General Situations of Development of Photovoltaic Agriculture

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Abstract This paper firstly introduced policy of photovoltaic agriculture in China. It discussed significance of developing photovoltaic agriculture. Then, it introduced progress in application of photovoltaic agriculture at both home and abroad. Finally, it pointed out existing problems in photovoltaic agriculture and came up with recommendations for development of photovoltaic agriculture in China.

Key words Photovoltaic agriculture, Policy, Significance, Application, Recommendations

Solar energy is radiant light and heat from the sun harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture and artificial photosynthesis. At present, it is the safest, most reliable and cleanest natural energy in the world. Photovoltaic agriculture is a new industry rapidly developed recently. It converts solar energy photovoltaics into electricity and applies to agricultural production activities, such as planting, breeding, irrigation, and plant diseases and pest control, as well as agricultural mechanical power[1]. Photovoltaic agriculture brings new development mode for low carbon energy saving agriculture, and brings agricultural transformation of farms becoming factories and fields becoming workshops, plays a great significance in wide application of modern agriculture, and has high ecological and economic benefits.

1 Policy of developing photovoltaic agriculture

In view of huge prospect of photovoltaic industry, Chinese government provides energetic support in policies, such as formal implementation of *Renewable Energy Law of the People's Republic of China* on January 1, 2006 and *Trial Measures for Pricing and Cost Sharing Management for Renewable Energy Power* issued by National Development and Reform Commission. In policy and finance, it provides energetic support for development of renewable energy. As essential part of renewable energy, the photovoltaic industry enters the new stage of development. In February, 2012, Ministry of Industry and Information Technology formulated 12*th Five-Year Plan for the Solar Photovoltaic Industry* and clearly determined that solar energy photovoltaic power station can obtain financial support of the state[2].

As new high technology, photovoltaic technology has already had internationally competitive photovoltaic products in China. However, photovoltaic facilities are high in construction cost, and domestic enterprises have limited ability in accepting them. As a result, photovoltaic products rely excessively on foreign market. In July 2013, in order to accelerate application of China's photovoltaic technology in domestic market and realize sustainable development of domestic photovoltaic industry, the State Council promulgated *Opinions on Promoting the Healthy Development of Photovoltaic Industry*, setting forth the objective of total installed capacity up to 35 GW. This will play a great role in promoting development of photovoltaic industry in China.

Photovoltaic agriculture is organic combination of modern agricultural technology and photovoltaic technology. On the basis of creating ecological and economic benefits, photovoltaic agriculture realizes sustainable development of agricultural production, which is consistent with China's agricultural industry development policies. In July 2013, the State Council issued notice to improve financial support of central finance for development of photovoltaic industry, and strengthen support for solar energy resource survey, key technology and equipment material research and development and industrialization, application of photovoltaic power generation in rural areas and pastoral areas, and construction of photovoltaic power generation projects in areas having no electricity. On June 5, 2014, Feng Yulin, director of Department of International Cooperation of Ministry of Agriculture stated that combination of photovoltaic technology and agriculture should explore an agricultural development mode suitable for different areas, regions and forms; it is recommended to make farmers understand and grasp social benefits of photovoltaic power generation and increase of agricultural value; only through win-win of agriculture and photovoltaic industry, domestic photovoltaic agriculture may be promising. These show Chinese government spares no effort in supporting photovoltaic agriculture.

2 Significance of developing photovoltaic agriculture

2.1 Photovoltaic agriculture can accelerate solving three rural issues and promoting rapid development of China's agriculture At present, there are 5 modes of photovoltaic agriculture in China. They are closely connected with three rural issues and each mode has its unique advantages. (i) Photovoltaic agriculture greenhouse: supports greenhouse irrigation system, supplements light for plants, and satisfies heating demands of greenhouse crops in winter. (ii) Solar-powered water pump: compared with traditional gasoline and diesel water pump, solar-powered wa-

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ter pump is free from electricity storage, saves operating costs, and realizes zero emission of CO_2. (iii) Solar insecticidal lamp: without the need of setting up conventional power supply facilities, it replaces traditional fossil fuels, features energy saving and environment-friendly, and is a type of solar agricultural mechanical products with high popularization and application strength. (iv) Photovoltaic breeding farm: since factory-aquaculture model has replaced traditional pond, river and net cage culture, solar photovoltaic breeding farms can provide green energy, promote transformation of breeding model, and upgrade traditional breeding industry. (v) Photovoltaic sewage cleaning system: currently, environmental pollution in rural areas becomes serious and serious, sewage is a big issue, photovoltaic sewage cleaning system is powered by solar energy, so the operating cost is basically zero and it is free of secondary pollution. Therefore, popularization of photovoltaic agriculture is closely connected with three rural issues of China.

2.2 Photovoltaic agriculture can promote development of facility agriculture and improve environmental control and equipment level Making thin film solar cell into transparent material and installing onto roof of greenhouse can supply power without influencing growth demand of plants and animals for light. It is highly practical, efficient, and save land, so it is a photovoltaic agricultural mode most suitable for China and should be developed firstly. In the past 30 years, rapid development of facility agriculture in China largely depended on expansion of facility scale. It occupied large area of farmland resource. The problem of low production benefit is very prominent. In extreme weather condition (such as low temperature, snow, successive cloudy days, and frequent occurrence of haze), the adverse environment resistance ability is weak. Solar cell can be installed on greenhouse roof, supplement light for greenhouse plants, meet heating demands for plants in winter, resist weather disaster, and keep rapid growth of agricultural crops, so as to raise environmental control and equipment level of greenhouse, and promote transformation of facility agriculture.

2.3 Photovoltaic facilities can realize multiple use of one greenhouse Photovoltaic cells can supply power to support agriculture, can prevent wind, rain, snow and hail, and have expansion function in collecting rainwater and production fresh water, and can be applied in breeding and daily life of farmers. Photovoltaic cells can be used in forestry production, water conservancy construction, and irrigation system, and can turn barren land with high evaporation volume into protected farmland. Economic benefits of photovoltaic agriculture are extraordinary.

2.4 Photovoltaic power generation technology has high economic benefit Solar radiation has high heat energy. According to present thermal conversion efficiency, one cell board can generate 0.7 degree of electricity on average. One year, it can generate 42100 degrees of electricity in theory. Taking an 8000 hm^2 vegetable planting area as an example, if this vegetable plot is built into a greenhouse and installing solar polycrystalline silicon cells on all greenhouse roofs, the daily power generation capacity will be at least 10 million degrees. This electric energy can provide power for agriculture, supply electricity for industry, commerce and living of residents, thus it can save water, electricity and coal. According to statistics, the annual rate of return for photovoltaic agriculture greenhouse investment exceeds 10%, and the payback period is 6 to 10 years. Photovoltaic facilities can be built in any open area and can satisfy demand of agricultural production in agricultural area, which can save a lot of power transmission cost. Photovoltaic facilities bring electricity to farmers in remote areas, and transmit extra electricity to state grid, realizing income of agricultural products and income of photovoltaic power generation, and greatly improve living conditions of farmers. Solar energy is the most clean, safe and reliable energy. Use of solar energy is free from limitation of geographical position. China is a large agricultural country. Agriculture is the economic lifeline of China. China has attached great importance to development of photovoltaic agriculture. In future, China will have a new time of rapid development of photovoltaic agriculture.

3 Progress in application and researches of photovoltaic agriculture at home and abroad In foreign countries, especially in American-European countries, photovoltaic application develops rapidly. In World Expo Shanghai 2010, photovoltaic power generation technology was applied in China Pavilion, Germany Pavilion, France Pavilion, and Pavilion of Future. Israel is a country with powerful agriculture. It is rich in solar energy resources. Besides, non-farming land suitable for installing solar energy system is broad. Israeli government attaches great importance to construction of photovoltaic solar energy. It has issued a lot of construction licenses. It is a country with rapidest development of photovoltaic agriculture. It has established a complete set of photovoltaic agricultural system and made outstanding achievements in application and popularization of photovoltaic technology, which are worth learning by China[3]. With the aid of powerful technological and financial support, Japan brings into play application of photovoltaic technology in agriculture thoroughly, which shows good example for development direction of photovoltaic agriculture. Fukushima earthquake nuclear power plant accident in 2011 destroyed all local communities. Local residents got extremely frightened. Thus, Japanese scientists accelerated research, development and application of solar energy replacing nuclear energy. In Fukushima, they built Fukushima Recovery Solar-Agri Park, which contains more than 2000 solar panels to supply power for greenhouse vegetable. It provides 64 tons vegetable to a large local chain supermarket. Through accurate temperature and humidity control by computer system, crops grow faster than in normal conditions. Compared with traditional greenhouse, both yield and efficiency can increase one time. Besides, power generated from Solar-Agri Park satisfies electricity demand of local 170 families, and extra power is sold to Tokyo Electric Power Company. This sets a model for agricultural and industrial reconstruction of disaster areas. According to reports, local government is actively pro-

moting solar energy agriculture to participate in local industrial and commercial construction, such as offshore wind power plant and the largest solar industrial park in Japan, to help Fukushima realize renewable energy self-sufficiency objective in 2040[4].

China is vast in territory. Photovoltaic agriculture starts late. However, with support of government, China rapidly popularized photovoltaic agriculture and has made significant achievements. In 2009, Ledu County of Qinghai Province established the first project of combining solar power generation and facility agriculture in Qinghai, which is the model of combination of solar photovoltaic technology with plateau agriculture. More than 50000 farmers in Ledu County are engaged in greenhouse vegetable production. With economic benefits brought by photovoltaic agriculture, most local farmers have shaken off poverty. In 2010, Ningxia Zhongwei Shalubao Agricultural Technology Company and China Enfi Engineering Corporation jointly built photovoltaic ecological greenhouse in Zhongwei City desert facility agriculture sci-tech demonstration base, which is the first photovoltaic greenhouse in western areas. This system belongs to solar energy power generation system combined with roof technology. It consists of 20 crystalline silicon solar cells and 3 sets of inverter. The installed capacity is 3.45 kW, and power generation output is 370 kWh. It can provide reliable standing power for desert greenhouse, to ensure normal operation of agricultural facilities in greenhouse. In winter, it can provide heat for greenhouse to accelerate growth of counter-season vegetables. In addition, it also functions of collection, storage and application of rainwater and snow water, so it can be reputed as a new modern high sci-tech agricultural and ecological project integrating energy saving, environmental protection, local carbon, and sightseeing. This photovoltaic ecological system promotes development of flowers and plants, and fruit industries, so it has broad market development space.

At present, photovoltaic agriculture is mainly applied in greenhouse agricultural production. Since film cells installed on greenhouse roof are not highly transparent, it will influence lighting in greenhouse. However, there are few researches about increasing transparency. In October, 2009, Taiwan Lite-On Green Technologies built the first domestic film solar energy greenhouse power generation in Shangrao of Jiangxi Province, and the power generation has generated electricity by way of merging two or more grid systems[5]. This company also has signed contract with Yingtan City government to jointly build film solar greenhouse power generation plant. In 2010, in farmland of Pukou of Nanjing, two side transparent conductive electrode and semi-transparent noncrystalline silicon panel were used. Thus, some light still can pass through. Greenhouse roof turns into solar energy power plant. Within the greenhouse, it is able to plant various green vegetables. Hebei Province has established Dashan Photovoltaic Power Generation Project Company and moved solar cells into facility greenhouse. This project has total installed capacity of 120 MW and total investment amount about 3 billion yuan. It consists of hydrogen fuel cell and photovoltaic components with independent intellectual property right. With photovoltaic cells installed on greenhouse roof, it is able to provide heat for greenhouse, further improve vegetable quality, extend production period, and realize counter-season production. Besides, it can solve problems of supplementing light, killing pests, and irrigation. In January 2013, the first domestic film solar greenhouse power generation system in China with complete independent intellectual property right was successfully developed by Baoding Tianwei Group Company. It used transparent film solar photovoltaic glass to replace traditional film greenhouse. This method provides energy for photosynthesis of green plants, converts light energy to electric energy, realizes low cost light energy power generation, and has successfully been applied in Shandong Shouguang 17 kW film solar greenhouse. This project has annual power generation of 26000 kWh. All is transmitted to local grid of Shouguang with cost lower than 40% for polycrystalline silicon solar cells. R&D personnel of this company considered light intensity necessary for different vegetable types and growth stages, and designed 60%, 40%, 20% and 10% transparency schemes, including electrical design, photovoltaic system design, and inverter configuration schemes[6]. According to incomplete statistics, there are already near 30 demonstration sites of film solar cell agricultural greenhouse power plants.

Application of photovoltaic technology and Internet of Things into farms will be the frontier level of modern agriculture. In 2012, Quanzhou Bright Solar Energy Company explored unique application of solar energy in agriculture. This company planed to build a demonstration farm, integrate solar energy and Internet of Things into farms, to make farmers witness miracle of high technology agricultural production. Greenhouse built with solar glass cell panel not only can generate power, but also can provide cool air in summer and warm air in winter. Sensor buried in soil can automatically sense soil temperature, humidity and fertility. Driven by solar power, it can automatically water and apply fertilizer for plants within greenhouse. These are production scenes in future solar farms and also key points to be tackled by Quanzhou Bright Solar Energy Company.

4 Problems in developing photovoltaic agriculture and recommendations

With considerable economic, ecological and social benefits, photovoltaic agriculture has broad application prospect. However, its development time is not long and technology is still not mature, so it is difficult to popularize. Application of photovoltaic agriculture needs integration of many disciplines, involving agricultural planting, machinery manufacturing, and solar energy technology, and sensing technology. Nevertheless, the present situation is every discipline doing things in its own way and the repetitive research is serious, which will influence development and application of photovoltaic technology in agriculture. As a new industry combining new energy and agriculture, photovoltaic agriculture needs powerful national support, including policy and financial support. In addition, the scope to which photovoltaic agriculture belongs is not

clear and there is no pertinent subsidy standard. Commonly used electricity is alternating current, while photovoltaic power generation is direct current. Most agricultural machines use alternating current. Thus, it is necessary to transform current agricultural machinery. This is a difficult problem. Besides, the construction cost is high and payback period is long, so it is not suitable for small scale operation. Due to transparency, the requirement for plants is high and it is still to be further studied on application of light loving plants. At present, the construction of photovoltaic agriculture is still in the period of beautiful planning and small area pilot. There are many problems to be solved by government and scientific researchers.

Photovoltaic agriculture is a huge industry chain and it needs joint effort and cooperation of industry, schools and research institutions. In view of setback in foreign market, it is recommended to actively popularize application of photovoltaic products in agricultural fields, exploit domestic market, improve environmental quality using photovoltaic technology, and make the masses obtain benefit. As to photovoltaic agriculture, China should take it as an integral part of agricultural modernization, as a mark of realizing beautiful China and beautiful countryside, organize multi-disciplinary scientists to solve technical problems in connection of photovoltaic and traditional agricultural facilities and devices, improve solar cell performance, reduce costs, and study adaptation of crops to photovoltaic facilities. Besides, government should encourage photovoltaic enterprises to research and develop, and produce photovoltaic agricultural facilities and products, and increase financial subsidies standing at the height of saving energy and protecting environment. As a large agricultural country, combination of photovoltaic agriculture and ecological civilization construction has become a completely new model of modern agriculture. Photovoltaic agriculture is an engine for solving long term problem of modern agricultural development, inevitable choice for further developing rural economy and improving people's livelihood, and also the trend of transformation of agricultural production mode.

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divided into direct and indirect consumption. The direct energy for consumption mainly includes diesel fuel, electricity, coal and gasoline, while the main indirect energy for consumption is natural gas. (ii) During 2005 -2012, China's energy consumption in agricultural production increased year by year, from 60.711 million tce in 2005 to 67.844 million tce in 2012, an increase of 11.7%. (iii) In terms of energy consumption structure, the main energy consumed for China's agricultural production includes fertilizers and pesticides, diesel fuel, electricity, coal, and gasoline. (iv) The direct and indirect energy consumption per unit of agricultural output value decreased year by year during 2005 -2012, indicating that the efficiency of agricultural energy consumption was increased annually.

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