altitude		High Temp&Humdity		High Temp&Irrdiation		Temperate Zone	
Project location	Qinghai,CN		Hainan,CN		Saudi Arabia		Italy	
Mounting system	Fixed 2P		Fixed 2P		Tracker 1P		Tracker 1P	
Project Info	Same Capacity 100MWp							
Module Type	TigerNeo3.0	BC	TigerNeo3.0	BC	TigerNeo3.0	BC	TigerNeo3.0	BC
LCOE[1]	Lower 0.5%	BSL	Lower 0.78%	BSL	Lower 1.9%	BSL	Lower 1.5%	BSL
TOPCon premium price for same LCOE[2]	0.22 UScents/w more expensive	BSL	0.305 UScents/w more expensive	BSL	1.02 UScents/w more expensive	BSL	0.78 UScents/w more expensive	BSL
LCOE[3]	/		Lower 4.73%	BSL	/		Lower 2.62%	BSL
TOPCon premium price for same LCOE[4]	/		1.9 UScents/w more expensive	BSL	/		1.34 UScents/w more expensive	BSL

Notes

1: LCOE values calculated based on the difference in specific generation simulated by PVsyst; 3: LCOE values calculated based on the difference in power generation per watt from TigerNeo Field test report.

2 & 4 Premium: BOS costs of each technology module remaining unchanged, TigerNeo3.0 modules need to be priced higher than BC modules to achieve the same LCOE result.

In summary, to achieve an equivalent LCOE, investors can justify a price premium for TOPCon products in the range of 0.22-1.02 UScents/W in the global market. When combined with the result from TigerNeo Field test report, this premium can be even higher, reaching 1.9 UScents/W. Therefore, TOPCon modules have been and will continue to be the mainstream choice in the market in the future, with broad application prospects.

7.2 Development History and Shipment Status of Tiger Neo 3.0 Products

	Launch time	Module Efficiency	Power	Accumalated Shipment
Tiger Neo 1.0	2021	22.3%	620W	160GW
Tiger Neo 2.0	2022	23.23%	635W	
Tiger Neo 3.0	**2024**	**24.8%**	**670W**	

*By the end of April 2025

7.3 Deliverable time and Guided Prices for Different Power Bin

Type		Tiger Neo 2.0	Tiger Neo 3.0		
Power	···	**640W**	**650W**	**660W**	**670W**
Delivery	···	2025/04/01	2025/06/01	2025/09/01	2025/12/01
Guide Price	···	···	**10% Premium**		
Capacity By the end of 2025	**40-50GW+**				

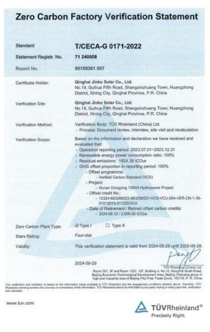
08 | Carbon Footprint and Sustainability Certification

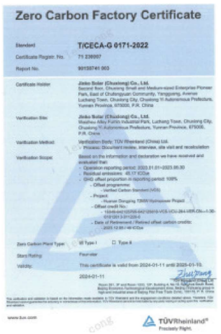
Today, many countries around the world have set clear carbon reduction targets. Since the Paris Agreement entered its full implementation phase in 2020, the PV industry has been accelerating its green revolution driven by technological innovation, providing zero-carbon solutions for sustainable human development. With the rapid development of the PV industry, the carbon emissions throughout the entire life cycle of the PV industry chain have become a focus of attention for governments, enterprises, and institutions around the world. Some countries are establishing international green trade barriers based on Life Cycle Assessment (LCA) and carbon footprint metrics. In this context, the carbon footprint performance of PV products has evolved from a technical indicator to a core strategic competitive advantage for enterprises, serving as a key to accessing international high-end markets.

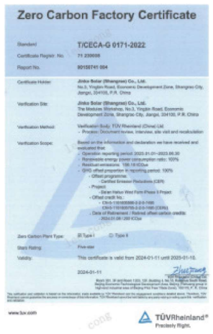
8.1 Carbon Footprint Performance

JinkoSolar actively engages in the construction and upgrading of its carbon management system. The Jinko Carbon Management System has obtained compliance certification from the German TÜV Rheinland Group, indicating that the system is highly aligned with international greenhouse gas accounting standards. Through intelligent algorithms, it meets corporate carbon certification requirements and ensures the scientific accuracy and consistency of carbon emissions data; through architectural design, it enables in-depth analysis of collected data, helping JinkoSolar precisely identify energy-saving potential and support the achievement of sustainable development goals.

To further decarbonize and reduce carbon emissions in its operations, JinkoSolar is actively advancing the construction of "zero-carbon factories". As of now, there are a total of nine "zero-carbon factories," and 100% of the company's production facilities have completed ISO 14064 greenhouse gas verification. As of the end of 2024, there were a cumulative total of 9 products certified under the Italian Environmental Product Declaration (EPD), including 3 products currently on sale; a cumulative total of 44 products certified under the French Product Carbon Footprint Certification, including 11 products currently on sale; and a total of 7 PV and energy storage products certified under ISO 14067. JinkoSolar is further expanding its international influence in carbon management, continuously expanding the scope of EPD certificates to cover Norway and Sweden, with carbon emissions in France reaching as low as 300 kg CO_2/MW. Additionally, JinkoSolar successfully passed the target verification of the Science Based Targets initiative (SBTi) in December 2023, becoming the first PV company globally to complete all three SBTi targets (short-term, long-term, and net-zero) verification.







*JinkoSolar possesses multiple (module - cell - wafer) supply chains, all of which have obtained TUV Rheinland's Zero-Carbon Factory Certification, positioning the company at the forefront of the PV industry.

8.2 Module Recycling Program

JinkoSolar actively practices the concept of a circular economy in the entire product life cycle management process, improves the recyclability of product materials, and has successfully achieved technical reserves for the recyclability of PV products, laying a solid foundation for sustainable development in the future.

Process	Concept	Circular Benefits
Product Design and Development >>>	Using international standard designs and connection methods, we optimize component structures and adopt a modular design for products to simplify the disassembly process and improve recycling efficiency.	Through segmented and integrated frame designs, we achieve 100% disassembly of aluminum frames for recycling. We also recycle aluminum frames and other waste generated during production through methods such as disassembly, melting, and reprocessing.
Raw Material Procurement and Use >>>	During the initial stages of new material introduction, conduct assessments and evaluations of material reliability, cost, manufacturability, and recyclability.	While ensuring product quality, actively identify and promote the introduction of recyclable or renewable raw materials, such as recyclable aluminum frames, glass, paper packaging materials, and granular silicon.
Packaging Recycling and Reduction >>>	Reduce the use of redundant materials and introduce recyclable packaging materials such as cardboard boxes, wooden pallets, and biodegradable pearl cotton. Implement battery cell packaging and silicon wafer wooden pallet recycling and reuse projects.	The recycling rate of silicon wafer pallets has reached 76.7%. Implement battery cell packaging recycling and reuse projects to achieve a 92% reuse rate for recycled packaging materials.
Product Recycling and Reuse >>>	Continuously innovate and improve recycling technologies and processes to enhance module recycling rates; actively develop resource recovery channels and provide customized recycling services tailored to customer needs, including "reuse" and "recycling" models.	Obtained PV CYCLE LEED certification, signifying that all photovoltaic products meet 100% recycling standards; customer recycling request response rate, recycling channel regional coverage rate, and compliance rate for the disposal of used modules all reach 100%; tempered glass, aluminum frames, and other materials achieve over 98% recycling rate through physical methods, while silicon, silver, and copper achieve over 95% recycling rate through chemical methods.

As a global member of international recycling organizations such as PV Cycle, the company strictly adheres to the relevant regulations of the EU's Waste Electrical and Electronic Equipment (WEEE) Directive, actively fulfills its extended producer responsibility (EPR) obligations, and assumes responsibility for the recycling, reuse, and waste management of PV modules at the end of their lifecycle. In addition, the company actively participates in the development of product recycling-related standards, such as the "Recycling and Treatment Methods for Crystalline Silicon PV Modules". The company also participates in the development of industry standards such as the "General Specifications for the Secondary Use of Retired PV Modules (Draft Version)" and the "Technical Specifications for Pollution Control in the Recycling and Treatment of Waste PV Equipment (Draft for Public Comment)". As a key member of the PV Subcommittee of the China Green Supply Chain Alliance (ECOPV), the PV Module Recycling Working Group of the China PV Industry Association, and the Wind and Solar Equipment Recycling Subcommittee, the company actively participates in the development of various recycling standards and policies within these committees.

08 | Carbon Footprint and Sustainability Certification

8.2 Module Recycling Program

SORÉN (Société de la filière de l'Énergie Solaire et de l'Éolien), the core institution responsible for PV module recycling in France, is the primary entity implementing the EU WEEE Directive in France and the only government-approved PV-specific recycling institution in the country. SORÉN established the "Eco-design" working group, which issued module recycling standards (Eco-Modulated Criteria) and thresholds, and developed the following four implementation standards:

a) PPE2 V1 ⩽ 450 or PPE2 V2 ⩽ 630
b) Silver ⩽ 14 mg/W cell
c) Recycled content rate ⩾ 3% using the established calculation method
d) Lead content < 0.1% by weight

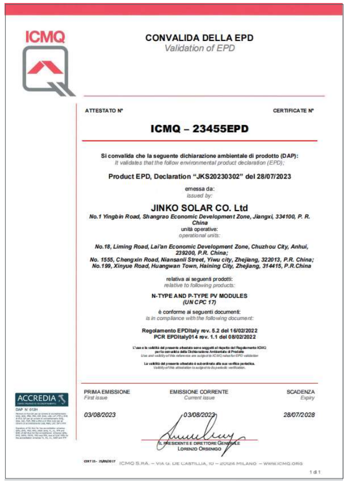
JinkoSolar completed the Soren (Eco-design) project in Q1 2025, meeting the three Eco-design (Soren) standards and achieving the lowest module recycling price, leading the industry. This initiative is expected to save customers in France a total of approximately 1 million euro in module recycling costs in 2025

PV.1 – Modules photovoltaïques mono et poly cristallins (cSi)

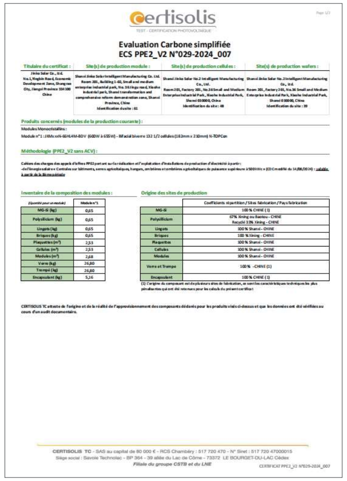
Par équipement	Module avec cadre en aluminium					
Tranche de poids	Référence	Contribution standard € HT / module	Référence	2 critères de modulation s'appliquent € HT / module	Référence	Au moins 3 critères de modulations s'appliquent € HT / module
Moins de 1kg exclu	PV.11101	0,14€	PV.111011	0,11€	PV.111012	0,02€
De 1 kg à 10 kg exclu	PV.11102	0,22€	PV.111021	0,18€	PV.111022	0,02€
De 10 kg à 20 kg exclu	PV.11103	0,44€	PV.111031	0,36€	PV.111032	0,04€
De 20 kg à 30 kg exclu	PV.11104	0,69€	PV.111041	0,55€	PV.111042	0,06€
De 30 kg à 40 kg exclu	PV.11105	0,97€	PV.111051	0,77€	PV.111052	0,08€
De 40 kg à 50 kg exclu	PV.11106	1,24€	PV.111061	0,99€	PV.111062	0,10€
Par tranche de 10 kg supplémentaire entamée		*0,22€*		*0,18€*		*0,02€*

Pa[illegible]	[illegible]inium					
Tr[illegible]	[illegible]	[illegible]	[illegible]nce	2 critères de modulation s'appliquent € HT / module	Référence	Au moins 3 critères de modulations s'appliquent € HT / module
M[illegible]	[illegible]	[illegible]	[illegible]011	0,13€	PV.112012	0,02€
De[illegible]	[illegible]	[illegible]	[illegible]021	0,21€	PV.112022	0,03€
De[illegible]	[illegible]	[illegible]	[illegible]031	0,41€	PV.112032	0,05€
De[illegible]	[illegible]	[illegible]	[illegible]041	0,64€	PV.112042	0,07€
De 30 kg à 40 kg exclu	PV.11205	1,11€	PV.112051	0,89€	PV.112052	0,09€
De 40 kg à 50 kg exclu	PV.11206	1,43€	PV.112061	1,14€	PV.112062	0,12€
Par tranche de 10 kg supplémentaire entamée		*0,26€*		*0,21€*		*0,03€*

In this example, the same panel can have an eco-contribution of **€0.69**, **€0.55**, or **€0.06**, depending on whether it meets **none**, **two**, or at least **three** eco-design **criteria**.


CONVALIDA DELLA EPD
Validation of EPD
ICMQ – 23455EPD
JINKO SOLAR CO. Ltd


ATTESTATION D'EVALUATION DES CRITÈRES D'ÉCOMODULATION SOREN


Evaluation Carbone simplifiée
ECS PPE2_V2 N°029-2024_007