Utility Wind-Solar Hybrid Product Solutions

LONGi Whitepaper

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This report is the result of a collaboration between LONGI and TÜV Rheinland, with contributions from Empower Engenharia, and Inova Energy

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The report was produced by Longi Green Energy Technology Co., LTD

Cover photograph: Ningxia 180MW Project with LONGi Hi-MO Series products

Abstract

As the global energy transition accelerates, wind and solar power have seen rapid growth, accounting for 13.4% of global electricity generation in 2023 and projected to reach one-third by 2030. By 2050, wind and solar energy are expected to replace fossil fuels and become the absolute mainstream. With evolving land policies and increasing industry competition, maximizing comprehensive energy utilization has become critical. Wind-solar hybrid solutions offer higher system efficiency, balanced investment returns, and notable cost-performance advantages compared to single-energy approaches. This article explores the challenges and opportunities of wind-solar hybrid systems, highlights the value of scenario-based solutions centered on LONGi Hi-MO9 modules, and aims to provide optimal module strategies for owners and EPCs in hybrid energy projects.

1. Core Goal

Focusing on our utility Hi-MO9 module products, we, as LONGi, will create the optimal photovoltaic solutions for wind-solar hybrid scenarios, explore the core needs and value embodiment of such scenarios, anchor the high-value positioning of LONGi's Hi-MO9 BC products as the "king of module products for wind-solar hybrid scenarios" in wind-solar hybrid applications, form differentiated advantages at both the module and system levels, establish a premium moat for Hi-MO9 module products, and consolidate and strengthen LONGi and its products' competitiveness and influence in wind-solar hybrid scenarios.

2. Usage and Value Points

- **Release of the wind-solar hybrid white paper:** Guided by breakthrough innovation, we deeply explore unexplored areas. With forward-looking vision and strong R&D capabilities, we take the lead in creating unique products and services, accurately responding to market demands, filling the long-standing gaps in the wind-solar hybrid scenario within the industry, and bringing users an unprecedented value experience.

- **Support for regional department promotion:** Through in-depth analysis of market demands in the Latin American region, precise identification of industry pain points, and integration of cutting-edge technologies and resources, we have accumulated a rich reserve of wind-solar hybrid product solutions. These solutions can be quickly transformed into core competitiveness in front-line promotion, effectively shortening the response cycle, enhancing the persuasiveness of the solutions, and providing strong support for regional departments to successfully secure orders.
- **Promoting the establishment of relevant industry norms:** Wind-solar hybrid is still an emerging field in the industry's development. In the continuous exploration and practice, we systematically sort out the accumulated valuable experience, formed standardized processes, overcome key technical problems, etc., into replicable and promotable cases and data. These provide solid material support for the formulation of relevant industry norms for wind-solar hybrid, leading the industry to advance towards a higher-quality and more socially valuable dimension, and helping the entire field accelerate on the track of standardization and professionalization.
- **Cross-field cooperation and co-creation:** We have in-depth cooperation with leading enterprises in the wind power field, taking "collaborative co-creation" as a link to break industry barriers and build a cross-field innovation community. From jointly carrying out technical research to solve the problems of wind-solar resource coordinated dispatching; to jointly exploring business model innovation to optimize the whole-life cycle management of new energy projects; and then to jointly building an industrial chain cooperation platform to integrate upstream and downstream resources to form a development synergy, we will work together to open up broader prospects for the high-quality development of the new energy industry, allowing the value of green energy to shine more brilliantly in collaboration.

3. Quick Overview of Value Calculation Conclusions

Use PVsyst simulation software to model the layout scheme of wind-solar hybrid systems, calculate the power generation performance of TOPCon modules and Hi-MO9 modules under the same layout scheme, and quantify the advantages of Hi-MO9 modules over TOPCon modules in shaded application scenarios of wind-solar hybrid systems. The calculation results are as follows:

item	unit	TOPCon	Hi-MO9	difference
Module power	Wp	620	660	40
Result				
BOS cost	Yuan/W	1.7414	1.7114	Save ¥0.03
Power generation dispatched to grid in 30 years	Ten thousand kWh	54 258	55 802	2.85%(0.5% anti-shading)
Power generation revenue in 30 years	Ten thousand yuan	13 564	13 951	386
Module premium	Yuan/W	Base	+0.080	

Table A – simulation calculation result data

Under the scenario of wind-solar hybrid projects with the same capacity and the same land area, the system BOS cost using Hi-MO9 is 0.03 yuan per watt lower than that of TOPCon. The power generation per kilowatt of Hi-MO9 modules is 2.2% ~ 2.85% higher than that of TOPCon, moreover, under the condition that the total investment IRR is the same, Hi-MO9 has a premium of about 0.08 yuan per watt compared with TOPCon.

4. Quick Overview of Empirical Data

- Ningxia empirical project -- Empirical evidence shows that, in the case of no occlusion, the average power generation gain per kilowatt of BC modules is 1.39%, and the maximum daily value can reach 79.43% (snowy weather), in the case of column occlusion, the average power generation gain per kilowatt of BC modules is 31.61%, and the maximum daily value can reach 62.99%.

	Data	Hi-MO9	TOPCon	Power generation gain
Without occlusion (2024.09.28~ 2025.02.28)	Cumulative power generation per kilowatt (kWh/kWp)	634.02	625.34	**1.39%**
Column occlusion (2024.09.28~ 2024.12.25)	Cumulative power generation per kilowatt (kWh/kWp)	299.95	227.9	**31.61%**

Table B – accumulated power generation data of the empirical project in Yinchuan, Ningxia

- CGC Hainan empirical project -- Empirical evidence shows that, in the case of no shading, the power generation per watt of BC modules is on average increased by about 2.03% compared with that of TOPCon modules, in the case of shading by columns, the power generation per watt of BC modules is on average increased by about 14.96% compared with that of TOPCon modules.

	Data	Hi-MO9	TOPCon	Power generation gain
Without occlusion (2024.09.28~ 2025.02.28)	Cumulative power generation per kilowatt (kWh/kWp)	320.86	314.47	**2.03%**
Column occlusion (2024.09.28~ 2024.12.25)	Cumulative power generation per kilowatt (kWh/kWp)	69.848	60.756	**14.96%**

Table C - accumulated power generation data of the CGC Hainan empirical project

5. Core Conclusions of Third-Party Verification

In the TÜV Rheinland anti-shading comparison test, in the case of single-point shading, the power generation of the BC module has a maximum power generation loss reduction of approximately 7.31% compared to the TOPCon module. In the case of multi-point shading, the power generation of the BC module has a maximum power generation loss reduction of approximately 16.92% compared to the TOPCon module.

Test Module	LONGi BC	TOPcon Module	difference
Characteristic	ΔP[%]	ΔP[%]	
Single-spot shading 1	**-5.42%**	**-12.73%**	**7.31%**
Single-spot shading 2	-3.71%	-5.65%	1.94%
Single-spot shading 3	-4.92%	-6.38%	1.46%
Single-spot shading 4	-6.40%	-7.79%	1.39%
Single-spot shading 5	-1.13%	-1.54%	0.41%
Single-spot shading 6	-7.25%	-13.74%	6.49%
Multi-spot shading 1	-21.45%	-32.46%	11.01%
Multi-spot shading 2	**-18.67%**	**-35.59%**	**16.92%**

Table D- TÜV Rheinland anti-shading occlusion comparative test data

Under the same experimental conditions, in the hot spot comparison test conducted by TÜV Rheinland, the local temperature of LONGi BC modules was reduced by up to 42% compared with that of TOPCon modules under the highest conditions, effectively reducing the risk of module failure.

Module Type	LR7-54HVH	Topcon Module
Measurement at 1st worst case shading cell at edge of module		
Maximum measured cell temperature [°C]	127.0	160.0
Shading rate [%]	50	60
Measurement at 1st worst case cell of complete module		
Maximum measured cell temperature [°C]	107.0	169.0
Shading rate [%]	60	60
Measurement at 2nd worst-case cell of complete module		
Maximum measured cell temperature [°C]	101.0	171.0
Shading rate [%]	50	50
Measurement at lowest leakage current cell of complete module		
Maximum measured cell temperature [°C]	98.0	169.0
Shading rate [%]	40	40

Table E- TÜV Rheinland hot spot contrast test

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Chapter 1 - Current Status and Policy Analysis of Wind-Solar Hybrid Projects

Against the backdrop of the global energy transition, wind and solar energy have experienced rapid growth, with their share in the global energy mix increasing year by year. In 2023, the power generation from wind and solar energy accounted for 13.4% of the global total power generation. It is expected that by 2030, the power generation from wind and solar energy will reach one-third of the global electricity generation, and by 2050, wind and solar energy will replace fossil fuel energy and become the absolute mainstream.

With the intensification of industry involution and the adjustment of land development policies, issues such as the comprehensive energy utilization rate have become more prominent. Compared with single energy forms, the wind-solar hybrid solution can effectively increase the comprehensive power generation and value of the system. Moreover, it performs outstandingly in indicators such as comprehensive power generation, balance of project investment and return rate. The system has made significant improvements in investment and possesses comprehensive competitiveness and cost performance advantages.

This article aims to identify and analyze the pain points and opportunities of wind-solar hybrid solution, excavates the value of scenario-based products and system solutions around Hi-MO9, and is committed to providing the optimal module solutions for owners and EPCs in wind-solar hybrid scenarios.

1.1 The Current Development Status of Global Energy, Wind Energy and Solar Energy

In recent years, the degree of electrification in fields such as transportation, industry, and construction has gradually increased, emerging high-power-consuming industries such as 5G, big data, cloud computing, and artificial intelligence have grown rapidly, and the growth rate of global electricity demand has also gradually increased. According to the prediction of the International Energy Agency (IEA), the global electricity demand is expected to increase by approximately 4% in 2024, and the global electricity consumption will continue to show a strong growth trend in 2025.

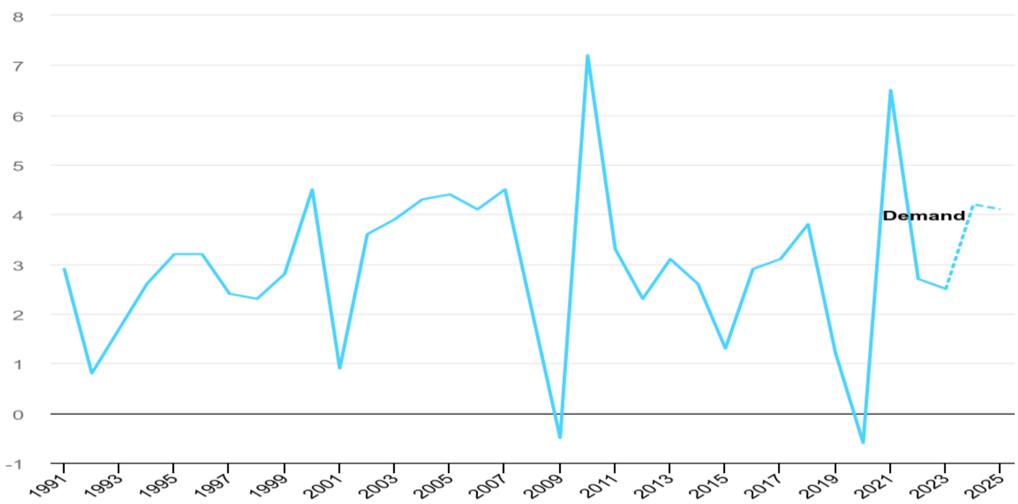


Figure 1 - Annual growth rate of global electricity demand from 1991-2025 [Source: IEA, 2024

As two major sources of energy in the renewable energy sector at present, solar and wind energy have witnessed a rapid growth in power generation installed capacity in recent years, their status in the global renewable energy structure has been continuously rising, making them the core driving force behind the rapid development of global renewable energy.

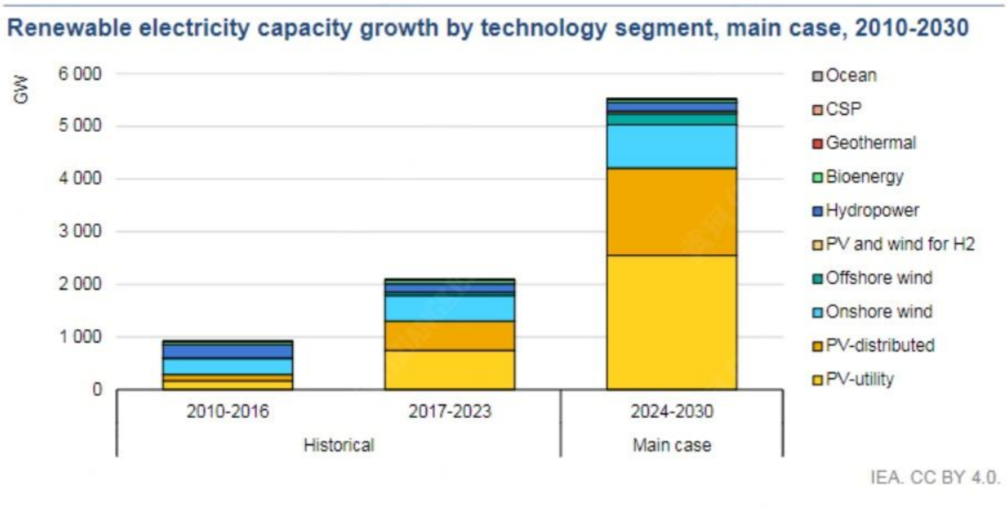


Figure 2 - IEA's Forecast of the Structural Proportion of Renewable Energy such as Solar and Wind Power [Source: IEA, 2024

1.2 Concept of Wind-Solar Hybrid and Project Characteristics

Wind-Solar hybrid refers to an energy development model where a wind power generation system and a solar power generation system are simultaneously deployed on the same site, and connect to the grid through the same collector line. This model integrates wind and solar resources, improving energy utilization efficiency through coordinated optimization. Practical cases of this model include the first-batch projects of China’s first ten-million-kilowatt multi-energy complementary integrated energy base, the new energy stations designed with wind-solar hybrid in Huanxian, Gansu, and the world’s first far-sea floating photovoltaic demonstration project for wind-solar hybrid, among others.

The characteristics of the wind-solar hybrid projects can be summarized as follows:

1. **Optimize grid connection:** The output characteristics of wind energy and solar energy are complementary (for example, when the sunlight is strong during the day, the photovoltaic power generation efficiency is relatively high, while the wind is weak; at night or on cloudy days, the wind is strong and the photovoltaic power generation is weak). Connecting them to the grid together can smooth the power output curve of the wind-solar hybrid project, reduce the impact on grid stability, and thus reduce the difficulty of dispatching.

2. **Improve resource utilization efficiency:** Wind power and photovoltaic power share infrastructure such as transmission lines and substations to reduce construction and operation costs. For example, the Longdong Wind-Solar Integrated New Energy Demonstration Project has improved land utilization and reduced the repeated construction of facilities such as lines and roads through “wind-solar hybrid and mixed arrangement of wind turbines”.

3. **Enhance the reliability of energy supply:** When one type of energy is affected by weather conditions (such as low photovoltaic output on cloudy days, or insufficient wind power when there is no wind), the other type of energy can partially compensate, relying on each other to ensure the continuous supply of electricity. Compared with a single power generation form, this greatly enhances the reliability of energy supply.

4. Reduce environmental impact: Compared with building wind farms or photovoltaic power plants separately, the construction of wind-solar hybrid can reduce the division and occupation of land, thereby reducing damage to the ecological environment.

5. Enhance economic efficiency and competitiveness: Through resource sharing and collaborative optimization, the total project cost and power generation cost per watt are reduced. At the same time, it provides technical support for the subsequent integration of wind-solar-storage, as exemplified by the Huanxian Project in Gansu Province, thus improving competitiveness in the energy market.

6. Promote technological innovation: On the basis of wind-solar hybrid, continuously promote the integration of wind power and photovoltaic technologies and drive technological progress in photovoltaic modules. For example, the deep and distant sea floating photovoltaic projects have verified the wind and wave resistance as well as weather resistance of floating bodies, anchoring systems and power generation modules in complex marine environments, exploring paths for the large-scale development of offshore photovoltaics in the future.

7. Multi-energy complementarity and coordinated development: Some projects are equipped with energy storage (for example, Shanghai requires the configuration of new energy storage with an output not less than 20% of the photovoltaic installed capacity), or combined with thermal power peak regulation (such as the “wind-solar-thermal-storage” mode in the Longdong base), so as to improve the stability of power consumption and promote the transformation of energy structure.

In addition, the development of wind-solar hybrid projects also faces challenges such as high difficulty in resource matching (different distribution patterns of wind and solar resources), concentrated meteorological risks (extreme weather affecting both), high energy storage demand (to meet the needs of extreme situations), and complex planning and approval processes (approval for new energy projects). However, it is expected that these challenges can be gradually optimized and overcome through advanced forecasting technologies, intelligent dispatching systems, and cross-regional allocation, among other means.

1.3 Policies and Market Insights on Wind-Solar Hybrid

- Advantages in Resource and Cost optimization

Wind-solar hybrid reduces construction and operation costs by sharing infrastructure such as transmission lines and booster stations. For instance, the time-cycle characteristics of wind power and photovoltaic output are naturally complementary (photovoltaics generally dominate power generation during the day, while wind resources are more abundant at night), which allows for self-optimization of current output before grid connection. This makes the current output curve smoother, reduces the impact on grid stability, and enhances the reliability of energy supply. Take the wind-solar hybrid project located in Wushan County, Chongqing as an example, by building a 220 kV booster station jointly for the wind farm and photovoltaic power station, it realizes wind-solar hybrid power generation at the same site. While efficiently utilizing wind and solar resources, it further saves project construction land, reduces construction costs, and improves the utilization value of land.

- Technological innovation drives development

With the continuous development of the photovoltaic industry and the saturation of the market, the competition among photovoltaic module enterprises has shifted from the traditional “low-price competition” to “technological competition and matching”. The technological integration of the battery technologies such as TOPCon, BC and HJT continues to accelerate, and many new materials and process applications are constantly emerging. Emerging market requirements such as high conversion efficiency, high weather resistance, strong anti-PID performance, and scenario-specific specialization have driven technological innovation in the photovoltaic industry to reach new heights. This innovation development trend has also expanded to the field of offshore photovoltaic project. In December 2021, the world's first deep and distant sea wind-solar hybrid floating photovoltaic demonstration project – SPIC Shandong Peninsula South No. 3 Project – successfully generated electricity. It verified the wind and wave resistance and weather resistance of components such as floating bodies, anchoring systems, and photovoltaic modules in complex marine environments, as well as the technical feasibility of grid connection for wind-solar hybrid, and has emplored a path for the global large-scale development of offshore photovoltaics.

- The global competitiveness of Chinese enterprises

China holds a core position in the global photovoltaic and wind power industry chains. By the end of 2024, the cumulative grid-connected installed capacity of wind power in China was approximately 530 million kilowatts, ranking first globally for many consecutive years. Among the top 10 global wind power enterprises in terms of new installed capacity in 2024, Chinese enterprises accounted for 6 seats. In 2024, the production of PV modules in China accounted for over 80% of the global total, with production costs far lower than those of India, Europe, and the United States. Chinese enterprises even dominated the top 10 list of global PV module shipments in 2024. In terms of technological innovation, Chinese PV enterprises lead in technological tracks such as TOPCon, HJT, and perovskite. The number of patent applications for solar cells in China ranks first globally, their outstanding competitiveness and R&D capabilities provide strong technical support for wind-solar hybrid projects.

- Market trends and challenges

Against the backdrop of the global trend of energy transition, the co-development of wind and solar energy, as a resource development model for multi-energy complementarity, has huge market potential. However, it also faces challenges such as high difficulty in resource matching (due to differences in the distribution laws of wind and solar resources), high demand of energy storage (to smooth power fluctuations), and complex offshore operation and maintenance (due to wind, waves, salt spray, and variable weather). In the future, with the continuous advancement of the "dual-carbon" goal and the continuous progress of technologies (such as intelligent dispatching systems and new energy storage technologies), wind-solar hybrid will develop in a more efficient and economical direction, the practical experience of China in this field will also provide reference for the world, promoting the efficient development of wind-solar energy.

- Wind and solar resource maps and comprehensive analysis (insights into global distribution and proportion)

The distribution of wind and solar resources globally is not uniform. The main distribution areas of wind energy resources are as follows:

1. The coastal areas of the continent, such as the coastal regions in western Europe, western North America, and eastern Asia, these areas are influenced by the ocean, the thermal difference between the land and the sea leads to the formation of land-sea breezes. At the same time, strong winds from the ocean are likely to be transported to the land, making the wind energy resources in coastal areas quite considerable.

2. In some inland areas, such as regions with relatively flat and open terrains like Central Asia and the central part of North America, without the obstruction of terrains such as mountains, the wind can flow relatively smoothly, thus forming a certain amount of wind energy resources.

3. In the middle-latitude sea areas, such as some regions of the North Atlantic Ocean and the North Pacific Ocean, they are often affected by the westerlies. The frictional force on the sea surface is relatively small, enabling the wind to blow continuously and steadily, thus forming good wind energy resource conditions.

The wind resources in Latin America are mainly concentrated in Chile and Argentina in South America. The southern part of Chile is in the prevailing westerlies zone. Coupled with the topographical influence of the Andes Mountains, the venturi effect is significant, which enhances the wind force and makes the wind energy power density in this region relatively high. In some coastal and open areas in southern Argentina, the terrain is relatively flat, greatly influenced by the ocean, with stable wind and relatively high wind speed, thus having good development potential for wind resources. Due to the influence of sea-land breezes and special terrain, some coastal areas in Central America also have certain development potential for wind resources.

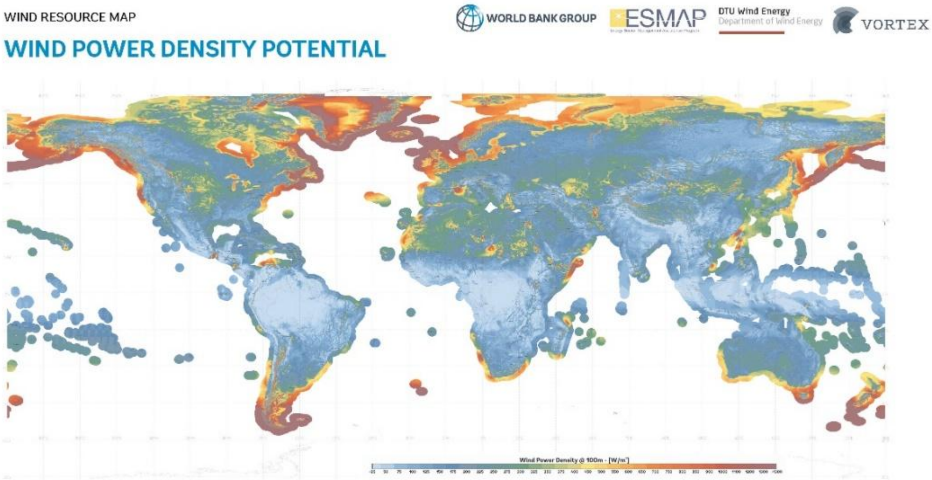


Figure 3 - global distribution of wind power generation potential [source: Global Wind Atlas, 2025]

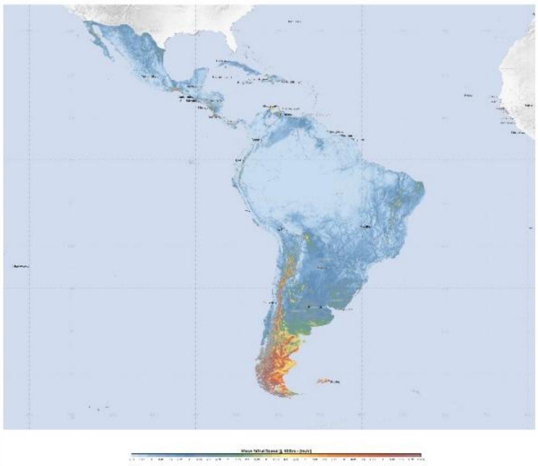


Figure 4 - distribution of wind power density potential in Latin America and the Caribbean [source: Global Wind Atlas, 2025]

Solar energy resources are mainly concentrated in low-latitude and some mid-latitude regions with arid and less-rainy climates and more sunny days. For example, the Middle East and north Africa regions with arid and less-rainy climates and strong sun radiation; the central and western regions of Australia with a dry climate and vast territory; the southwestern desert regions of North America with abundant solar energy resources and long sunshine hours. In addition, some regions in West Asia and Central Asia, such as Xinjiang and Qinghai in northwest China, have sufficient sunshine and an arid climate, and thus relatively abundant solar energy resources. In southern European regions such as Spain and Italy, the climate is relatively dry, there are more sunny days, and the conditions for solar energy resources are relatively good.

The solar energy resources in Latin America are mainly concentrated in the western region of South America. The coastal area in the western part of the Andes Mountains has a tropical desert climate, there is scarce precipitation throughout the year, with many sunny days and high atmospheric transparency, the solar radiation is less weakened by clouds, at the same time, this region has a relatively low latitude, a relatively large solar altitude angle and strong solar radiation intensity, making the solar energy resources extremely impressive and having the potential for large-scale development of solar photovoltaic projects; some areas in the northeast of Brazil also have relatively abundant solar energy resources. The climate in these areas is relatively arid, with less precipitation, long sunshine hours, and a large amount of received solar radiation, making it suitable for the development and utilization of solar energy.

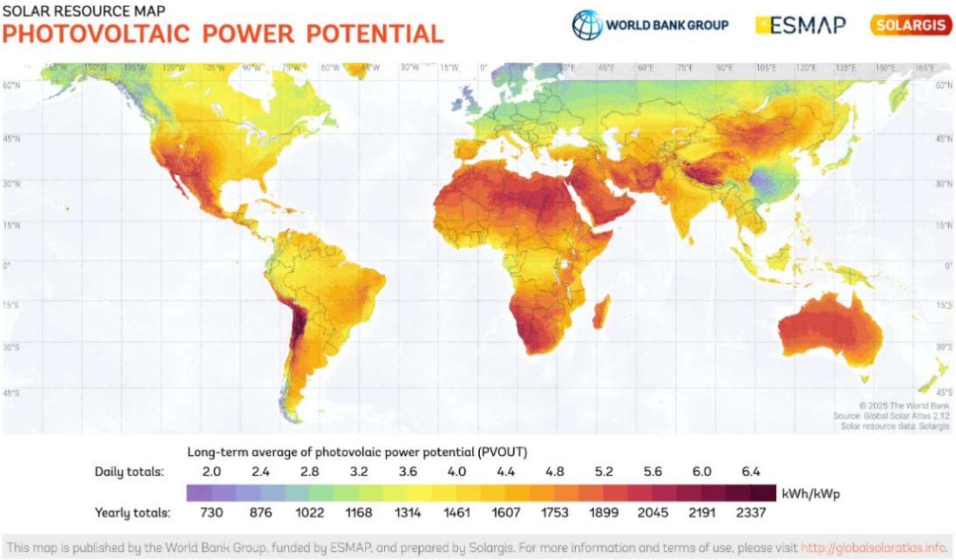


Figure 5 - global distribution of photovoltaic generation potential [source: Solargis, 2025]

Figure 6 - distribution of photovoltaic power generation potential in Latin America and the Caribbean [source: Solargis, 2025]

By comparing the global wind power density potential map and the global photovoltaic power density potential map, it can be seen that there are a large number of overlapping areas between global wind resources and solar energy resources. For example, most of the Middle East and North Africa regions are dominated by the tropical desert climate, with arid climate and scarce precipitation, abundant sunlight makes the solar energy resources extremely rich, the vast and flat desert terrain has low ground friction, and influenced by the atmospheric circulation, there are often relatively stable winds, so the wind energy resources also have certain development potential; the southwestern region of the United States and the central and western parts of Australia are rich in solar energy resources, and the wind energy resources also have certain development value. In the Latin America region, the northern part of Chile belongs to the tropical desert climate, with extremely arid climate and scarce precipitation, this region receives solar radiation for a long time and with high intensity, so the solar energy resources are very rich, at the same time, the terrain is relatively open, and influenced by the atmospheric circulation, the wind is relatively stable, so there is good wind energy development potential, it is a region in Latin America with a high overlap of wind energy and solar energy resources. The northeastern part of Brazil and some inland areas of Argentina also have the conditions for the simultaneous development of wind power and photovoltaics, and the prospects are quite promising.

Chapter 2 - Challenges and Opportunities in Wind-Solar Hybrid

As a new hybrid energy solution, compared with traditional sources or single energy solutions, wind-solar hybrid faces some new challenges while also presenting development opportunities in the process of development, promotion and application.

2.1 Challenges of Land Use in the Large-Scale Development of Wind Turbines

In the traditional single wind power generation, the distance between wind turbines is large, resulting in a relatively low land utilization, the large amount of vacant land increases the land cost per watt of power generation.

In the development of wind-solar hybrid projects, the first thing to consider is how to "save land", that is, through repeated design and calculation, rearrange the positions of wind turbines and photovoltaic modules in the site to reduce the existence of vacant land, improve the land utilization rate, and achieve the effect of maximizing power generation and minimizing site waste. A typical application case is the Longdong Integrated Energy Base: it is constructed in the way of "wind-solar co-location, mixed arrangement of wind turbines and modules", under the same geological conditions, the permanent footprint of wind turbine foundations is saved by more than 40%, on the basis of meeting the land demand of large-scale base wind power projects, the installed capacity per unit of land is increased by more than 20%, and the land use is reduced by about one-third under the same installed capacity scale.

The second thing to consider is how to "avoid shading". As the sun rises in the east and sets in the west every day, the shadows of the wind turbine columns and blades rotate accordingly, inevitably projecting shadows on the surface of modules, causing partial shading, thus affecting the power generation effect of the modules, and even further triggering hot spots on the modules, affecting the safety of the photovoltaic power generation site. Therefore, the overall layout of the wind turbines and modules also needs to be adjusted with reference to the range of shadow shading, trying to reduce the impact of wind turbine shadows on the power generation effect of the modules, and form a optimal arrangement that achieves a balance in all aspects.

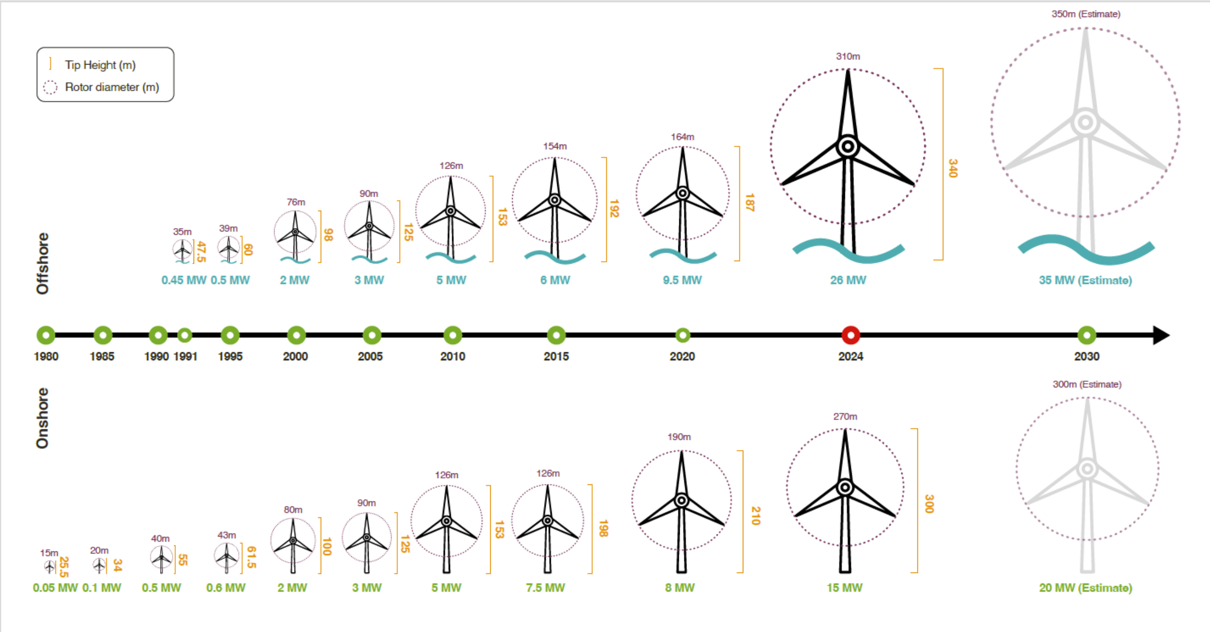


Figure 7 - GWEC 2025 development trend diagram of onshore and offshore wind turbine sizes [source: GWEC, 2025a]

2.2 Challenges of Power Output and Investment Fluctuations of Wind and Solar Energy

Wind power projects and photovoltaic projects developed in the same area can share integrated circuits and equipment, thus reducing the BOS cost. Considering that the main power generation times of photovoltaics and wind power are different, photovoltaics mainly generate power between 8:00 a.m. and 6:00 p.m. during the day and reach their peak around 12:00 noon. On the other hand, wind power receives more wind at night and has a higher power output. The overlapping time of the two using the transmission line is extremely short and their powers are not high. Therefore, when designing and installing shared auxiliary systems such as combiner boxes, inverters, and transmission lines, corresponding adjustments need to be made to the power and capacity to prevent redundancy and idling. The layout positions of the integrated circuits and equipment also need to be specifically designed to achieve the shortest and most cost-saving lines, thus maximizing the reduction of construction costs.

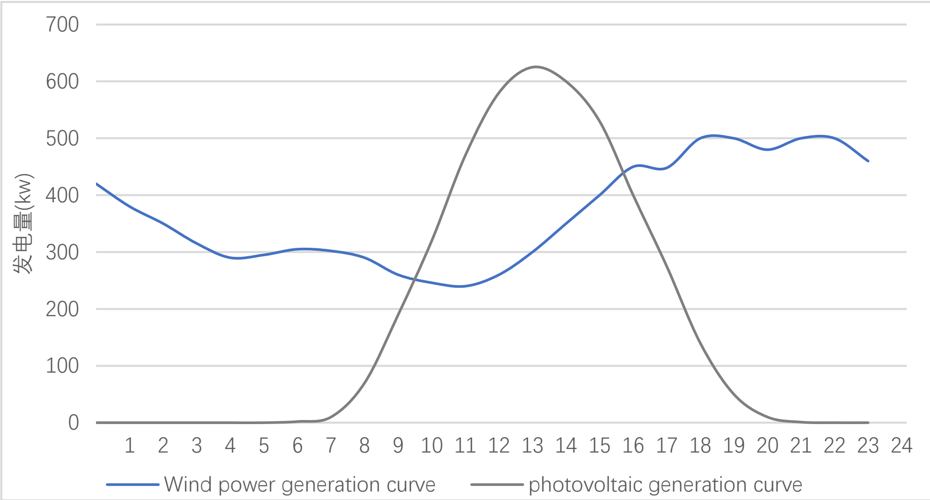


Figure 8 wind-solar hybrid power generation system–output characteristic curve of wind power and photovoltaic

Some countries and regions worldwide have rolled out policies mandating energy storage allocation for wind and solar projects. For instance, India enforces that photovoltaic and wind power projects install energy storage devices, aiming to tackle the intermittency and volatility issues of new energy generation, as well as promote the integration of renewable energy and grid stability. In such regions, wind-solar hybrid projects hold considerable advantages, primarily in following aspects:

1. **The wind-solar hybrid project can better meet policy requirements:** the power generation of the wind-solar hybrid project is relatively stable, with the same energy storage capacity configured, it can better meet the policy requirements for the stability and reliability of power output, reduce the penalties or restrictions faced due to non-compliance with policy requirements, and ensure the normal operating and revenue of project.

2. **High utilization rate of the energy storage system:** the complementary characteristics of wind-solar hybrid projects enable more balanced and frequent charging and discharging of the energy storage system. The energy storage system can play a role when there is excess power generation from both photovoltaic and wind power. Compared with standalone wind power or photovoltaic projects, the utilization rate of the energy storage system is higher. This helps improve the investment efficiency of energy storage equipment, reduce the unit cost of the energy storage system, and thereby enhance the investment return of the entire project.

3. **Enhance flexibility and adaptability of the project:** the integration of energy storage systems with wind-solar hybrid projects enables the project to be more flexible and adaptable in the electricity market. For instance, during peak periods of electricity demand, the energy storage system can release stored electrical energy, working in conjunction with wind and solar power generation to meet load requirements, thereby improving the project’ s power supply capacity and revenue. When there are significant fluctuations in electricity market prices, optimized power dispatch can be achieved through rational control of the charging and discharging of the energy storage system, leading to higher market returns. Additionally, the energy storage system can provide backup power in the event of grid failures or emergencies, ensuring the continuous operation of the project, reducing power outage losses, and indirectly enhancing the return on investment.

2.3 Challenges such as High Wind Load and Shadow Occlusion

The site selection for wind power generation is usually in areas such as the seaside and Gobi where the wind speed is high, the wind volume is large, and the wind resources are abundant. Large-scale wind turbines are set with cut-in and cut-out wind speeds, when the wind speed reaches the cut-in wind speed, the wind turbine starts to operate, and when the wind speed reaches the cut-out speed, the control system of the wind turbine will activate the protection mechanism to stop the impeller from rotating, preventing the blazes from being damaged in excessive wind speeds. Referring to the protection measures of wind power generation, whether it is to insert and install modules in existing wind farms or to build new wind-solar hybrid power generation fields, higher requirements are put forward for the load-bearing capacity of modules, the reliability of brackets, and the installation and connection methods of modules and brackets. PV enterprises need to conduct targeted research and development tests, match the load-bearing capacity of wind turbines, and improve product reliability.

At the same time, the combined layout with wind turbines will inevitably cause more frequent shadow shading to the modules, resulting in a loss of the module’ s power generation capacity. Ultimately, the effectiveness of the wind-solar hybrid project will fall short of expectations. It is more likely to trigger problems such as module hot spots and junction box failures, posing a serious threat to the safety of the power plant. Improving the anti-shading ability of modules is also a pain point that urgently needs to be addressed.

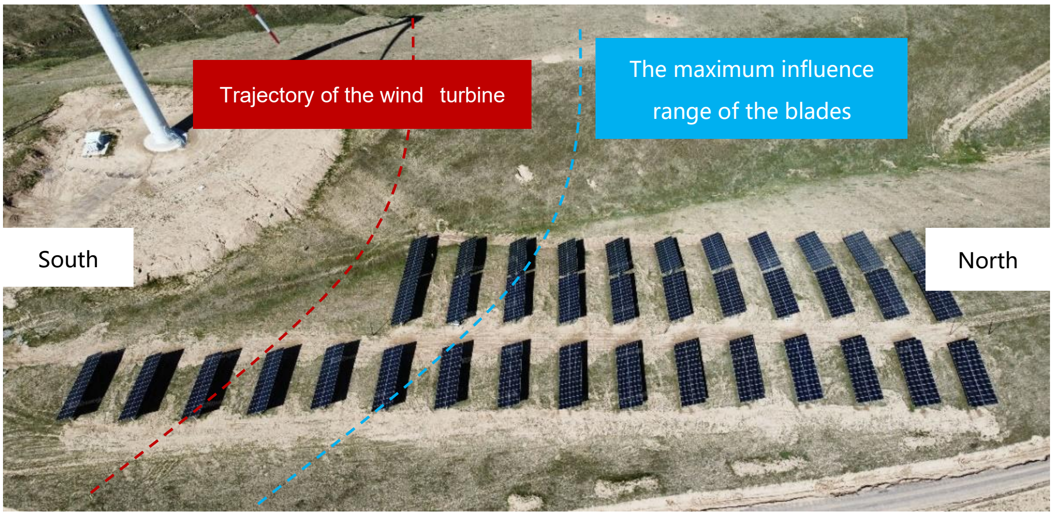


Figure 9 - schematic diagram of blade trajectory and shadow occlusion range

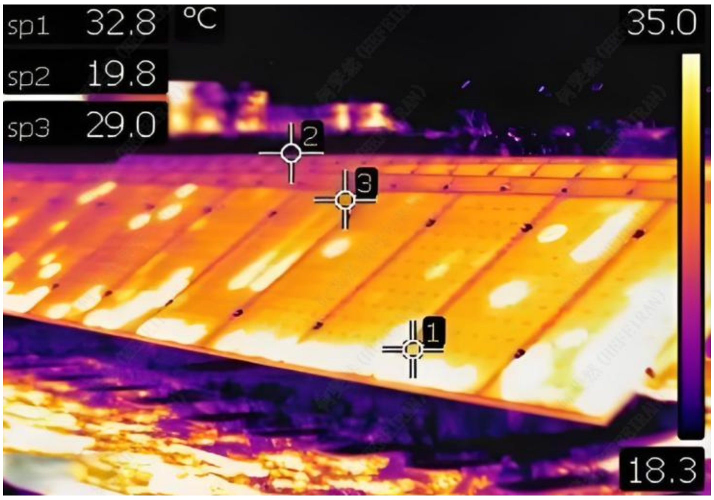


Figure 10 - the intermittent blockage of the wind turbine blazes leads to uneven current distribution inside the modules, a decline in power generation performance, and an exacerbation of the hot-spot effect. This will cause the diodes to conduct frequently, accelerate the aging rate of the components, and effect the lifespan of the modules.

Chapter 3 - Advantages of Hi-MO9 in Wind-Solar Hybrid

Based on the various opportunities and challenges faced by wind-solar hybrid solution, the scenario-specific Hi-MO9 product launched by LONGi can better address scenario-specific pain points, meet development and construction needs, deeply tap into scenario value, and take a result-oriented approach to provide the best industry solutions for professional EPCs and owner partners.

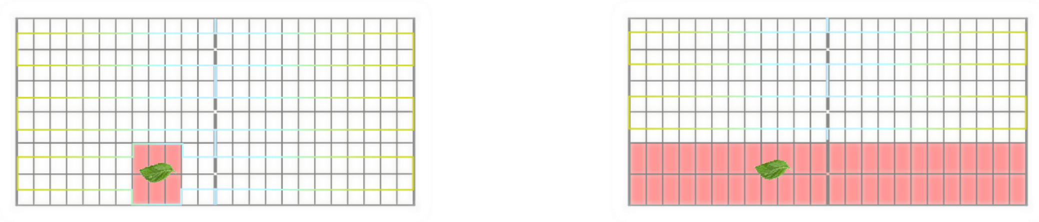
3.1 the High Power and High Efficiency of Hi-MO9 Reach New Heights

Thanks to a large amount of R&D investment and the unremitting technological research of the company’ s professional technical team, Hi-MO9 has further achieved technological rejuvenation, significantly improved product performance, and led the industry’ s technical level to a new height. According to the latest data, the highest conversion efficiency of Hi-MO9 products reaches 24.8%, the highest module power reaches 670W, and the module bifaciality factor is as high as 80%. The latest Hi-MO9 products combine five process upgrades, including silicon wafer substrate, battery process remodeling, graphical grid line technology, matrix string welding, and cell-level shading optimization, to comprehensively achieve product leadership in the four fields of performance, reliability, standards, and manufacturing, and become a benchmark product in the photovoltaic module field.

3.2 Hi-MO9 Anti-shadow Occlusion Ability Optimization

In photovoltaic application scenarios with complex environments, the uneven irradiance distribution caused by the shadow shading effect (including shadow occlusion from vegetation, poles, etc.) will lead to a twofold power loss in the modules: the power loss caused by the attenuation of direct radiation, and the electrical mismatch caused by the operation of the bypass diode. Traditional modules adopt a centralized bypass protection architecture. When a local battery string is occluded, the corresponding bypass diode is forced to conduct, which will cause the entire string circuit to stop generating electricity, and the system efficiency will decline in a step-by-step manner.

The BC module achieves a battery-level intelligent protection mechanism through a revolutionary intrinsic parallel circuit design. Its unique distributed micro-grid structure enables each battery cell to have an independent bypass function, when a single-piece battery is blocked, only the local equivalent diode is triggered to conduct, forming an independent current path, the single-piece battery bypasses itself without the need to activate the cascade protection device, ensuring that the shading loss is strictly controlled within the physical area of the blocked unit and does not affect the power output of the entire string of batteries.



Hi-MO9 traditional module

Figure 11 - comparison of the shading impact on single-cell batteries of Hi-MO9 modules and traditional modules

In the laboratory tests, 50%, 100% of one half-cell, and two half-cells of the BC module and the TOPCon module were respectively shade, and the changes in their power output were monitored. The results are shown in the figure below. When a single solar cell was shaded, the power change of the BC module was relatively small, while the TOPCon product experienced a significant power drop. The strong anti-shadow shading ability of the BC module enabled its power output to increase by up to 34% compared with that of the TOPCon module.

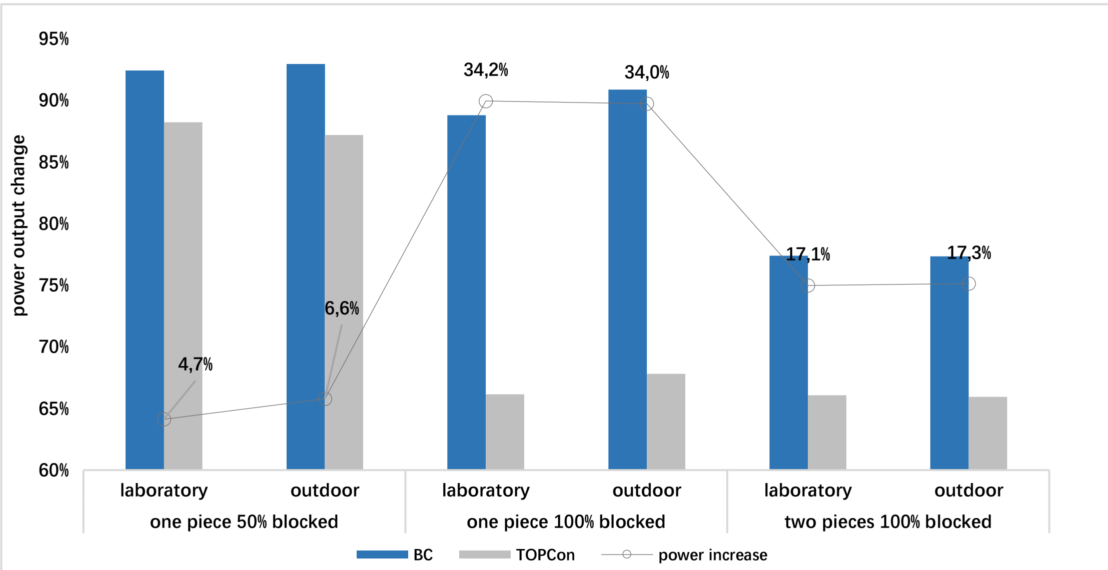


Figure 12 - power output changes of BC modules & TOPCon modules after shading

In the empirical test (CGC Hainan Empirical Project), the situations of column shading and partial shading were simulated for Hi-MO9 modules and TOPCon modules respectively, and a comparative empirical study was conducted on the changes in the power generation capacity of the two types of modules. The results are shown in the figure below.

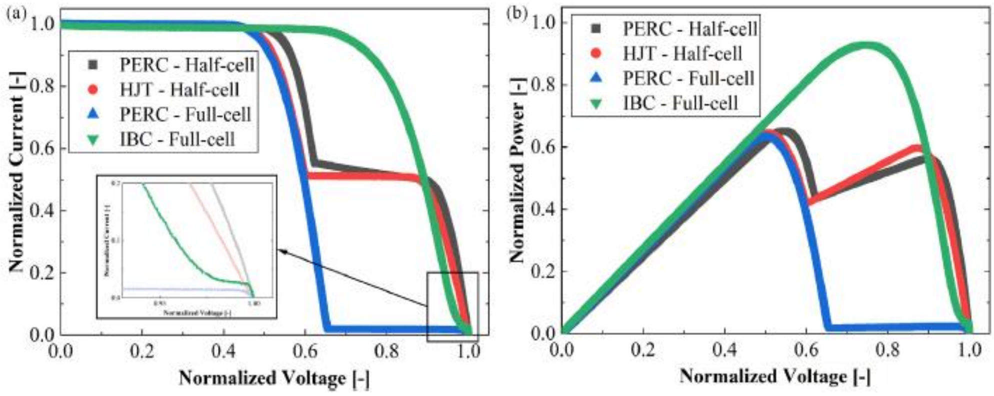
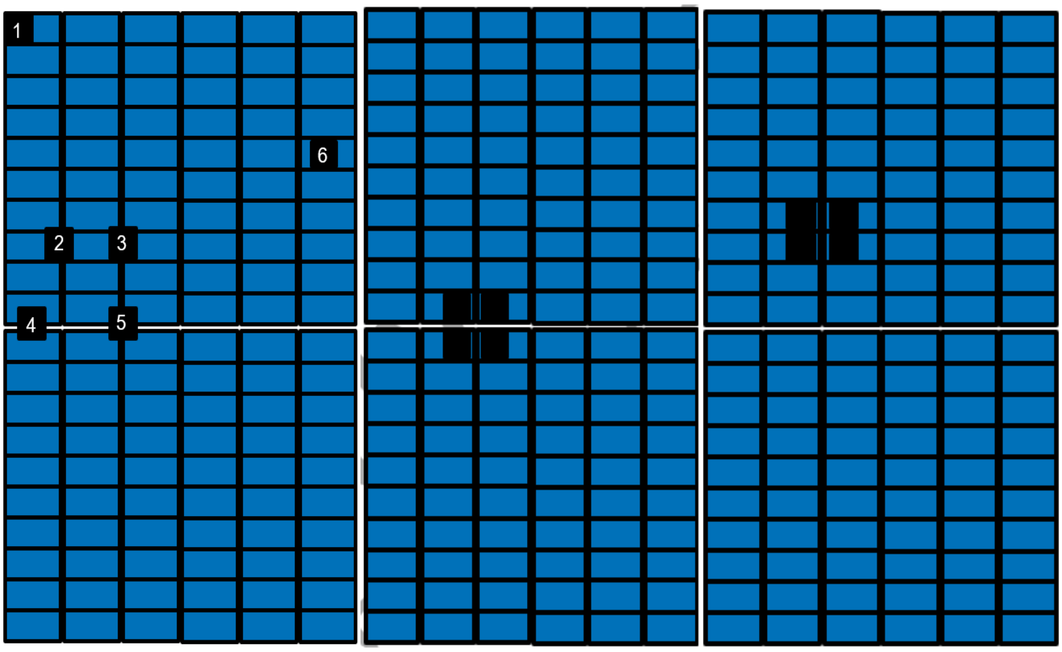


Figure 13 - comparisons of power curves of BC modules and other modules after cell shading

In the TÜV Rheinland anti-shading comparison test, 6 representative single-point shading and 2 multi-point shading scenarios were simulated for LONGi BC modules and TOPCon modules using shading sheets with an area of 50% of a half-cell, and a comparative test was conducted on the power generation capacity changes of the two types of modules. The results are shown in the table below. In the case of single-point shading, the power generation of the BC module has a maximum power generation loss reduction of approximately 7.31% compared to the TOPCon module. In the case of multi-point shading, the power generation of the BC module has a maximum power generation loss reduction of approximately 16.92% compared to the TOPCon module. Moreover, the LONGi BC module has also obtained the TÜV Rheinland anti-shading 2PfG 2926/05.25 Class A+ certification.

Test Module	LONGi BC	TOPcon Module	difference
Characteristic	ΔP[%]	ΔP[%]	
Single-spot shading 1	-5.42%	-12.73%	7.31%
Single-spot shading 2	-3.71%	-5.65%	1.94%
Single-spot shading 3	-4.92%	-6.38%	1.46%
Single-spot shading 4	-6.40%	-7.79%	1.39%
Single-spot shading 5	-1.13%	-1.54%	0.41%
Single-spot shading 6	-7.25%	-13.74%	6.49%
Multi-spot shading 1	-21.45%	-32.46%	11.01%
Multi-spot shading 2	-18.67%	-35.59%	16.92%

Table 1- TÜV Rheinland anti-shading occlusion comparative test data



a)Single-spot shading 1-6 b) Multi-spot shading 1 c) Multi-spot shading 2

figure 14 - schematic diagram of TÜV Rheinland anti-shading occlusion comparison test

Figure 15 - the LONGi BC module obtained the TÜV Rheinland anti-shading 2PfG 2926/05.25 Class A+ certification

In addition to reducing shading power loss, the enhancement of the shadow occlusion optimization function also improves the safety of the modules. Its unique weak conduction design (similar to a bypass diode) can significantly reduce the local temperature under shadow occlusion and prevent local overheating of the modules. Under the same experimental conditions, in the hot spot comparison test conducted by TÜV Rheinland, the local temperature of LONGi BC modules was reduced by up to 42% compared with that of TOPCon modules under the highest conditions, effectively reducing the risk of module failure.

Module Type	LR7-54HVH	Topcon Module
Measurement at 1st worst case shading cell at edge of module		
Maximum measured cell temperature [°C]	127.0	160.0
Shading rate [%]	50	60
Measurement at 1st worst case cell of complete module		
Maximum measured cell temperature [°C]	107.0	169.0
Shading rate [%]	60	60
Measurement at 2nd worst-case cell of complete module		
Maximum measured cell temperature [°C]	101.0	171.0
Shading rate [%]	50	50
Measurement at lowest leakage current cell of complete module		
Maximum measured cell temperature [°C]	98.0	169.0
Shading rate [%]	40	40

Table 2- TÜV Rheinland hot spot contrast test

3.3 Hi-MO9 High Wind Load and Reliability Performance

The wind vibration frequency in the wind farm area is relatively high, the bending moment generated by the wind load on the photovoltaic modules will cause bending stress inside the modules, and the pulsating component of the wind will generate shear stress on the surface of the photovoltaic modules. When the modules are subjected to wind load and wind vibration for a long time, it is likely to cause failure phenomenon such as hidden cracks in the cells, deformation of the frames, and breakage of the glass, which poses a huge challenge to the reliability of the modules.

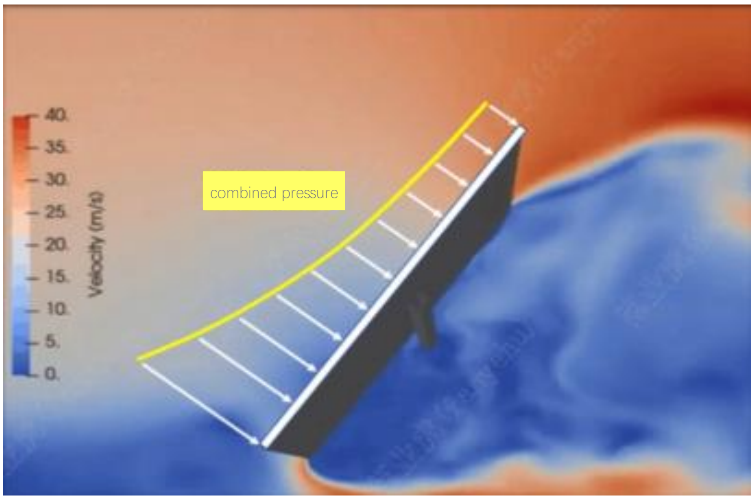


Figure 16-module wind load distribution

Through the dual innovation of structural design and manufacturing process, the BC module systematically solves the risks of hidden cracks and cell fragmentation in photovoltaic modules during mechanical load testing, construction and installation, and long-term operation. Its innovative welding process design based on a full-back electrode layout adopts a single-side welding process and a "one-line" continuous welding technology, breaking through the limitations of traditional Z-type welding. It achieves a significant leap in reliability through three core advantages: 1.The linear solder tape path eliminates stress-concentrated areas and reduces the risk of edge fragmentation; 2.The welding contact area is significantly expanded to form a high-strength mechanical connection interface; 3.The tensile and shear resistance of solder joints are significantly superior to traditional processes.

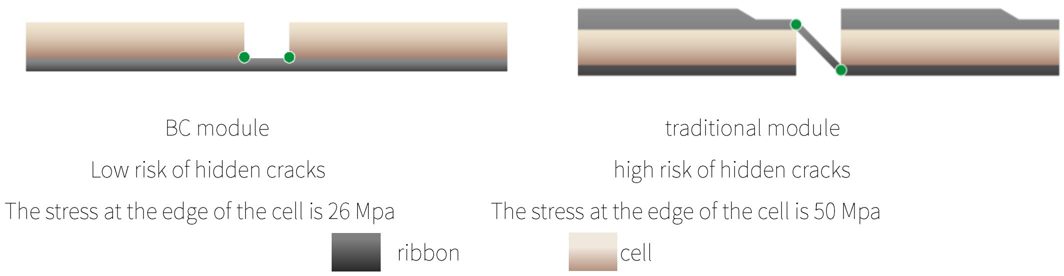


Figure 17-cell edge stress of BC modules & traditional modules

At the same time, the BC module reconstructs the stress distribution through digital topology optimization technology, combines with the 0BB full-string welding system to achieve precise process control, enhances the mechanical load performance of the module, and achieves three core characteristics: 1. The strengthen retention rate of the connection interface in extreme temperature environments is leading in the industry; 2. The residual stress decay rate under dynamic load is reduced to 40% of the industry average; 3. The fatigue resistance is increased to more than three times that of conventional modules. This significantly improves the anti-deformation ability of the module under complex loads, the unique stress dispersion structure can effectively cope with snow loads, wind loads, and asymmetric external forces during the construction process, minimizing the probability of hidden cracks and ensuring the reliability throughout the installation and operation and maintenance cycle.

The high reliability of the BC module has also been recognized by a third-party organization. TUV SUD, a third-party organization, conducted a strengthened wind tunnel test on the BC double-glass module at an installation angle of 30 degrees (the conventional test is at 15 degrees) and a strengthened dynamic load test at 1500 Pa (1.5 times the IEC standard), after these tests, there were no hidden cracks in the BC module. Combining with the reliability EL test data, the BC module can reduce the hidden-crack risk by approximately 87%. Considering the characteristic of high wind speed levels in the wind-solar hybrid scenario, LONGi has provided a variety of installation solutions for high-load scenarios to meet the design requirements of different scenarios, its load-bearing capacity can reach up to +6000Pa/-5400Pa, corresponding to a typhoon level of 16. In actual tests, using the benchmark installation scheme, the maximum wind-bearing speed can reach +64.4 m/s and -62.4m/s, equivalent to a typhoon of level 18.

<table>
<tr><th colspan="4">Committed load</th><th></th><th>Actual test</th></tr>
<tr><td rowspan="2">Load capacity</td><td rowspan="2">Installation method</td><td colspan="2">Wind speed(m/s) corresponding to the 15° inclination angle of the fixed bracket</td><td rowspan="2">Corresponding typhoon level</td><td></td></tr>
<tr><td>10-minute maximum average</td><td>3-second maximum average</td><td rowspan="8">+64.4m/s and -62.4m/s can be achieved by adopting the benchmark installation scheme, equivalent to typhoon level 18</td></tr>
<tr><td>+5400/-2400</td><td>Benchmark installation scheme: out four-hole bolt installation, 1400 hole,4 bolts</td><td>34.37</td><td>48.59</td><td>Level 12</td></tr>
<tr><td>+6000/-3600</td><td>1400 hole, 4 bolts + 4 elliptical washers</td><td>42.09</td><td>59.52</td><td>Level 14</td></tr>
<tr><td>+6000/-4200</td><td>1400 hole, 4 bolts + 4 elliptical washers + 4 pressing blocks</td><td>45.46</td><td>64.28</td><td>Level 14</td></tr>
<tr><td>+6000/-4800</td><td>1400 hole, 4 bolts + 4 elliptical washers + 4 hook pressing blocks</td><td>48.60</td><td>68.72</td><td>Level 15</td></tr>
<tr><td>+6000/-(5000/4000)</td><td>3 purlins, 400/1400 hole, 6 bolts + 6 elliptical washers + 6 pressing blocks</td><td>49.60</td><td>70.14</td><td>Level 15</td></tr>
<tr><td>+6000/-(5000/4800)</td><td>3 purlins, 400/1400 hole, 6 bolts + 6 elliptical washers + 6 hook pressing blocks</td><td>51.55</td><td>72.89</td><td>Level 16</td></tr>
<tr><td>+6000/-5400</td><td>4 purlins, 400/1400 hole, 8 bolts + 8 elliptical washers + 8 hook pressing blocks</td><td>51.55</td><td>72.89</td><td>Level 16</td></tr>
</table>

Table 3 - relationship between high wind load carrying capacity level, installation method and wind speed of Hi-MO9

Chapter 4 - Value Calculation and Analysis of Wind-Solar Hybrid Power Generation

After specifically introducing the value points and advantages of the product, we will analyze the Hi-MO9 product solution in wind-solar hybrid scenarios through a project calculation model, and measure the scenario-based gains and high-value manifestation of the Hi-MO9 product in wind-solar hybrid scenarios.

4.1 Introduction to the Value Calculation Model for Wind-Solar Hybrid Solution

To comprehensively simulate the scenario-based advantages of Hi-MO9 under the layout of wind-solar hybrid, a mainstream 5MW wind turbine on the market is selected as the model. The same-type-plate BC modules and TOPCOn modules are used to compare the overall power generation performance. The specific construction of the calculation model is shown in the following table:

	TOPCon		Hi-MO9	
bifaciality	~80%		~80%	
Module efficiency	~22.9%		**24.8%**	
Module power	~630W		**670W**	
Temperature coefficient	~-0.29%/°C		**-0.26%/°C**	
Degradation	First-year degradation	linear degradation	First-year degradation	linear degradation
	⩽ 1%	⩽ 0.4%	**⩽ 1%**	**⩽ 0.35%**
Low irradiance performance	Normal performance		**Better low irradiance performance**	
Reliability	Conventional welding, ordinary wafer		**Backside one-line welding, LONGi Tairay wafer**	
Special design	/		**Resistance to uneven light irradiation & low current unbalance risk**	

Table 4 - comparison of key parameters between Hi-MO9 and Topcon products

	name	Unit capacity	Product selection
1	Wind turbine generator	5MW*4 =20 MW	Mainstream 5MW wind turbine
2	Photovoltaic power generation	Not exceeding 50% of wind power, i.e. 10MW	LONGi Hi-MO9—210R-670W; Competitor TOPCon-210R-630W
3	Design principle	The minimum spacing of photovoltaic modules is set to insure no shading for 6 hours on the Winter Solstice; the east-west spacing between photovoltaic modules and wind turbines is arranged with a minimum spacing of no shading for 4 hours on the Winter Solstice. If the capacity is higher than 10MW, the spacing from the wind turbine is increased to reduce shading.	
4	Calculation scenario	Hami, Xinjiang, subject to the selection of the project site	
5	Calculation method	Equal DC side capacity, equal land area + fixed bracket	
6	BOS saving points	Increase the spacing of Hi-MO9 to have the same footprint as TOPCon; increase the power of a single set of brackets and reduce the cost per watt of the brackets	
7	Power generation value	Hi-MO9 features low attenuation and low temperature coefficient; reduces shading losses	
8	Evaluation indicators	Evaluation cycle: 25/30 years; Evaluate the project investment return rate and LCOE value of Hi-MO9 from the perspective of photovoltaics	

Table 5 - the main calculation standards of wind-solar hybrid projects

4.2 Comparison and Calculation of Wind-Solar Hybrid Project Plans

Use PVsyst simulation software to model the layout scheme of wind-solar hybrid systems, calculate the power generation performance of TOPCon modules and Hi-MO9 modules under the same layout scheme, and quantify the advantages of Hi-MO9 modules over TOPCon modules in shaded application scenarios of wind-solar hybrid systems. Assume that the shortest east-west distance between the wind turbine and the photovoltaic module is 163-180m, and the shortest north-south distance is 60m.

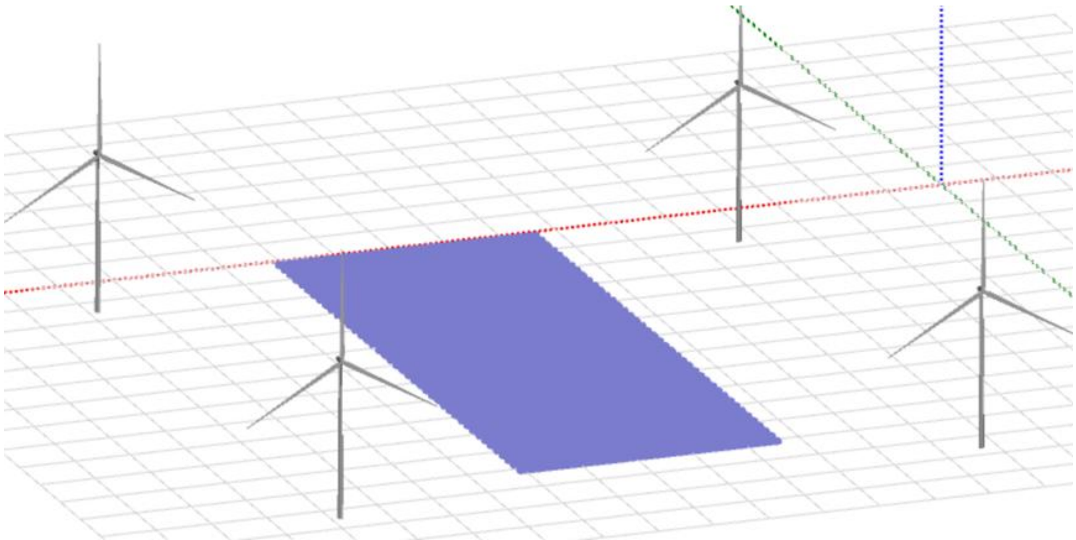


Figure 18- - schematic diagram of simulated wind turbine layout and photovoltaic layout

The calculation results are as follows:

item	unit	TOPCon	Hi-MO9	difference
Module power	Wp	620	660	40
DC capacity	MWp	10	10	/
Power of bracket string	KWp	17.36	18.48	6.45%
Land area	Mu	199	199	/
Electricity price	Yuan/kWh	0.25	0.25	/
		Result		
BOS cost	Yuan/W	1.7414	1.7114	Save ¥0.03
Power generation dispatched to grid in 25 years	Ten thousand kWh	46 059	47 060	2.20%(0.5% anti-shading)
Power generation revenue in 25 years	Ten thousand yuan	11 515	11 765	250
Module premium	Yuan/W	Base	+0.078	
Power generation dispatched to grid in 30 years	Ten thousand kWh	54 258	55 802	2.85%(0.5% anti-shading)
Power generation revenue in 30 years	Ten thousand yuan	13 564	13 951	386
Module premium	Yuan/W	Base	+0.080	

Note:

1) the 0.5% anti-shading advantage of Hi-MO9 is derived from PVsyst simulation results;

2) the premium of Hi-MO9 is based on the assumption that the total investment IRR over 25 years and 30 years is the same as that of TOPCon respectively.

Table 6 - simulation and calculation results of wind-solar hybrid systems over 30 years

Based on the above analysis results, the following conclusions can be drawn:

Under the scenario of wind-solar hybrid projects with the same capacity and the same land area, the system BOS cost using Hi-MO9 is 0.03 yuan per watt lower than that of TOPCon. The power generation per kilowatt of Hi-MO9 modules increases 2.2% ~ 2.85%, moreover, under the condition that the total investment IRR is the same, Hi-MO9 has a premium of about 0.08 yuan/W compared with TOPCon.

Chapter 5 - Comparison of Empirical Power Generation for Wind-Solar Hybrid

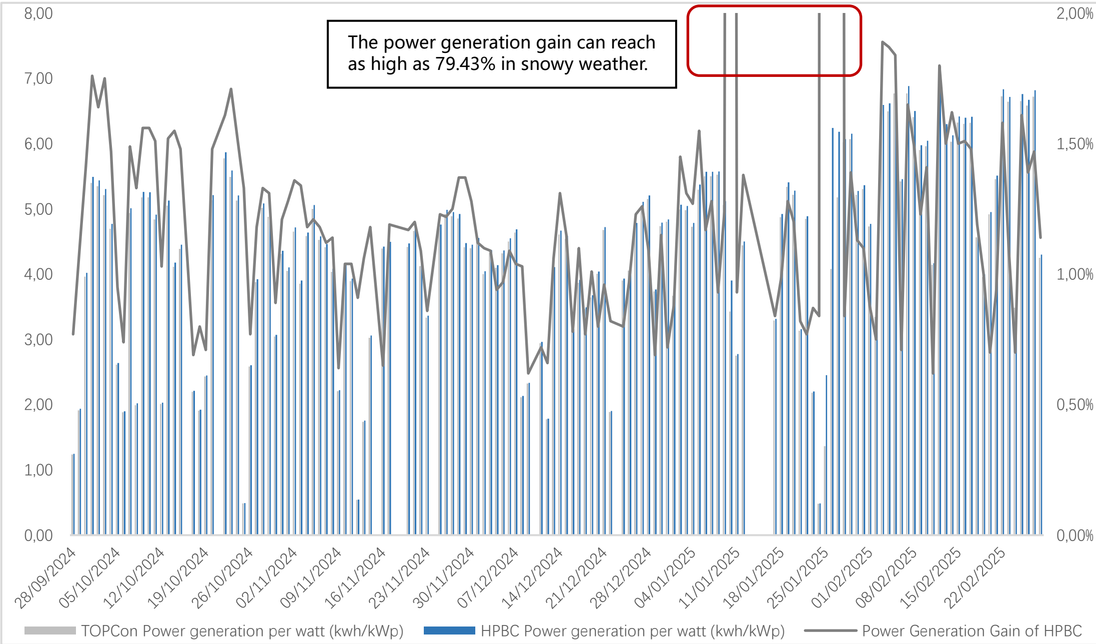
5.1 Empirical Study on the Comparison of Static Shadow Occlusions in Ningxia

To practically test the differences in the power generation capabilities of Hi-MO9 modules and TOPCon modules under shadow occlusion, we established a simulated empirical power plant in Binggou, Ningxia. By simulating shadow occlusion from wind turbine towers, chimneys, etc., we recorded and compared the power generation of Hi-MO9 modules and TOPCon modules respectively.

Pictures of the empirical site is as follow:

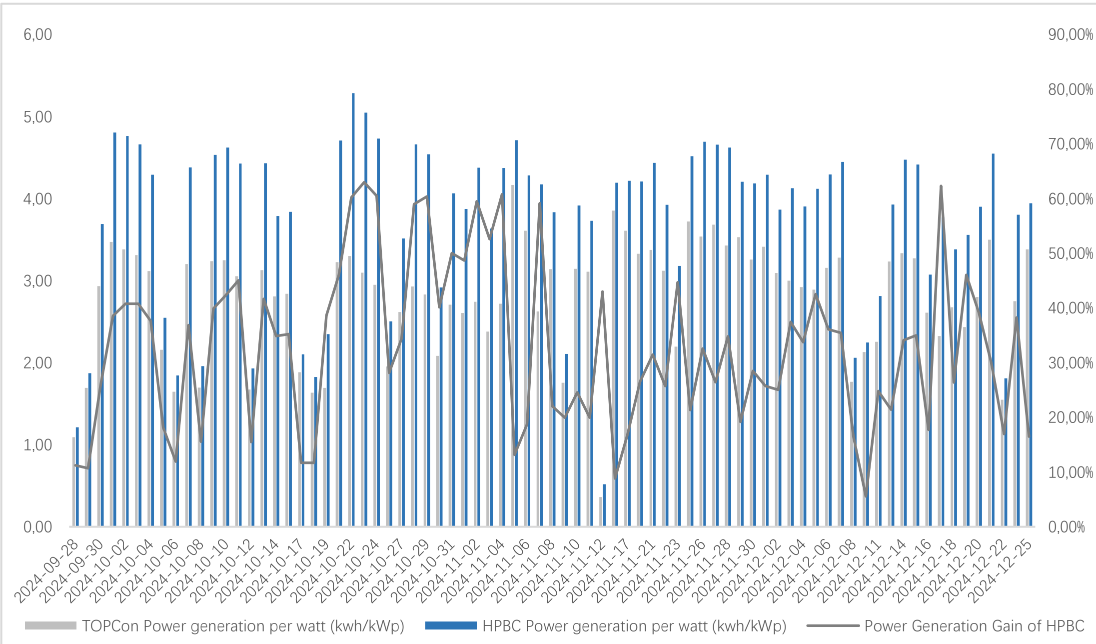
Figure 19-picture of the Ningxia wind-solar hybrid empirical site

In the empirical field, 2 module arrays are set up (18 Hi-MO9 modules and 18 TOPCon modules each). An unobstructed module control group and a column obstruction control group are set up respectively. The daily power generation data of HPBC2.0 and TOPCon are compared, as well as the power generation of modules under obstructed/unobstructed conditions and the anti-obstruction effect. The result is as follows.



without occlusion

the power generation per watt of BC is 1.39% higher than that of TOPCon



Column occlusion

The power generation per watt of BC is 31.61% higher than that of TOPCon

Figure 20 - Data of the empirical project in Yinchuan, Ningxia

Empirical evidence shows that, in the case of no occlusion, the average power generation gain per kilowatt of BC modules is 1.39%, and the maximum daily value can reach 79.43% (snowy weather), in the case of column occlusion, the average power generation gain per kilowatt of BC modules is 31.61%, and the maximum daily value can reach 62.99%.

	Data	Hi-MO9	TOPCon	Power generation gain
Without occlusion (2024.09.28~ 2025.02.28)	Cumulative power generation per kilowatt (kWh/kWp)	634.02	625.34	**1.39%**
Column occlusion (2024.09.28~ 2024.12.25)	Cumulative power generation per kilowatt (kWh/kWp)	299.95	227.9	**31.61%**

Table 7 - accumulated power generation data of the empirical project in Yinchuan, Ningxia

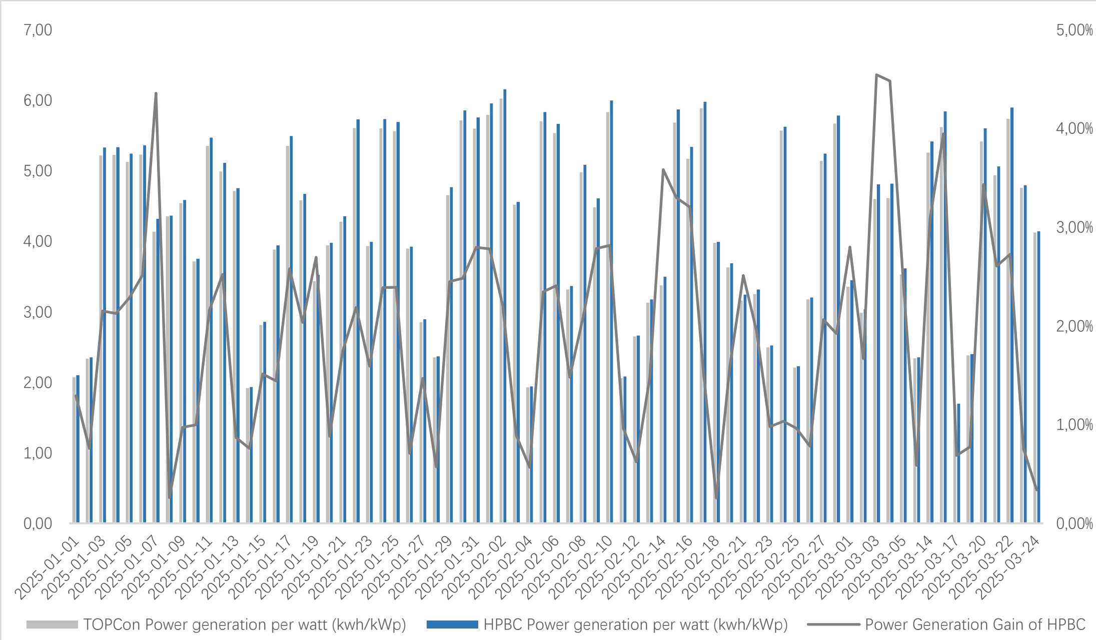
5.2 CGC Hainan Shadow Occlusion Comparison Empirical Evidence

In the empirical test (CGC Hainan Empirical Project), for Hi-MO9 modules and TOPCon modules, an unobstructed module control group and a column-obstructed control group were set up respectively. The daily power generation data of HPBC2.0 and TOPCon were compared, as well as the power generation of the modules under the conditions of with/without obstruction and the anti-obstruction effect.

Pictures of the empirical site is as follow:

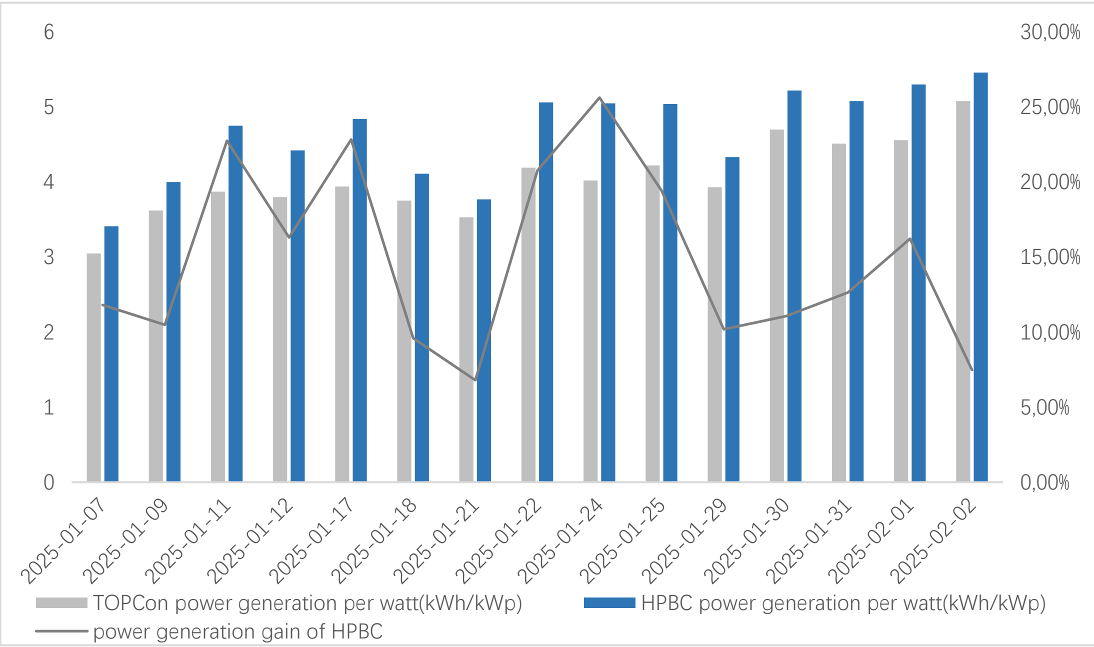
Figure 21 - CGC Hainan empirical site photo

A total of 4 module arrays were set up at the empirical site (10 Hi-MO9 modules and 10 TOPCon modules each), and the results are shown in the figure below.



Without occlusion

The power generation per watt of BC is 2.03% higher than that of TOPCon



Column occlusion

The power generation per watt of BC is 14.96% higher than that of TOPCon

Figure 22 - comparison of power generation with column obstruction in CGC Hainan empirical tests

Empirical evidence shows that, in the case of no shading, the power generation per watt of BC modules is on average increased by about 2.03% compared with that of TOPCon modules, in the case of shading by columns, the power generation per watt of BC modules is on average increased by about 14.96% compared with that of TOPCon modules.

	Data	Hi-MO9	TOPCon	Power generation gain
Without occlusion (2024.09.28~ 2025.02.28)	Cumulative power generation per kilowatt (kWh/kWp)	320.86	314.47	**2.03%**
Column occlusion (2024.09.28~ 2024.12.25)	Cumulative power generation per kilowatt (kWh/kWp)	69.848	60.756	**14.96%**

Table 8 - accumulated power generation data of the CGC Hainan empirical project

Chapter 6 - Future Outlook

6.1 - BC Technology has Significant Advantages in the Offshore Floating Scenario

DNV predicted in their Energy Transition Outlook 2024 report that by 2050, the evolution of the global power supply will shift towards a significant transition to renewable energy. Due to the significant progress in wind power generation and photovoltaic technology and the rapid annual decline in the LCOE cost, it is expected that by the middle of this century, solar energy is likely to account for 40% of the global energy structure, while wind energy will account for 30% of the energy structure.

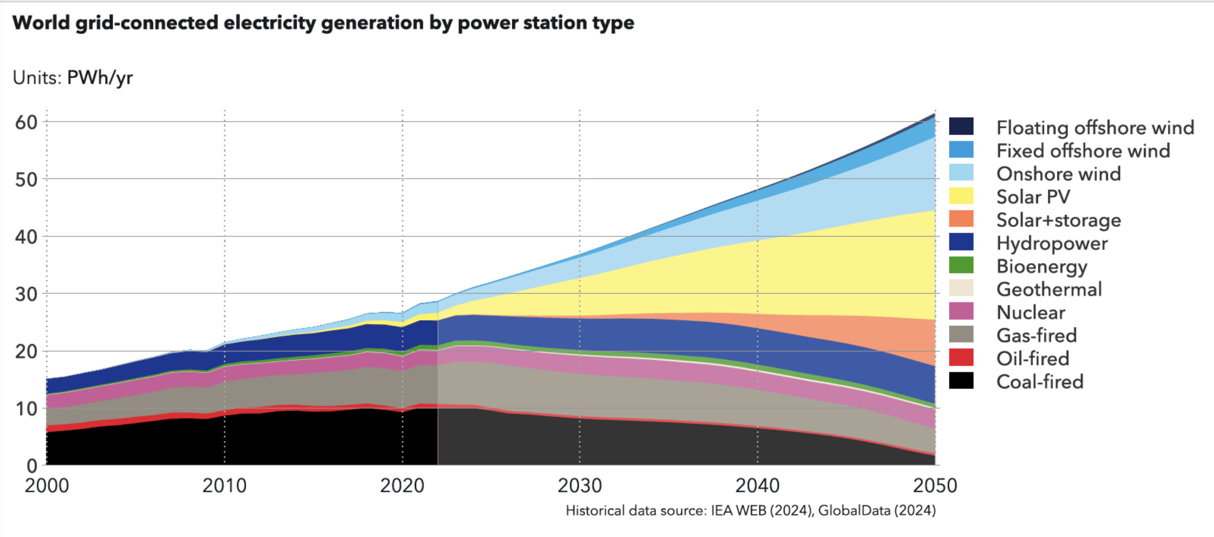


Figure 23 - DNV's forecast of the proportion of energy types in global grid-connected power generation of the new power system [source: DNV, 2025]

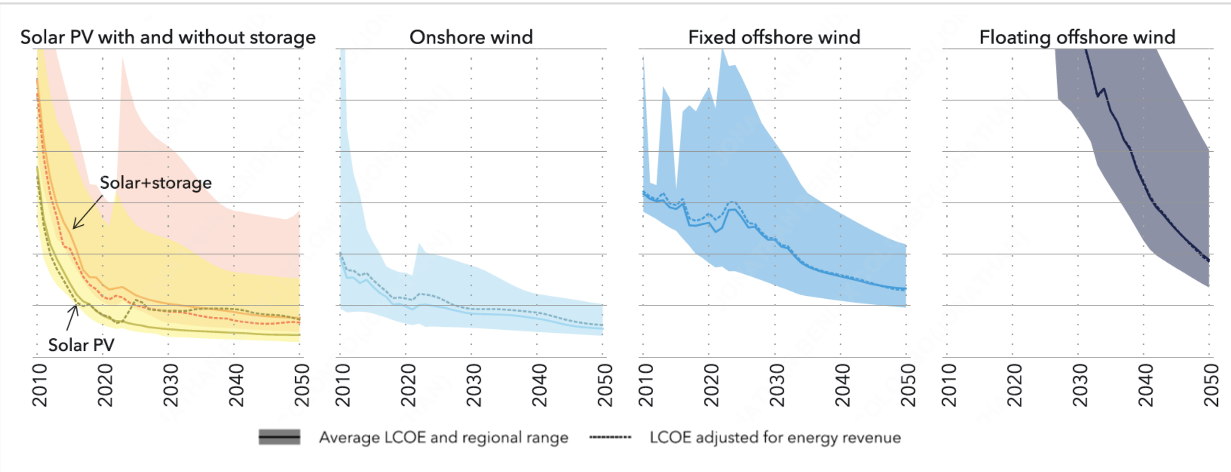


Figure 24 - development forecast of PV and Wind power LCOE [source: DNV, 2025]

With the upgrading and iteration of technology, floating offshore wind farms have also emerged. As a major innovation, they can develop deep-sea wind energy resources that were previously inaccessible. In December 2024, the Ministry of Natural Resources issued the Notice on Further Strengthening the Sea Use Management of Offshore Wind Power Projects, requiring that new offshore wind power projects should be located in waters more than 30 kilometers away from the shore or with a water depth greater than 30 meters. At the same time, it encourages the use of the “wind power +” model for offshore wind power projects to achieve “multiple uses of one sea”. This provides policy support for the combination of wind energy and light energy development in the deep-sea and far-sea areas, promotes the development of comprehensive development models such as “wind power + photovoltaic”, realizes the complementarity of multiple energy sources, and enhances the comprehensive utilization value of offshore space.

In the development of offshore wind-solar hybrid scenarios, BC modules have unparalleled advantages. First of all, the sea surface is subject to unpredictable wind and weaves, and the light reflectivity of the water surface is much lower than that of land, which greatly weakens the power generation capacity of the back of the modules. The positive and negative electrodes of BC modules are both set on the back of the modules, and there is no busbar blocking on the front, so it can absorb light energy to the greatest extent, give full play to the advantage of high power generation efficiency on the front of the modules, and is less affected by the fluctuations of sea weaves.

Secondly, the floating offshore system is usually cooled naturally by water bodies, but the high temperature in summer may still cause the temperature of modules to rise. The back electrode design of BC modules helps to more efficiently conduct heat out through the back, reducing the operating temperature and thus decreasing the power attenuation caused by high temperatures, its innovative weak conduction technology can even reduce the local temperature of modules, preventing problems such as hot spots caused by local overheating.

Thirdly, offshore floating platforms may have issues such as support shadows and occlusion by adjacent modules (temporary shadows caused by weave fluctuations). BC modules have no front-side busbars, and local occlusion has a smaller impact on the overall power generation efficiency, the power loss is lower than that of conventional modules, making them particularly suitable for densely arranged floating arrays.

Finally, the sea weaves and wave impacts will generate continuous mechanical stress on the modules. The Tairay silicon wafers used in BC modules are 10μm thicker than those in the industry, featuring better mechanical properties. Their unique straight-line welding structure reduces the stress on the cells, improves the modules' ability to resist hidden cracks, coupled with the strengthened frames and packaging materials, the modules have better bending and impact resistance, reducing the risk of hidden cracks caused by vibration or deformation.

Relying on these advantages, BC photovoltaic modules can better adapt to the complex offshore environment in the offshore floating scenario, while enhancing the stability and economy of long-term operation. Compared with other technologies, BC modules can create more value for the offshore wind and solar power system.

6.2 Market Capacity and Prospects for Scenario Applications

As of the end of 2024, the global installed capacity of offshore wind power reached 83.2GW. Among them, China ranked first with a cumulative installed capacity of 41.8GW, accounting for 50.3% of the global total, while Europe had a total installed capacity of over 36GW, accounting for 44%. In 2024, the global offshore wind power auction volume reached 56.3GW, a record high, with 23.2GW in Europe and 17.4GW in China. The industry is facing challenges such as macroeconomic difficulties and policy instability, but the medium-term prospects are optimistic. It is estimated that by 2034, the global new installed capacity will exceed 350GW, with the total capacity reaching 441GW.

Latin America has one of the world's leading wind power potentials. Brazil, with 8,000 kilometers of coastline and an extensive continental shelf, is extremely suitable for fixed seabed projects and has a technical potential of over 1,200GW of offshore wind energy installed capacity. Colombia, located in the Caribbean region, is particularly promising in offshore wind energy development and is gradually becoming a key hub for offshore wind energy. The development of offshore wind energy projects provides Latin America with a unique opportunity to diversify its energy structure, create employment opportunities, mitigate the impact of climate change, and thus join the ranks of global pioneers in energy transition.

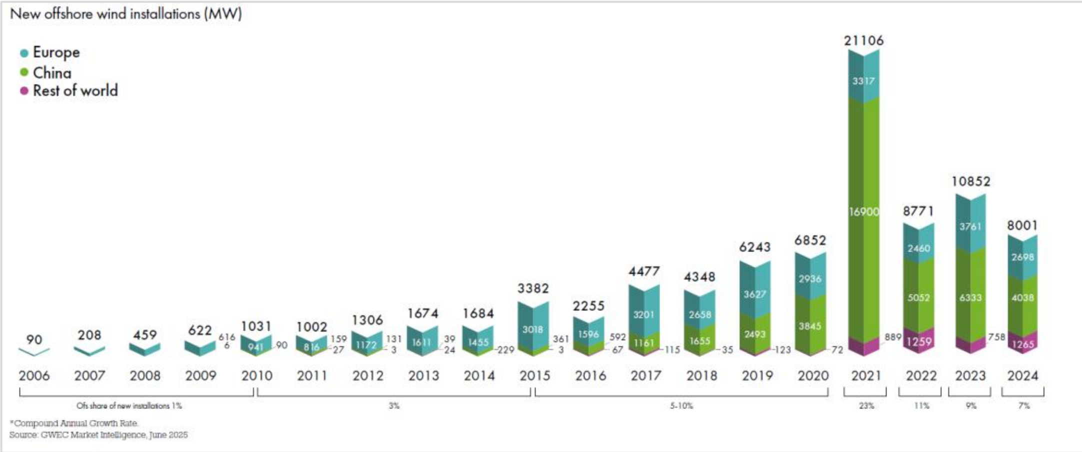


Figure 25-annual newly installed capacity of global offshore wind power (MW) [source: GWEC, 2025b]

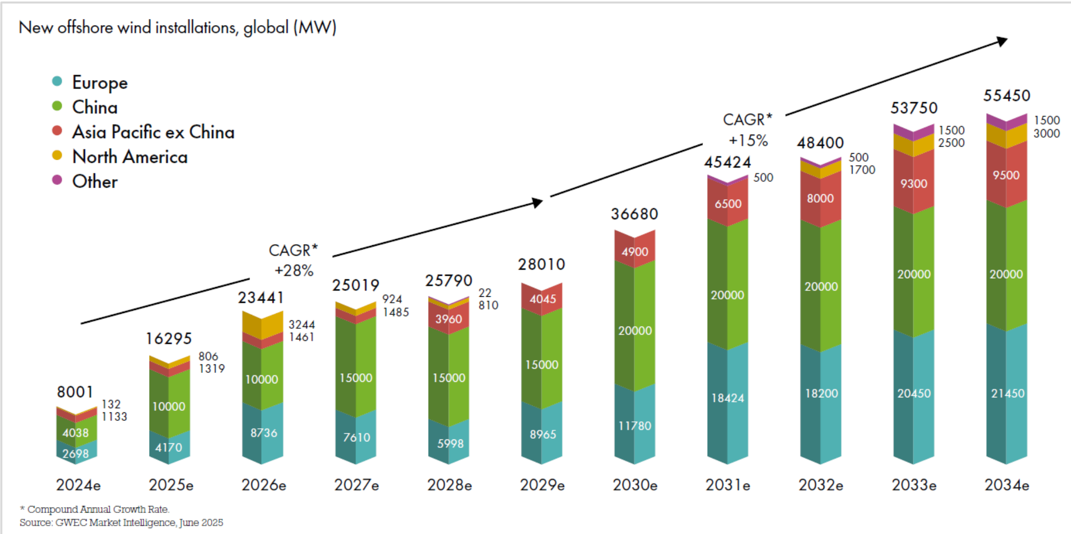
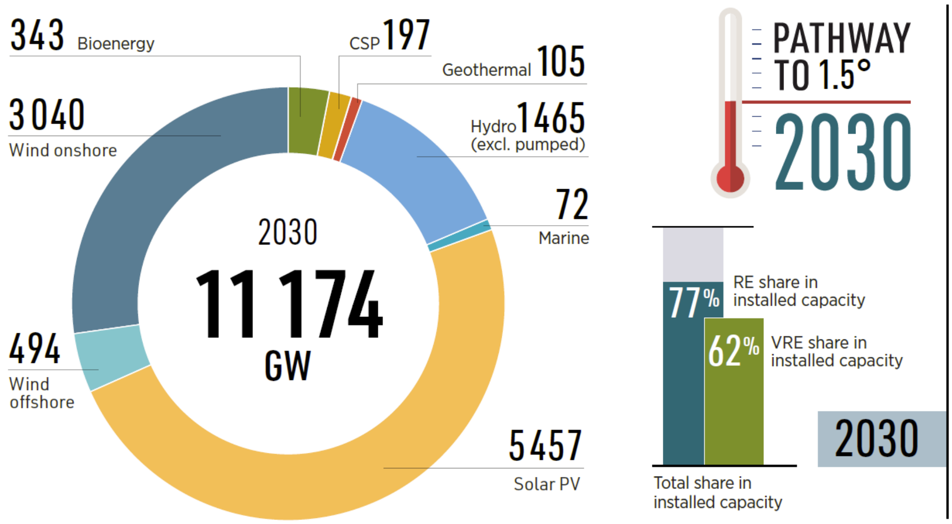


Figure 26- Projected annual global offshore wind power installed capacity [source: GWEC, 2025b]

With its technological leadership and scene adaptability, LONGi Hi-MO9 provides a "highly reliable and highly profitable" solution for the wind-solar hybrid model. In the future, as the industrialization of BC technology accelerates, multi-energy complementary systems improve, and policy coordination deepens, Hi-MO9 is expected to become the core carrier of wind-solar hybrid projects, driving the transformation of new energy from "scale expansion" to "value creation". However, it is necessary to continuously address bottlenecks such as energy storage costs and grid resilience, and achieve sustainable development of wind-solar hybrid through global cooperation and technology sharing. From the perspective of overall development forecasts, due to the significant land constraints on the development of onshore wind turbines, their growth will gradually be outpaced by that of offshore wind turbines, which will also bring opportunities for the development of offshore wind-solar hybrid projects.

RENEWABLE CAPACITY ADDITIONS	2023	Average annual additions 2024-2030
Annual additions (GW/yr):		
Renewable power capacity	473	1 044 GW/yr
Solar PV	346.9	578
Wind energy	114.5	360
Hydropower	6.6	29
Bioenergy	4.6	28
Geothermal	0.4	13
CSP	0.3	27
Marine energy	0.002	10



Based on: (IRENA, 2023a; 2024a).

Notes: GW = gigawatt; CSP = concentrated solar power; PV = photovoltaic; RE = renewable energy; VRE = variable renewable energy; bioenergy includes biogas, biomass waste, and biomass solid; hydropower data excludes pumped hydro.

Figure 27 - energy production capacity map from 2024 to 2030 in sustainable energy [source: IRENA, 2024]

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About

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Founded in 2000, LONGi (Stock code: 601012. SH) is committed to being the world's leading solar technology company, focusing on customer-driven value creation for full scenario energy transformation.

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