China Geology 6 (2023) 361−364

China Geology

Journal homepage: http://chinageology.cgs.cn
https://www.sciencedirect.com/journal/china-geology

News and Highlights

Motivation of desert to Oasis: Photovoltaic power generation and carbon neutrality

Li-qiong Jia*, Xi-jie Chen, Ting Jia, Zi-guo Hao

Development and Research Center of China Geological Survey, Ministry of Natural Resources, Beijing 100037, *China*

China has vast areas of deserts, gobis, and desertified lands, with a total area of 3.96 × 10^6 km^2, accounting for 41.3% of the national land area. The desert area is 6.88 × 10^5 km^2, the Gobi area is 6.61 × 10^5 km^2, and the desertification land area is 2.61 × 10^6 km^2, respectively (National Forestry and Grassland Administration, 2018). These are mainly distributed in the northwestern and northern regions west of the "Hu Huanyong Line" (Fig. 1), including Taklimakan Desert, Gurban Tungut Desert, Badain Jalan Desert, Tengger Desert, Ulan Buhe Desert, Kubuqi Desert, Qaidam Basin Desert and Kumtag Desert, Mu Us Sandy Land, Hunshandak Sandy Land, Horqin Sandy Land and Hulun Buir Sandy Land.

The formation of these deserts, gobis, and desertified lands is due to the climate in China. China is mainly controlled by two types of climate, the east monsoon climate, and the northwest continental climate. Affected by the monsoon, southeastern China has abundant rainfall, resulting in a better ecological environment. Influenced by the continental climate, it is difficult for the monsoon to reach northwestern China, resulting in low rainfall, high evaporation, and lots of deserts. In the past three thousand years, northwestern China has been one of the areas where the earliest civilizations occurred. People in these areas built cities along rivers (such as the Tarim River in Xinjiang). The increase in cities led to an increase in water consumption. As the population increased, the scale of farming and grazing was expanded, and many grasslands degenerated into deserts. In the past one hundred years, the climate has been becoming warmer and warmer, and the drought has been getting worse and worse, which resulted in more and more deserts in northwestern China. For thousands of years, the Chinese have been trying to control desertification and dreaming of turning the deserts into oases but yielded unremarkable effects. The reason is that desertification control methods, such as planting trees and grasses, need lots of investment but yield little output or even no economic benefits, leading to unsustainable desert governance.

Today, the flourishing development of desert photovoltaic power generation, an emerging industry, makes it possible for turning the vast deserts in northwestern China into oases.

1. Driving force for the development of the desert photovoltaic power generation industry

1.1. Carbon peaking and carbon neutrality goals

Carbon neutrality is an important method to achieve social, economic, and natural sustainable development. China's commitment to carbon peaking by 2030 and carbon neutrality by 2060 has created an urgent demand and challenge for the research of scientific mechanisms and technological pathways to carbon neutrality. Photovoltaic power generation technology uses the photovoltaic effect to convert solar energy into electric energy. Compared with traditional thermal power generation, photovoltaic power generation can optimize energy structure, ensure energy security, effectively reduce carbon emissions and other pollutant emissions, and improve the regional ecological environment (Mu CF et al., 2017).

Developing photovoltaic technology in the ecologically fragile desert and gobi region can not only improve the production efficiency of photovoltaic systems (Wang Q et al., 2020) but also contribute to desertification prevention and improve ecological functions. The main reasons are that : (1) Photovoltaic array (PA) can reduce solar radiation and soil water loss, which is beneficial to plant growth; (2) PA also has a rainwater collection function, which can promote the growth and succession of plant community under array; (3) PA can weaken sandstorm and wind-sand flow activities (Chang ZF et al., 2018). The combination of photovoltaic power generation system and ecological restoration can give full play to the functions of the PA-vegetation ecosystem,

* Corresponding author: *E-mail address*: jialiqiong1225@163.com (Li-qiong Jia).

Literary editor: Li-qiong Jia
doi:10.31035/cg2023036
2096-5192/© 2023 China Geology Editorial Office.

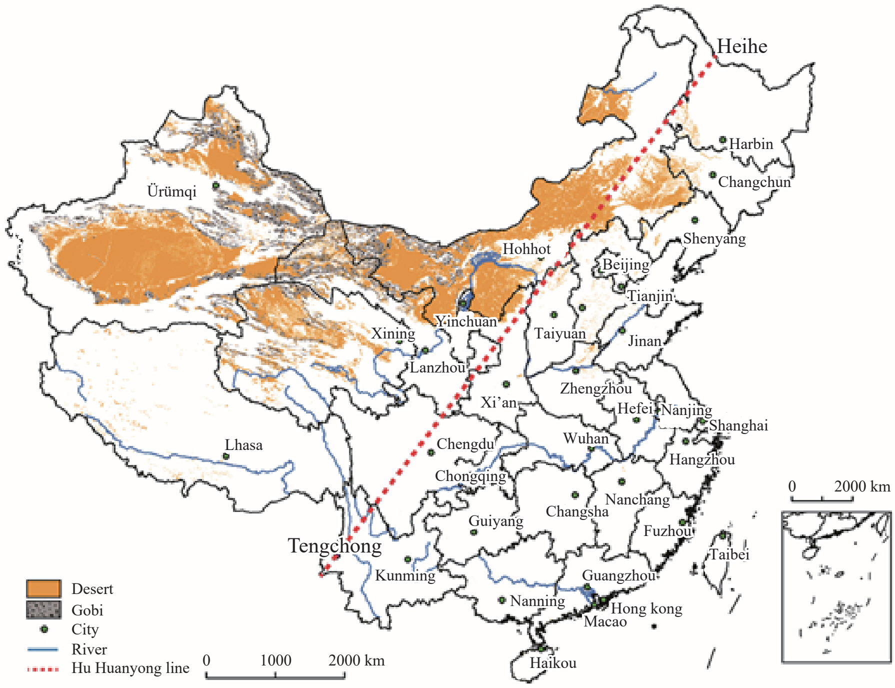

Fig. 1. Relationship between the distribution of deserts and gobis and the Hu Huanyong Line (after Wang JH et al., 2013).

such as water storage and soil conservation, wind-breaking and sand fixing, and climate regulation, which not only converts abundant solar resources into clean energy but also increases carbon sink, promoting the achievement of carbon neutrality.

1.2. Driving force for land resource utilization

The new energy industry, represented by photovoltaic power generation, has created huge wealth for the country and local governments in the desert. At the same time, the harsh environment in the desert area has been effectively controlled. Additionally, the forest and grass industry based on photovoltaic bases has also been developed and utilized (Chen AJ et al, 2022).

China's photovoltaic power generation projects have been promoted in many northwestern provinces and regions, which combine photovoltaic power generation with the development of sand fixation, ecological restoration, grassland husbandry, and even the forestry and fruit industry. The power generation-sand control mode sets up photovoltaic panels on the leveled sand, under which sand barriers based on the grass grid and regenerative plant are arranged. Sand fixation plants are grown inside these sand barriers. The function of sand barriers is to increase the roughness of the quicksand surface to weaken the wind speed, reduce the density and intensity of sand flow, control wind erosion, and fix quicksand. Regenerative plant sand barriers are formed by growing sand plants without shoots that could survive by cuttage to promote the self-renewal and reproduction of vegetation. Combined with the forest and grass industry, photovoltaic projects can achieve efficient utilization of land resources while effectively managing deserts (Chen AJ et al., 2022).

1.3. Driving force for economic benefits

The economic benefits of photovoltaic power generation can be reflected in both direct and indirect aspects.

At the micro level, the direct economic benefits of photovoltaic power generation projects are for the local people and government. As for farmers, photovoltaic power generation projects can increase the income of rural residents and effectively prevent people from returning to poverty after being lifted out of it (Shen YZ et al., 2022).

The electricity generated by photovoltaic power plants could not only support family use but the remaining portion could also be sold, adding a source of income for local impoverished households and reducing the pressure of living expenses. Additionally, photovoltaic power generation projects could pay for the land transfer rent and labor reward, increasing the income of local people. For the local government, photovoltaic power generation projects could enhance the efficiency of regional resource utilization, optimize the allocation of production factors, such as land and labor, and stimulate the development of the local economy. On the other hand, the revenue from photovoltaic power stations can be used to carry out public welfare projects such as village construction, patriotic health campaigns, and student funding, improving the supply level of public goods in rural areas and laying material foundations for the rural revitalization and beautiful rural construction.

The indirect economic benefits of photovoltaic power generation projects are reflected at the meso-level, known as the benefits to the photovoltaic industry and county economy. For the photovoltaic industry, photovoltaic power generation projects enable photovoltaic companies to participate in government procurement. The participation of photovoltaic companies from other regions in the investment and construction of photovoltaic power stations not only expands the market but also introduces the photovoltaic industry to underdeveloped areas. Guided and supported by government procurement policies, the photovoltaic industry can promote the upgrading of local industrial structures and coordinated economic development between regions (Xu F, 2010). As for the county economy, the promotion and implementation of photovoltaic power generation projects in local rural areas are conducive to improving the level of the county economy and promoting green and sustainable development.

2. Possibility of turning deserts into oases in China

2.1. Current situation of desert photovoltaic power generation

Currently, China's photovoltaic power generation projects have been promoted in lots of northwestern provinces and regions and the power generation is growing at an astonishing rate. By the end of 2021, the total installed capacity of power generation in China was up to 2.378×10^9 kW, including 307×10^6 kW of photovoltaic power generation (China Electricity Council, 2022). The total installed capacity of power generation in the northwestern region reaches 357×10^6 kW, accounting for 15% of the whole country. The installed capacity of photovoltaic power generation is 68.3×10^6 kW, accounting for 22.3% of the whole country (Pan L et al., 2022). In 2021, China's total electricity generation reached 8.4×10^{12} kW·h, of which photovoltaic power generation increased by 327×10^9 kW·h. The total electricity generation in the northwestern region reached 1.21×10^{12} kW·h, accounting for 14.4% of the total electricity generation in the country, among which the photovoltaic power generation was 88.1×10^9 kW·h, accounting for 26.9% of the whole country. From 2016 to 2021, the utilization rate of photovoltaic power generation in Shaanxi Province, Gansu Province, Ningxia Hui Autonomous Region, and Xinjiang Uygur Autonomous Region increased from 93.1%, 69.6%, 92.9%, and 67.8% to 98%, 98.5%, 97.5%, and 98.3%, respectively, with an increase of 4.9%, 29%, 4.7 %, and 30.5%, respectively (Fig. 2).

2.2. Desert photovoltaic power generation cases

The Kubuqi Desert in Inner Mongolia, located at the

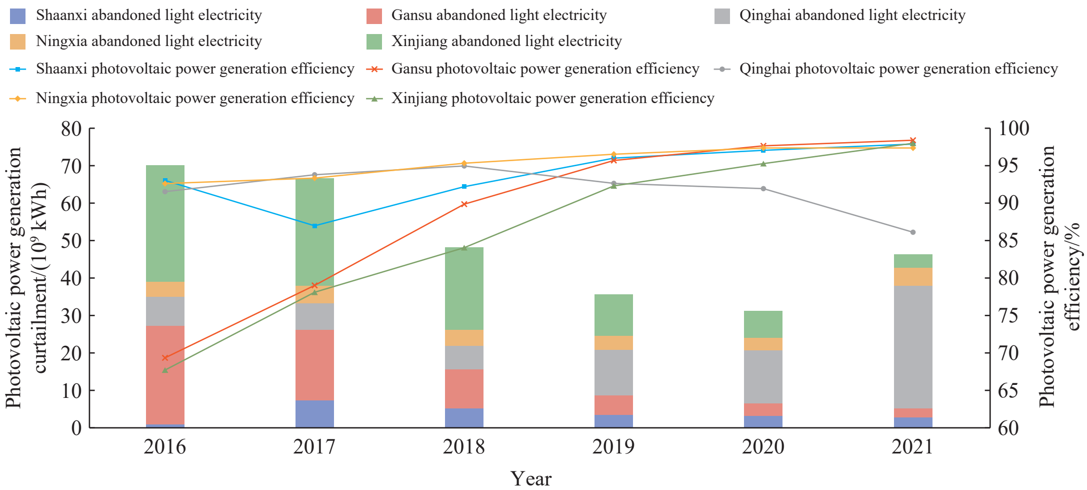

Fig. 2. Utilization rate of grid connection of photovoltaic power generation in the northwestern provinces (Date source: National Energy Administration). The squares represent the abandoned photoelectric quantity, and the line represent PV power utilization ratio.

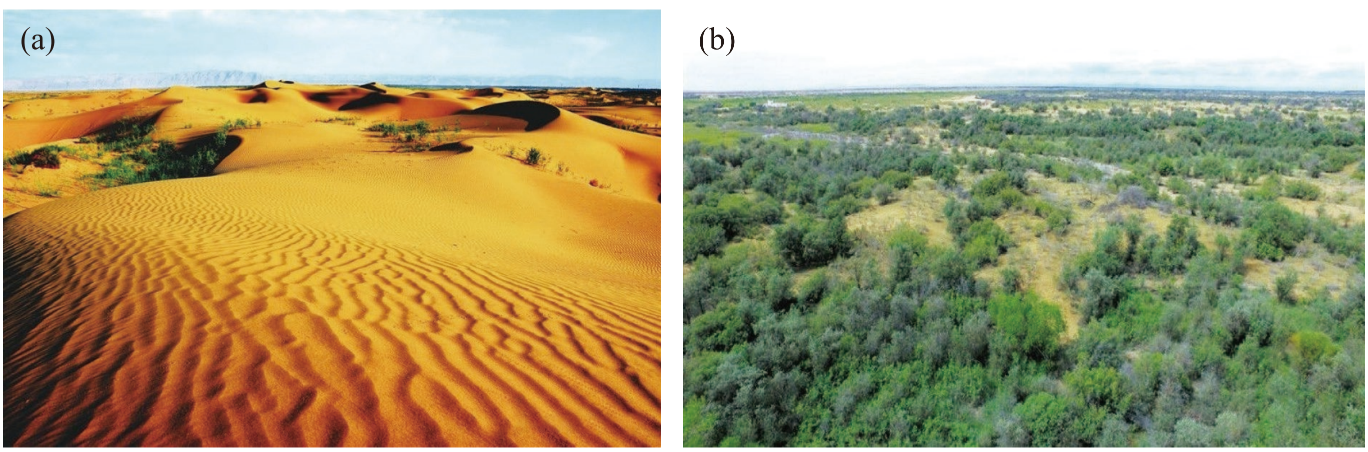

Fig. 3. a–Photo showing the photovoltaic power generation - sand control in Dengkou County (from the website of State Power Investment Group Beijing Electric Power Co., Ltd.); b– Twenty miles of Salix in the Ulan Buh Desert after governance (from the website of Dengkou County Government; after Xiao JH et al., 2022).

junction of the northern Ordos Plateau and the Hetao Plain, is the seventh largest desert in China, with a total area of 18600 km^2. With the maturity of photovoltaic power generation technology and the continuous decrease in equipment cost, the Kubuqi Desert has witnessed a new desert governance model, which combines power generation and desertification control (Fig. 3).

At present, the total installed capacity of photovoltaic power generation in the Dalad application base has reached 1000 MW, with an annual power generation capacity of 2×10^9 kW·h. According to *China Electric Power Yearbook 2021*, the coal consumption for thermal power units in China is approximately 282.9 g/ kW·h. The electricity of 2×10^9 kW·h is equivalent to burning 565800 t of standard coal. Given the calculation that thermal power generation of 1 kg of standard coal results in carbon dioxide emissions of 2.46 kg, the base in Dalat can reduce carbon dioxide emissions by 1.4×10^6 t per year. From the perspective of economic and social benefits, the base in Dalat produces 2×10^9 kW·h of electricity annually, which not only generates considerable economic benefits but also increases local fiscal revenue. In addition, photovoltaic power generation projects can not only generate electricity and control desertification, but also drive the joint development of various industries, such as technological innovation, characteristic planting, and desert tourism, thereby building a new industry model that integrates desert governance, energy industry, and ecological economy. Especially, the implementation of environmental protection and restoration projects effectively alleviates the impact of land degradation and other behaviors on the ecosystem, greatly improving the fragile ecological environment in the Kubuqi Desert. Farmlands have witnessed the most significant change, with an increase of nearly 1000 km^2 in the area and a growth rate of over 100%. The warming and humidification trend of the eastern climate has led to the evolution of Artemisia ordosica and small grass communities towards Artemisia ordosica with crust and increased the area of sand rice, sand bamboo, and low wetland meadows distributed alternately. On the other hand, vegetation construction carried out on sandy land with good habitat conditions has significantly increased the area of Artemisia ordosica, salix, or carag communities and decreased the area of semi-drifting sand. At the same time, the influence of grazing has increased the area of the communities of Artemisia ordosica, sophora alopecuroides, and cynanchum komarovii. For example, the area of stable psammophytic vegetation mainly composed of Artemisia ordosica has increased by 1009 km^2 from 1978–1979 to 2002. The area of sand vanguard plant has also undergone significant changes, decreasing from 7851 km^2 in 1978–1979 to 7303 km^2 in 2002, which indicates a decrease of nearly 550 km^2 in the area of drifting and semi-drifting sandy land (desert) (Li CS et al., 2007).

In addition, the Ulanbuhe Desert in Dengkou, Inner Mongolia, has also formed a complete industrial chain of “desert-photovoltaic power generation-ecological agriculture”, preliminarily achieving the goal of transforming the desert into a granary. The Ulanbuhe Desert is also a typical example of the utilization of nature, achieving carbon reduction, and creating beautiful living space (Chen XJ et al., 2022）

If all the deserts in China are covered with photovoltaic panels, it is estimated that the power generation will be sufficient for global use, and many deserts will become grassland and even farmland. According to statistics, 500000 km^2 of arable land will be added, and the northwestern region will become an important grain-producing area after finishing desert governance in China. Food security issues will also be resolved to a certain extent. It may come true that all the deserts in China become oases. Photovoltaic power generation will be the biggest driving force and factor.

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