中国电建
POWERCHINA

中国电建集团中南勘测设计研究院有限公司
ZHONGNAN ENGINEERING CORPORATION LIMITED

秉责 创新 卓越

Design, Construction and Typical Case Analysis of Solar PV Power Generation

2022.10

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Lecturer Profile

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★ Senior Engineer

★ **Deputy Chief Engineer/Project Manager of International Company**

★ **Engaged in the implementation of overseas projects since July 2010, and engaged in the implementation of overseas renewable energy projects since January 2018.**

★ **Engaged in the project execution in Cambodia, Indonesia, Vietnam, Thailand, and Morocco respectively. Served as the Manager of 2 highway projects and 3 PV EPC project groups.**

★ **A Young Expert of PowerChina Zhongnan Engineering Corporation Limited.**

★ **Won many awards such as the Quality Project Award in Hunan Province, "Typical Case Award for Foreign Investment and Economic Cooperation" of Hunan Construction Industry Association, "Typical Case Award for Foreign Investment and Economic Cooperation" of Hunan Construction Industry Strategic Alliance, "Typical Case Award for Foreign Investment and Economic Cooperation in Changsha in 2021" of Changsha Association of Enterprises for Foreign Investment and Economic Cooperation, and Outstanding Project Manager of PowerChina Zhongnan.**

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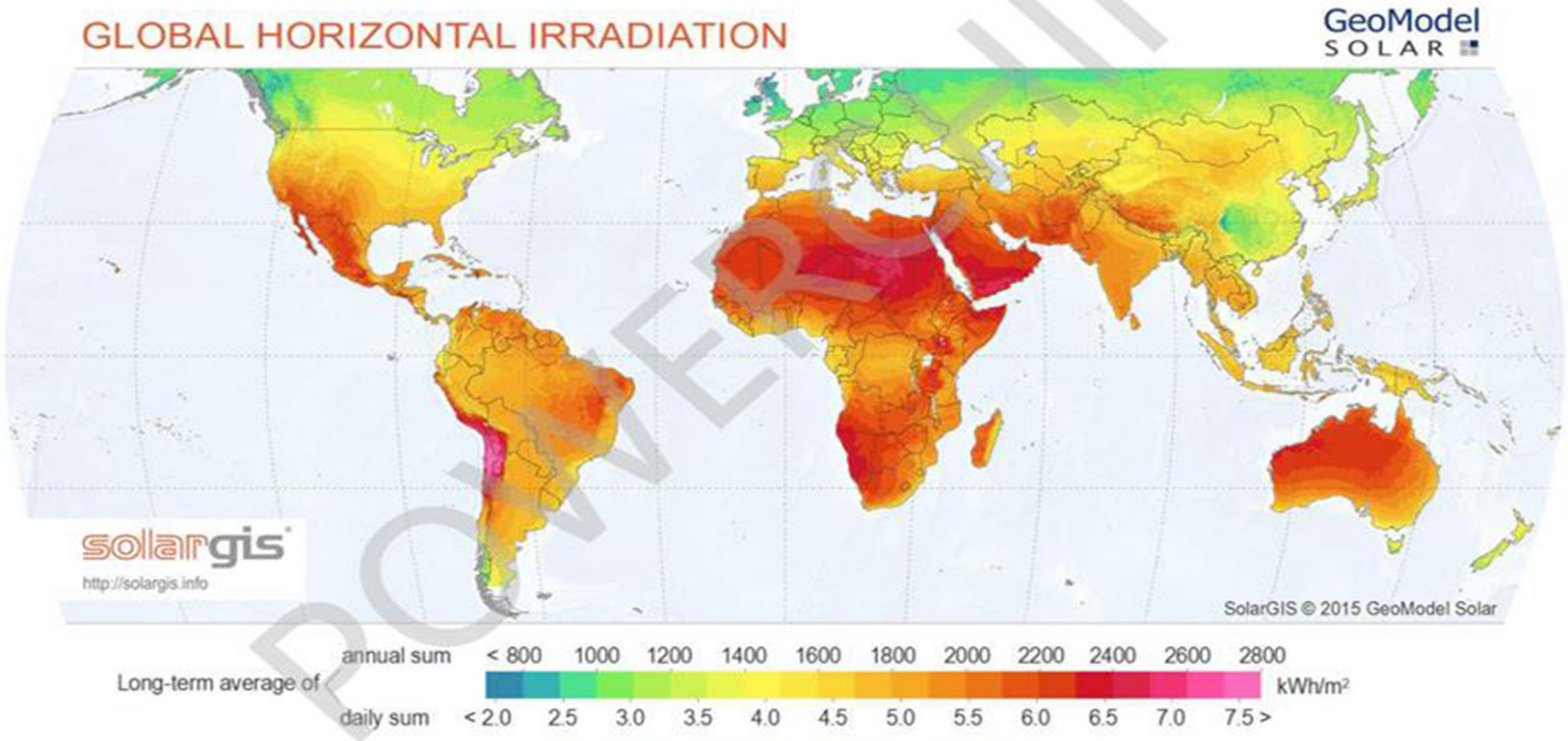
1. Current Situation in Terms of Development and Trend of PV Industry

Reserves and Distribution of Global

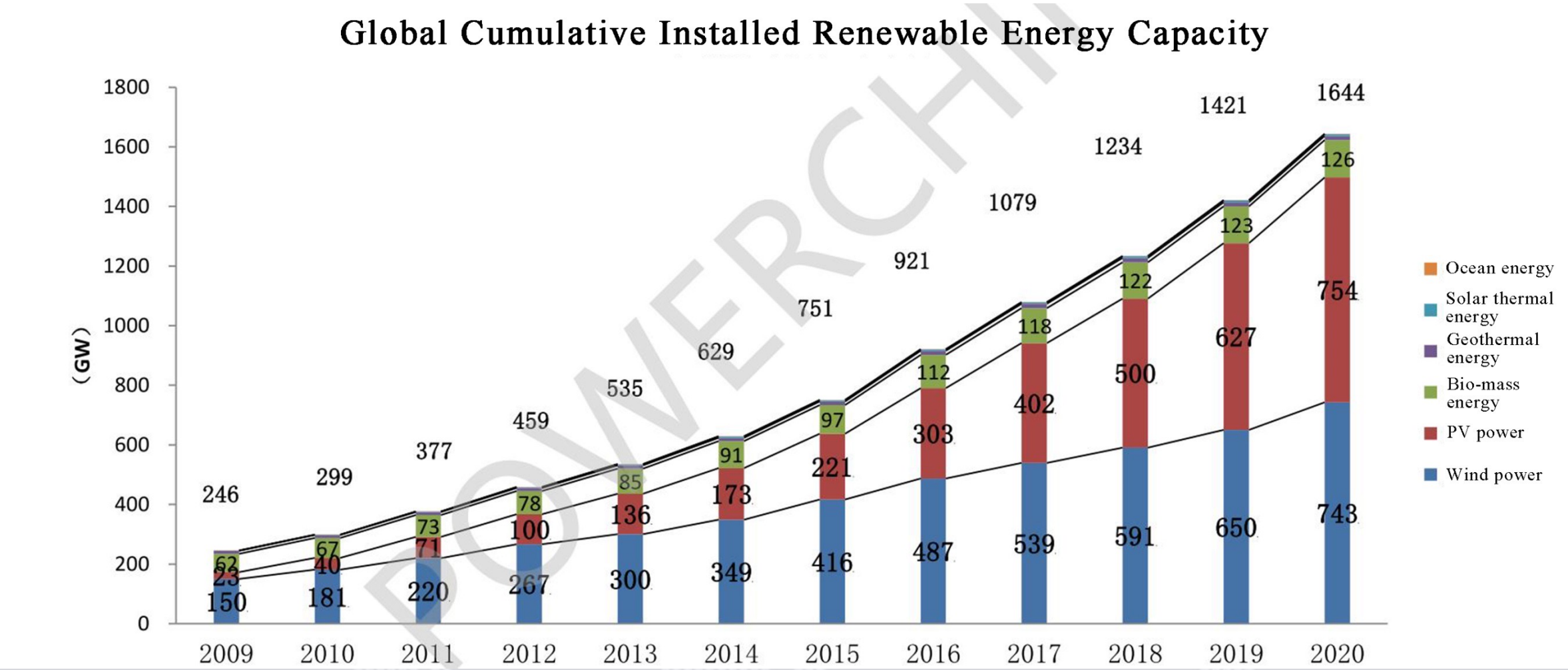


Intensity Distribution of Global Solar Irradiation

Reserves and Distribution of Global

Region	Theoretical potential (trillion KWh/a)			Remarks
	Wind energy	Solar energy	Hydroenergy	
Asia	500	37500	18.3	
Europe	150	3000	2.4	
Americas	600	27000	13.2	
Africa	650	60000	3.9	
Oceania	100	22500	0.7	
Total	2000	150000	38.5	The reserves of wind power are 50 times the hydroenergy and those of solar energy are 3,900 times the hydroenergy

Status Quo of Global Renewable



Status Quo of Global Renewable Energy Development: Annual and Cumulative Proportions of PV Development in 2020 (GW)

FIGURE 2.5: GLOBAL PV MARKET IN 2020

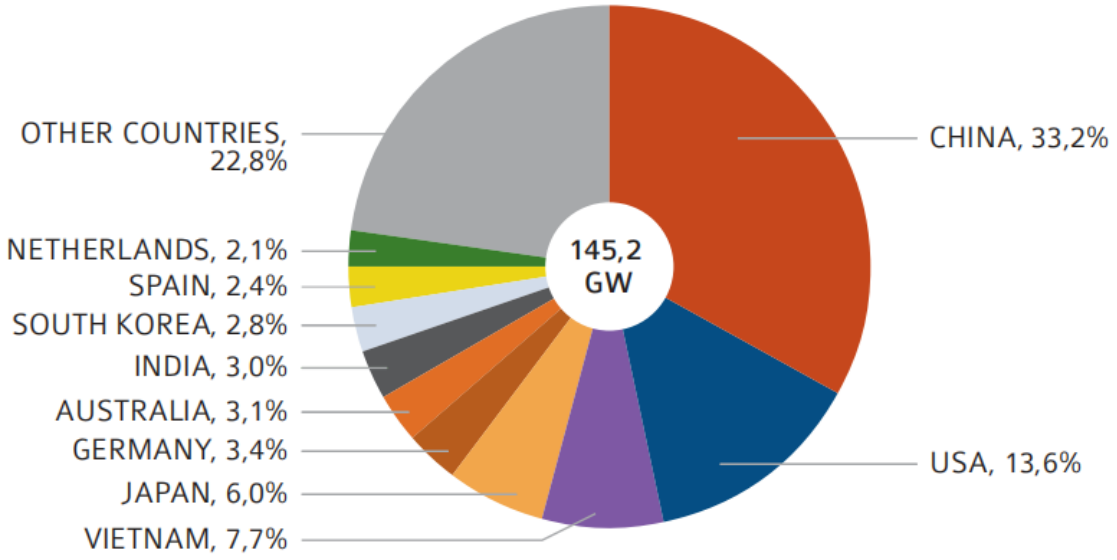
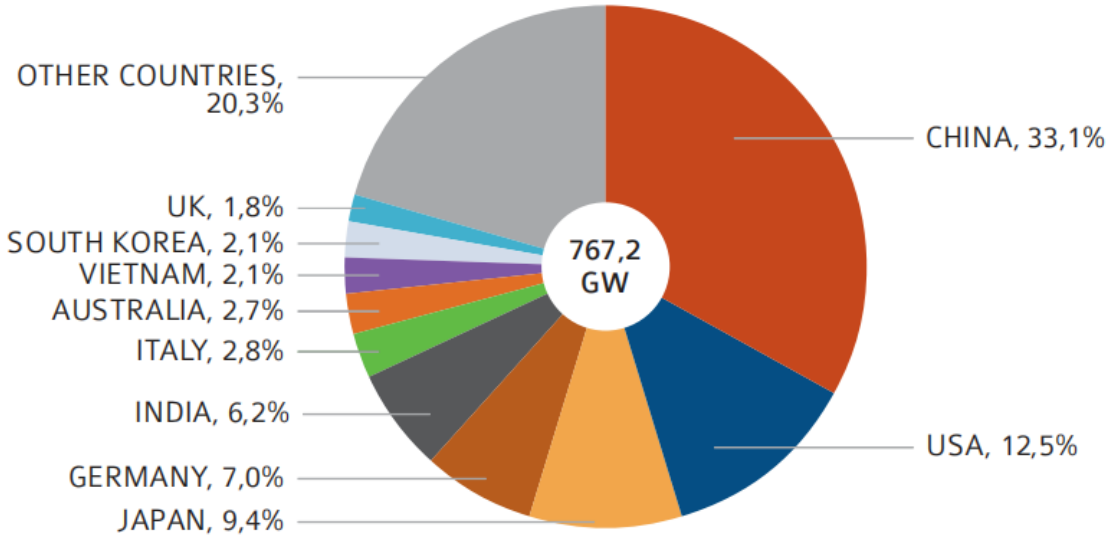


FIGURE 2.6: CUMULATIVE PV CAPACITY END 2020

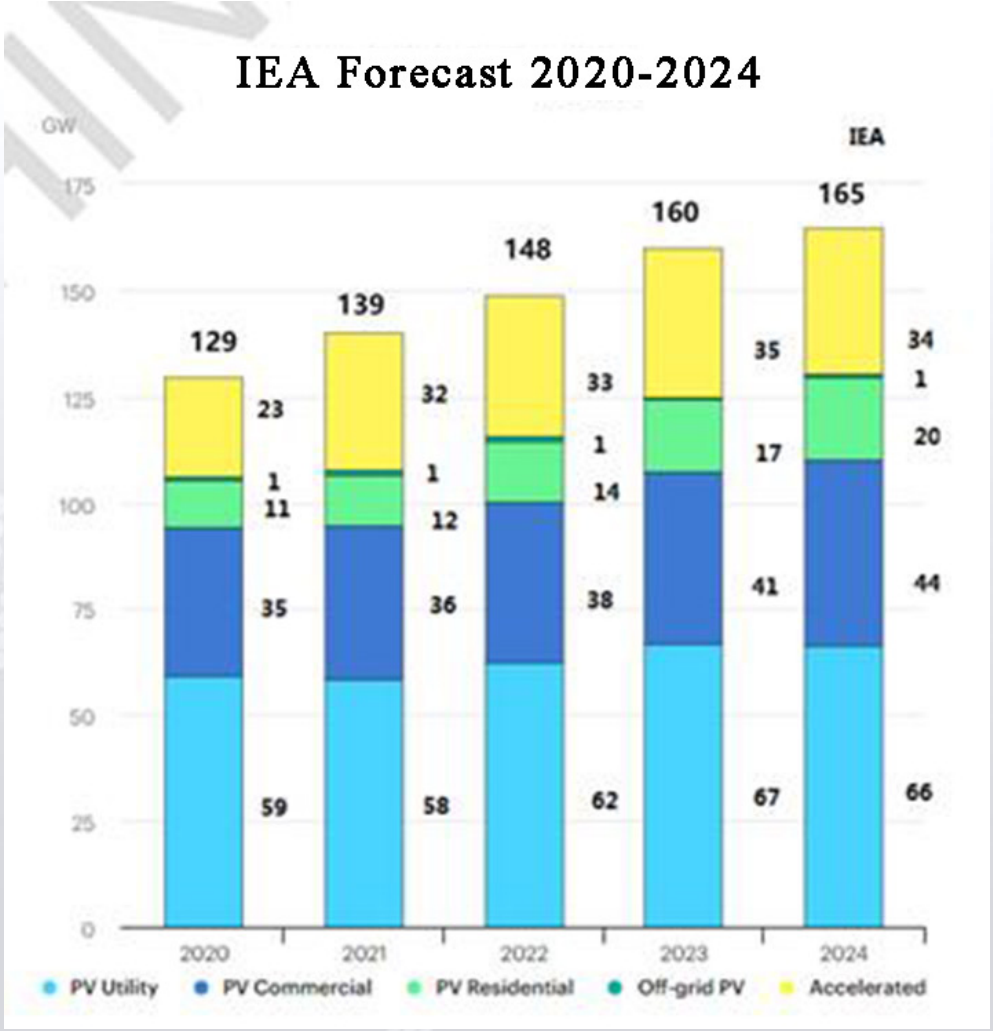


Status Quo of Global Renewable Energy Development

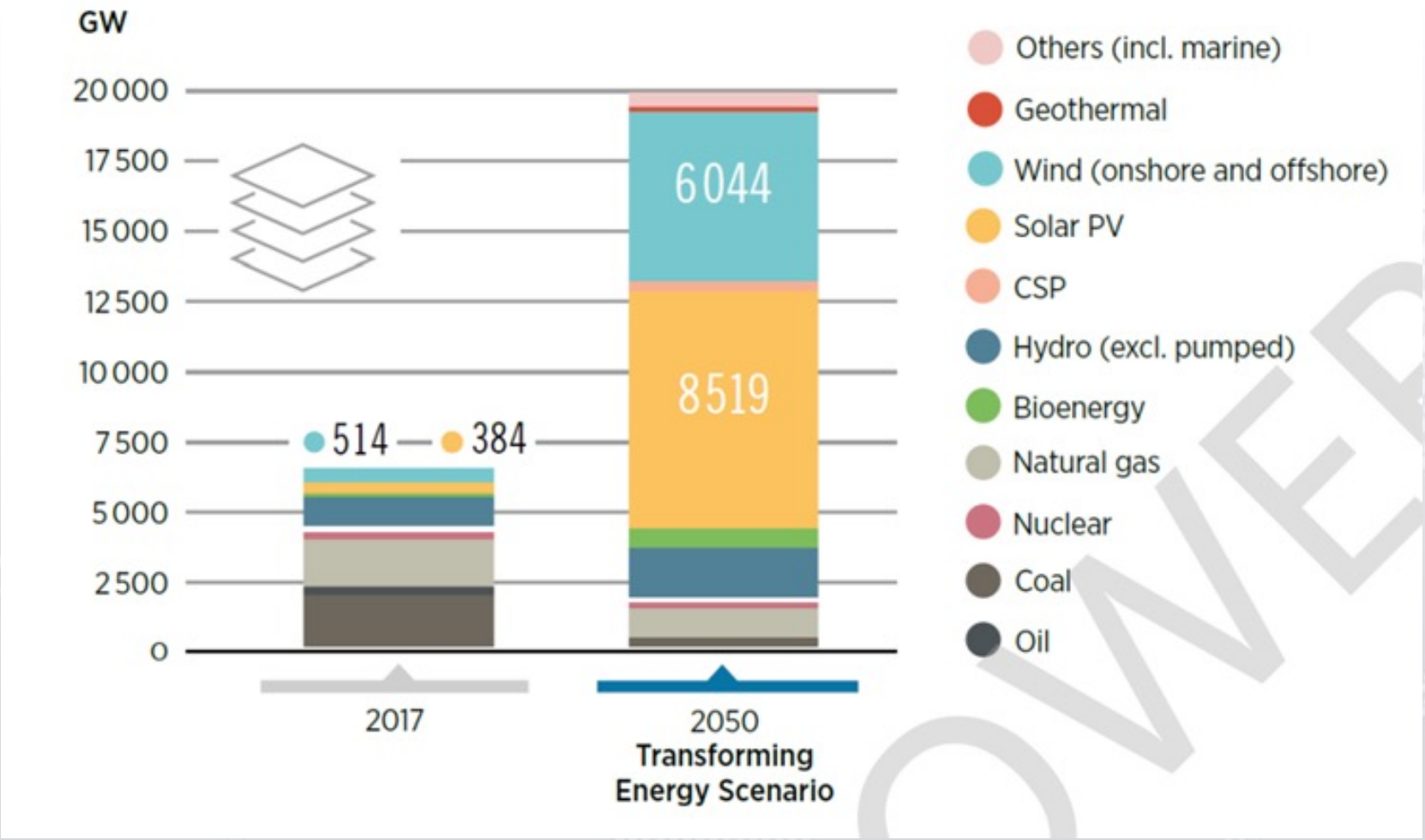
1) According to the forecast of the International Energy Agency, the installed capacity of renewable energy PV in the world will be 741 GW from 2020 to 2024, and the cumulative capacity will reach 1,368 GW in 2023.

2) The annual growth gradually increases, reaching 160 GW/a in 2024

3) The installed PV capacity growth is large in China, the United States, India, Japan, the Middle East, Latin America, Asia Pacific, etc.; Africa is currently a huge potential for PV development!

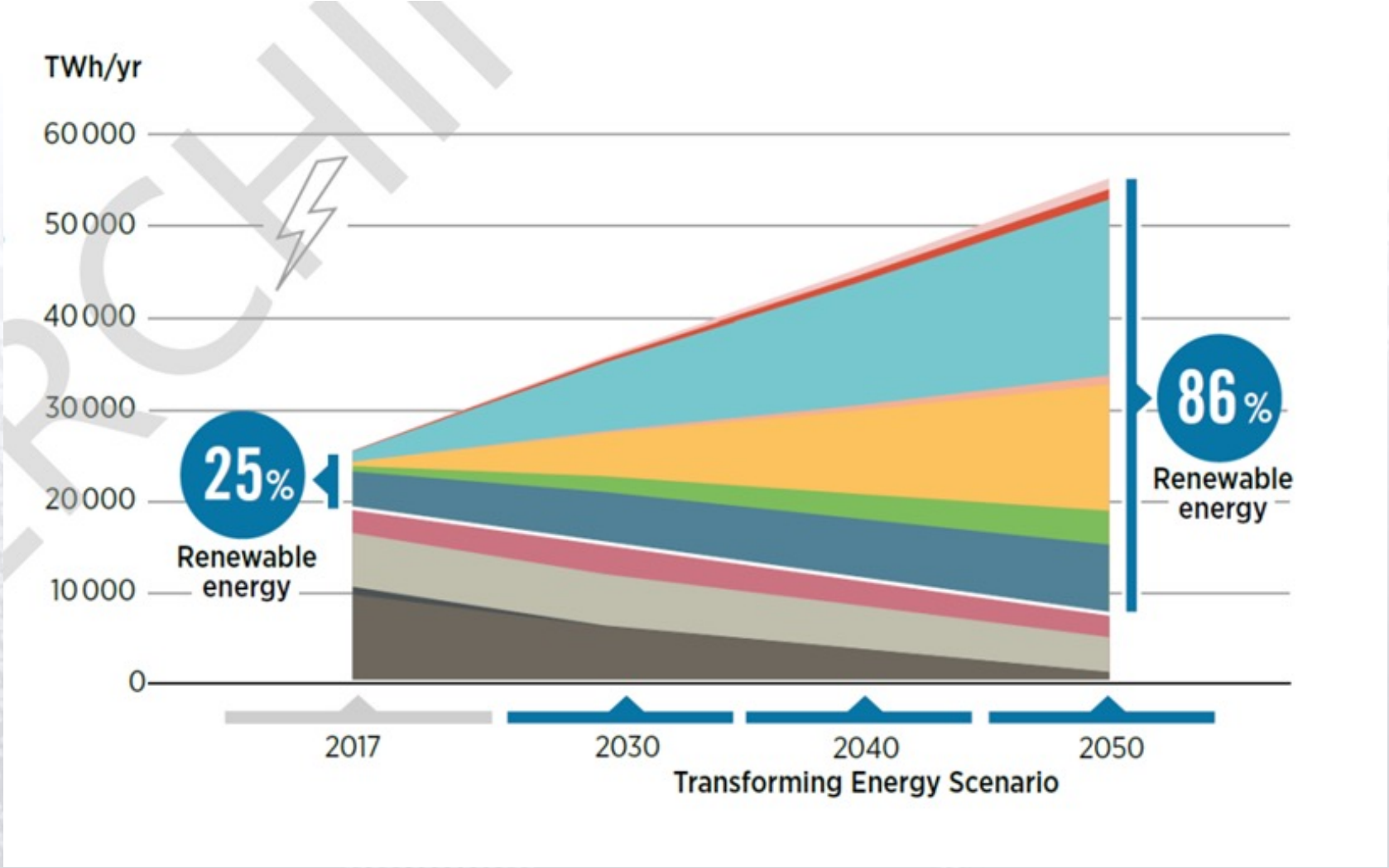


Global Power Supply Structure by 2050 - Forecast



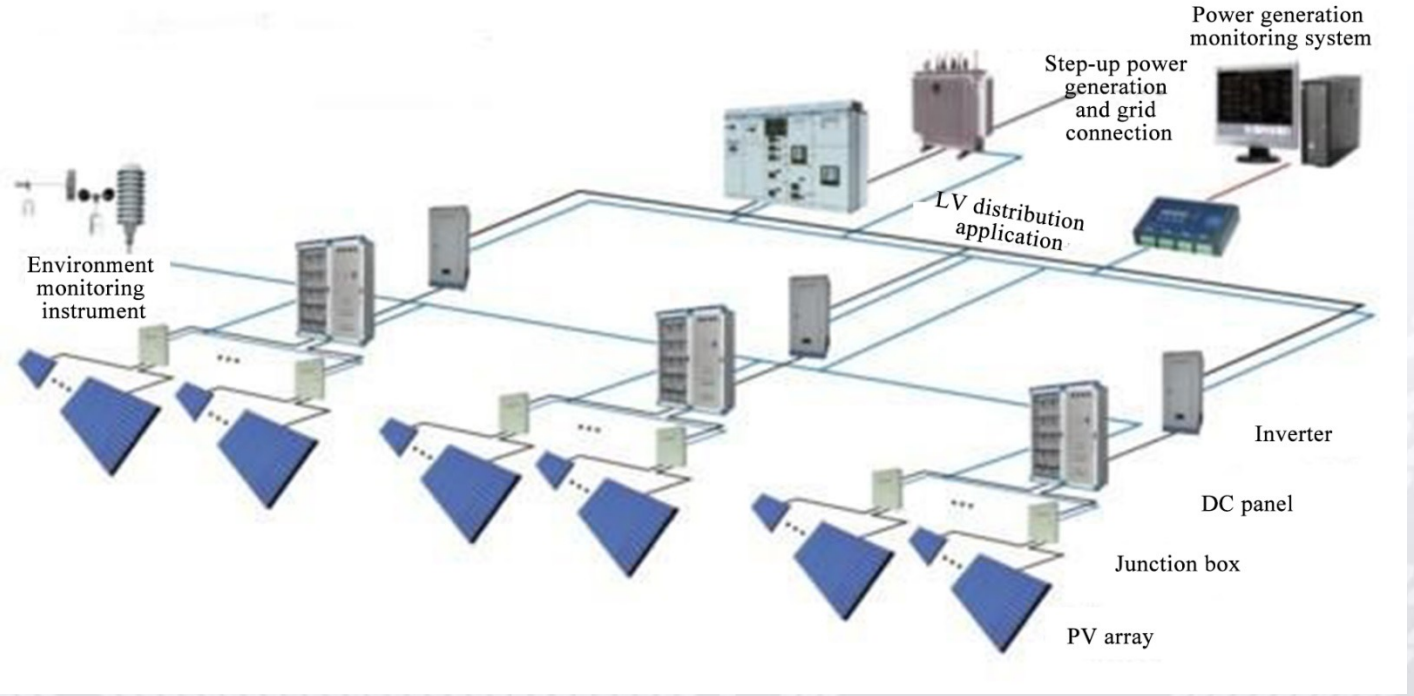
Global Power Supply Structure by 2050 - Forecast

According to the vision for 2050 of Renewable Energy Agency, in line with the target of controlling the temperature rise by 2 Celsius degrees, by 2050, the installed capacity of PV and wind power will reach 8,519 GW and 6,044 GW, respectively, and the installed capacity of wind power and PV will account for 73% of the renewable energy; the share of renewable energy in power generation needs to increase from 25% in 2017 to 86% by 2050.



2. Design of PV Plant System

Typical Components of PV Power Station



The ground PV Power Station mainly consists of the PV array, lightning protection junction box, DC power distribution cabinet, grid-connected inverter, AC power distribution cabinet, SVG reactive power compensation system, booster system, HV protection system, DC system, metering connection system, supervision & control and communication system, AC/DC cable, meteorological station, support system, lightning protection system, lighting system, fire protection system, HVAC system, water supply and drainage system, security system, etc. In addition, the unit inverter room, LV distribution room, HV power distribution room, fire communication room, and comprehensive building (for living, office, and supervision & control management in the station area) are designed.

Site Selection

1) Disruptive influences:

- Solar energy resources at the site
- Available land (or roof) area, slope orientation, topographic conditions
- Grid access conditions
- Geological conditions
- Flood impact
- Whether there are environmental constraints at the site

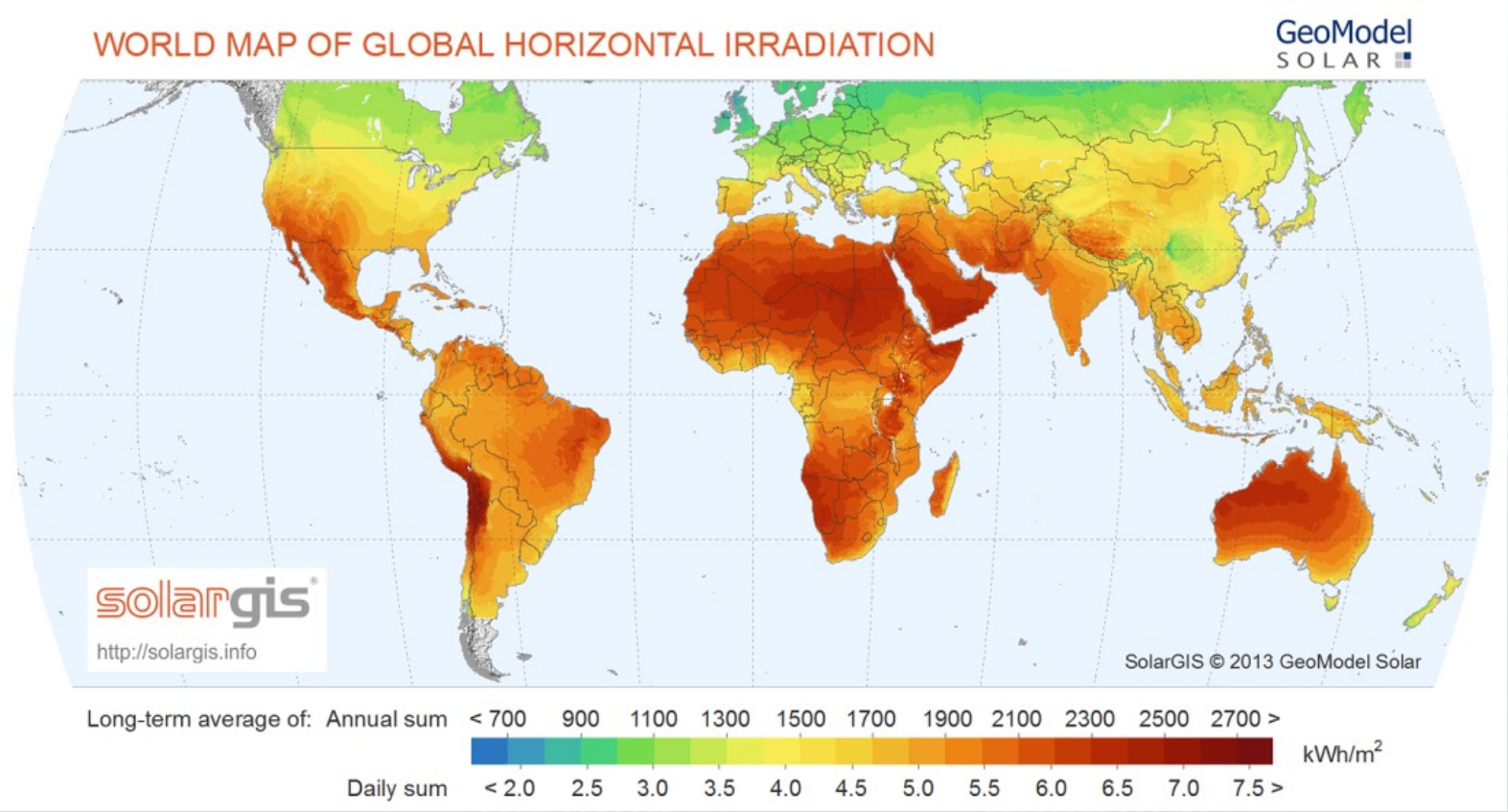
Site Selection

2) Non-disruptive influences:

- Transportation
- Extreme weather conditions and salt spray corrosion
- The conditions of water and electricity for construction
- Topography and geomorphology of the site area

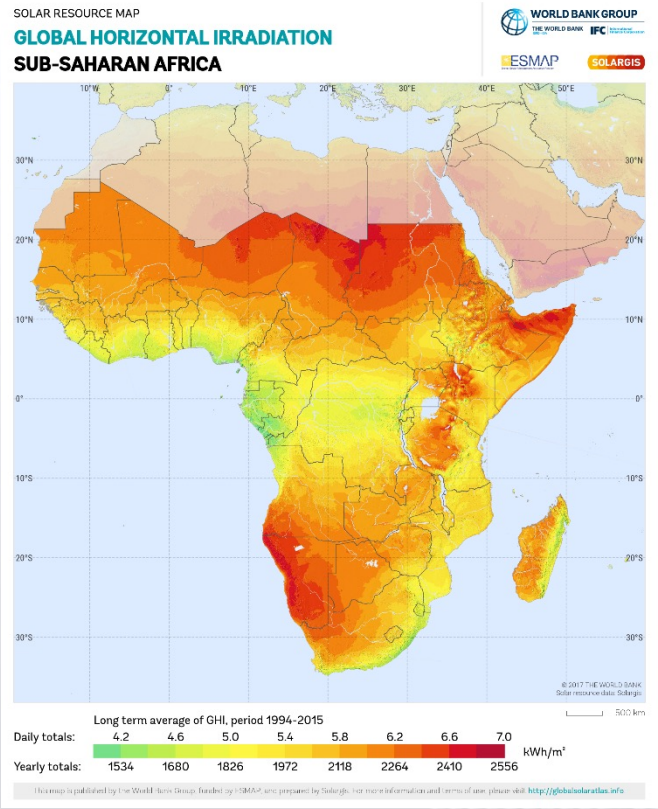
It mainly affects the difficulty and construction cost of later work

Solar Energy Resource Analysis



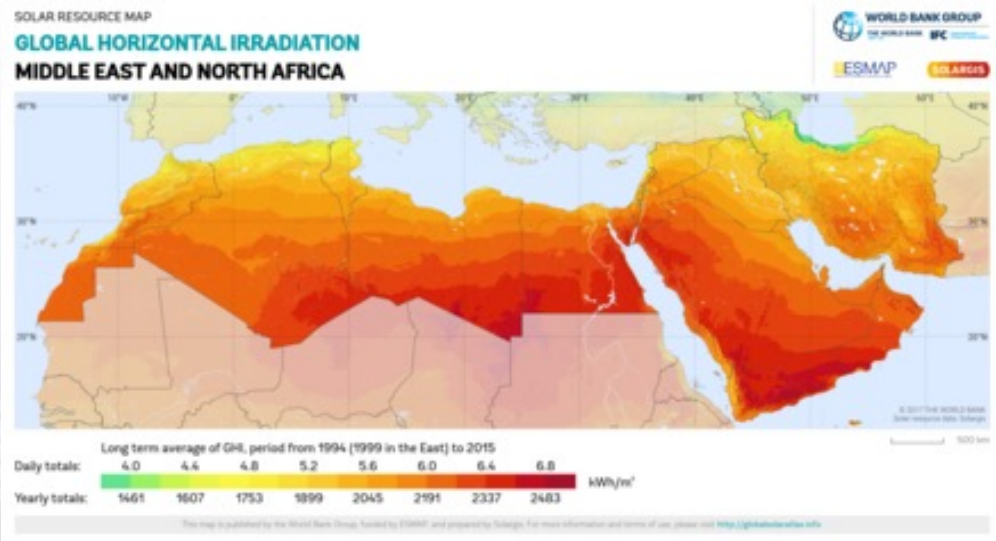
- Globally, except for Antarctica, the total annual solar irradiation is mostly between 900 kWh/(m2·a) and 2,100 kWh/(m2·a).

Solar Energy Resource Analysis



●The total annual solar irradiation across sub-Saharan Africa is mostly between 1,850 kWh/(m^2·a) and 2,500 kWh/(m^2·a), while the total solar irradiation in North Africa is mostly between 2,000 kWh/(m^2·a) and 2,500 kWh/(m^2·a), making the entire region of Africa **very rich in solar energy resources.**

●The distribution in sub-Saharan Africa is extremely high in the northern and southern and slightly lower in the central part.And North Africa is very rich in overall solar light, at the extreme value of global solar light.

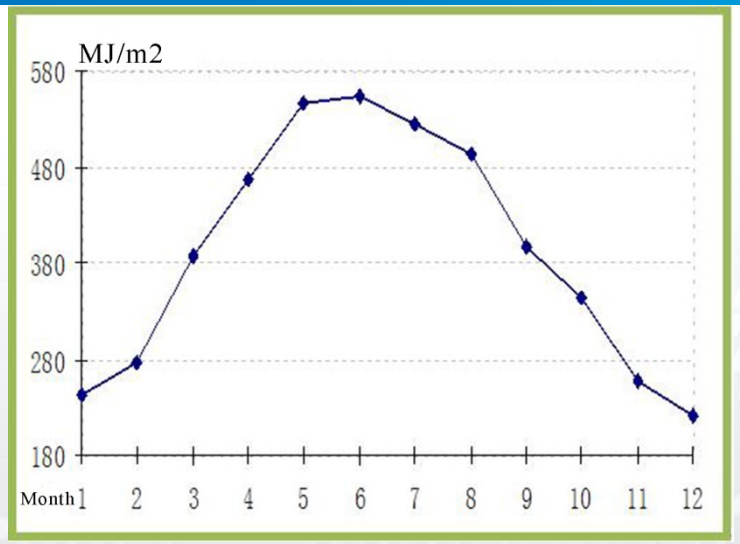


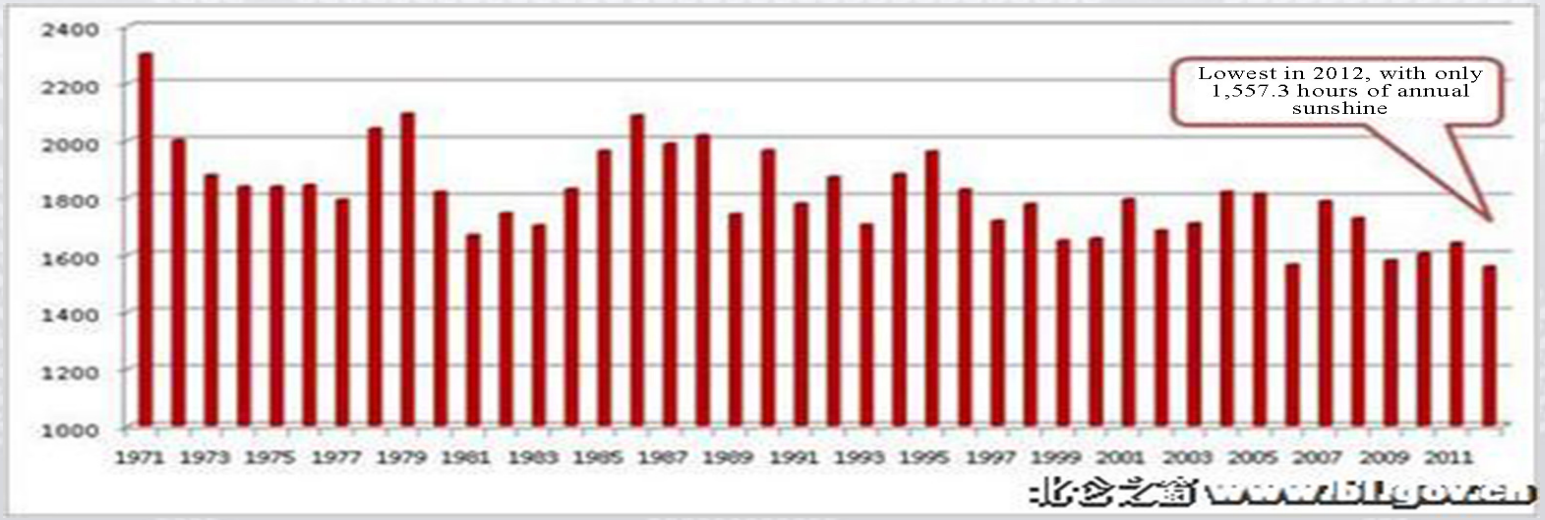
Distribution of Solar Energy Resources in Palestine

Solar Energy Resource Analysis

- **Annual variation of irradiation quantity:** It reflects the variation trend of solar radiation quantity in each month of the year at the place where the power plant is located.

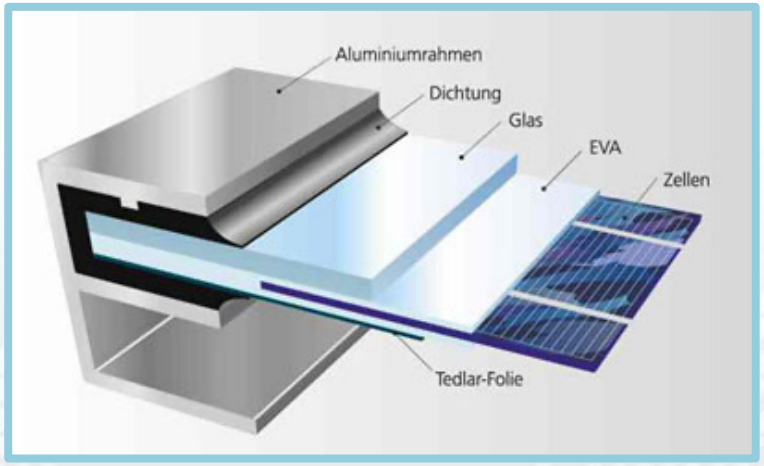
- **Interannual variation of irradiation quantity:** It reflects the variation trend of solar radiation quantity for many years (generally 30 years) at the place where the power plant is located.





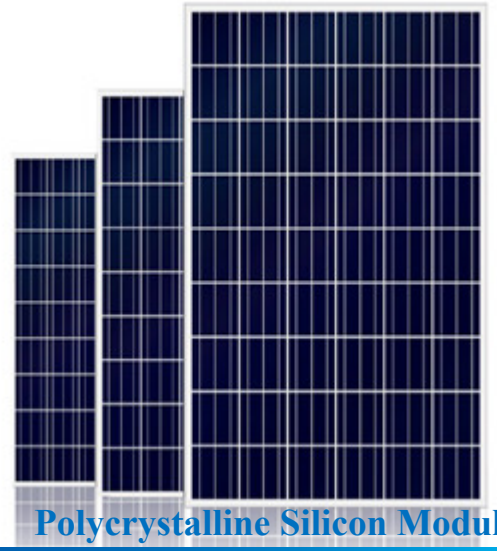
Selection of PV Module

Monocrystalline Silicon Module



Schematic Diagram of Packaging Structure of Crystalline Silicon Modules

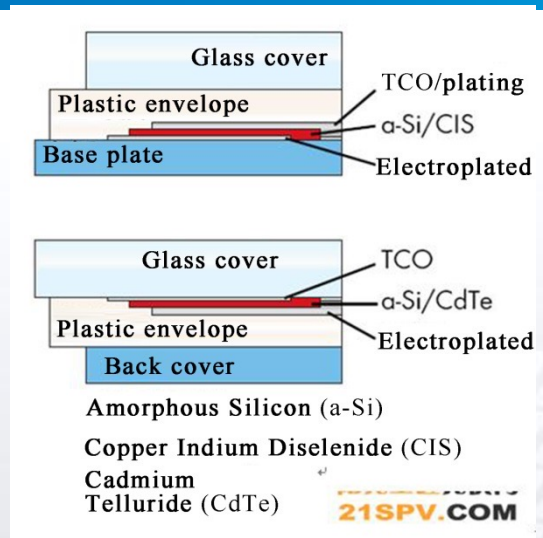
Crystalline silicon module: It is either the monocrystalline silicon solar cell module or the polycrystalline silicon solar cell module. At present, the conversion efficiency of the mass-produced monocrystalline silicon module can reach 23% and above. The conversion efficiency of the polycrystalline silicon module is generally about 20%.

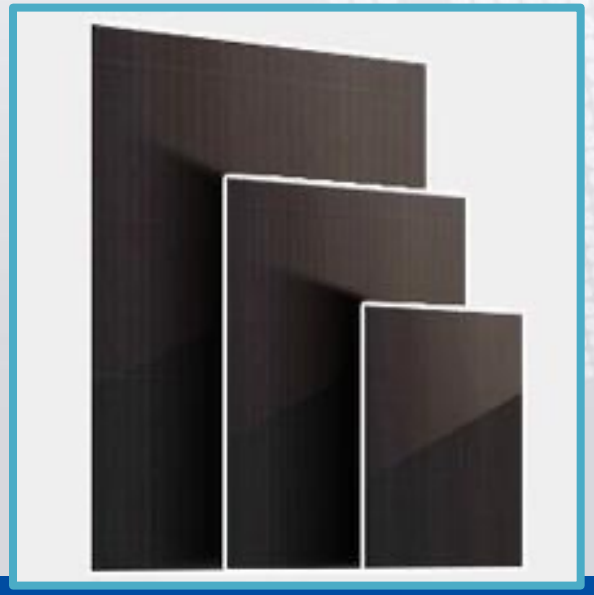


Polycrystalline Silicon Module

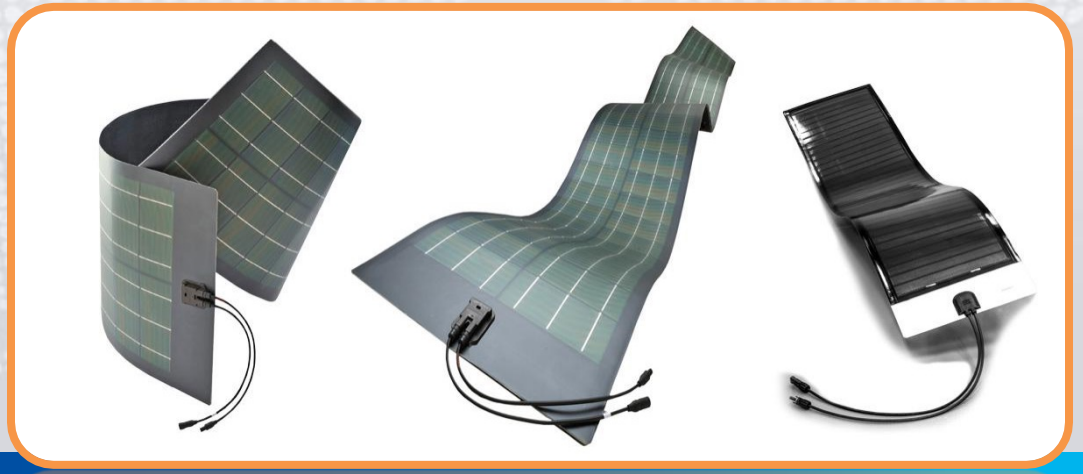
Selection of PV Module

Thin-film module: Typical thin-film solar cells can be divided into the following four categories according to the materials used, i.e. amorphous silicon (a-Si) and thin-film silicon (TF-Si); cadmium telluride (CdTe); copper indium gallium selenium (CIS or CIGS) and dye sensitized solar cell (DSC) with other natural materials.





Schematic Diagram of Thin Film Module Structure



Selection of PV Module

Comparison of two types of crystalline silicon solar cell modules:

(1) Weak light: The spectral response characteristics of monocrystalline are better than those of polycrystalline, and the energy output of monocrystalline is higher than that of polycrystalline under different irradiances. The difference is obvious when the irradiance is lower than 500W/m2, and the weak-light performance of monocrystalline is better than that of polycrystalline.

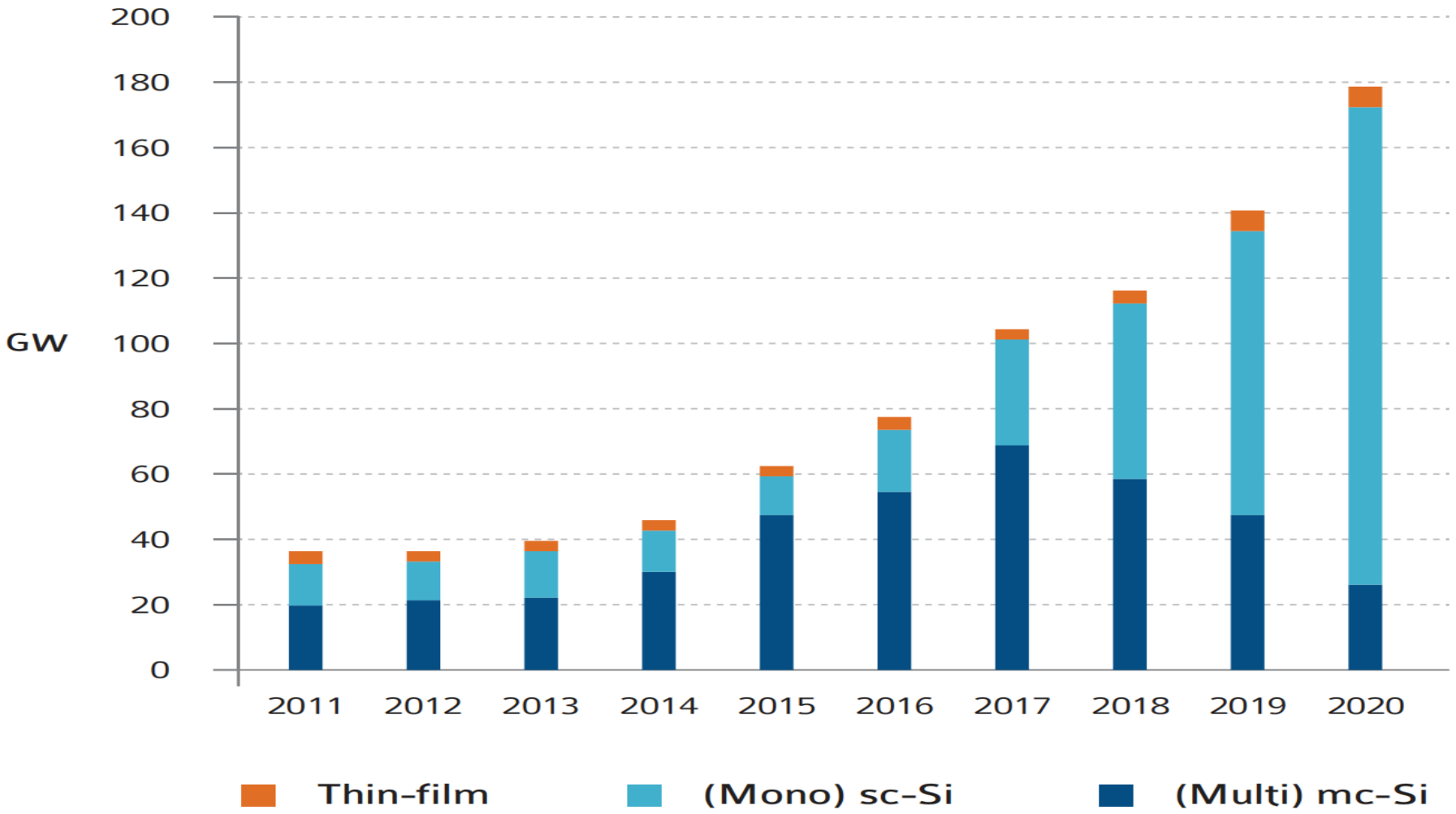
(2) Working temperature: According to the principle of temperature coefficient, the output power of the module decreases by 0.41% for every 1° C increase in the working temperature of the module compared with the standard temperature. In general, the temperature difference between monocrystalline and polycrystalline modules is 3-5° C in winter and 8-12° C in summer. According to the law of energy conservation, the photoelectric conversion efficiency of monocrystalline modules is high, and more solar energy is converted into electric energy. Therefore, the photothermal conversion of monocrystalline modules is relatively less, the module temperature increases slowly, and the power loss is reduced accordingly.

(3) Spectral response: According to the experiment, the spectral response range of monocrystalline is 5.68% - 7.68% wider than that of polycrystalline, so the quantum efficiency of monocrystalline is higher than that of polycrystalline. Therefore, in general, the system startup time of monocrystalline in the morning is 15 - 30 minutes earlier than that of polycrystalline, and the system shutdown time in the afternoon is 15 - 30 minutes later than that of polycrystalline. The daily energy output of monocrystalline is more than that of polycrystalline.

(4) Less line loss: For monocrystalline and polycrystalline with the same installation capacity, the quantities of monocrystalline are 8% less than those of polycrystalline, the number of power cables of monocrystalline is less, and the corresponding transmission loss is less.

(5) Low long-term decay: According to the measured data, the average annual decay of monocrystalline modules is about 0.55% from the second year, which is less than that of polycrystalline modules by 0.73%.

Selection of PV Module

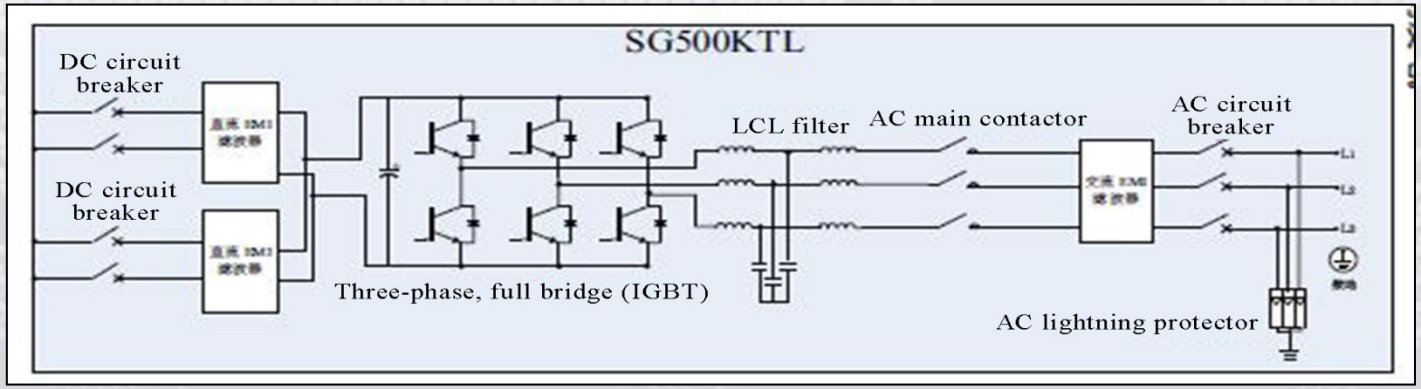


PV module selection

classification		2019	2020	2021E	2022E	2023E	2025E
Polycrystalline	BSF P-type polycrystalline black silicon battery	19.3%	19.4%	19.5%	-	-	-
	PERC P-type polycrystalline black silicon battery	20.5%	20.8%	21.0%	21.2%	21.5%	21.7%
P-type single crystal	PERC P type ingot single crystal battery	22.0%	22.3%	22.5%	22.7%	22.9%	23.2%
	PERC P-type single crystal battery	22.3%	22.7%	23.0%	23.2%	23.4%	24.0%
N-type single crystal	N-PERT/TOPCon battery	22.7%	23.3%	23.5%	23.8%	24.0%	24.5%
	HJT battery	23.0%	23.5%	24.0%	24.5%	25.0%	25.5%
	Back layer battery	23.6%	23.8%	24.1%	24.3%	25.0%	25.5%

Selection of Inverter

Centralized inverter



Selection of Inverter

The grid-connected inverter is an important device responsible for converting PV DC power into AC power and realizing the connection with the public power grid. It is equipped with power grid signal detection, anti-islanding protection, DC input detection, maximum power tracking, communication, and other functions. It is mainly divided into the centralized inverter, string inverter, and module inverter.

String inverter

Characteristics: The scattered MPPT of PV circuit is optimized, which can better solve the problem of energy output loss caused by "mismatch" of PV module and the problem of high cost of system.

Application: small PV power generation system, ground power plant and floating power plant with complex topography.

Distributed inverter

Characteristics: The MPPT unit in the intelligent junction box is used to optimize the PV string, and then the centralized inverter is used to boost the voltage and connect to the grid. The system scheme is clear and easy to implement.

Application: large centralized power plant.

Module Inverter

Characteristics: AC busbar is adopted to convert and output power of each cell module separately. The system structure is simple.

Application: small distributed grid-connected household power generation system.

Selection of Tracking Method

At present, the most widely used, relatively low-cost, and most mature array operation method for large PV plants is the method of fixed tilted angle installation. The solar radiation received on the surface of the PV module at different inclinations is different. The optimal tilted angle for installation is the angle corresponding to the maximum annual total solar radiation on the tilted plane, which is close to the latitude value of the project site.

Fixed inclination

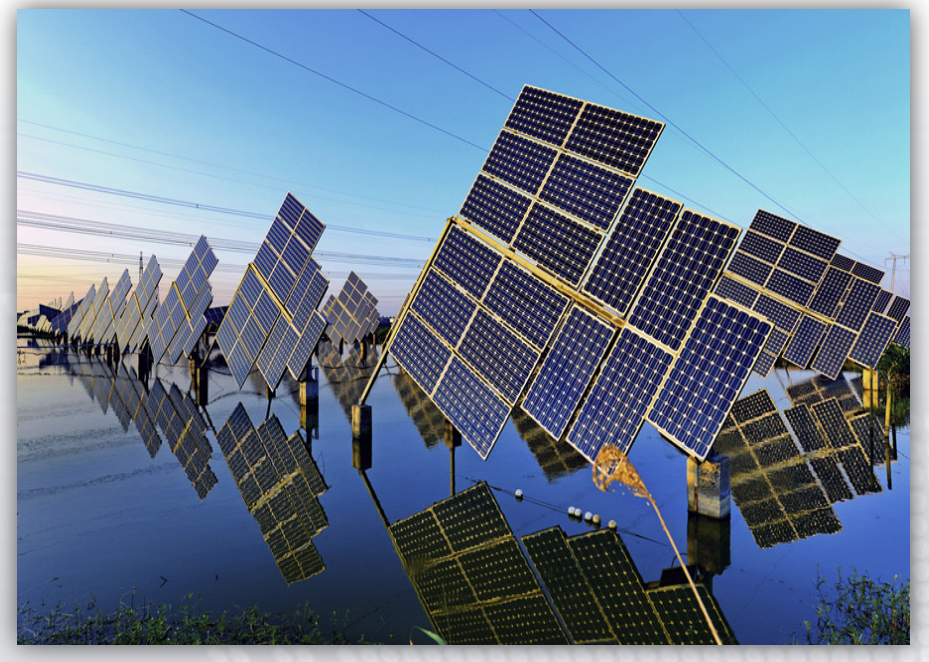
Selection of Tracking Method

Horizontal single-axis tracking means that the PV array can track the sun along a horizontal axis in the east-west direction. In low latitude regions, horizontal single-axis tracking has a good effect on increasing energy output.

Methods of horizontal single-axis tracking

This base planned: Horizontal single-axis tracking boosts energy output by about **12%** over fixed inclination.

Selection of Tracking Method



Tilted single-axis tracking

Tilted single-axis tracking boosts energy output by about **15%** over fixed-tilt types.

The vertical line of the cell panel tracked by the horizontal single-axis and the solar light always form an included angle . The included angle is large in the high latitude region. In order to improve the solar radiation received by the cell panel, the rotating axis of the cell panel can be installed in a tilt way. Therefore, tilted single-axis tracking supports are applicable in high latitude region.

Selection of Tracking Method

The dual-axis tracking PV array moves along two rotating axes and is able to track the change of azimuth angle and altitude angle of the sun, theoretically allowing complete tracking of the sun's orbit to achieve a zero angle of incidence.

Dual-axis tracking boosts energy output by about **20%** over fixed-inclination types.

Pile foundation selection

Common pile foundation types of photovoltaic projects:

1) Cast in place pile: A cast-in-place pile is a pile made by placing a hole in place and pouring concrete or reinforced concrete.

(2) PHC pipe pile: prestressed high-strength concrete pipe pile. It is a kind of hollow cylindrical concrete precast member made by pre tensioned prestressed centrifugal forming process and steam curing at 10 atmospheres (about 1.0Mpa) and 180 ℃.

(3) Spiral steel pile: spiral steel pile is a kind of special-shaped pile with complex geometric surface, which is composed of a central steel shaft and several spiral blades. According to the layout of blades, it is generally divided into layered blade type spiral steel pile and continuous blade type spiral steel pile.

(4) Shaped steel pile: Shaped steel pile, commonly including "I" type and H type according to the section shape. Both I-shaped and H-shaped steel piles can be used in the bearing of horizontal load and vertical load.

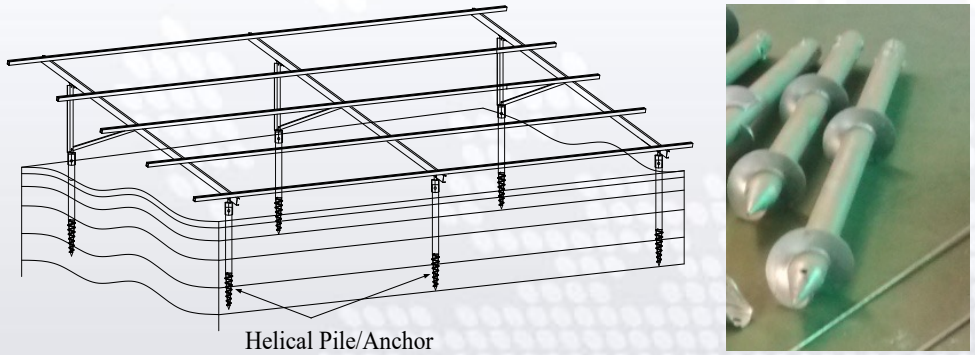
Pile foundation selection

Analysis of characteristics of each foundation type

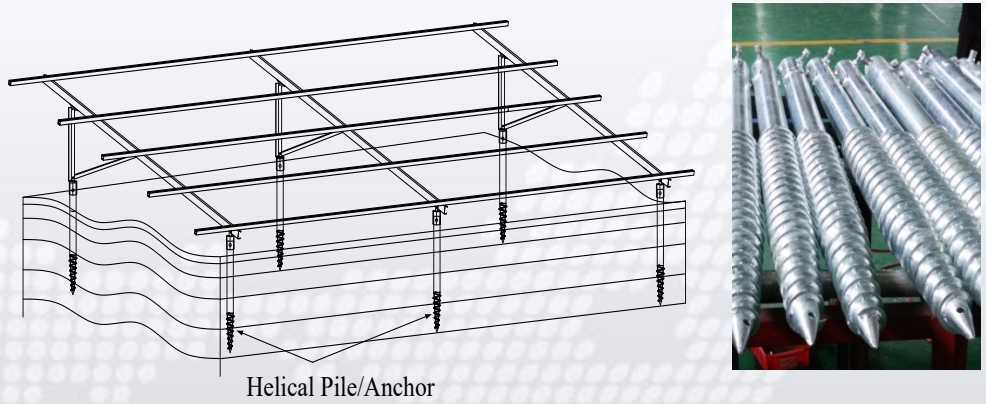
NO.	Foundation type	Applicable foundation type	Construction method	Advantages and disadvantages
1	Large blade screw pile	Applicable to loose soil (SPT value N<8)	The pile driver directly drives the screw pile into the soil	Advantages: ① Convenient quality control; ② Good environment and recyclability; ③ High adjustability. Disadvantages: ① Large steel consumption and relatively high cost; ② The corrosion resistance of screw pile foundation is poor
	Small blade screw pile	Suitable for loose soil with medium density, such as gravel, sand, sand and clay (SPT value 8<N<30)		
2	Cast-in-place pile	Suitable for clayey soil, silt, seasonally frozen soil, expansive soil, and hard clay or dense sand bearing stratum	The down the hole machine is used for hole forming, and the reinforcement cage is put into the post pouring concrete, and the pile is densified by the vibrating rod	Advantages: ① It is not limited by stratum change; ② Low construction noise; ③ High bearing capacity, compression and uplift resistance. Disadvantages: ① The construction process is relatively complex, and the construction quality control is not easy to control; ② The construction speed is relatively slow.
3	PHC pipe pile	Applicable to cohesive soil, sandy soil, silt, seasonally frozen soil and expansive soil	The pile sinking equipment presses (or hammers) the pile into the soil.	Advantages: ① The construction speed is fast; ② Convenient purchase and transportation. Disadvantages: ① Great impact on the environment.
4	Profiled steel pile	Applicable to cohesive soil and silt areas	The pile driver directly drives the profile steel pile into the soil	Advantages: ① The construction process is simple, the construction speed is fast, and the impact on the environment is small. Disadvantages: ① The lateral strength of the pile is weak and easy to bend or tilt; ② Poor corrosion resistance.

Pile foundation selection

Common pile foundation types of photovoltaic projects:



Large blade screw pile



Small blade screw pile

Pile foundation

Common pile foundation types of photovoltaic projects:

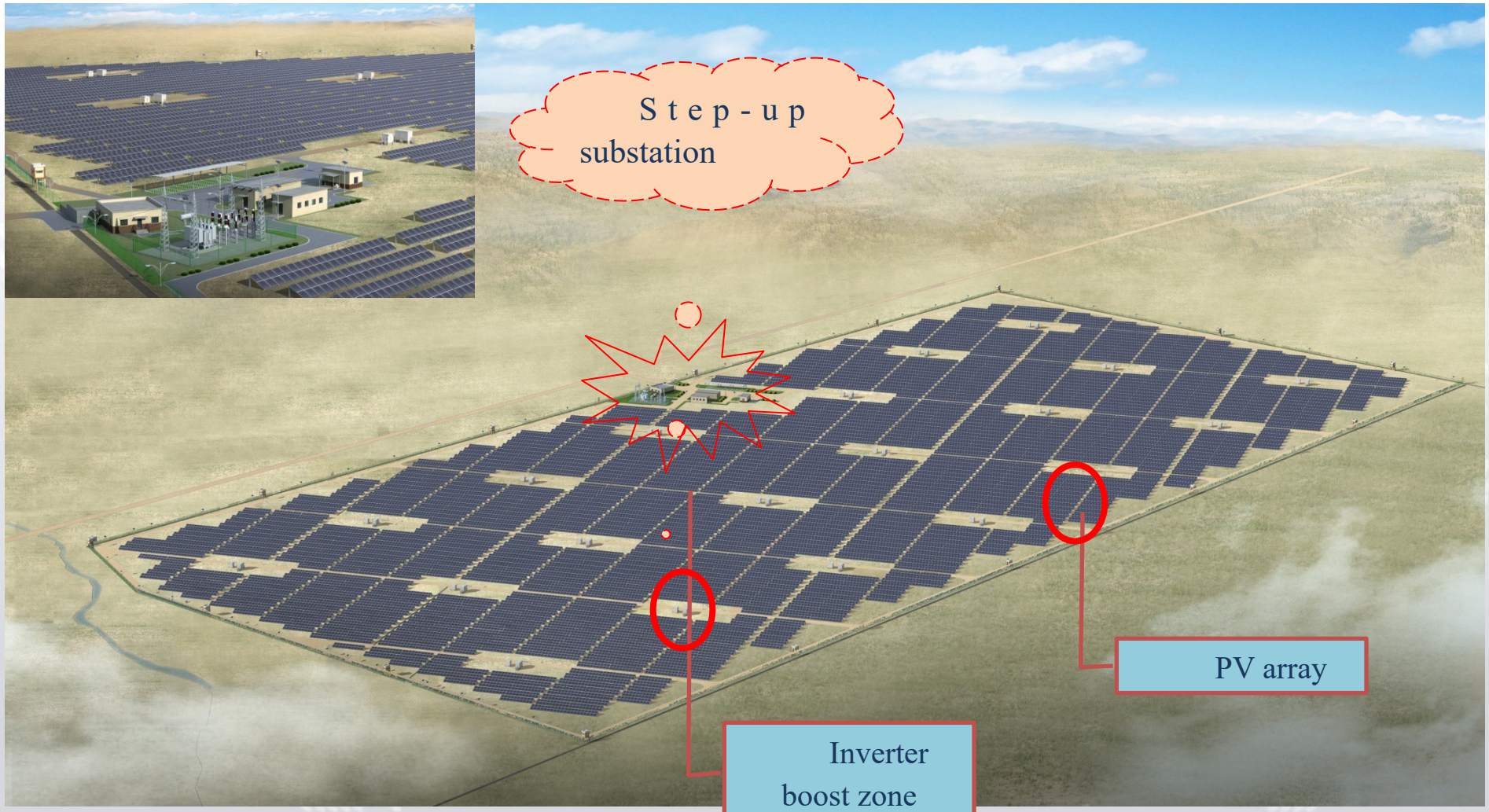
Cast-in-place pile

PHC pipe pile

Profiled steel pile

In order to ensure the working performance of the support structure, the foundation of the support structure shall meet the requirements of bearing capacity, and factors such as economic cost, durability, environmental protection and construction speed shall be comprehensively considered.

General Layout



3. Construction and Operation of PV Power Station

Civil Works

- Site leveling;
- Supports and other equipment foundations;
- Site and underground facilities (roads in site area, cable trenches, water supply and drainage, site grounding, etc.);
- Buildings or structures (guard room, water pump house, comprehensive building, step-up substation, etc.)

Installation Works

- Support installation
- Module installation
- Installation of junction box, inverter and step-up box-type substation
- Electrical secondary system
- Other electrical equipment installation (high and low voltage switchgear, main transformer, station power system, reactive power compensation, etc.)
- Lightning protection and grounding
- Line and cable laying

Commissioning of PV Power Station System

With the progress of the project, PV modules, equipment, wires, cables, inverters, etc. have been installed, powered on and tested; no-load trial operation has been kicked off; at this stage, corresponding system schemes shall be made to guide the commissioning of corresponding system. At the same time, the details of the commissioning shall be paid attention to and treated with timely solutions.

Operation of Power Plant

Monitor the main operation parameters of power plant equipment, count energy output of power plant, and receive the dispatching instructions of power grid.

Check the condition of power plant equipment through patrol inspection, check the integrity and contamination level of cell modules and supports, and check the operation of electrical equipment.

Perform the switching operation of power cut-off and transmission of electrical equipment in accordance with dispatching instructions of power grid and maintenance requirements.

Maintenance of Power Plant

1) The surface of PV modules shall be kept clean. Dry or wet, soft and clean cloth shall be used to wipe the PV modules. Do not wipe the PV modules with corrosive solvents or hard objects; PV modules shall be cleaned when irradiance is lower than 200W/m2, and it is not proper to clean modules with liquid with large temperature difference to modules;

2) PV modules shall be inspected regularly, and shall be adjusted or replaced promptly in case of the following problems:

a) PV modules have broken glass, scorched back panel, or obvious color change;

b) PV modules have bubbles which connect module edge or any circuit;

c) Junction boxes of PV modules suffer from deformation, distortion, crack or burn, and terminal blocks cannot connect properly.

3) Live warning signs on PV modules shall not be lost.

Maintenance of Power Plant

1) Structural and electrical connection of inverter shall be kept complete, and shall be free of corrosion and ash deposition; the inverter shall have good heat dissipation environment, and shall be free of major vibration and abnormal noise during operation;

2) Warning signs on the inverter shall be complete without breakage;

3) Cooling fans of modules, reactors and transformers in the inverter shall be automatically started and stopped normally according to temperature, and cooling fans shall be free of major vibration and abnormal noise when in service, or shall be checked with power disconnected in case of abnormal conditions.

4) The circuit breaker at AC output side (grid side) will be disconnected regularly, and the inverter will stop power feeding to the grid promptly.

5) The DC busbar capacitor in the inverter shall be replaced in time in case of too high temperature or beyond service life.

Maintenance of Power Plant

1) Cables shall not be put in operation under overload, and lead sheath of cable shall be free of expansion and crack;

2) The positions where cables are led into and out of equipment will be plugged properly to prevent the holes with diameter of greater than 10 mm, or such holes will be plugged with fireproof putty;

3) Cable supporting points shall be intact in the positions with too high pressure and tension of cables to equipment shell;

4) The orifice of cable protection steel tube shall be free of perforation, crack and visible uneven part, and inner wall shall be smooth; metal cable tube shall be free of severe corrosion, and shall be free of burr, hard object and waste; in case of burr, the tube shall be filed smoothly, and then wrapped and bound tightly with cable sheath;

5) The sediments and waste stacked in outdoor cable shaft shall be cleaned in time; and damaged cable sheath shall be handled.

6) Damage to cables shall be prevented during the inspection of indoor open cable trenches; and bracket grounding and heat dissipation in the trench shall be ensured to be in good state;

4. Typical Case of Large Ground PV (Power Station)

Typical Case

Authentic Record of 550MW PV Project which was built in 6 months - Loc Ninh Project in Vietnam

- The 550MW PV project in Loc Ninh, Vietnam was located in Loc Shi and Loc Sinh Communes, Loc Ninh County, in the northwest corner of Tinh Binh Phuoc Province, near the Vietnam-Cambodia border and about 130km from Ho Chi Minh City. Loc Ninh Project covered a total area of approximately 690 hectares and had a total installed capacity of 550MWp.

- Project characteristics:
- A. It was a short, flat and fast project with many and centralized risk points , and the effective construction period was only 6 months. No error could be tolerated in any links such as procurement, contract, production, logistics, settlement, design, construction, and grid-connected commissioning.
- B. Impact of COVID-19 on the progress: The impact on the progress was all-round, the unexpected epidemic caused a huge impact on the flow of people, logistics and capital, which induced the slow land acquisition, the failure to guarantee the delivery date of equipment production, the irregular shipping time of international maritime logistics, the delay in the collection of advance payment and payment from onshore Suppliers, etc., and the progress was greatly constrained.
- C. Logistics management: The project had a large volume of goods, with a total of about 3280 containers. According to the progress plan, about 30 containers would be distributed every day on average. Fine management of logistics must be carried out. Every process of shipping from the departure port of logistics and receiving from the destination port needed to be thoroughly known, and contingency plan must be provided.

Typical Case

Positive Impact of the Successful Completion of the Loc Ninh Project in Vietnam

- A. It has accelerated the industrialization of Tinh Binh Phuoc Province in Vietnam, making it gradually transition from an agricultural province to an industrial province. At present, some factories have stationed one after another in Tinh Binh Phuoc Province and the gradual improvement of the power infrastructure has evoked the investment enthusiasm of other industrial manufacturers.
- B. During the implementation of the project, the localized workers at the operation level reached 100%. During the installation of the project supports and modules, the peak number of workers employed reached more than 4,000, all of whom were from Tinh Binh Phuoc and surrounding provinces in Vietnam, which significantly improved the local employment, promoted local consumption and boosted the local economy.
- C. The local skilled workers were unable to meet the market requirement in 2019, when the PV project in Vietnam was kicked off. In response to this situation, we organized Chinese engineers and senior technicians to carry out systematic skills training for local workers in 2020, so that they can be capable of completing the construction of the PV farm.

Typical Case

Implementation of Project in Loc Ninh, Vietnam

Pile foundation

Supports installation

Typical Case

Implementation of Project in Loc Ninh, Vietnam

Module installation training

On-site teaching and explanation for Vietnamese engineers

Typical Case

Implementation of Project in Loc Ninh, Vietnam

PV panel installation

Transformer FAT

Typical Case

Implementation of Project in Loc Ninh, Vietnam

HV equipment installation

Box inverter lifting

Typical Case

Implementation of Project in Loc Ninh, Vietnam

The completed step-up substation

The completed power collection system

Typical Case

Implementation of Project in Loc Ninh, Vietnam

The completed photovoltaic farm

Typical Case

Implementation of Project in Loc Ninh, Vietnam

The completed photovoltaic farm

Thanks!