Status and trend analysis of solar energy utilization technology

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Abstract. Based on global distribution of solar energy and its feature, this paper discusses a review about solar energy’s utilization techniques, mainly discusses the latest development of photo-thermal and photoelectric utilization technology, which are mature and widely used. Through looking forward to the development trend of solar energy utilization from the aspects of improving efficiency, reducing cost, and diversifying utilization methods etc., we find that the utilization of solar energy resources has entered the fast track of development. In order to promote the connectivity of solar energy technologies and standards and to enhance the capacity of the solar energy industry, this paper put forward the advices on setting up an international platform for technological innovation and cooperation to make efficient use of global technological innovation resources.

1. Introduction
Carbon dioxide and other global warming emissions are the current challenges facing the humanity across the globe. These emissions can have serious harmful impacts on the environment, climate and health, which are currently being addressed by encouraging renewable energy resources contribution [1]. Such as, renewable energy is becoming a priority for Latin America and Caribbean (LAC) countries because of energy demand growth, high dependence on imported fossil fuels, and climate change [2]. Renewable energy resources are used could promoted green and low-carbon development, expanding the scale of cleaner production technology application, and the new energy technology revolution. Especially in the absence of primary energy supply such as oil, natural gas, and coal etc., the development and utilization of new energy has become an important options for compensating energy shortages, responding to climate change, and developing energy conservation and emission reduction. Its large-scale use can effectively reduce the dependence on fossil energy, and its development prospects are favored by various countries [3]. The United States, European Union, and Japan have made solar energy etc. as the focus of energy supply security after 2030, such as the Million Roof Plan in USA, Thousand Top Plan in Germany and Asahi Seven Years Plan in Japan etc [4]. China’s 13th-Five Year Development Plan for National Strategic Emerging Industry proposed to accelerate the development of advanced nuclear power, high-efficiency photoelectric and photo-thermal, and large-scale wind power. By 2020, nuclear power, wind power, solar energy and biomass...
energy will account for more than 8 percent of total energy consumption [5,6]. Judging from above all, the new energy industry will enter a rapid development trend in the future.

2. Characteristics and distribution of solar energy resources

Compared with conventional energy sources, solar energy resources have the advantages of abundant reserves, longevity, universality, clean and safe, but at the same time there is also a lack of resource dispersion, discontinuity and instability, low efficiency and high cost.

There is quite different for solar energy resources on the different regions. The regions with strong radiation levels include northern Africa, Sahara, Australia and so on. That with stronger radiation levels includes southern Africa, Central Europe, and southern South America etc. And that in north and south poles with poor radiation levels [7,8]. Details are shown in table 1.

| Radiation Level | Global distribution of solar energy resources |
|-----------------|-----------------------------------------------|
| Total Radiation Exposure (MJ/m².a) | Stronger | Strong | Moderate | Poor |
| ≥10000          | 8000~10000 | 5000~7000 | ≤2500 |
| Regions         | North Africa, Sahara, Australia, Southern Europe, Southwest United States, Southwest China, etc.. | Southern Africa, Central Europe, Southern South America, America etc. | Southeast Asia, Central America, Central Asia, Northern South America, East Asia etc. | North and South Bipolar Region |

3. Solar energy utilization and application

There are four utilization means of solar energy, include photo-thermal, photo-electric, photo-biological and photo-chemical conversion utilization. In which, photo-thermal conversion utilization has owned the widest application, the lowest cost, and the best technology; photo-electric conversion utilization has been attracting more and more attention and used more and more widely; but photo-biological and photo-chemical conversion utilization are still in early stages and have few large-scale applications.

| Utilization Means | Average Efficiency | Life | Original Investment | Maturity | Envir. friendly | Scope |
|-------------------|--------------------|------|---------------------|----------|-----------------|-------|
|                   | %                  | a    | -                   | -        | -               | -     |
| Solar lighting    | 10~30              | 20~30 high | high               | high     | high            | lighting |
| Solar water heaters | 40~65             | 5~15 medium | high               | high     | medium          | Hot water |
| Solar heating     | 22~35              | 15~20 medium | medium high        | Heating, hot water |
| Solar refrigeration | 35~40          | 10~15 high | medium            | medium   | medium          | Air-conditioning refrigeration |
| Solar heat pump   | 40~75              | 10~15 medium | low               | medium   | medium          | Heating, hot water, Air-conditioning |
| Solar air collector | 50~80            | 20~30 low  | high               | high     | high            | Heating, drying, ventilating |
| Solar PV generation | 10~20            | 10~15 high | high               | low      | Household electricity, communications, transportation, etc. |

By comparing the status of four different solar energy utilizations, we found that the efficiency range of solar energy utilization is 30-80%; the average efficiency of solar lighting and photovoltaic power generation did not exceed 30%, and initial investments were higher. Considering both technological maturity and investment, solar energy utilization is relatively cost-effective. However,
due to the large-scale development of photovoltaic cells, that leads photovoltaic power generation into large-scale application, so it is also widely used in the market [9]. Details are shown in table 2.

Solar thermal and photoelectric technologies are widely used in the world. There are also typical examples of solar energy applications in world-renowned cities such as Tokyo, London, Paris, Beijing and so on [10-12]. The application examples are shown in table 3.

Table 3. The selected examples of solar technology applications.

| Regions         | Annual total radiation MJ/m²*a | Selected Examples                                      | Related technology                                      |
|-----------------|--------------------------------|--------------------------------------------------------|--------------------------------------------------------|
| Tokyo           | 4220                           | Ginza Monterey Hotel                                  | Construction Shading                                    |
| London          | 3640                           | Tower of London, “Dingdunling Energy Development” Ecological Village | Natural lighting, solar photovoltaic, solar ventilation chimneys |
| Paris           | 4013                           | Signal Tower                                           | Solar and wind power                                    |
| Hamburg         | 3430                           | German Hamburg District Heating Project                | Solar hot water                                          |
| Moscow          | 3520                           | Crystal Island                                         | Solar photoelectric, solar ventilation cooling          |
| Tibet, China    | 6700                           | Yanbajing grid PV power station                        | Solar PV                                                |
| Beijing         | 4500                           | Yanqing Solar Thermal Power                            | Solar photothermal power generation                     |
| Yanqing         |                                 | Experimental Station                                   |                                                        |

4. Solar energy utilization technology

4.1. Solar energy photo-thermal technology

According to the working temperature of solar energy utilization system, it can be divided into three types: low-temperature heat utilization (＜100°C), mid-temperature heat utilization (100-250°C) and high-temperature heat utilization (>250°C); According to the application field, it can be divided into solar hot water, solar stove, solar house, solar greenhouse, solar refrigeration, solar heating, solar desalination, solar drying and so on. Heating, hot water and thermal power generation are the more common ways of solar energy thermal utilization in EU [13,14]. At present, the solar water heater is the common way in China.

4.2. Solar energy photovoltaic power technology

The photovoltaic power system is composed of photovoltaic cell assemblies, controllers, power storages and inverters [15,16]. Solar radiation energy is directly converted into electricity through photovoltaic cell, and through cables, controllers, and energy storage, is stored to provide load.
According to the relationship with the power system, there are stand-alone photovoltaic system and a grid-connected photovoltaic system, see figure 1 for the grid-connected system.

For the photovoltaic power generation system, the core technology is solar cell technology. The efficiency of photovoltaic cell components determines that of photovoltaic power generation system. According to the types of materials, solar cells mainly include monocrystalline Silicon, polysilicon, amorphous silicon solar cells and so on. In which the conversion efficiency of monocrystalline Silicon solar cells is 26.7 ± 0.5 % due to different materials can absorb different spectral energy of the solar light source [16-20]. The photo-electric conversion efficiency of several solar cells is shown in table 4.

| Types                      | Material   | Conversion efficiency (%) |
|----------------------------|------------|---------------------------|
| Crystal silicon solar cells| Monocrystalline Silicon | 26.7±0.5               |
|                            | polysilicon| 22.3±0.4                 |
| Amorphous Silicon solar cells | a-Si    | 10.2±0.3                |
| Compound solar cells       | GaAs       | 28.8±0.9                |
|                            | CIGS       | 21.7±0.5                |
| Organic solar cells        | /          | 9.7±0.3                 |

4.3. Photo-thermal power generation technology

Solar photo-thermal power generation refers to use large-scale array parabolic or disk-shaped mirror to collect solar thermal energy, to provide steam to turbine generators for power generation [13,14]. The photo-thermal power generation system consists of four parts: heat collecting system, heat transmission system, heat storage and heat exchange system, and power generation system (see figure 2). Using solar photo-thermal power generation technology could avoid the expensive Silicon crystal photoelectric conversion process, which can greatly reduce the cost of solar power generation.

5. Status of solar energy utilization technologies

5.1. Development of solar energy thermal utilization technology in domestic and foreign

China has been the largest producer and user of solar energy, producing heat collectors up to 76 percent of the world's, but the per capita was relatively lower, and it ranks seventh in the world in the field of solar energy utilization. According to the existing plan, by 2020, China's heat collector capacity is 270 million m², and the population at 1.5 billion, the area per capita can reach 0.18 m². But there have reached 0.608 m² per capita in the developed countries.
The developed countries that focus sustainable development and use of renewable energy sources, pay great importance to the research and application of solar energy thermal technology, especially countries with advanced solar technology, such as Israel and Austria. The commonly used technologies and products have the following characteristics [8,13].

- More than 95% of the collectors are flat, and a small number of metal flow-vacuum tube collectors, the all-glass vacuum tube collectors have basically eliminated;
- The installation of collectors is mostly inlaid, building materials, and some or all of them replace traditional building materials;
- The Flat Panel Production Line has basically achieved mechanization and semi-automation;
- There are more large and ultra-large scale systems;
- Collectors are mostly associated with heating and cooling units. In addition to supplying hot water for domestic use, and also partially solve the demand for heating and cooling, have high comprehensive benefits.

The level of solar energy thermal utilization technology is uneven in China, and there are few high technology enterprises in this field. Now there are more than 4,000 companies are engaging in the research, development and production of solar water heaters in China. The annual production and installation of solar water heaters exceeds 1 million m², and the output value is more than 10 billion yuan, ranking first in the world. However, there are only a handful of companies that truly master core technology, only supply for low-end household products such as all-glass vacuum tube water heaters [21-24].

5.2. Development of photovoltaic power generation technology in domestic and foreign

5.2.1. Development of photovoltaic power generation technology in China. During the 12th Five-Year Plan period, the installed capacity of photovoltaic power generation in China has increased 168 times. Since 2013, and reached growth of 10 million kilowatts annually. In 2017, there are new installed capacity 53.06 GW, has an increase of 18.52 GW year-on-years, growth rate up to 53.62%. In addition, the new installed capacity in 2017 is 1.5 times that of 2016, 3.5 times that of 2015 and 5 times that of 2014 [25]. It is the fastest growing renewable energy source in China. Details are shown in figure 3.

![Figure 3. Installed capacity of PV power generation from 2013-2017 in China.](image-url)

5.2.2. Development of photovoltaic power generation technology in foreign. In 2017, the global new installed capacity was about 102 GW, an increase of 37% year-on-year. By the end of 2017, the global cumulative installed capacity had reached 405 GW. In 2017, there were at least 8 countries in the world owned new photovoltaic installed capacity more than 1 GW, of which China ranked first.
with 53 GW, followed by 10.6 GW in the United States and 9.1 GW in India, and the top 10 countries added 88.35 GW in total, accounts for 90% of the total new installed equipment. In 2017, China and India’s market locate in the Asian market maintained rapid growth in new installed capacity, and became an important force to support global photovoltaic development. The United States and Germany, the represent of Europe and the Americas, their new installed capacity experienced a slowdown or even negative growth. In addition, such as Brazil and Australia etc. emerging markets are beginning to develop, and has significant growth [9]. Global total installed capacity is shown in figure 4.

![Figure 4. Global installed capacity of PV power generation from 2011-2017.](image)

5.2.3. Development of solar cell technology in domestic and foreign. In 2017, there were 8 enterprises with more than 10,000 tons of polysilicon production capacity in China. The output was 242,000 tons, an increase of 24.7% year-on-year, accounting for 454.8% of the world's, remained at a relatively high producing level. The output of Silicon chips, battery chips, and components all had about 40% growth rate, accounting for more than 70% of the total global production [17,18]. Details are shown in table 5.

| Table 5. Production and growth of PV products in China in 2017 (From CPIA). |
|-------------------------------------|-------------|-------------|-------------|
| Polycrystalline Silicon            | Silicon wafer | Cell Chip   | Component   |
| Output                             | 24.2×104tons | 91.7 GW     | 72 GW       | 75 GW       |
| Growth rate                        | 24.7%        | 41.5%       | 41.2%       | 39.7%       |

With the rapid growth of the PV market, the global production scale and output of all types of photovoltaic products kept increasing in 2017, and the growth rate was faster than market demand. For polysilicon, the effective production capacity reached 516,000 tons, an increase of 5.3% year-on-year; The output reached 442,000 tons, a year-on-year increase of 10.5%; in which, China ranked first with a output of 242,000 tons, accounting for 53.7%; South Korea plus Malaysia's factory output ranked second with 87,600 tons, Germany ranked third with 56,000 tons, and the United States and Japan produced 41,600 tons and 10,000 tons, respectively, ranking fourth and fifth. For Silicon wafers, the global effective production capacity was approximately 122.3 GW, an increase of 22.3% year-on-year, and the output reached 105.2 GW, an increase of 40.6% year-on-year. In which, Poly Yixin's silicon wafers production has reached 23.9 GW, ranking first in the world, significantly ahead of other companies. For components, the global production capacity reached 148 GW or more, and the output was 105.5 GW, an increase of 35.4% year-on-year. China is still the largest producer of solar cell
components, producing approximately 75 GW [19-21].

5.3. Status of photo-thermal power generation technology in domestic and foreign

Solar thermal power has been into a large scale using in foreign. Spain cumulative installed capacity accounts for 62.3% of the global total. It showed Spain is the key solar thermal power market in the world. At present, in some developed and underdeveloped countries such as the United States, Australia, Morocco, the Sudan, Spain, India, Iran and Thailand, the installed capacity under construction is huge, about 16 GW. Among the power stations under construction in developed countries, tower-type solar-thermal power stations account for 4.37%, slot-type solar-thermal power stations account for 94.57%, the ratio between slot-type and tower-type is close to 22. In contrast, the linear Fresnel-type and disc-type power station were less than 1%. That is the slot-type solar-thermal power station accounted for the vast majority [14].

The solar thermal power generation is still in the start-up phase in China. Compared with foreign, there are 50 years gap in materials, design, technology, and theory. It was not until the 1970s that some basic research began to do and the lack of design and integrated technology capacity of solar thermal power generation. The key technologies such as high-temperature polymerization, heat absorption and heat storage are now in integration demonstration, and the commercial operation needs to be accelerated. In 2012, the first solar thermal power plant, Yanqing solar thermal power plant, was successfully tested in China [11]. On March 1, 2016, China Aviation Industry Xi'an Aviation Engine CO., Ltd. invested China's first megawatt Stirling Solar Power Generation Demonstration Test Base using disc-type technology in the Potou Industrial Park in the New District of Tongchuan City. Now there are 50 units of disc solar power generation equipment installed. This project can be used as a basis for establishing standard of the dish solar thermal power industry [27]. And this project could promote the industrialization of the dish solar thermal power generation.

6. Trends on solar energy utilization technologies

6.1. Trends on solar photo-thermal technology

Solar energy photothermal utilization technology is widely used in domestic and foreign, and is relatively mature, but in combination with the development of the technology itself and related industries, there are the following trends on the application in the future:

- Optimizing collector design, improving utilization efficiency and reducing costs
  The collector is the core component of the solar energy heat utilization system, and is the key to affect the performance and cost of the system. Through the research and optimization of the key components of the focused solar energy efficient composite conversion system, to develop flat plate heat collector with high performance and the feature could be used as building materials directly, that is the inevitable trend of the future development of solar energy utilization technology.

- Coupling solar heat collect and storage, improves system stability
  Through coupling the collection and storage of heat, and taking complex applications measures with other energy systems, such as ground source heat pumps and so on, to solve the instability of the solar thermal utilization system, expanding its application scope will become the future development direction.

- Promoting the integration of solar energy and construction
  In recent years, the thermal use of solar energy in the construction field has developed rapidly [26]. On the one hand, is to install the heat collector on the wall of the building facade to form an integrated system to provide hot water for living; On the other hand, is to develop the solar heat collecting pipes into building materials, all or part to replace traditional building materials to achieve solar energy utilization. These two means not only do not affect the overall beauty of the building, but also solve the problem of the low use in high buildings due to the occupation of land. It will be one of the future development directions.
6.2. Trends on solar Photo-electric technology
With regard to the current application and research of solar photo-electric technology, there will be the following developments in solar cells and power generation methods:

- Breakthrough solar cell key technologies to improve cell efficiency and reduce costs

For the inefficient conversion of solar cells, Germany has increased solar cells conversion rate to over 23% by placing rare earth metal element erbium (Er) in monocrystalline Silicon. Therefore, breaking through the technical bottleneck of advanced crystalline silicon cells and key equipment, improving the efficiency of thin-film solar cells, and strengthening the research and development of new high-efficiency and low-cost solar cell technologies such as perovskite, dye sensitization, and organic will become the future development trend.

- Promote diversified and comprehensive development of photoelectric utilization

Photovoltaic power generation has the advantages of large scale and convenient construction, but at the same time it also occupies a large amount of agricultural and forestry land, which is limited to the shortage of land resources. In the future, it will develop a power generation system of agricultural light, forest light, and fishing light complementary [28], which will not affect agricultural, forestry and fisheries production, and could full use solar energy to produce electricity. At the same time, through overall planning of the power market and external transmission channels, to promote the development of photovoltaic power generation in deserts and desert areas and the comprehensive development and utilization of solar energy in various forms, to accelerate distributed photovoltaics development will become the trend in the future.

7. Conclusions
With the increasing severity of the global climate change situation, the use of renewable energy has become the focus of all countries in the world. In which, solar photovoltaic and photothermal utilization have received more and more attention. The use of solar energy can not only replace conventional fossil energy sources, but also play an important role in optimizing the energy structure. The European Joint Research Center's forecast of changes in the global energy composition: After 2030, solar photovoltaic and photothermal power generation will develop rapidly, and by 2050 it will account for about 30% of the world's energy consumption, gradually replace traditional energy. At present, the utilization of solar energy resources has entered the fast track of development; especially the technology of photoelectric utilization has matured, and presents a new development trend. Therefore, the global community should set up an international platform for technological innovation and cooperation in a more open and inclusive manner, make efficient use of global technological innovation resources, vigorously promote the connectivity of solar energy technologies and standards, and enhance the capacity of the solar energy industry in an all-round way. That will promote green and low-carbon development and make important contributions to addressing global climate change.

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