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Industrial Competitiveness of Photovoltaic Manufacturing Industry: China and the United States

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Abstract: The photovoltaic (PV) manufacturing industry in China and the United States plays and will continue to play crucial roles in the world's solar energy development. For example, China has become the world's largest PV supplier, and the U.S. is the second largest one. However, this industry in both countries is facing challenges: China faces the threat of overcapacity, while the U.S. grapples with dependence on imports. These challenges are vital for policy-makers to consider making new or modifying current policies to address. Recognizing the connections between threats and policies, this paper highlights these two factors based on SWOT analysis and evaluates the competitiveness of PV manufacturing in China and the U.S. based on International market share (IMS), Revealed Comparative Advantage (RCA), and Trade Competitiveness Index (TCI). The key finding of this paper is that despite its overcapacity threat, China still maintains its first position in this industry; while the U.S. has strong potential, its development just started. The outlook of this industry based on competitiveness and technology innovation of both countries will also be included in this paper.

Keywords: Photovoltaic manufacturing, China, industrial competitiveness

1. Introduction

Solar energy is known as one of the most promising clean energies, and as an integral part of solar energy, the PV manufacturing industry has received great attention from the main countries in the world, because the production of solar modules can directly influence the gross solar energy installed capacity of generation. As the demand for solar energy in the world keeps increasing to achieve the energy transition and 2050 net-zero goal, the scale of the photovoltaic PV manufacturing industry has enlarged rapidly worldwide at the same time.

This paper aims to present a competitive comparison of the current status and future outlook of the PV manufacturing industry in China and the U.S.. It is the contention of this paper that the PV manufacturing industry in China and the U.S. is facing threats and opportunities, and this industry in both countries is policy-guided. Because of the importance of policies in both countries to this industry, this paper also conducts a policy analysis to investigate incentive policies for the PV manufacturing industry in China and the U.S.. The evaluation of the industrial competitiveness and exploration of the future outlook for this industry in both countries will be included as well.

This paper will help readers understand the supply chain structure of the PV manufacturing industry, and, through its SWOT analysis and comparison, help readers understand the current status

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of the PV manufacturing industry in China and the U.S.. This industry in both countries is changing. In China, after a decade of rapid development, this industry is facing overcapacity, with the implications of a slowdown in the profit growth of related manufacturing firms and a low value of capacity utilization. In the U.S., because of its incomplete supply chain, this industry relies highly on imports; but when the Inflation Reduction Act (IRA) came into law in 2022, the U.S. was trying to improve its domestic supply structure to reduce the reliance on import of PV products. This paper, together with its policy analysis, can scientifically analyze opportunities for PV manufacturing industry development in both countries. The competitiveness evaluation and the future outlook regarding technology innovation and international trade relationships between China and the U.S. can provide reasonable industry predictions and help promote sustainable development of the PV manufacturing industry in both countries.

This paper will first present a SWOT analysis to describe the strengths, weaknesses, opportunities, and threats of the PV manufacturing industry in China and the U.S.. Then, the policy analysis will be introduced through the SWOT analysis because both the opportunity in China and the U.S. can be their incentive policies. To evaluate the competitiveness of the PV manufacturing industry in China and the U.S. under a conceptual framework, this paper uses three simple indexes: Internal Market Share (IMR), Revealed Comparative Advantage Index (RCA), and Trade Competitiveness Index (TCI) [1]. The value of these three indexes can reflect the international competitiveness of one industry. At last, this paper explores technological innovation to conduct a qualitative analysis aiming to explore the future trends of this industry in both countries, and the conclusion and discussion be introduced right after the outlook exploration.

Through the research, the findings of this paper are that despite its threat of overcapacity, China still has a strong competitiveness in this industry. Although the U.S. has strong potential, it just starts, the year 2023 is just the start stage of the IRA. Furthermore, his industry in both countries is policy-guided, but because of their different political frame, the effects of their policies differ. Both China and the U.S. have their unique advantages in developing PV manufacturing, and this industry in both countries will continue to play crucial roles in the global energy transition.

2. Industry Background and SWOT Analysis

2.1. General Information about the Photovoltaic Manufacturing Industry

The PV manufacturing industry undertakes the production of PV products, and most of today's solar cells are crystallize-silicon(C-Si) cells. This industry has a rounded supply chain for manufacturing C-Si PV products.

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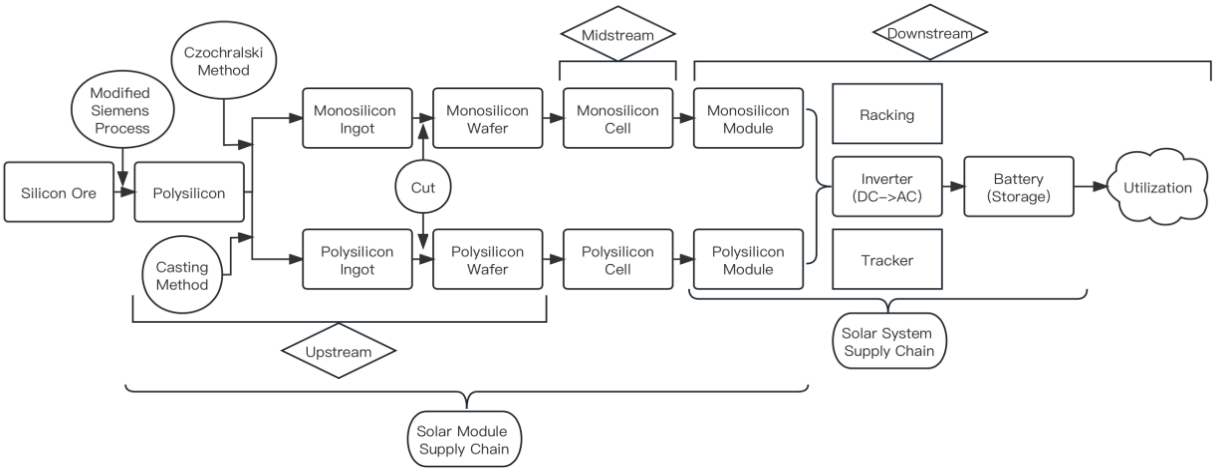

Figure 1: C-Si industry supply chain (Picture credit: Original)

As shown in figure 1, this paper divided the supply chain of PV manufacturing supply chain in into three parts, upstream, midstream, and downstream, based on the technology content. The upstream industry,including production of polysilicon and other silicon by-products, such as the ingot and wafer, has the highest technology content, needs a large amount of upfront investment, and has the longest return period; however, it has the highest profit rate. By contrast, the technology content of downstream industry is much lower, it includes module assembly and the production of accessory equipment. Most of the countries chose to develop the downstream industry first, such as China and the U.S., and then shift to upper-stream industry to develop a full-supply chain.

In addition to crystalline silicon(C-Si) cells, another majorly utilized type worldwide is amorphous silicon solar cells; with thin-film (TF) cells being a typical representative. However, the proportion of amorphous silicon solar cells is currently small. They are expected to become a focal point of technological innovation in the solar manufacturing industry in the foreseeable future. (this paper talks about this in the 5. Industry Outlook part)

In 2022, the solar energy in the world generated 1322.6 billion Kwh, which increased by 24.9%, the production of polysilicon is 1.1 million tons, which increased by 55.9%, and the production of wafers 381.1GW (96% of the production is monosilicon), increased by 60%.

2.2. Industry in China

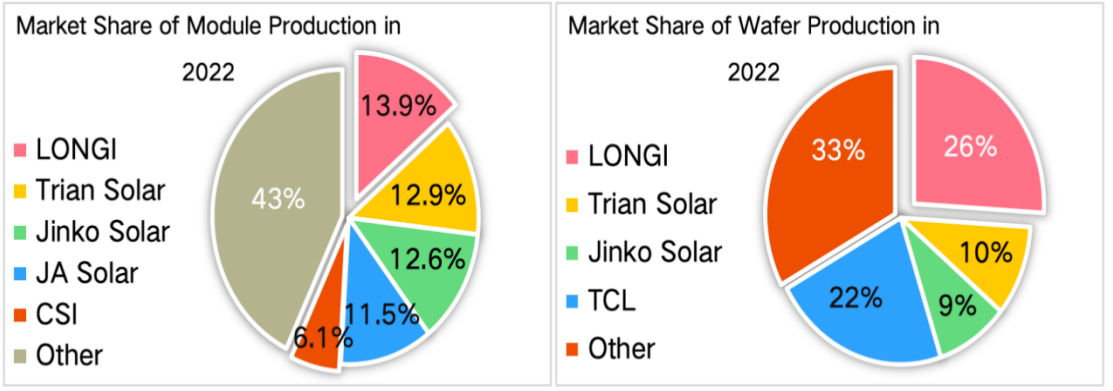

Figure 2: The 2022 market share of PV manufacturers in China (Data Source: Stock Market Data)

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As shown in figure 2, most of the PV manufacturing firms in China are private companies(LONGI, Trian Solar, Jinko Solar, and JA Solar), there are still some government-owned corporations(TCL), but they are not the majority. Big firms like LONGI and Trina Solar, production covers all products in the "Solar Module Supply Chain"(except polysilicon material). Their superiority is huge capital investment, which can support their R&D on the production of upstream products. LONGI, for example, its domestic market share of wafers and modules in 2022 is 26% and 13.9% , marked a leading position in China domestic PV manufacturing. However, most of China's PV manufacturing companies are undertaking production of midstream, especially downstream products. These companies are much more vulnerable to overcapacity than those giants, and many of them suffered bankruptcy in 2021 to 2023.

2.3. SWOT Analysis about China

2.3.1. Strength

China is the largest developing country in the world, endowed with abundant labor resources and rapidly developing infrastructure; this enables China to possess the resource and labor-oriented basic manufacturing industry, such as the rapid development of the PV manufacturing industry.

Table 1: Annual PV production in China

	Polysilicon (Million tons)	Global Share (%)	Wafer (GW)	Global Share (%)	Cell (GW)	Global Share (%)	Module (GW)	Global Share (%)
2023.1-10	1.076	N/A	440	N/A	392	N/A	359.7	N/A
2022	0.827	82.6	357	93	318	92	288.7	84.7
2021	0.505	78.7	227	97.4	198	88	182	85

As shown in table 1, through about a decade of rapid development, China has built the world's most complete C-Si PV supply chain which covers all the segments of PV manufacturing, from polysilicon to modules; and due to its excellent PV manufacturing industrial foundation, China has become the world largest PV supplier. In 2022, the global share of China's polysilicon, wafer, cell, and module is over 80%; marked a dominated position of China's PV manufacturing industry.

2.3.2. Weaknesse

Production of high purity polysilicon, as the top of the upstream supply chain, has always been the cause of China's bottleneck situation. Due to technological backwardness, the production of high-purity polycrystalline silicon in China is characterized by high energy consumption and high costs [2]. The comprehensive energy consumption for international production of polysilicon is 100-150kWh/kg, while in China it is 150-250kWh/kg, almost twice the internal level.

2.3.3. Opportunity

Because of China's government-dominated political framework and its unique national capitalist market system, incentive policies can be the most important opportunity that stimulate the development of the PV manufacturing industry. Early in the year of 2013, the State Council implemented the "Several Opinions on Promoting the Healthy Development of the Photovoltaic Industry"; with the content of fixing the scale and timeline of subsidy of electricity price, marking the initial rapid development of China's PV manufacturing industry. About ten years later, in 2022, the State Council initiated the "Opinions on Improving the System, Mechanism, and Policy Measures

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for Energy Green and Low Carbon Transformation", aiming to mitigate the current severe overcapacity situation and accelerate the energy transition by set regulations of market competitions and production scale. This policy provides a good opportunity for China's PV manufacturing industry to address or mitigate its overcapacity threat and achieve its sustainable development.

2.3.4. Threat

Capacity utilization, defined as the actual output divided by the potential output, demonstrates overcapacity when its ration falls below a specific threshold. There is no universal standard for this threshold. There is no universal standard for this threshold, but generally speaking, below 75% is severe overcapacity [3].

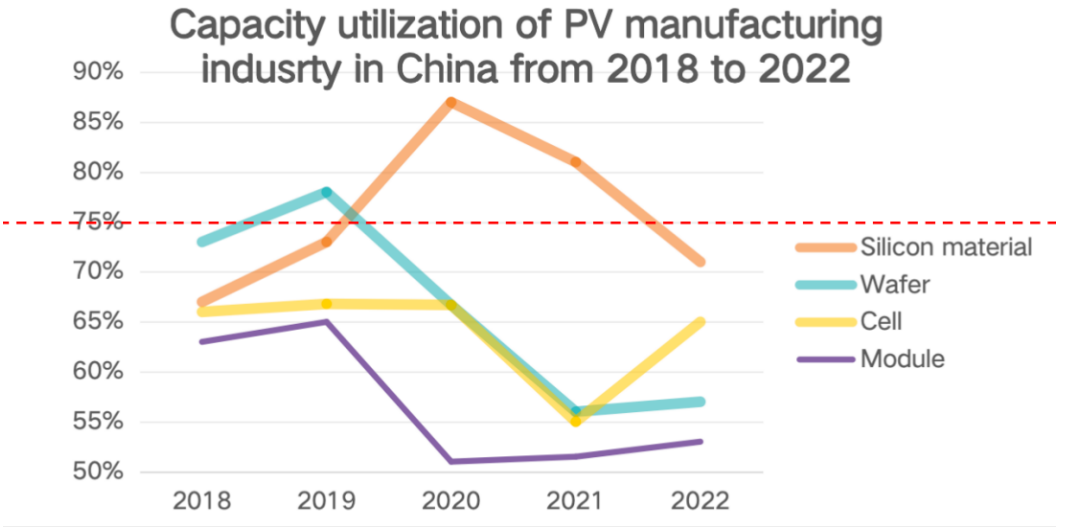

Figure 3: Capacity utilization of PV manufacturing industry in Cina from 2018 to 2022 (Data Source: China Photovoltaic Industry Association)

As the figure 3 shown, According to the China Photovoltaic Industry Association (CPIA), the capacity utilization of all parts in module supply chain in China, including the production of silicon material, wafer, cell, and module, is below 75% in 2022,. Midstream and downstream parts such as cell and module production, their capacity utilization are always under 70%; in 2022, they dropped to about mere 55%. which means the PV manufacturing industry in China is suffering a severe overcapacity.

The overcapacity can also be identified by a slowdown in the profit growth of related manufacturing firms.

Table 2: LONGI's third-quarter financial report

LONGI's Financial Report	gross revenue	year-on-year growth	gross profict	year-on-year growth
2023 third-quarter financial report	94.1 Billion yuan	8.55%	12.9 Billion yuan	3.55%
2022 third-quarter financial report	86.7 Billion yuan	54.24%	16.4 Billion yuan	60.32%
2021 third-quarter financial report	56.2 Billion yuan	66.13%	8.66 Billion yuan	16.29%

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LONGI is a famous PV production firm that can represent this industry in China. As the table 2 shown, from 2021 to 2022, the profit growth rate of the company increased from 16.29% to 60.32%. However, in 2023, it dropped to a mere 3.55%, which can also imply overcapacity in this industry.

2.4. Industry in the U.S.

The PV manufacturing industry in the United States is also dominated by private enterprises (Figure 3), such as the domestic company "First Solar."

However, these American companies are currently primarily focused on the research and manufacturing of solar cells and modules, while they still lack sufficient production capacity in silicon materials and wafers. Till 2022, the U.S. PV manufacturing companies won't produce any polysilicon, wafers, and ingots, and the U.S. still needs to import these materials to support their module production. According to the report of the SEIA, in 2022, the U.S. produced 5GW modules; the SEIA also expected that at the end of 2023, with the help of the IRA, the domestic module production can increase to 8.5GW, and the production of polysilicon can increase from 0 to 8GW [4].

Top 5 solar panel manufacturers

Company	USA location(s)	Current USA manufacturing capacity	Top-performing solar panel
First Solar	Ohio, Alabama	2.4 GW	Series 7 TR1
Qcells	Georgia	1.7 GW	Q. PEAK DUO BLK ML-G10+
Silfab Solar	Washington	800 MW	Elite SIL-380
Jinko Solar	Florida	400 MW	EAGLE 72HM G5b
Mission Solar	Texas	300 MW	MSE PERC 66

Figure 4: 2023 Top 5 Solar Panel Manufacturers in the U.S. [5]

As shown in figure 4, First Solar is the largest PV manufacturer in the U.S. in 2022, its production capacity is up to 2.4GW, much larger than the Qcells, the second-largest one. The capacity of the U.S.domestic manufacturers is still very low compared with Chinese company LONGI's 85GW production capcacity of monosilicon module, and some of them are forigen companies, Qcells, South Korean; Jinko Solar, China.

2.5. SWOT analysis about the U.S.

2.5.1. Strength

Strong Technology Innovation Capability

The photovoltaic manufacturing industry in the United States has always been technology-oriented. Unlike the situation where crystalline silicon (C-Si) cells dominate in China, the photovoltaic manufacturing industry in the United States adopts a diversified development strategy involving various types of cells. For instance, the largest solar supplier in the U.S., First Solar, primarily focuses on the research and development of Cd-Te thin-film (TF) cells. Cd-Te cells generate only about 60% of the environmental pollution produced during the production process of traditional crystalline silicon solar cells and have lower production energy consumption. Additionally, the United States is

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also pushing for the development of next-generation perovskite stacked modules. This upgraded version of modules has the potential to increase the power output of solar panels from the current 22% of crystalline silicon modules to 30%.

2.5.2. Weakness

Incomplete supply chain

The incomplete solar supply chain issue has always constrained the development of the U.S. PV manufacturing industry and solar energy utilization. Till 2022, the U.S. currently has NO domestic solar ingot, wafer, or cell manufacturing capacity and only a modest capacity to produce solar modules, inverters, and trackers [4]. The U.S. solar supply chain only covers downstream segments such as module production and supporting equipment (inverter and racking). The U.S. is a developed country, and the construction of its infrastructure has long been completed and halted; its basic manufacturing industry has also undergone transformation and relocation, allowing the country's economic structure to shift more towards the tertiary sector to enhance economic efficiency. However, for basic manufacturing industries like the PV manufacturing industry, which require a large labor force and raw materials, the U.S. currently lacks the manpower and industrial base to vigorously develop this industry. Therefore, like other basic industrial products, the United States primarily relies on importing finished PV products, such as cells and modules, to meet domestic solar installation demands. Although 2022 was the second-highest solar year on record, the number was still short of the 30% growth anticipation before the start of the year, based on market outlooks from research companies Wood Mackenzie and BloombergNEF. Failure to meet the anticipated growth was due to supply chain challenges, while the limited availability of solar panels continued to constrain the industry [6].

2.5.3. Opportunity

Incentive Policies

For the PV manufacturing industry in the United States after 2022, the Inflation Reduction Act (IRA) represents the largest development opportunity since the Recovery and Reinvestment Act of 2009. Thanks to the IRA, PV manufacturers in the U.S. can use the investment tax credit (ITC), which was originally set at 30% of eligible project costs. The IRA also provides 100% production tax credits (PTC) for solar manufacturing development. The impact of the IRA on the U.S. PV manufacturing industry will be profound. The goal of the IRA for the solar industry is to establish America's own PV supply chain in the future. By 2023, several silicon material production factories have already begun construction in the United States, and it is expected that the silicon material production capacity in the United States will reach 50GW in 2024.

2.5.4. Threat

High Reliance on Import

According to the report of the U.S. Customs and Border Protection, in 2022, the U.S. imported 27.9GW solar modules with total revenue of 9.57billion dollars, which means approximately 88% of solar panel shipments in the United States were imported, and mainly imported from Asia, including China. Vietnam accounted for the largest share of US PV module imports in the second quarter, with 31.2%, followed by Thailand with 22.5%, Cambodia with 13.7%, and Malaysia with 12.9%. This kind of reliance threatens the growth of installed capacity of solar energy in the U.S.. With the enforcement of the Uyghur Forced Labour Prevention Act (UFLP), the U.S. has already cut off import links with Xinjiang, China, and lead installation is at 11.8GW for 2022, 31%below 2021; it’s a sharp decline compared with 2021. The significant dependence on imported finished PV products will

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constrain the growth of domestic PV installation capacity in the United States for the foreseeable future [6].

2.6. Comparative analysis of current status of Sino-American photovoltaic manufacturing industry

Through the industry background and SWOT analysis, the different development statuses of the PV manufacturing industries in China and the U.S. can be observed. The threat faced by China is overcapacity, indicating that China's PV manufacturing industry has developed to a mature stage and even to an oversaturated extent. Therefore, for China, the opportunity in this industry lies in maintaining and improving the industry's status quo through policies, strictly regulating domestic PV manufacturing competition to alleviate industry overcapacity, and thus maintaining China's leadership position in the international market for this industry [7].

For the United States, the current status of its PV manufacturing industry is completely different from that of China. The industry in the U.S. is currently underdeveloped, but the SWOT analysis can identify enormous development potential: the technological prowess of the U.S. supports its PV manufacturing and new product research and development efforts. The significant support from the IRA is aiming to transform the U.S. PV manufacturing industry into a global powerhouse similar to China's.

The current industrial status in China and the U.S. is fundamentally different. Although the opportunities in front of their PV manufacturing industries are both driven by government incentive policies, however, the opportunities address different issues: China needs to regulate its scale of manufacturing, mitigate its overcapacity caused by rapid development; while the United States aims to develop domestic manufacturing and reduce import dependency vigorously.

3. Policies and Factors

3.1. Policies in China

In 2005, the People's Congress in China initiated the "Renewable Energy Law of the PRC" (REL)to promote the development and utilization of renewable energy. In 2013, an important document was initiated by the State Council of the PRC: "Several Opinions on Promoting the Healthy Development of the Photovoltaic Industry"(Opinions). This document has a lasting impact on the PV manufacturing industry in China because it fixed the scale and timeline of subsidy of electricity price, which clarified the photovoltaic on-grid electricity price policy and subsidy standards. It stipulated benchmark electricity prices of 0.9 yuan/kWh for Class I resources, 0.98 yuan/kWh for Class II resources, and 1 yuan/kWh for Class III resources.

In 2022, the State Council initiate the "Opinions on Improving the System, Mechanism, and Policy Measures for Energy Green and Low Carbon Transformation". According to the National Development and Reform Commission, this policy aims to establish a relatively complete standard, market, and regulatory system for clean energy. Regarding solar energy in China, this policy plans to mitigate the current severe overcapacity situation by enforcing a strict market regulation system to prevent vicious competition and appropriately control domestic PV production.

3.2. Policies in the U.S.

In 2009, the American Recovery and Reinvestment Act (Recovery Act) signed by President Obama, provided more than $90 billion in strategic clean energy investments and tax incentives to promote job creation and the deployment of low-carbon technologies [8]. The Recovery Act authorized a 30-percent tax credit for investments in more than 180 advanced energy manufacturing projects

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providing $2.3 billion for renewable energy generation. This act marks the revival of the United States' new energy industry from the 2008 global financial crisis.

In 2022, President Biden signed the Inflation Reduction Act into law. In the field of solar energy, entities and individuals adopting photovoltaic technologies are eligible for up to ten years of tax incentives. Those installing photovoltaic systems between 2022 and 2032 will receive a 30% tax credit. These acts have greatly stimulated the demand for U.S. domestic PV products, thereby promoting production. Out of a total investment of 369.7 billion USD, 30 billion USD will be allocated for production tax credits, providing subsidies across the entire photovoltaic supply chain. Subsidy standards are proposed for manufacturing processes, including photovoltaic modules, inverters, and energy storage batteries [9]. Due to factors such as tariff barriers, the United States is one of the countries with the highest photovoltaic installation costs globally, 1.6 times that of China. Subsidies from the IRA for the manufacturing sector can roughly reduce the cost of U.S. photovoltaic modules by a quarter.

3.3. Compare and Discussion

The policy analysis above implicates that the nature of these policies is the same: they are the government's fiscal plan, which means a form of macroeconomic regulation. However, the policy framework and economic structure in China and the U.S. are quite different, and the effects of their policies differ.

In China, the government and policy-dominant economic structure can stimulate the rapid development of the PV manufacturing industry in a short time, but not good for sustainable development; numerous studies indicate that government subsidies and investments can lead to overcapacity. This is because China's market is mainly government-controlled, and government incentive policies often lead many enterprises to disregard market mechanisms and engage in large-scale production solely to meet subsidy quotas, resulting in market distortions, cutthroat competition, and ultimately, severe overcapacity in the PV manufacturing industry today[10-12]. The Chinese government is recommended to appropriately reduce or even eliminate China's subsidies for the PV manufacturing industry [13]. That’s why the “Opinions on Improving the System, Mechanism, and Policy Measures for Energy Green and Low Carbon Transformation” in 2022 contains regulations rather than investment and subsidies.

The United States adheres to the principles of capitalism, with a domestic environment characterized by a free market, dominated by private enterprises in competition, and government regulation playing a supporting role. While explosive short-term growth might be challenging. This is why, despite the significant subsidy measures in the Recovery and Reinvestment Act of 2009, it has not been able to propel the development of the U.S. PV manufacturing industry as rapidly as China's during the same period. Nevertheless, the free market economic system in the U.S. with proper government regulation, can maintain sustained and healthy industry operations. The goal of the IRA is to achieve sustainable development in the U.S. new energy manufacturing industry within 10 to 20 years. Its objective is to elevate America's manufacturing capabilities to an international leadership level, without necessarily pursuing rapid development akin to that of China.

Due to the differences in the national conditions of China and the U.S., policies of a similar nature can promote rapid development of PV manufacturing industries in China but may also bring about problems. Conversely, in the United States, they can achieve sustainable development but may require a longer period.

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4. Evaluation of Industrial Competitiveness

4.1. Methodology Introduction

This paper employs an evaluation of the actual competitiveness of the PV manufacturing industry. The International market share (IMS), Revealed Comparative Advantage (RCA), and Trade Competitiveness Index (TCI) are selected as competitiveness analysis indicators to quantitatively compare and analyze the international competitiveness of the photovoltaic industries between China and the U.S. [1].

The IMS reflects the value of a country's specific industry exports compared to the total value of similar industry exports in the global market during the same period. The IMS can demonstrate the true international market proportion of a country's specific industry products and is a good reflection of its industrial competitiveness level.

The RCA can reflect the competitive advantage of the country's industry in international trade. When the calculated value of the RCA is greater than 1, it indicates a relative competitive advantage of the country's industry in international competition. Conversely, if the calculated RCA index value is less than 1, it indicates that the country's industry does not have a competitive advantage globally.

The TCI, is also known as a country's industrial trade competitiveness index. This index is commonly used to compare a country's competitiveness and strength in supplying products with other countries in the same industry during exchange activities. Its value ranges from -1 to 1.

4.2. Calculation

IMS formula:

$$IMS_{pn} = X_{pn} \div X_{pW} \tag{1}$$

Amoung them, p here refers to photovoltaic products, n represents a country, and W represents the world; X is the export volume

RCA formula:

$$RCA_{pn} = (X_{pn}/X_{tn}) \div (X_{pW}/X_{tW}) \tag{2}$$

Among them, p here refers to photovoltaic products, n represents a country, t refers to all products, and W represents the world; X is the export volume.

TCI formula:

$$TCI_{pnt} = (X_{pnt} - M_{pnt}) \div (X_{pnt} + M_{pnt}) \tag{3}$$

Among them, p here refers to photovoltaic products, n represents a country, t refers time(here equeals to 1year); X is the export volume; M is the import volume.

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Table 3: The import and export information regarding PV products

Unit: Billion USD	Gross Export Revenue	Gross Import Revenue	Export Revenue of PV	Import Revenue of PV
The World	12400	12300	95.8	N/A
China	3593.6	2716	51.2	3.59
The U.S.	3009.7	3957.8	2.5	9.57

Table 4: The value of IMS, RCA, and TCI

2022Competitiveness	IMS	RCA	TCI
China	53.4%	1.83	0.868
The U.S.	2.6%	0.11	-0.586

As shown in table 3 and table 4, according to the export and import data from UN-Comrade, the General Administration of Customs of the PRC, and the U.S. Customs and Border Protection, this paper calculated the IMS, RCA, and TCI for the PV manufacturing industries in both China and the U.S. for the year of 2022. The value of IMS of China's PV manufacturing is 53.4%, means China has a large market share in international market. The value of the U.S.' is 2.6%, indicating a lower international share. China's value of RCA is 1.83, exceeding 1, means China's PV maufactring industry has a strong competitiveness when compared with U.S.' RCA value of 0.11. The TCI value of China's is also much larger than the U.S.', compared with 0.868 versus -0.586.

4.3. Evaluation

By calculating and comparing the IMS, RCA, and TCI of the PV manufacturing industries in China and the U.S., it's obvious that China holds a significant advantage over the United States in these three indices measuring industry international competitiveness. This suggests that China's PV manufacturing industry still maintains strong competitiveness worldwide.

2022 and 2023 mark the initial stages of the IRA. The rapid development of the U.S. PV manufacturing industry has just begun, with issues such as incomplete supply chains and imports yet to be resolved. Consequently, it has not yet established a strong competitive position.

5. Industrial Outlook: Next Generation Solar Technologies

The next generation of solar cells and modules follows two technological pathways. The first involves improving the structure of traditional crystalline silicon(C-Si) cells to enhance efficiency while reducing maintenance costs and efficiency degradation. A representative example is LONGi's HBPC cell from China. The second pathway involves the use of new materials and the development of novel thin-film (TF) amorphous silicon solar cells. A representative example is First Solar's Series 6 Cd-Te TF solar cells from the U.S..

The HBPC cell means Hybrid Passivation Back Contact Cell. This type of cell first installs wires on the front of traditional crystalline silicon solar cells, moving them between the cell layers, and reducing sunlight reflection by 30%, thus enhancing cell efficiency.

Cd-Te cells, on the other hand, construct the entire cell using Cadmium Telluride instead of silicon material. These thin-film non-crystalline silicon cells have a theoretical maximum efficiency of 28%, but due to technical limitations, currently only achieve 19%-20%. Because of its material advantage, this kind of cell is much more durable and environmental friendly.

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Table 5: Performance of two new cells and one traditional cell

	HBPC Cell	Series 6 Cd-Te TF Module	Traditional PERC C-Si Cell
Efficiency	25.5%	19%	22%
Lifespan	20 years	30 years	20 years
Production Pollution	100%	50%-60%	100%

As shown in table 5, due the modification, the HBPC cell has the efficiency up to 25.5%, much higher than traditional PERC C-Si cell and Series Cd-Te TF cell. However, because of its advantage of material, the Series 6 Cd-Te TF cell has the lifespan of 30 years, much longer than 20-years lifespan of C-Si cells(HBPC and PERC); and its production pollution is only about half of C-Si cells'.

From a technical standpoint, the potential of crystalline silicon solar cells is dwindling. Despite being the current mainstream, crystalline silicon cells are constrained by materials and structures, limiting their development potential compared to the newer, more environmentally friendly, and durable non-crystalline silicon cells. Therefore, from the technological pathways of the PV manufacturing industries in both China and the U.S., it is evident that constrained by technology and industrial layout, China's PV manufacturing industry tends to focus on improving existing technologies. Meanwhile, leveraging its technological advantage, the United States can develop non-crystalline silicon cells that better represent future demands instead of relying solely on crystalline silicon cells.

In terms of technological prospects, the U.S. holds a greater advantage over China, considering that research and development are strengths of the U.S..

6. Conclusion

This paper employs a combination of quantitative and qualitative analyses, including SWOT analysis, policy analysis, and indicative calculations of industrial competitiveness. Through these research methods, this paper aims to assess the current status of the PV manufacturing industries in China and the United States, analyze their industrial competitiveness, and explore the industry outlook of both countries through their respective next-generation solar energy technologies.

Based on all the analysis above, this paper can draw a safe conclusion that despite facing severe overcapacity, China's PV manufacturing industry still surpasses the United States in competitiveness by a significant margin and continues to maintain its leading position in the world. The U.S. has strong potential, such as the great support from the IRA and its strong capability of technology innovation, and from the perspectives of technology and development status (China overcapacity versus U.S. nascent), the outlook of the industry in the United States is better than those in China. However it just started, the year 2023 is just the start stage of the IRA, that's why its competitiveness is still low. Furthermore, this industry in both countries is policy-guided, but because of their different political frame, the effects of their policies differ. China is suitable for rapid development in a short time but causing some problems. At the same time, the U.S. is suitable for long-term and sustainable development. Both China and the U.S. have their unique advantages to develop PV manufacturing, based on China's substantial production capacity and market share, along with the United States' innovation in next-generation solar technology, the PV manufacturing industry in both countries will continue to play crucial roles in the global energy transition.

While China possesses significant competitiveness in the industry, the issue of overcapacity is becoming increasingly severe. This is an issue that cannot be overlooked. For the Chinese government, it is crucial to adhere to market principles and effectively utilize macroeconomic regulation. The government should not disregard sustainable development in pursuit of rapid growth. For China, it is

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imperative to implement reasonable control over the PV market and manufacturing industry, even if it means reducing production. Only then can China maintain its competitive advantage in the PV manufacturing industry.

The U.S. has a good outlook in the PV manufacturing industry, but for the U.S., maintaining normal trade relations with China is crucial. It is legitimate not to fully depend on other countries' industries to protect domestic workers and maintain technological advantages. However, a complete disconnection from Chinese products in this industry could have serious implications for the United States' solar development.

Globalization is unstoppable, both China and the U.S., as a leading supplier of PV products, should take on responsibilities of global energy transition and the achievement of the 2050-net zero goal.

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