Renewable and Sustainable Energy Reviews 73 (2017) 1–9

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Photovoltaic agriculture - New opportunity for photovoltaic applications in China

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ARTICLE INFO

Keywords:
Photovoltaics
Agriculture
Renewable energy
Development
Opportunity

ABSTRACT

Photovoltaic industry has been an important development direction of China's strategic emerging industries since 2012, and more and more attentions have been paid to broaden the domestic demand to solve the problem of overcapacity of China's PV industry. Photovoltaic agriculture, the combination of photovoltaic power generation and agricultural activities, is a natural response to supply the green and sustainable electricity for agriculture. There are several main application modes of photovoltaic agriculture such as photovoltaic agricultural greenhouse, photovoltaic breeding, photovoltaic wastewater purification, photovoltaic water pumping and new type rural solar power station. Photovoltaic agriculture can effectively alleviate the contradiction between more population and less land, powerfully promote the development of controlled environmental agriculture, evidently increase economic benefits of farmers, and significantly improve environment due to emissions reduction in China. In recent years, photovoltaic agriculture has a rapid development in China due to powerful support policies, flourishing controlled environmental agriculture, policy-oriented rural electrification and promising electric machinery for greenhouse. Therefore, photovoltaic agriculture provides new opportunity for China's photovoltaic industry, thus not only to solve the dilemma of overcapacity for China's photovoltaic industry effectively, but also to accelerate the development of modern agriculture in China. However, the more theoretical researches and practical exploration must be conducted to optimize the combination of photovoltaic power generation and agricultural planting. And the unified standards must be established to standardize the design and scale of projects of photovoltaic agriculture. Also, photovoltaic enterprises need to produce widely applicable photovoltaic products for agricultural production and farmers' life.

1. Introduction

Solar energy is the most safe, reliable and clean natural energy by far, and PV power generation is one of the most important ways of utilizing solar energy in the world. In the face of crisis on global energy and environment today, PV power generation has obvious advantages in resource sustainability and environmental friendliness.

PV industry has been explosively developed on the basis of the combination of semiconductor technology and new energy requirements, and has been taken as an important development direction of China's strategic emerging industries [1,2]. Now China has become one of the most important countries in PV products manufacturing in the world. Fig. 1 illustrates the annual production and installed capacity of the China's PV industry from 2008 to 2014 [3–5]. From Fig. 1, the annual production and installed capacity of the China's PV industry are increasing gradually, but the main market of China's PV products is abroad. Of course, it experiences ups and downs. Since 2004, China's PV industry had shown a rapid development due to the demand for solar energy in Europe and USA, and the polysilicon price topped to $400/kg, as shown in Table 1. But, China's PV industry suffered severely because the global financial crisis has led to weak markets in USA and Europe from 2008. Particularly, anti-dumping and anti-subsidy survey launched by USA and Europe in the end of 2011 pushed this dilemma to the extreme - serious overcapacity of China PV industry, and the polysilicon price fell to $15/kg. Until 2013, the PV market became warmer mainly due to China's support policies which have activated the domestic market, the annual installed capacity was up to 10 GW compared to 4.5 GW in 2012 (see Fig. 1). In addition, the annual production was increased rapidly from 25.1 GW in 2013 to 47.37 GW in 2014, but the annual installed capacity was added up to 2 GW compared with that of 2013. Therefore, the warmer domestic market did not solve the dilemma of overcapacity of China's PV industry effectively, and it is necessary to broaden the application of PV products.

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http://dx.doi.org/10.1016/j.rser.2017.01.098
Received 12 December 2015; Received in revised form 21 November 2016; Accepted 15 January 2017

Nomenclature

AEVs	Agricultural electric vehicles
CAAPRC	Certification and Accreditation Administration of the People's Republic of China
CDB	China Development Bank
CEA	Controlled Environmental Agriculture
COD	Chemical Oxygen Demand
CPC	Communist Party of China
GOSC	General Office of the State Council
LED	Light Emitting Diode
MIIT	Ministry of Industry and Information Technology
MLSS	Mixed liquor suspended solids
MOF	Ministry of Finance
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NGOA	National Government Offices Administration
PV	Photovoltaic
SAQSIQ	State Administration of Quality Supervision, Inspection and Quarantine
SAPRC	Standardization Administration of the People's Republic of China
SGCC	State Grid Corporation of China
SLGOPAD	The State Leading Group Office of Poverty Alleviation and Development
TN	Total Nitrogen
TP	Total Phosphorus
VAT	Value added tax

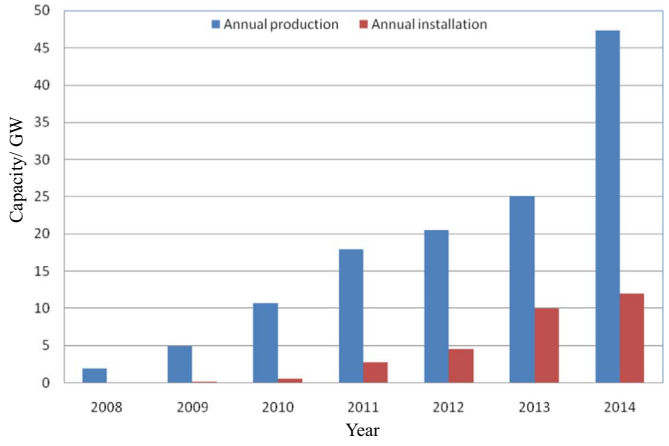

Fig. 1. Annual production and installed capacity of PV industry in China from 2008 to 2014. It should be noted that the production capacity refers to the manufacturing goods (PV panels, inverter, etc.) for the Chinese PV industry, and the installed capacity is about the consumption of the goods by the Chinese PV industry.

Modern agriculture depends heavily on the energy supply obtained mainly from fossil fuels [6]. It is a natural response that PV technology is applied to agriculture sector, called PV agriculture, that is, solar PV power generation is utilized to supply the green and sustainable electricity for agricultural production activities such as planting, breeding, irrigating, etc. Jarach [7] studied economic feasibility of the application of PV to agriculture 20 years ago. Subsequently, Reuss et al. [8] mainly considered technical possibilities, and performed experiments in ventilation, pumping and irrigation.

PV technology has been applied to agriculture gradually due to technological progress and cost reduction in recent years [9,10]. China is a large agricultural country and is developing modern agriculture vigorously, PV technology combined with agriculture can not only realize energy saving and environmental protection, but also promote the transformation of traditional agriculture to modern agriculture. In fact, it can expand the domestic market to cast off the dependence on exports and effectively solve the crisis of overcapacity.

Table 1
Developing stages of China's PV industry.

Stage	Polysilicon price	Main reasons
Rapid development period (2004–2007)	Up to $400/kg	Support policies of PV power generation, e.g. German Renewable Energy Act and USA's PV Buildings Plan and Million Solar Roof Plan.
First adjustment period (2008–2009)	Down to $40/kg	Global financial crisis and reduced subsidies for PV power generation in Germany and Italy.
Explosive recovery period (2009–2010)	Rising quickly to $90/kg	Scrambling for installation due to the fallen price and China's economy stimulus plan of $602 billion.
Severe adjustment period (2011–2012)	Down to $15/kg	Extremely serious overcapacity mainly due to USA and Europe's anti-dumping and anti-subsidy survey.
Gradual warmer period (2013~)	Rising slightly to $18 / kg	Densely issued PV support policies in China, solved China-EU's PV trade disputes and Japan's PV subsidy policy.

2. Application modes of PV agriculture

Green and sustainable solar energy has become a natural choice, due to the increase in demand for energy in agriculture and the negative environmental impacts and limited sources for fossil fuels. PV agriculture has a broad industrialization prospects mainly with the following application modes.

2.1. PV agricultural greenhouse

One of purposes of PV agricultural greenhouse is to obtain higher agricultural income by flexibly creating a suitable environment for crops growth. For example, farmers can plant high value added crops such as organic agricultural products and rare and expensive seedlings. The anti-season planting is achieved because greenhouse can be heated