

Photovoltaic Energy Investment Research

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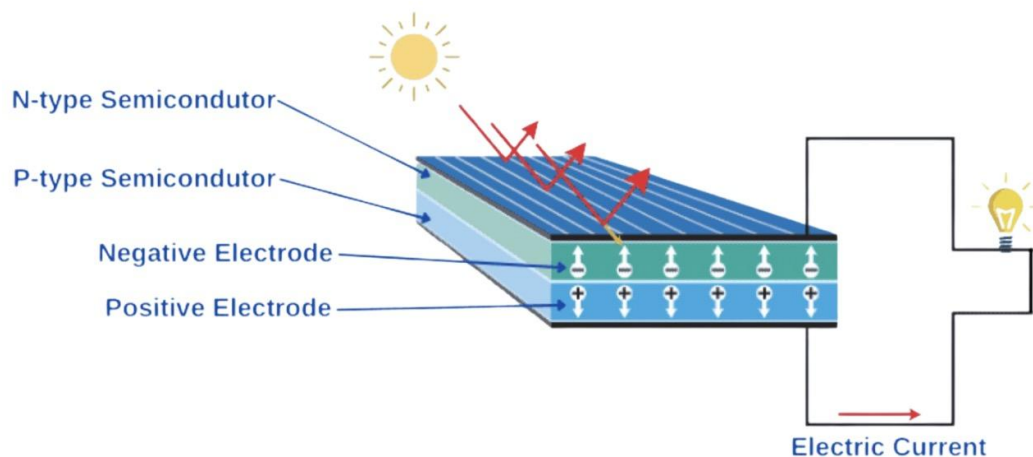


1.Introduction

1.1 Overview of photovoltaic technologies

1.1.1 Principles of photovoltaic technology

The core principle of photovoltaic technology, also known as solar cell technology, is the use of semiconductor materials to convert sunlight into electricity. This process is mainly realized through the photogenerated voltammetric effect, i.e. when sunlight strikes a photovoltaic material, photons (the energy unit of sunlight) interact with electrons in the semiconductor, causing the electrons to be excited from the valence band to the conduction band, resulting in the generation of free electrons and holes. These free electrons and holes move in different directions under the action of an electric field, forming an electric current. With an external circuit connection, this current can be captured and used for power supply. The basic unit of a photovoltaic cell is the solar cell, and multiple cells are connected in series or parallel to form a solar panel, which in turn can be assembled into a larger solar power system. Photovoltaic technology is regarded as one of the important directions for future energy technology because of its clean and renewable characteristics.



Picture 1: Schematic diagram of photovoltaic power generation

Source: Wikipedia

1.1.2 Types of photovoltaic technologies

The development of photovoltaic (PV) technology provides diversified ways for human beings to utilize solar energy. Each technology type has its own unique advantages and application scenarios

based on different materials and manufacturing processes. Below are several types of PV technologies currently available in the market:

Monocrystalline silicon photovoltaic cells: Monocrystalline silicon photovoltaic cells are solar cells made using a single crystal of silicon, a material with a highly uniform lattice structure that allows for a smoother flow of electrons, which improves the conversion efficiency of the cell. Monocrystalline silicon cells typically have **conversion efficiencies of 20% or more**, making them one of the **most efficient types of commercially available photovoltaic cells**. However, the process of producing monocrystalline silicon wafers is relatively complex and energy-intensive, resulting in their relatively **high cost**. In addition, the manufacturing process for monocrystalline silicon PV cells produces a **high level of silicon losses**.



Picture 2: Monocrystalline silicon photovoltaic cells

Source: Wikipedia

Polycrystalline silicon photovoltaic cells: Polycrystalline silicon photovoltaic cells consist of multiple small crystals of silicon wafers that are randomly aligned as the material cools, resulting in more impeded electron flow and making polycrystalline silicon cells slightly **less efficient than monocrystalline silicon cells**, typically in the range of **15 to 17 per cent**. However, the simpler and lower cost of polysilicon production makes polysilicon photovoltaic cells **a cost-effective option**, especially **for large-scale power generation applications**.



Picture3: Polycrystalline silicon photovoltaic cells

Source: Wikipedia

Thin film photovoltaic cells: Thin film photovoltaic cells are a type of cell made using extremely thin layers of photovoltaic materials, including copper indium gallium selenide (CIGS), cadmium zinc (CdTe) and amorphous silicon (a-Si). The advantages of thin-film PV cells are that they are low-cost, lightweight and flexible, and can be applied to a wide range of surfaces, such as the walls and roofs of buildings and even wearable devices. However, the conversion efficiency of thin-film PV cells is typically **lower than that of crystalline silicon PV cells, ranging from about 10-13 per cent.**



Figure 4: Thin film photovoltaic cells

Source: Wikipedia

Chalcogenide PV Cells: Chalcogenide PV cells are based on a material called chalcogenide, which is structurally similar to the mineral chalcogenide found in nature. Chalcogenide photovoltaic cells are characterized by their ability to be fabricated by low-cost solution-processing methods, as well as their potentially high efficiency. In recent years, significant progress has been made in the research of chalcogenide PV cells, with **laboratory conversion efficiencies exceeding 25%**, approaching or even exceeding those of monocrystalline silicon PV cells. The biggest challenges for chalcogenide

photovoltaic cells are **long-term stability and environmental sustainability**, and researchers are actively looking for ways to address these issues.

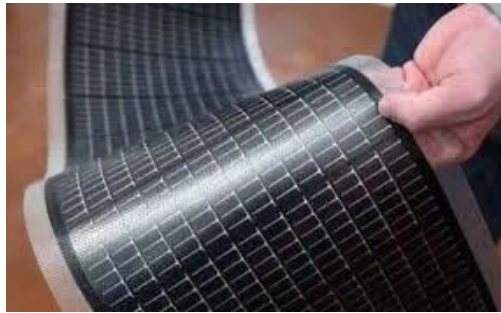


Figure 5: Chalcogenide photovoltaic cells

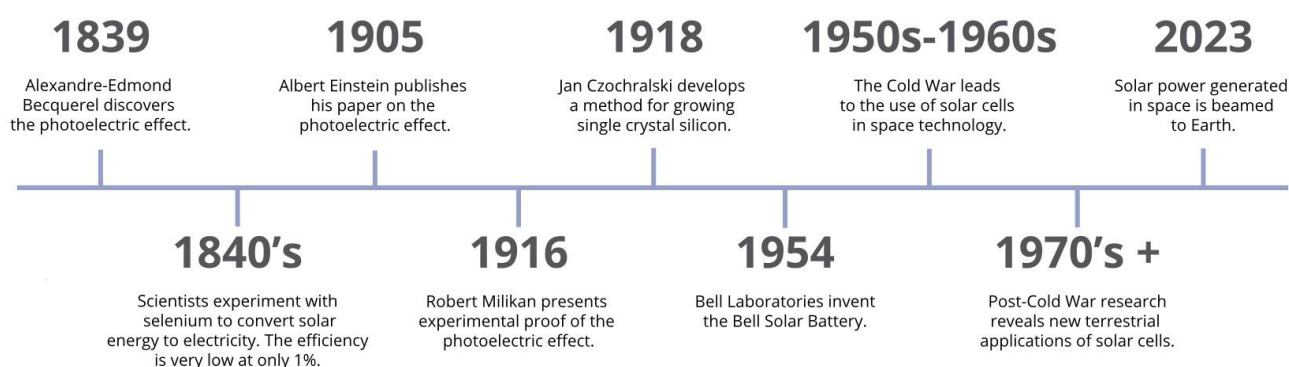
Source: Wikipedia

1.1.3 Development History of Photovoltaic

The development history of photovoltaic technology can be traced back to the end of the 19th century, when scientists first discovered the photoelectric effect, which is the theoretical basis of photovoltaic technology. By 1954, Bell Labs developed the first practical silicon solar cell, marking the birth of modern PV technology. The conversion efficiency of this cell was about 6%, which was low but sufficient to stimulate widespread interest in the commercial potential of solar cells.

Since then, photovoltaic technology has gone through several important stages of development. the oil crisis of the 1970s led to a worldwide search for alternative sources of energy, and solar energy was initially applied and developed. In the 21st century, as the global demand for sustainable energy and reduction of carbon emissions increased, PV technology has rapidly evolved to become one of the most competitive renewable energy technologies. Technological breakthroughs, especially advances in materials and manufacturing processes, have significantly improved the efficiency and reduced the cost of photovoltaic cells. Monocrystalline and polycrystalline silicon technologies are becoming more mature, and new technologies such as thin-film PV technology and chalcogenide PV cells are emerging, injecting new momentum into the continued growth of the PV industry.

Today, PV technology is in a phase of rapid development, not only in the traditional rooftop and ground-mounted areas of significant achievements, but also in the transport, building integration, wearable devices and space applications and other emerging areas to show great potential. Global research, investment and application of photovoltaic technology are continuing to grow, signaling that photovoltaics will play an increasingly important role in the energy system of the future.



Picture 6: History of photovoltaic development

Source: Wikipedia

1.1.4 Latest Technological Progress in Photovoltaics

The latest technological advances in PV technology are mainly reflected in the following aspects, which not only promote the improvement of PV cell efficiency, but also open up new ways for the wide application of PV technology:

Efficiency Improvement: The current academic community has been seeking ways to improve the conversion efficiency of photovoltaic cells through in-depth research on material science and innovations in cell structure design. For example, the photovoltaic conversion efficiency of cells has been effectively improved through the introduction of new high-efficiency light-absorbing materials, the development of surface nanostructures to reduce light reflection, and the optimisation of charge transport paths within the cell. In recent years, laboratory-tested photovoltaic cell efficiencies have reached breakthrough new highs, with some high-efficiency cells achieving conversion efficiencies approaching or exceeding 30%.

Development of new materials: Chalcogenide and organic photovoltaic (OPV) materials are two of the most cutting-edge new materials in the field of photovoltaics in recent years. Chalcogenide materials have attracted attention because of their excellent light absorption ability, adjustable bandgap and relatively low production costs. Organic photovoltaic materials, on the other hand, are characterized by their ability to be produced by solution processing, their bendable nature and their adaptability to different spectra, opening the door to new applications for photovoltaic cells. The development of these new materials is not only expected to further reduce the cost of photovoltaic power generation, but may also promote the development of photovoltaic technology in new application areas.

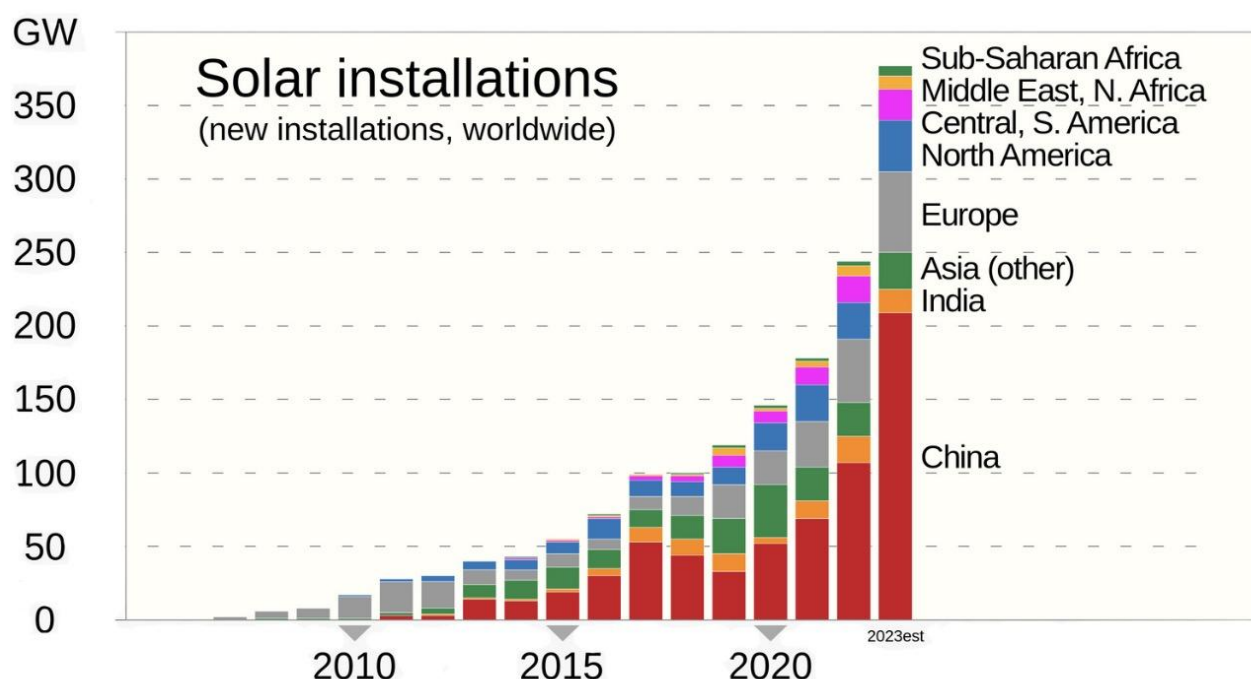
Advances in production technology: Printed photovoltaic technology is an emerging production method in the photovoltaic industry, which allows for the direct printing of photovoltaic cells on a variety of substrate materials, including plastics, fabrics and paper. This technological development allows for a more flexible and less costly production process, while also offering the possibility of integrating PV cells into everyday objects and building materials. Advances in printed photovoltaic technology, particularly in printing efficiency and stability of cell performance, have paved the way for large-scale adoption of PV technology.

Integration and application innovations: As technology continues to advance, the applications of PV technology have expanded from traditional solar panels to include building-integrated photovoltaics (BIPV), PV-powered transportation (e.g., PV cars), and wearable devices. These innovative applications not only demonstrate the flexibility and wide applicability of PV technology, but also provide new ideas and directions for realizing a sustainable energy future. Especially in the field of construction, combining PV technology with building materials not only provides the required energy, but also adds to the aesthetics and functionality of the building.

1.2 Current Status of Photovoltaic Applications

1.2.1 Comprehensive Overview of the Current Status of PV Applications

Between 2019 and 2023, the global installed capacity of PV power generation continues to grow significantly. According to the International Energy Agency (IEA), the **annual installed capacity of solar power increases from 100 GW in 2019 to more than 420GW in 2023, a compound annual growth rate of approximately 39%.**



Picture 7: Change in installed capacity of PV 2010-2023

Source: Canary Media

Technological progress is a key factor driving the development of the photovoltaic industry. The conversion efficiency of photovoltaic cells has been significantly improved in the past few years, and the conversion efficiency of monocrystalline silicon solar panels, in particular, has exceeded 25 per cent. At the same time, due to the expansion of production scale and technological advances, the cost of PV cells and systems has dropped by more than 80 per cent over the past decade, making solar power an economically efficient option for an increasing number of countries and regions. **The European energy crisis caused by the Russian-Ukrainian conflict and the pursuit of peak carbon and carbon reduction targets by many countries around the world have prompted governments to introduce a series of policies to encourage PV power generation.** These policies, which include subsidies, tax breaks and fixed tariff buyouts, aim to reduce investment risks and increase investment returns, thereby incentivising more companies and individuals to invest in the construction and operation of PV projects. Currently, PV has a number of major applications, including large-scale PV power plants, distributed PV, PV-integrated buildings, and off-grid and microgrids.

Centralized large-scale PV power plants: By installing large-scale PV systems on the ground, these plants can generate tens to hundreds of megawatts of electricity, providing large amounts of renewable power to the national grid.



Picture 8: Centralized Solar Power plant

Source: Wikipedia

Distributed photovoltaics: Photovoltaic systems on the roofs of residential and commercial buildings are able to generate electricity at the proximal end of its consumption, reducing losses in long-distance transmission and improving the stability and immunity of the grid.



Picture 9: Distributed photovoltaics

Source: Wikipedia

Building Integrated Photovoltaic (BIPV): The combination of photovoltaic elements with building materials not only provides the electricity needed for the building, but also adds to the aesthetics and modernity of the building, making it an important part of green building design.



Picture 10: Building Integrated Photovoltaic

Source: Wikipedia

Off-grid and micro-grid systems: In remote areas or areas not covered by the grid, photovoltaic systems provide a solution for supplying electricity independently of the traditional grid, enabling residents in these areas to enjoy stable and reliable electricity services.



Picture 11: Off-grid systems in remote area of the China

Source: Wikipedia

1.2.2 AI Training Energy Consumption and Current Status of PV Applications

AI training energy consumption problem: AI models, especially large deep learning models, need to be trained on large-scale datasets to achieve high accuracy. This process often requires a large number of GPUs (Graphics Processing Units) or other dedicated hardware accelerators to run continuously for days or even weeks, consuming large amounts of power. According to the Stanford Artificial Intelligence Institute's Artificial Intelligence Index 2023 report, the Great Language Model GPT-3 consumes 1,287 megawatt-hours of power for a single training session. And a Tesla Model-Y uses 28 kWh of electricity per 100 miles. Therefore, the power consumption of ChatGPT for one training session is roughly equivalent to 3,000 Tesla electric cars running together for 200,000 miles each. The aforementioned report also suggests that a single training session of the large language model GPT-3 is equivalent to the emission of 552 tonnes of carbon dioxide, which is equivalent to the annual carbon emissions of 126 households. This is clearly contrary to the "dual-carbon" goal. A paper published in Joule on 10 October 2023 by researcher Alex de Vries shows that the power consumption of traditional internet operations increases exponentially with AI technology. The paper's data shows that a standard Google search consumes 0.3 watt-hours of electricity, the AI Big Language model ChatGPT uses about 2.96 watt-hours to respond to a single user request, and a single Google search powered by the AI Big Model consumes 8.9 watt-hours of electricity. In addition to power consumption, AI Big Models are also very water intensive. The data center servers that support big model computing can consume a lot of water to dissipate heat. One study showed that the AI big language model GPT-3 consumed nearly 700 tonnes of water during training, and 500 milliliters of water for every 20 to 50 questions it answered thereafter. The Virginia Tech study states that Meta used more than 2.6 million cubic meters of water in 2022, mainly that of data centers.

Data centers applying photovoltaic energy: in order to reduce the carbon footprint caused by AI training, more and more companies and data centers are starting to use photovoltaics as their means of power supply. moroHub's project in dubai is a prominent example. moroHub is currently building the world's largest solar-powered data center in dubai. This facility, located in the Mohammed bin Rashid solar park, uses 100 per cent renewable energy and has a capacity of over 100 MW. In addition to this, Australia's EdgeCentres has also announced its first 100% solar-powered off-grid data center in Victoria. Equipped with 1 MW of solar panels and 48 hours of battery and uninterruptible power supply (UPS) backup technology, the facility is committed to launching a series of standalone,

autonomous data centers designed to provide data services to the Australian region in a carbon-negative manner through ground-mounted and rooftop solar arrays and battery storage.

1.2.3 Status of AI Application in PV Industry

The photovoltaic industry, as a representative of clean energy, has developed rapidly with technological progress and the global pursuit of sustainable development goals. In recent years, the application of Artificial Intelligence (AI) technology in the PV industry has gradually increased, significantly improving the efficiency of PV system design, operation and maintenance. The following are some of the current status of AI applications in the PV industry:

PV system design and optimisation: AI technology can help design more efficient PV power generation systems. By using machine learning algorithms to analyze geographic locations, climatic conditions, and historical weather data, AI can predict the amount of solar radiation at a specific location, thereby optimizing the layout and angle of PV panels and improving power generation efficiency. In addition, AI is able to simulate the performance of a PV system during the design phase, helping decision makers select the most appropriate components and configurations.

Predictive Maintenance and Fault Diagnosis: By monitoring and analyzing PV system operation data in real time, AI can predict potential equipment failures and maintenance needs. This predictive maintenance approach can effectively reduce unplanned downtime and lower maintenance costs. At the same time, AI algorithms can also quickly diagnose the causes of system failures, provide repair recommendations, and improve the reliability and stability of PV systems.

Capacity prediction and energy management: AI technology can accurately predict PV power generation and help grid operators and PV plant managers better plan power supply. By analyzing historical weather data, seasonal changes and real-time weather conditions, AI models can predict power generation in the coming hours or even days, which is important for ensuring grid stability and optimizing power resource allocation.

Automated Operation and Intelligent Monitoring: Using AI's image recognition technology, automatic detection and cleaning of PV panels can be realized to ensure the efficient operation of PV systems. In addition, AI can analyze the monitoring screen to automatically detect potential safety hazards in PV power plants, such as intrusion events, thus improving the safety management level of PV power plants.

Integration and virtual power plant (VPP) management: AI technology shows great potential in managing distributed PV resources. By virtually combining PV systems scattered in different locations into one large power resource, AI can optimize the production, storage and distribution of power, improve energy utilization and reduce carbon emissions.

2. Photovoltaic energy development prospects

2.1 Driving Factors

The Paris Agreement is a historic global climate accord aimed at limiting global warming to well below 2 degrees Celsius, with efforts to keep the increase to 1.5 degrees Celsius. Parties to the agreement commit to reducing greenhouse gas emissions through nationally determined contributions (NDCs) to achieve this goal and regularly update their commitments to reflect the highest level of ambition and action.

To promote low-carbon and sustainable development, green finance and climate-related investments are rapidly growing. This includes green bonds, climate funds, investments in renewable energy, and financial products and services that support energy efficiency and clean technologies. International financial institutions, the private sector, and governments are taking measures to ensure that financial flows support climate action goals.

Accelerating the energy transition from reliance on fossil fuels to renewable energy sources is key to addressing climate change. Globally, the installation of solar power is increasing rapidly, and many countries and regions have established clean energy targets and policies to reduce carbon emissions and enhance the sustainability of energy systems.

2.2 The Role of Photovoltaic Energy in the Energy Structure

In modern society, the transformation of energy structures has become a global focal point. Among various renewable energy sources, photovoltaic (PV) energy is increasingly significant in the global energy landscape due to its sustainability, cleanliness, and cost-effectiveness. This discussion delves

into the multifaceted role of photovoltaic energy in current and future energy structures.

Firstly, as a renewable energy source, photovoltaic energy is crucial for achieving global carbon reduction targets. Compared to traditional fossil fuel energy, the process of photovoltaic power generation does not produce greenhouse gas emissions, helping to mitigate climate change and slow global warming. Photovoltaic energy not only provides clean electricity around the world but also improves air quality and has a positive impact on ecosystems.

Secondly, the proliferation of photovoltaic energy is significant for enhancing national energy security. It breaks the reliance on single energy sources, reduces geopolitical risks associated with energy supply, and stabilizes energy availability. Solar energy can be harnessed almost anywhere globally, and its distributed nature means that local generation and consumption of electricity is possible, which is particularly important for enhancing energy independence.

Economically, the development of photovoltaic energy brings substantial economic benefits and numerous job opportunities. As photovoltaic technology advances and production scales, the cost of photovoltaic equipment has significantly decreased, making solar power one of the most cost-effective energy solutions in many regions. This cost competitiveness has increased the prevalence of photovoltaic energy in emerging markets and developing countries. Furthermore, the growth of the photovoltaic industry has spurred employment in related sectors from manufacturing and installation to maintenance, contributing new impetus to global economic growth.

The advancement of photovoltaic energy technology also brings immense potential for innovation. Developing more efficient photovoltaic cells, energy storage technologies integrated with photovoltaic systems, and smart grid technologies are key factors in promoting wider application of photovoltaic energy. Technological innovations have enhanced the performance and reliability of photovoltaic systems, allowing them to meet a more diverse range of energy needs.

Additionally, policy support and market incentives are crucial for the promotion of photovoltaic energy. Many countries globally encourage the development of photovoltaic energy through subsidies, tax incentives, and other policy measures. These policies reduce the initial investment costs of photovoltaic projects, improve the return on investment, and accelerate the innovation and market expansion of photovoltaic technology.

Photovoltaic energy provides efficient off-grid solutions for remote areas and regions beyond the reach

of the power grid. The flexibility of solar energy systems makes them an ideal choice for providing reliable and economical electricity to these areas, helping to improve the quality of life for local residents and promote economic development.

In the entire power system, with the advancement of energy storage technology, the integration of photovoltaic energy has become easier. The development of storage technology allows photovoltaic power to provide electricity even when there is no sunlight, enhancing the stability of power supply. Additionally, distributed photovoltaic systems help alleviate the burden on central grids, optimize power distribution, and make the grid more efficient and reliable.

In summary, photovoltaic energy plays a vital and multifaceted role in the current transformation of energy structures. From providing clean, sustainable electricity to enhancing energy security, from fostering economic development to driving technological innovation, the role of photovoltaic energy is ubiquitous. As global demand for renewable energy increases, the future position of photovoltaic energy in the global energy structure will only become more significant.

2.3 Photovoltaic Renewable Energy Development Technology Trends



2.3.1 Energy storage technology



Picture 12: Battery Technology

Source: Wikipedia

Lithium-Ion Battery Technology

- **High Energy Density:** Lithium-ion batteries have a high energy density, enabling the use of electric vehicles and portable electronic devices.
- **Extended Lifespan:** Improvements in battery materials and design have significantly enhanced the cycle life and safety of lithium-ion batteries.

Solid-State Batteries

- **Safety:** Solid-state batteries use a solid electrolyte instead of a liquid one, enhancing battery safety.
- **Higher Energy Density:** Solid-state batteries are expected to offer higher energy densities and longer lifespans, and are currently under development.

Flow Batteries

- **Large-Scale Energy Storage:** Flow batteries are particularly suited for large-scale energy storage applications, such as grid storage, because their storage capacity and power can be adjusted independently.
- **Cycle Stability:** Flow batteries exhibit good cycle stability and longer lifespans.

Supercapacitors

- **Rapid Charging and Discharging:** Supercapacitors support extremely fast charging and discharging rates. Although they have a lower energy density compared to batteries, they are ideal for applications that require rapid energy release.



2.3.2 Smart Grid



Picture 13: Smart Grid

Source: Wikipedia

Smart Grids and Digitalization

Decentralized power production, such as wind turbines, solar power plants, residential photovoltaic solar panels, and small hydroelectric dams.

Smart Meters

Smart meters are the foundational infrastructure of the smart grid, capable of real-time collection and transmission of user electricity data. This provides accurate energy consumption information to both users and energy suppliers and supports advanced functionalities like Demand Response. The widespread deployment of smart meters is a crucial step in enhancing grid management efficiency and optimizing energy consumption behaviors.

Distributed Energy Resources (DERs)

This includes solar photovoltaic panels, wind turbines, energy storage devices (like battery storage systems), and micro-generators. The integration of these resources is facilitated by smart grid technologies, allowing locally produced electricity to be consumed on-site with excess power fed back into the grid, thereby improving energy utilization.

Demand Response Management

Through smart grid technologies, energy providers can monitor grid load in real-time and send requests to reduce electricity use when necessary to balance the grid load. Users can receive financial incentives by reducing consumption or utilizing backup generation in response to these requests.

Virtual Power Plants (VPPs)

Virtual power plants manage a diverse set of energy resources—including renewable energy generation, energy storage, and demand response—through software and intelligent control technologies. As a unified entity, VPPs provide power services and enhance grid flexibility and reliability while promoting the integration of renewable energy.

Advanced Distribution Management Systems (ADMS)

ADMS are integrated software solutions designed to monitor and optimize grid operations, handle faults, and manage distributed energy resources. These systems enhance operational efficiency, reduce outage times, and improve the reliability of electricity supply.

Energy Management Systems (EMS)

On the consumer side, EMS helps households and businesses monitor and manage their energy consumption, optimize energy usage, and reduce energy costs. EMS typically includes functionalities such as intelligent heating controls, lighting controls, and appliance management.

2.3.3 Agricultural Greenhouse



In agricultural greenhouses, the application of photovoltaic technology extends beyond simply providing energy. It also includes the integration of intelligent management systems, optimization of greenhouse environmental controls, and research to enhance crop yield and quality. For example, by installing transparent photovoltaic panels, sunlight can be captured for electricity generation without obstructing light from reaching the crops. Additionally, photovoltaic systems can power automated irrigation, temperature regulation, and pest management systems, achieving automation and precision in agricultural production. The combination of these technologies significantly improves the energy efficiency and economic benefits of agricultural greenhouses, advancing the development of modern agriculture.

2.3.4 Solar Water Storage

Solar powered water pump systems are an efficient and environmentally friendly water extraction solution, especially suitable for remote, non-electrified areas. This system mainly consists of solar photovoltaic panels, water pumps, controllers and other components. Solar panels convert sunlight into electricity, and a controller regulates the operation of an electric pump as needed. Such systems can be used for agricultural irrigation, livestock watering, domestic water supply and even small

community water supply.

Compared with traditional water pumps that rely on the grid or fossil fuels, solar water pump systems have clear advantages: firstly, it can significantly reduce operating costs, because sunlight is completely free as an energy source; secondly, such systems have lower maintenance costs because of their The structure is relatively simple and durable; in addition, the solar water pump system is environmentally friendly, does not produce greenhouse gas emissions, and helps mitigate climate change.

In addition, with the continuous advancement of photovoltaic technology and the reduction of costs, solar water pump systems are becoming more and more cost-effective, making this technology more popular. Governments and non-governmental organizations are also promoting the use of solar water pump systems, especially in developing countries, to support sustainable development in rural areas and improve the living conditions of local residents.

To sum up, the solar-driven water pump system is not only technologically mature, economical and practical, but it also promotes the utilization of renewable energy, which is of great significance to promoting global sustainable development. With the continuous development of related technologies and the expansion of application scope, its future application prospects are undoubtedly very broad.

2.4 Photovoltaic energy economics and environmental impact analysis

1. Solar Photovoltaic Energy

Breakthroughs in Technology: Photovoltaic technology, especially the improvements in the efficiency of monocrystalline and polycrystalline silicon solar cells, as well as the creation of new photovoltaic materials like perovskite solar cells, have made it much easier to turn sunlight into electricity.

Cost Reduction: Over the past decade, the cost of solar photovoltaic modules has dramatically

decreased. According to the International Renewable Energy Agency (IRENA), the global average cost of solar photovoltaic modules fell by about 82% from 2010 to 2020.

2. Energy Storage Technology

Technological Breakthroughs: Advancements in battery storage technology, particularly in increasing the energy density and extending the life cycle of lithium-ion batteries. Additionally, the development of emerging storage technologies such as solid-state batteries, flow batteries, and supercapacitors, provides more possibilities for energy storage.

Cost Reduction: The cost of lithium-ion batteries has significantly dropped over the past decade. According to Bloomberg New Energy Finance, the average cost of lithium-ion batteries decreased from about \$1100 per kilowatt-hour in 2010 to \$137 per kilowatt-hour in 2020, a reduction of approximately 89%.

3. Solar Thermal Water Heating Systems

Solar thermal water systems are devices that convert solar energy into thermal energy to heat water. They primarily consist of solar collectors and storage tanks. According to market data, if a household uses a gas or electric water heater, the average annual energy cost is about 2000 yuan. However, using a solar thermal water system can reduce the annual energy cost by more than 50%, saving over 1000 yuan in energy costs per year.

4. Environmental Impact of Photovoltaic Energy

Reduction of Greenhouse Gas Emissions: Compared to fossil fuel power generation, photovoltaic energy produces almost no greenhouse gas emissions during operation, helping to mitigate global climate change.

Reduction in Air and Water Pollution: The operations of photovoltaic energy projects do not generate air pollutants or harmful wastewater, improving air quality and protecting water resources.

Resource Recycling: The recycling and reuse of photovoltaic energy equipment (such as solar panels) are current focuses of research and policy, aimed at ensuring the long-term sustainability of the photovoltaic energy industry.

2.5 AI and photovoltaic energy industry

2.5.1 Industry Analysis and Application

The connection between photovoltaic (PV) technology and Artificial Intelligence (AI) primarily manifests in the application of AI in the operation and maintenance of PV systems. AI can optimize the efficiency of power generation at solar power stations through data analysis, predict maintenance needs, reduce downtime, and increase energy output. Additionally, AI plays a role in the design and manufacturing process of PV components, using machine learning algorithms to improve material performance and enhance photovoltaic conversion efficiency. Overall, AI technology offers new possibilities for enhancing the performance and reducing the costs of PV systems.

PV Power Generation Forecasting

- AI can accurately predict the power generation of PV systems by analyzing historical weather data, sunlight intensity, temperature, and other factors. This helps grid operators to more effectively schedule resources, enhancing the stability and economic performance of the system. For example, using machine learning models to predict solar power generation in specific areas can optimize power generation plans and electricity distribution.

Fault Detection and Preventative Maintenance

- Using AI technology, equipment in solar power stations can be monitored in real time to quickly identify potential faults and issue warnings. Image recognition technology allows AI to automatically detect stains, cracks, and other issues on solar panels, significantly improving the efficiency and accuracy of inspections and reducing maintenance costs.

Optimization of PV System Configuration

- AI algorithms can assist in designing the optimal configuration of PV systems, including the layout and tilt angle of panels, to maximize power generation efficiency. Moreover, AI can provide decision support for the planning and deployment of PV projects based on geographical location, climatic conditions, and other factors.

Energy Management and Storage

- Integrating AI technology enables smarter management of PV power generation and energy storage systems, achieving a dynamic balance between electricity supply and demand. AI can analyze user consumption patterns, predict power demand, and optimize charging and discharging strategies for energy storage systems, enhancing the overall energy efficiency and economic performance of the system.

2.5.2 AI training energy consumption and photovoltaic challenges

The intermittency and instability of photovoltaic (PV) power generation present significant challenges. These issues, along with the broader implications for areas such as AI training centers that demand consistent and reliable power, are outlined below:

Intermittency and Unreliability: One of the primary challenges with PV power is its intermittent nature. Solar power generation depends on sunlight conditions, which means power output diminishes during nighttime or cloudy weather. This intermittency can lead to insufficient power supply, especially problematic for AI training which requires continuous and stable electricity.

Need and Cost for Storage Solutions: To counteract the intermittency issue, robust energy storage systems, such as batteries, are necessary to ensure power availability during periods without sunlight. However, effective storage solutions are typically expensive and require regular maintenance and replacement, adding to overall costs.

High Initial Investment: Although the operational costs of PV power are relatively low, the initial investment is considerably high. For AI training centers that require extensive power, installing sufficient PV panels and storage systems to meet their needs demands significant upfront capital.

Geographical Restrictions: The location of optimal generation sites, which are typically in areas with plenty of sunlight, affects the efficiency of PV power generation. However, not all data centers can be established in these areas, especially those that need to be near users or specific infrastructures.

Environmental Impact and Resource Demand: While PV power is considered a clean energy source, manufacturing PV panels requires significant resources and has environmental impacts during

production. Additionally, managing and recycling old PV panels poses challenges, necessitating sustainable solutions.

Need for Technological Advancements and Upgrades: PV technology is rapidly evolving, and new advancements may render existing systems relatively outdated. To maintain efficiency and competitiveness, periodic investments in system upgrades may be necessary.

These factors collectively illustrate the complexities involved in integrating photovoltaic systems with high-demand applications like AI training centers, emphasizing the need for advanced solutions to address these challenges effectively.

3. Global PV Policies and Outlook

3.1 PV Policies in Multiple Countries

Renewable energy is not only promoting environmental protection but also driving future economic development. Hence, multiple countries formulated a series of strategic plans and economic-incentive policies to promote the development of the PV industry. In the following paragraphs, policies related to PV in the US, the Netherlands, and Germany are discussed below.

3.1.1 PV Policies in the US

The United States has introduced a range of federal initiatives, policies, and rules to promote the expansion of solar energy throughout the country. These efforts are designed to encourage the development of solar technologies, back research, and innovation, and oversee the incorporation of solar energy into the national grid.

The U.S. federal government offers financial incentives like the Federal Investment Tax Credit (ITC), also known as the solar tax credit, which allows homeowners who install solar panels to deduct 30% of the installation costs from their taxes from 2022 to 2032.

The Modified Accelerated Cost Recovery System (MACRS) allows for accelerated depreciation of commercial solar equipment over five years, reducing taxable income and providing extra value

depending on the tax rate of the owner.

The Public Utilities Regulatory Act of 1978 (PURPA) has also facilitated the expansion of solar energy in the U.S. by mandating utilities to buy electricity from qualifying facilities (QFs), which include small power producers (80 MW or less) and cogeneration plants, at a cost equivalent to what the utilities would have otherwise spent on power generation.

The Solar Energy Technologies Office (SETO) within the U.S. Department of Energy (DOE) supports research and development in solar technology to improve affordability, reliability, and its impact on the national grid. SETO focuses on advancing photovoltaic (PV) systems, enhancing grid performance, and developing new business models. Moreover, the DOE has set ambitious targets to make solar power cost-competitive without subsidies by 2030.

The U.S. Energy Information Administration (EIA), an impartial entity within the DOE, gathers detailed energy statistics and provides market analyses, predictions, and long-term projections. The resources of EIA, including the State Energy Data System (SEDS) and the Electric Power Annual, provide crucial information on state-specific energy consumption, production, prices, and solar energy distribution.

3.1.2 PV Policies in the Netherlands

In order to promote the transformation of energy, the Netherlands government highly supports the techniques related to innovation and application of sustainable energy, including solar photovoltaic, and provides a series of policy incentive measures.

SDE++, Sustainable Energy Production and Climate Transition Incentive Scheme, is the main instrument of renewable incentive policies in the Netherlands, which is broadened from SDE+ to other CO₂ emission reduction measures within the SCE++ scheme, such as CCS. SDE++ in the Netherlands offers subsidies to both companies and non-profit organizations that either produce renewable energy or engage in large-scale CO₂ emission reduction.

The WBSO R&D tax credit supports two kinds of projects: development projects, which include the creation of technically new physical products, production processes, or software (or parts of them), and technical-scientific research, which involves exploratory technical research.

The Energy Investment Allowance allows taxpayers to deduct 40% of their investment costs from personal or corporate income tax. This allowance applies to all assets listed on the annual Energy List, compiled by the Netherlands Enterprise Agency (RVO), and proposals for assets not included in this list can be submitted annually.

The Environmental Investment Allowance (MIA) permits up to 45% of investment costs to be deducted from profits, thus reducing taxable income. Additionally, the Arbitrary Depreciation of Environmental Investments (Vamil) scheme allows for the depreciation of up to 75% of the investment costs at any chosen time, potentially yielding a tax advantage exceeding 14% of the investment.

Furthermore, SolarNL is a national program aimed at advancing PV manufacturing within the Netherlands and Europe, supported by a subsidy from the National Growth Fund as of June 30, 2023.

3.1.3 PV Policies in Germany

The German PV industry has started to develop rapidly since the initial publication of the Renewable Energy Sources Act (EEG) in 2000 by proposing discrepant fixed electricity prices. In 2022, the revised EEG and Solar Package I plans fostered the stagnant PV industry significantly again, making Germany return to the top of additional solar installation over Europe in 2023 (Aúz, 2024).

The Renewable Energy Sources Act (EEG) is Germany's primary legislation promoting solar energy, providing a guaranteed feed-in tariff for producers, ensuring they receive a specified amount for each kilowatt-hour of electricity produced.

The Federal Ministry for Economic Affairs and Energy (BMWi) extends various grants to solar projects, particularly those in high-potential solar areas or utilizing innovative technologies.

State governments across Germany also have their support mechanisms for solar energy, which differ regionally, making it essential for stakeholders to consult local authorities for specific details.

In May 2023, BMWK introduced a strategy called Solar Package I to the German government, detailing 11 key areas for revamping Germany's solar PV strategy and enhancing the overall energy framework (Aúz, The evolution of Germany's photovoltaic strategy: photovoltaik-strategie, 2024):

- Ground-mounted Solar: The Federal Land Utilization Ordinance has been relaxed to aim for a

50% deployment in ground-mounted solar projects. This includes special subsidies for agricultural and biodiversity-focused solar installations.

- **Rooftop Solar:** Regulations for rooftop solar installations are being relaxed, with efforts to streamline direct marketing to make it more user-friendly and accessible.
- **Tenant Power:** The adoption of solar installations by landlords is being encouraged through the reduction of bureaucratic hurdles and the provision of tax incentives.
- **Balcony Solar:** Deregulation of the registration process for balcony solar setups, inclusion in the German Act on the Ownership of Apartments and the Permanent Residential Right (WEG), and the temporary acceptance of analog meters until a replacement is feasible.
- **Grid Connections:** The process for connecting to the grid is being simplified, alongside the streamlining and digitization of certification and registration, especially for smaller solar systems.
- **Public Acceptance of Solar:** Efforts to boost community solar projects by reducing bureaucracy and incorporating solar topics into the agenda of the Fachagentur Windenergie an Land.
- **Tax Barriers:** Removal of tax impediments to new solar installations and reclassification of ground-mounted solar to foster growth.
- **PV Production:** Revitalization of domestic PV manufacturing through tax benefits, research and development subsidies, and hybrid capital.
- **Skilled Workers:** Enhancement of education and training programs and recruitment from abroad to bolster the skilled workforce in the solar sector.
- **Research Funding:** Investment and subsidies linked to the re-establishment of PV production in Germany.
- **PV Subsidies:** Alignment of PV subsidies with European policies and acceleration of planning and approval processes by classifying renewable systems as of “overriding public interest.”

3.2 Business Model in the PV Industry

3.2.1 Solar Leasing

Solar Leasing, a financing option founded in 2007, allows homeowners to implement solar energy at very low prices of 0 dollars. Obviously, it was revolutionary since it eliminated the enormous costs of upfront installation, which also reduced the initial migration costs to transit to solar energy.

In the solar leading contract, the solar panels installed on the roof can be used to power the electrical appliances in the house, but the panels do not belong to the house owners but are owned by the leasing companies. The homeowners have to pay a fixed monthly usage fee, usually for 10 to 25 years.

Pros	Cons
• Zero upfront costs • Reduce energy bills • Not responsible for system maintenance/monitoring • Predictable lease payment every month • Shorter contract than PPA	• Not eligible for federal tax credit / certain local and state incentives • Lower long-term savings as compared to PPA • Price escalator • No added property value • Difficulty selling house

Resource: SolarReviews

Compared to the PPA, Power Purchasing Agreement, Solar Leasing saves more in the upfront costs, since it offers a fixed monthly rate regardless of usage, while PPA charges homeowners per KW-hour for solar energy production (Lane, 2024).

Nevertheless, the nature of solar energy brings about instability of supply. The power generation of solar panels depends on the number of sunny days actually available, so the homeowner may need to cover two sources of energy, like traditional electricity. Besides, the local or state incentive subsidies

only benefit solar developers, and homeowners are excluded (Hunder, 2023).

Picture 14: Solar Lease Example



Image resource: SolarReviews

3.2.2 Power Purchase Agreement

Similar to Solar Leasing, the Power Purchase Agreement (PPA) is another solar financing option, where a solar developer would install and own the solar panel on the roof of a homeowner. Likewise, PPA contractors do not benefit from local or state incentive subsidies, and homeowners do not have to be responsible for the equipment installation and system maintenance (Mack, 2023).

The only difference between a PPA and a solar lease is how the homeowners make the payment: Solar lease payments are fixed every month, whereas solar PPA payments are based on the amount of energy the solar panels actually generate. In the long term, PPA might save more than Solar Lease, since the monthly usage fee depends on the actual power produced by solar panels.

Pros	Cons
• Zero upfront costs • Possible to save more in the long term than a lease • Reduce energy bills • Not responsible for system maintenance/monitoring • Monthly bill tied to how much energy you use	• Not eligible for federal tax credit / certain local and state incentives • Price escalator • Long-term contract up to 25 years • No added property value • Difficulty selling house

3.2.3 Solar Direct Purchase

In this traditional model, customers have to invest a significant upfront cost for the installation of the entire solar system, and the buyers would own the whole solar system, relishing 100% of the electricity savings it generates, as well as the maintenance, operation, and financing costs.

Solar Direct Purchase allows buyers to fully benefit from federal and state incentives, including 30% tax credits and rebates and usually provides the highest long-term savings. Moreover, the solar panels on the roof add value to the property, since the homeowner has the proprietary rights to solar panels (Saxon Renewables, 2023).

Pros	Cons
• Benefit from federal tax credit / certain local and state incentives • Solar panels added to property value • Reduce energy bills • Enjoy full savings from solar system	• Significant full system costs • Responsible for solar system's performance, no energy assurance • Less than 5 year ROI, instead of immediate saving on electricity • Pays for Operation & Maintenance (O&M) Services

3.3 Outlook of the PV Industry

3.3.1 Photovoltaic Power Promotes Global Energy Transformation

Global sustainable development is threatened by environmental degradation and resource scarcity, impelling the transformation of the global energy system to green and low-carbon. The mainstream

objective of energy development is to promote the further development of renewable energy and to improve the cleanliness and low-carbonization of existing energy utilization.

Net-zero emission targets motivate the development of renewable energy: According to the Paris Agreement, almost all of the top ten countries in the world's economic ranking have set the goal of net-zero greenhouse gas emissions through policy statements or regulations. Among them, the development and utilization of solar energy, wind energy, and biomass energy have become important instruments to achieve net-zero emissions targets.

Solar energy is more favorable for its higher efficiency and less harm: Compared with other renewable energy sources, solar photovoltaic power has the shortest path from energy collection to conversion, the highest efficiency of conversion, the richest forms in the reservation, and the least influence on the environment, which made photovoltaic power a crucial element in the global energy transformation to green and low-carbon (China Business Research Institute, 2023).

3.3.2 Improvement of Technology Reduces Costs of PV Industry

With the development of the photovoltaic power industry, technology in each process of the industry chain is continuously innovated and elevated, such as the application of diamond wire cutting technology, the continuous improvement of PERC cell conversion efficiency, etc. All those technological advances effectively improved the efficiency of photovoltaic power generation while reducing the production costs.

The efficiency of PV cells is significantly improved: According to the China Photovoltaic Industry Association (CPIA), the average conversion efficiencies of PERC monocrystalline cells and polycrystalline cells reached 23.20% and 21.10% respectively in 2022, significantly elevated compared to 21.3% and 20.0% in 2017. Meanwhile, the average conversion efficiencies of TOPcon batteries, heterojunction batteries, and XBC batteries reached 24.5%, 24.6%, and 24.5%.

The drop in costs yields higher demands for PV power: Since 2007, the unit cost of photovoltaic power generation per kilowatt-hour in China has dropped by more than 90%, and the photovoltaic grid-connected electricity price has been closely approaching parity. Besides, the grid-connected price of photovoltaic power generation is expected to be lower than the cost of traditional coal-fired power generation in the foreseeable future. Furthermore, lower expectations of electricity costs will further enhance the market demands for photovoltaic power generation, thus bringing broader market

prospects to the photovoltaic industry.

3.3.3 Digital Drives Distributed PV Innovation

PV companies are using these digital technologies, such as cloud computing, big data, and IoT to promote digital transformation and innovation in energy, and the combination of those digital technologies and the photovoltaic industry contributes to a series of intelligent software and hardware products: Smart Energy Systems, Intelligent Operation and Maintenance Platforms, Photovoltaic Power Station Cleaning Robots, Drone Intelligent Inspection Systems.

Digital applications on PV power management elevate efficiency: The digital applications not only improved the efficiency of power station construction, realizing visual management of power station operation but also reduced the labor cost of power station operation and maintenance, thereby reducing the LCOE of photovoltaic power generation in multiple perspectives.

Combination of digital technologies innovate opportunities: The digital transformation of the photovoltaic industry is one of the critical tendencies in future development, which is not only important progress of the industry but also brings about huge development opportunities for PV companies. In conclusion, with the continuous exploration and application of digital technology, the products and services of the PV industry could be further optimized in terms of efficiency and sustainability.

4. Photovoltaic Industry Company Comparative Analysis

4.1 Company Analysis

4.1.1 Longi Green Energy Technology Co., Ltd.

In the dynamic landscape of the renewable energy sector, Longi Green Energy Technology Co., Ltd. stands out for its excellent financial performance, strategic operational efficiency, and forward-looking

investments in innovation and growth. The first half of 2023 highlighted Longi's robust position in the market, reflecting a harmonious combination of prudent financial management, keen operations, and visionary R&D initiatives.

Longi's financial condition is very stable, with company revenue growing by 28.36% to RMB 64,652,383,091.16. Meanwhile, net profit significantly increased by 41.63% to RMB 9,178,377,606.99. These figures are not just numbers but proof of Longi's expanding market share and its capability to capitalize on emerging opportunities in the renewable energy sector. A debt ratio of 55.99% further highlights Longi's strategic leverage in debt management, balancing ambitious expansion with good financial stability. The company's asset growth rate of 12.33% reflects the tangible expansion and scalability of its operations.

Market performance indicators paint a picture of confidence and growth potential for Longi. A price-to-earnings (P/E) ratio of 16.33 and a price-to-book (P/B) ratio of 2.18 indicate positive market evaluations of Longi's profit potential and asset value. These ratios reflect investor confidence, suggesting a well-regarded and stable investment outlook in the volatile renewable energy market.

Operational efficiency is a hallmark of Longi's excellent management. An asset turnover ratio of 0.41 indicates that Longi can skillfully utilize its asset base to generate considerable revenue. Moreover, a reduction of 13 days in inventory turnover days compared to the previous year highlights improved speed and efficiency of operations, enhancing liquidity and operational responsiveness. A Days Sales Outstanding (DSO) of 35.21 days further emphasizes Longi's effectiveness in managing receivables and ensuring stable and reliable cash flows.

The growth indicators for Longi are not only hopeful but are beacons of its steadfast rise in the renewable energy sector. Significant increases in revenue and net profit growth rates highlight Longi's solid market position and exceptional operational capabilities. These growth rates are clear indicators of Longi's successful strategic execution and market expansion, laying a solid foundation for continued growth.

Longi's investment in R&D and innovation is particularly noteworthy, with RMB 3.42 billion invested in the first half of 2023 alone. This investment represents 5.29% of its revenue, clearly demonstrating Longi's commitment to maintaining its technological leadership and exploring new areas in renewable energy. This strategic focus on R&D is crucial for Longi's long-term competitiveness and its ability to adapt to the rapidly evolving technological landscape of the renewable energy sector.

In conclusion, the performance of Longi Green Energy Technology Co., Ltd. in the first half of 2023 thoroughly demonstrates its strategic financial management, operational efficiency, and visionary innovation. With a solid financial foundation, market confidence, exceptional operations, and a commitment to innovation, Longi is well-positioned to continue its leadership in the renewable energy industry, driving sustainable growth and pioneering advancements in green technology.

4.1.2 JinkoSolar Holding Co., Ltd.

In the vibrant and rapidly evolving solar energy sector, JinkoSolar Holding Co., Ltd. has become a formidable player, demonstrating exceptional financial health, strong market performance, and a firm commitment to innovation and growth during the first half of 2023. This period marked significant achievements and strategic advancements that positioned JinkoSolar at the forefront of the industry.

The company's financial performance in the first half of 2023 was impressive. Revenue surged by 60.52% to RMB 53.6 billion, highlighting JinkoSolar's expanding market coverage and its capacity to meet the growing global demand for solar products. This growth is reflected in the company's net profit, which soared by 324.58% to RMB 3.8 billion, reflecting not only increased sales but also excellent operational execution and effective cost management strategies. The expansion of JinkoSolar's asset base, with total assets growing by 14.49% and net assets by 16.02%, underscores the company's financial stability and strategic investments for future growth.

These stellar financial metrics testify to JinkoSolar's operational efficiency. While specific ratios such as asset turnover rate, inventory turnover days, and Days Sales Outstanding (DSO) are not directly provided, the substantial growth in revenue and net profit indicates a highly efficient operational framework. Such efficiency is crucial for sustained growth in the competitive solar market, where operational flexibility and cost-effectiveness are key.

JinkoSolar's commitment to research and development (R&D) is the cornerstone of its strategic growth plans. With R&D spending increasing by 23.56% to RMB 2.7 billion, accounting for 5.10% of revenue, JinkoSolar not only invests in innovation but actively shapes the future of solar technology. This investment has propelled the development of N-type TOPCon solar cells, large-scale manufacturing processes, and cutting-edge solar panel technologies. JinkoSolar holds a significant market share in N-type solar product shipments, highlighting its leadership in N-type technology and demonstrating its ability to adapt to and drive technological advances in the solar industry.

The company's stock performance in October 2023 further validates its strong market position and investor confidence. With share prices significantly rising within a few days, the market responded positively to JinkoSolar's growth trajectory, operational efficiency, and innovation capabilities.

Looking ahead, JinkoSolar's strategic focus on expanding its global market share, enhancing operational efficiencies, and driving technological innovation lays a solid foundation for its continued growth. The company is committed to meeting global energy needs through cutting-edge solar solutions, not only highlighting its role as a leader in renewable energy but also underscoring its potential for ongoing success in the ever-changing global energy landscape.

4.1.3 JA Solar Holdings Co., Ltd.

In the rapidly advancing global renewable energy landscape, JA Solar Holdings Co., Ltd. has emerged as an industry pioneer, exhibiting extraordinary growth and innovation trajectories during the first half of 2023. The company's performance during this period demonstrates its strategic foresight, operational prowess, and commitment to sustainable energy solutions, positioning it as a distinguished beacon in the solar sector.

JA Solar's financial performance in the first half of 2023 highlighted its strong market expansion and operational efficiency. Revenue soared by 43.47% to RMB 40.84 billion, indicating the company's successful penetration into new markets and its ability to capitalize on the growing global demand for solar solutions. Additionally, net profit attributable to shareholders surged by 182.85% to RMB 4.81 billion, reflecting not only an enhancement in profitability but also the effectiveness of its cost management strategies. The cash flow from operating activities grew by an impressive 878.13% to RMB 4.83 billion, further underscoring JA Solar's financial health and skilled management of operational efficiency.

At the core of JA Solar's strategic operations is its comprehensive vertical integration model, which includes the manufacturing and sales of solar photovoltaic silicon wafers, cells, and modules, as well as the development, construction, and operation of photovoltaic power stations. This model has established JA Solar's strong influence both domestically and internationally, with strategically located production facilities optimizing the supply chain and market coverage. The company's emphasis on research and development has propelled significant advancements in photovoltaic technology, reinforcing its commitment to reducing costs, enhancing efficiency, and promoting

sustainable energy solutions.

JA Solar's global operational footprint is a key component of its competitive advantage. Its production facilities and sales networks span across the globe, effectively reducing the risks associated with market fluctuations and international trade barriers, ensuring a stable supply of high-quality solar products to a diverse customer base. This global influence not only expands JA Solar's market reach but also highlights its commitment to advancing global solar energy applications.

Technological innovation led by JA Solar is crucial for maintaining its leadership position in the solar market. With cutting-edge product offerings like the n-type Bycium+ cells boasting conversion efficiencies up to 25.6%, JA Solar continuously pushes the boundaries of solar technology. These advancements underscore the company's dedication to improving the cost-efficiency and performance of solar systems, making renewable energy more accessible and viable for broader applications.

In summary, JA Solar's performance in the first half of 2023 paints the picture of a company at the forefront of the renewable energy revolution. Through strategic vertical integration, global market expansion, relentless innovation, and a firm commitment to sustainable development, JA Solar not only navigates the complexities of the solar market but is actively shaping its future, making significant contributions to the global transition toward cleaner, more sustainable energy sources.

4.1.4 Trina Solar Co., Ltd.

In the first half of 2023, Trina Solar Co., Ltd. solidified its position as a key player in the global solar industry, demonstrating impressive growth, innovation, and strategic expansion. With a comprehensive array of photovoltaic products, intelligent solar systems, and leading smart energy solutions, Trina Solar not only facilitated the transition to renewable energy but also set new standards for technological advancements in the solar industry.

This period marked a significant financial milestone for Trina Solar, as the company reported a robust revenue increase of 38.21%, reaching RMB 49.38 billion. This remarkable growth reflects the growing global demand for solar solutions and Trina Solar's ability to capture and serve this emerging market. Furthermore, net profit surged by 178.88% to RMB 3.54 billion, showcasing not only a rise in sales but also improvements in operational efficiency and effective cost management strategies. The total assets grew by 30.22% to RMB 117.17 billion and net assets increased by 13.87% to nearly RMB 30

billion, highlighting Trina Solar's strong financial health and strategic investments for future growth and expansion.

At the heart of Trina Solar's success is its strategic business division, which encompasses a wide range of solar photovoltaic products and systems designed to meet the diverse needs of the global market. The launch of the Vertex N series, integrating advanced 210mm technology and N-type i-TOPCon cell technology, marked a significant leap in solar module efficiency and power output. Trina Solar's solar systems division offers intelligent solutions for large-scale installations, utilizing innovative tracking systems to enhance power generation efficiency. The company's foray into Building-Integrated Photovoltaics (BIPV) exemplifies its commitment to integrating solar technology into building materials, providing both functional and aesthetic value.

Trina Solar's investment in research and development is reflected in continuous technological breakthroughs, particularly in N-type i-TOPCon cell technology and perovskite-silicon tandem cells, achieving over 31% laboratory efficiency. These innovations not only solidify Trina Solar's leadership in the solar technology field but also assist the industry in transitioning towards more efficient, cost-effective solar solutions.

Looking ahead, the solar photovoltaic industry is poised for exponential growth, driven by global carbon neutrality initiatives and the increasing prevalence of renewable energy. With its strong R&D capabilities, global brand recognition, and extensive sales network, Trina Solar is uniquely positioned to capitalize on these market opportunities. The company's strategic focus on high-efficiency N-type technology, coupled with its efforts in developing smart energy storage and smart grid solutions, aligns with the industry's trajectory towards sustainable, efficient, and cost-effective solar solutions.

In summary, Trina Solar Co., Ltd.'s performance in the first half of 2023 exemplifies its strategic vision, exceptional operations, and firm commitment to driving innovation in the solar industry. With its comprehensive product development, global market expansion, and sustainable development approaches, Trina Solar is well-equipped to lead the transformation towards a cleaner, more sustainable energy future, making significant contributions to the global renewable energy landscape.

4.1.5 Canadian Solar Inc.

In the first half of 2023, Canadian Solar Inc. showcased its solid position as a global leader in the solar

industry, achieving significant growth in the market through innovation and strategic expansion. The company's focus on the production and sale of solar panels, as well as the development and operation of photovoltaic power plants, ensured its technological leadership and market expansion on a global scale.

Canadian Solar Inc. holds significant market share and competitive advantages in several key markets globally, especially in North America and Latin America. In the first half of 2023, the company's operating revenue reached RMB 26,104,560,698.99, representing a growth of 31.71% compared to the same period last year. This growth reflects strong demand for the company's products and the results of market expansion efforts.

Canadian Solar Inc. is known for its efficient, reliable products and robust global supply chain management capabilities. The company continuously drives technological innovation through research and development activities, resulting in a significant increase in net profit attributable to listed company shareholders, reaching RMB 1,922,871,039.22, a growth of 321.75% year-on-year. This significant growth reflects the company's strong profitability and cost-control capabilities.

From a financial perspective, Canadian Solar Inc. demonstrated significant performance in the first half of 2023. The net assets attributable to listed company shareholders increased from RMB 11,663,131,570.25 at the end of the previous year to RMB 19,421,793,933.51, representing a growth of 66.52%. This reflects the company's robust capital structure and confidence in future growth potential.

Looking ahead, Canadian Solar Inc. will continue to expand its global business scope, particularly in high-growth potential emerging markets. The company's strategic focus will remain on improving product efficiency and cost-effectiveness while increasing investment in smart energy storage and smart grid solutions to adapt to the trend towards sustainable, efficient, and cost-effective solar solutions.

Overall, Canadian Solar Inc.'s performance in the first half of 2023 reinforces its position as a leader in the solar industry. Through continuous product and technological innovation, as well as keen insights into global market dynamics, Canadian Solar is fully capable of leading the transition towards a cleaner, more sustainable energy future and making significant contributions to the global renewable energy landscape.

4.1.6 First Solar, Inc.

In 2023, First Solar, Inc. continued to strengthen its position in the global photovoltaic market, especially in the United States and the Middle East, leveraging its unique thin-film solar technology and comprehensive photovoltaic solutions. The company is one of the world's largest manufacturers of thin-film solar modules and is renowned for its leading position in the development of large-scale photovoltaic power plant projects.

First Solar primarily engages in the research and production of thin-film solar technology and provides construction, services, maintenance, and operation services for photovoltaic power plants. The company's advanced thin-film photovoltaic (PV) modules developed in research laboratories in California and Ohio represent the next generation of solar technology, offering high-performance and low-carbon alternatives compared to traditional crystalline silicon PV panels.

In 2023, First Solar manufactured a record-breaking 12.1 gigawatts of modules, a 33% increase compared to 2022, with a nominal capacity reaching a new high of 16.6 gigawatts. This growth was driven by the successful launch of production of the new series products, totaling 2.4 gigawatts, at the Series 7 factories in the United States and India.

From a financial perspective, First Solar achieved a net income per share of \$7.74 in 2023, a significant improvement compared to a loss per share of \$0.41 in 2022, indicating a substantial profitability improvement. The company ended 2023 with a cash balance of \$2.1 billion, despite the impact of capital expenditures to expand manufacturing capacity.

Looking ahead, First Solar will continue to drive manufacturing expansion and progress in its technology roadmap. The company announced a \$1.1 billion investment in Louisiana to establish a new manufacturing facility, expected to add 3.5 gigawatts of nominal capacity by 2026. Additionally, the company is expanding its manufacturing bases in Alabama and Ohio, with total capacity in the United States expected to reach approximately 14 gigawatts by 2026, and globally to reach 25 gigawatts.

Overall, First Solar's performance in 2023 reinforces its position as an innovator and market leader in solar technology. With its expertise in thin-film solar technology and global manufacturing capabilities, along with a deep understanding of market demand, the company continues to maintain a competitive advantage in the global photovoltaic market. Through continuous technological innovation and global market expansion, First Solar is fully capable of leading the transition towards

a cleaner, more sustainable energy future and making significant contributions to the development of global renewable energy.

4.2 Company Stock Comparison

Company	Stock Price	Market Value	P/E Ratio	Earnings Per Share	Dividend Yield
Longi Green Energy Technology Co., Ltd.	19.35 CNY	1466.35 billion CNY	9.44	2.05 CNY	2.05%
JA Solar Holdings Co., Ltd.	\$25.60 USD	55.523 billion CNY	2.55	\$10.05 USD	5.86%
JinkoSolar Holding Co., Ltd.	16.74 CNY	555.23 billion CNY	6.25	2.68 CNY	1.39%
Trina Solar Limited	23.06 CNY	502.56 billion CNY	8.12	2.84 CNY	0.04%
Canadian Solar Inc.	\$15.27 CAD	\$977.561 million USD	3.03	\$4.99 USD	N/A
First Solar, Inc.	Approximately \$151.20 USD	Approximately \$16.23 billion USD	47.77	\$3.17 USD	N/A

Picture 15 : Stock information of six companies

Information source: Yahoo Finance

For the major players in the solar energy industry, a brief analysis of each company's stock performance is first necessary:

Longi Green Energy Technology Co., Ltd.: The stock price is 19.35 yuan, the market value is 146.635 billion yuan, the price-to-earnings ratio is 9.44, the earnings per share is 2.05 yuan, and the dividend rate is 2.05%. LONGi exhibits a high price-to-earnings ratio, reflecting investors' optimistic expectations for its future growth, likely stemming from its leadership in the market for high-efficiency monocrystalline products.

JA Solar Co., Ltd.: The stock price is US\$25.60, the price-to-earnings ratio is 2.55, the earnings per share is US\$10.05, and the dividend rate is 5.86%. JA Solar exhibits high earnings per share and a

significant dividend yield, providing impressive returns to income-seeking investors, and demonstrating its profitability relative to its share price.

JinkoSolar Holdings Co., Ltd.: The stock price is 16.74 yuan, the market value is 55.523 billion yuan, the price-to-earnings ratio is 6.25, the earnings per share is 2.68 yuan, and the dividend rate is 1.39%. JinkoSolar has maintained a balanced approach to growth and profitability, with an extensive global sales network.

Trina Solar Co., Ltd.: The stock price is 23.06 yuan, the market value is 50.256 billion yuan, the price-to-earnings ratio is 8.12, the earnings per share is 2.84 yuan, and the dividend rate is 0.04%. Trina's mid-range price-to-earnings ratio and low dividend yield reflect the conservative nature of its dividend strategy, but it has a strong market position in the photovoltaic module and system services markets.

Canadian Solar: The stock price is 15.27 Canadian dollars, the price-to-earnings ratio is 17.77, and the earnings per share are 0.86 Canadian dollars. Canadian Solar's price-to-earnings ratio is in a relatively reasonable valuation range, but due to the lack of dividend yield data, it is difficult to make a comprehensive judgment on its specific investment value. The company achieved year-on-year growth in revenue and net profit in 2023, showing that it has strong room for long-term profit growth.

First Solar: The stock price is about \$151.20, the market value is about \$16.23 billion, the price-to-earnings ratio is about 47.77, and the earnings per share are \$3.17. First Solar is known for its expertise in thin-film technology and large-scale photovoltaic project development, and its high price-to-earnings ratio reflects market expectations for its high growth potential.

In the comparison of stock price levels, First Solar's stock price is as high as US\$151.20, which is significantly higher than its peers, reflecting the market's high expectations for its future development prospects. Followed by JA Solar at US\$25.60, Trina Solar at RMB 23.06, and Longi Green Energy at RMB 19.35. The stock prices of these companies are relatively close, showing a reasonable mid-to-high range. In comparison, the stock prices of JinkoSolar's RMB 16.74 and Canadian Solar's Canadian Solar's CAD 15.27 are relatively low, which may be related to their lower visibility as newly listed companies and the market's underestimation of their intrinsic value.

In terms of valuation level comparison, First Solar's price-to-earnings ratio is as high as 47.77 times, far higher than other companies. This may be due to optimistic expectations for its growth potential, but it also implies potential bubble risks. The P/E ratio of LONGi Green Energy is 9.44 times, that of

Trina Solar is 8.12 times, and that of JinkoSolar is 6.25 times. These ratios are relatively reasonable and in line with their industry status and growth. JA Solar's price-to-earnings ratio is only 2.55 times, which may be undervalued by the market. Although Canadian Solar's price-to-earnings ratio of 17.77 times is higher than the industry average, it is still within an acceptable range considering its performance growth.

In the analysis of stock price volatility, the stock prices of First Solar, JA Solar, and LONGi Green Energy fluctuated significantly, exceeding 50%, reflecting the market's divergence and uncertainty in the judgment of the prospects of these companies. The stock price fluctuations of Trina Solar, JinkoSolar, and Canadian Solar are relatively stable, with a fluctuation range of about 30%, indicating that the market's understanding and expectations of their businesses are relatively consistent.

Finally, from the perspective of the company's development stage, First Solar and Canadian Solar are relatively new companies, and the market's expectations for them are quite different, resulting in violent fluctuations in stock prices. As long-established companies in the industry, LONGi, Jinko, JA Solar, and Tianhe have relatively stable stock price performance, which is consistent with their mature operating conditions.

To sum up, the stock price performance of different solar companies reflects the market's different expectations for their development prospects. Among them, the high stock prices and high price-to-earnings ratios of First Solar and JA Solar highlight the market's optimistic view of their high growth; while the mid-range levels of Longi, Jinko, and Trina are more in line with their current development stages; Canadian Solar, as an emerging company, the market's assessment of the company's value will take time to verify. Analyzing these differences will provide an important reference for investment decisions.

4.3 Company Horizontal Comparison

In the competitive solar energy industry, companies like Longi Green Energy, JinkoSolar, JA Solar, Trina Solar, Canadian Solar, and First Solar each demonstrate unique market advantages and technological leadership. These companies excel not only in market dominance and brand strength but also in globalization and technological innovation.

Longi Green Energy is renowned for its high-efficiency monocrystalline products and is one of the

world's largest manufacturers in this segment. Its significant revenue growth (28.36%) solidifies its leadership position in the industry. Longi's global network ensures its high-quality products set the industry standard, while continuous technological innovation and commitment to sustainability maintain high investor appeal.

JA Solar is a major player in PV module production with a widespread sales and service network in 135 countries and regions globally. Notably, its advancements in efficient N-type cell and module technology, coupled with manufacturing facilities in key markets like the USA, showcase the company's strategic foresight and market expansion capabilities.

JinkoSolar is known for its high-performance PV products and extensive global sales network. Its relentless pursuit of quality and efficiency enhances the company's brand influence and market competitiveness. JinkoSolar's financial performance also demonstrates its market agility and competitive strength in the rapidly evolving industry.

Trina Solar has gained broad recognition in the global market for providing comprehensive PV solutions, including high-efficiency modules and system services. The company's R&D investments in N-type i-TOPCon cell technology have significantly improved production efficiency, while its global manufacturing layout further strengthens its position as an international brand.

Canadian Solar is recognized as a leading provider of solar PV solutions globally, particularly in North and Latin America. Its global business network and high-performance products reinforce its competitiveness in the global PV market, reflecting the company's global expansion strategy and market penetration capabilities.

First Solar occupies a unique position with its thin-film technology and comprehensive PV solutions, especially in the US and Middle East markets. As one of the world's largest thin-film module manufacturers, First Solar's investments in technological innovation and sustainable energy solutions reflect its high growth potential in the market.

The strategic innovation, global positioning, and financial achievements of these companies significantly influence the growth trajectory of the solar energy industry. Their collective efforts in driving solar technology development, improving product efficiency, and reducing costs play a crucial role. From a financial perspective, the revenue growth and profitability of these companies reflect the rapid rise in global demand for sustainable energy solutions.

Longi Green Energy, JinkoSolar, JA Solar, Trina Solar, Canadian Solar, and First Solar have established their leadership positions in the solar energy industry through their innovative capabilities and market adaptability. Longi's global expansion and revenue growth demonstrate its market penetration and industry leadership; JA Solar's technological advancements and global manufacturing base expansion showcase its role in driving industry standards; JinkoSolar's global sales network and high-performance products reinforce its market competitiveness; Trina Solar's R&D investments and efficient solutions ensure its technological leadership; Canadian Solar's global business network and market expansion strategy enhance its influence in emerging markets; and First Solar's focus on thin-film technology and large-scale project development brings unique advantages in specific markets.

The success of these companies is not only reflected in financial performance and market expansion but also in how they shape the industry through continuous technological innovation and acute insights into global market dynamics. As global demand for renewable energy and sustainable solutions continues to grow, these leading solar industry players will continue to lead the market, driving the transition to a greener future and paving the way for the adoption of more environmentally friendly energy solutions.



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