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Unveiling China's Overseas Photovoltaic Power Stations in Pakistan under Low-Carbon Transition

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Abstract: Under the China–Pakistan Economic Corridor, renewable energy projects gradually receive due attention, among which the photovoltaic power stations in Quaid-e-Azam Solar Park represents the most typical power stations in Pakistan. The construction and development processes of the photovoltaic power stations are divided into three stages, with enterprises involved including TBEA Xinjiang Sunoasis Co., Ltd., Urumqi, China and Zonergy Solar Technology Co., Ltd., Zigong, China. The development model of the photovoltaic power stations changed from engineering, procurement, and construction (EPC) plus operation and maintenance (O&M) mode to the Build–Own–Operate (BOO) mode. Through solar power generation and marginal emission factors of photovoltaic power stations, the cumulative electricity generation during the operation period can reach nearly 40.09 billion kWh, and the cumulative emission reduction potential of photovoltaic power stations can reach 23.82 Mt CO_2-eq. Based on the multi-stage construction of photovoltaic power stations in the solar park, the land, infrastructure, and transmission facilities could be arranged to simplify the procedures and attract overseas investment. The construction and development model of Quaid-e-Azam Solar Park could provide a reference for the promotion of low-carbon transition, the adjustment of traditional energy structures, the fulfillment of carbon reduction commitments, and the mitigation of climate change, which could provide policy implications for renewable energy development and low-carbon transition in Pakistan.

Keywords: low-carbon transition; photovoltaic power station; China–Pakistan Economic Corridor

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1. Introduction

A transformation of tranditional energy structures is urgently needed to address the impacts of environmental emissions and climate change caused by the utilization of fossil fuels in energy consumption [1,2]. Adjusting the energy structure with renewable energy is a practical approach to realizing green recovery in developing countries, which is also an essential component for the countries taking part in the Belt and Road Initiative (BRI) [3–5].

Pakistan locates in South Asia with a land area of 770,880 km^2 and a population of 220.89 million in 2020 [6]. The total electricity generation of all power plants in Pakistan is 133,330 Gaga Watt hours (GWh), of which 68% is thermal power [6–8]. Pakistan has no proven oil, coal, or natural gas reserves, and a limited domestic power production capacity, urgently requiring sustainable and renewable energy transition [9,10]. In particular, the average daily electricity gap is 4 million kWh, with the daily average electricity gap during summer as high as 7.5 million kWh [11,12]. In order to reduce electricity shortage, the government of Pakistan actively promotes electricity generation from fuel, coal, and renewable sources such as wind and solar [13,14]. In 2006, the Renewable Energy Development Policy was issued by the Pakistani government. In 2011, the Alternative and Renewable Energy Policy created an attractive and regulated investment environment to develop renewable energy sources [15,16], which established the strategy of renewable energy projects in Pakistan, highly dependent on foreign and domestic private investments.

With the most abundant sunshine, Pakistan has an estimation up to 100,000 MW of solar energy reserves [17–19]. In order to take advantage of solar energy resources and to develop large-scale solar power generation, the government chose the Quaid-e-Azam Solar Park project located in Bahawalpur, Punjab, Pakistan as a priority project [20–22]. In March 2015, the Pakistani government announced the amendment of the existing grid code and standard project documents for solar power plants. To attract investment, the government announced that solar energy projects could enjoy tax exemption with a return on investment of 17% along with the provision of other financing mechanisms, such as the offer of guarantees. Solar power development could increase electricity supplies, develop renewable energy sources, alleviate electricity supply problems, and fulfill carbon reduction commitments [23,24]. However, issues such as cleaner production and power crises still exist in Pakistan [25,26]. To promote renewable energy transition, the government also introduced a series of policies to accelerate the exploitation of renewable energy sources, such as hydropower, wind power, and photovoltaic energy [27,28]. Meanwhile, the optimization model considering renewable uncertainty and pumped-storage hydropower was also conducted and compared [29,30].

The China–Pakistan Economic Corridor (CPEC) is a massive collection of infrastructure projects aiming to promote Pakistan's economy and build an economic corridor between China and Pakistan. Officially launched in 2015, CPEC provided an opportunity for cooperation between China and Pakistan [31,32]. CPEC focuses on energy, transportation, the development of ports, and industrial collaboration, which also serves as a flagship project of the Belt and Road Initiative [33]. According to the preliminary plan of the CPEC, energy is one of the six critical areas of CPEC. Along with the proposal for green development, resource- and environment-related issues gradually attracted considerable attention due to infrastructural development [34]. To promote CPEC development, China has set up 15 priority projects, with a total investment of USD 22.29 billion and a total installed capacity of energy projects of 16.21 Gaga Watt (GW), thus providing an essential guarantee for alleviating electricity shortage in Pakistan [32].

Since the proposal of the Belt and Road Initiative, the CPEC has sponsored and established renewable energy projects to reduce carbon emissions in Pakistan. Meanwhile, the countries participating in the Belt and Road require further efforts since carbon inequality still exists between developed and developing areas [35,36]. Since renewable energy is experiencing vigorous development worldwide, these projects significantly contributed to reducing carbon emissions, realizing the self-imposed emission reduction target, and coping with climate change [37]. Meanwhile, the government of Pakistan also formulated policies concerning renewable energy sources and electricity tariff negotiation procedures by laying a foundation for cooperation in renewable energy sources [38,39]. Since the renewable energy market in Pakistan is just at the beginning stage, the industrial technology with a growing maturity in China can effectively compensate for the existing shortcomings in the renewable energy industry [40].

Up to now, existing studies mainly focused on the macro social-economic–environmental indicators in Pakistan and optimization selection and operation of the existing solar power stations [41,42]. At the same time, the development and finance models, the economic performance, as well as the cumulative emission reduction potentials regarding typical energy projects under CPEC have not been fully discussed. In this context, the innovation and contribution of this study mainly lie in the following aspects: firstly, this study aims to analyze the development model of photovoltaic power stations by stage; secondly, this study aims to analyze the economic performance of photovoltaic power stations under tariff changes; thirdly, this study aims to assess the cumulative carbon emission reduction potentials during the operation period of photovoltaic power stations.

Through separating the different stages of photovoltaic power stations in Quaid-e-Azam Solar Park, the development stages, the economic performance, the environmental benefits, and the energy policy evolution are discussed, followed by a summary including the possibilities and challenges faced during the construction and development of renewable energy utilization and cooperation. This study aims at providing an experience-based reference to promote, expand, and implement renewable energy projects in host countries, which is expected to provide a theory-based framework for China's overseas renewable energy projects under low-carbon transition. The rest of the study is structured as follows: Section 2 describes the case studies, Section 3 demonstrates the results, Section 4 discusses major findings and policy implications, and Section 5 draws conclusions.

2. Method and Materials

2.1. China–Pakistan Economic Corridor

The China–Pakistan Economic Corridor, an essential part of China's Belt and Road Initiative, was proposed in May 2013. With the economic corridor as the core, China and Pakistan have established a 1 + 4 cooperation pattern featuring Gwadar Port, transportation infrastructure, energy, and industrial cooperation as the focuses. Since the proposal of the China–Pakistan Economic Corridor, a series of Chinese power and energy projects have been initiated or completed and put into operation in Pakistan. Table 1 lists the renewable energy projects under CPEC. These projects gradually formed a system covering the entire industry chains and featuring varied forms of active investment by multiple parties with increasing social and economic benefits.

Table 1. Renewable Energy Projects under China–Pakistan Economic Corridor.

Project	Installed Capacity (MW)	Invested Amount (Million US Dollar)	Type
Quaid-e-Azam Solar Park	1000	1301	Solar
Hydro China Dawood Farm Thatta	49.5	112.65	Wind
UEP Wind Farm	99	250	Wind
Sachal Wind Farm	49.5	134	Wind
Three Gorges Power Projects	2 × 49.5	2 × 75	Wind
Karot Hydropower Station	720	1698.26	Hydro
Suki Kinari Hydropower Station	870	1707	Hydro
Kohala Hydel Project	1100	2364.05	Hydro
Cacho Wind Power Project	50	-	Wind
Western Energy (Pvt.) Ltd.	50	-	Wind
Azad Pattan Hydel Project	701	1650	Hydro
Phandar Hydropower Station	80	-	Hydro
Gilgit KIU Hydropower	100	-	Hydro

Source: CPEC authority.

2.2. Quaid-e-Azam Solar Park

The photovoltaic power stations in Quaid-e-Azam Solar Park, Pakistan, are among the 14 priority projects of energy cooperation in CPEC. These projects located in Bahawalpur, Punjab, with the location coordinates of (29°19′09″ N, 71°49′25″ E). The project covers an area of 4500 acres with a full scale of 1000 MW and an investment of over USD 1.50 billion. The construction processes are divided into three stages, with enterprises involved including TBEA Xinjiang Sunoasis Co., Ltd. and Zonergy Solar Technology Co., Ltd. The power stations consist of nearly 40,000 solar cells and will become the largest single photovoltaic power generation project worldwide after completion. The stations can provide about 1.50 billion kWh of renewable power generation every year, which is expected to alleviate electricity shortage in Pakistan significantly. Figure 1 presents the photovoltaic power stations in Quaid-e-Azam Solar Park, Pakistan.

Figure 1. Photovoltaic power station in Quaid-e-Azam Solar Park, Pakistan. Source: photographed by the author.

The photovoltaic power stations in Quaid-e-Azam Solar Park were typical renewable energy projects which served as a demonstration for the construction of CPEC based on the Belt and Road Initiative. It was the first project to be put into construction, to complete financing, to be grid-connected, and to be put into commercial operation as a component of CPEC. Within its scope, the first stage of the 100 Mega Watt (MW) photovoltaic power station was the first-megawatt photovoltaic power station in Pakistan, and the subordinate companies of the government acted as independent power producers (IPP). The construction and development processes are divided into three stages, of which the first stage was a 300 MW project starting in April 2015. The first 50 MW grid-connected power station was completed 90 days after the construction. In June 2015, the first stage of the 300 MW grid-connected power station was completed, making this project one of the renewable energy projects taking the lead in grid-connected power generation.

2.3. Theoretical Assessment Framework

For electricity generation, the photovoltaic power generation is derived from the officially released installed capacity of photovoltaic power generation as follows:

$$EG = W \times T$$

where, W represents installed photovoltaic power capacity, T represents annual effective utilization hours, and EG represents the photovoltaic power generation.

This study adopted carbon emission reduction factors of photovoltaic power generation and the Approved Baseline and Monitoring Methodologies for Large Scale CDM Project Activities, i.e., carbon emissions from thermal power plants replaced by photovoltaic power, which can be presented as follows:

$$ER = EG \times CM$$

where, ER stands for the carbon emission reduction potential of photovoltaic power generation, and CM represents carbon emission reduction factors.

The cumulative carbon emission reduction potential by year can be obtained by the newly added photovoltaic power generation and the carbon emission reduction factor in the same year. Generally, the life cycle of photovoltaic power stations is 25 years, and the cumulative newly added emission reduction potentials by year can be simulated through obtaining the carbon emission reduction potentials in the current year as follows:

$$ER_{i+n} = \sum_{i}^{n} (\triangle EG_i \times CM_i)$$

where, ER_{i+n} represents the carbon emission reduction potential generated by photovoltaic power generation, $\triangle EG_i$ represents the newly installed electricity generation, CM_i represents the carbon emission reduction factor of a certain year, i represents the initial year, and $i + n$ represents the definitive year for emission reduction potential assessments ($n \leq 25$).

3. Results

3.1. Construction and Development Model of Photovoltaic Power Stations

The solar park is one of the development models within the solar energy industry. Many countries, including China, Germany, Dubai, India, Mexico, and Egypt, have promoted the development of solar parks to realize the centralization of solar power generation. There are two different development models of solar park projects. One generally establishes an industrial development platform based on industrial parks, which integrates technology research and development, enterprise incubation, product display, demonstration application, comprehensive services, etc. China has developed several photovoltaic industrial parks, including Jiaxing Photovoltaic High-tech Industrial Park, Changzhou Photovoltaic Industrial Park, Wuxi Photovoltaic Industrial Park, and Zhenjiang Photovoltaic Industrial Park. The second aspect of development concerns site selection, taking into consideration of the solar radiation endowments and the government's land, infrastructure, and power transmission facilities. The developer generally signs a power purchase agreement (PPA) with the enterprises to be settled before building the plants. For example, Baden-Württemberg Electric Power Company in Germany announced in October 2019 that it would build the currently largest solar energy park in Germany with an estimated installed capacity of more than 180 MW. Beban Solar Energy Park, established by Egypt, has a total of up to 1.46 GW, including 32 solar power stations. Dubai has built the largest single-station solar park in the world, Mohammed bin Rashid Al Maktoum Solar Park, with a total investment of AED 50 billion (about USD 13.6 billion). The Ministry of New and Renewable Energy (MNRE) in India launched a development program of a solar energy park and exemplary cases of super-large solar projects in 2015 with a total power generation capacity of 20,000 MW.

The construction and development model of photovoltaic power stations could be separated into different stages. In the first stage, Chinese enterprises mainly participated in EPC, with TBEA Xinjiang Sunoasis Co., Ltd. providing EPC and O&M for the project by adopting the development model of EPC plus short-term operation (EPC + O&M). At this stage, the project was funded by the government of Punjab and the Bank of Punjab. During the construction of the 300 MW photovoltaic power station in the second stage, Zonergy Solar Technology Co., Ltd., as an IPP, basically formed the Build–Own–Operate (BOO) mode. Zonergy Solar Technology Co., Ltd. and China First Metallurgical Group Co., Ltd. signed the EPC contract for the 300 MW photovoltaic power station in the Punjab Province of Pakistan. At this stage, syndicated loans were provided by the Export–Import Bank of China, China Development Bank, Bank of Jiangsu, and Bohai Bank. The overseas investment insurance was underwritten by the China Export & Credit Insurance Corporation, and a guarantee of support was provided by institutions such as China United SME Guarantee Corporation. Among them, the Export–Import Bank of China and China Development Bank took the lead in syndicated loans, providing long-term and low-interest loans, and China Export & Credit Insurance Corporation provided overseas investment insurance for political risks such as war, confiscation, and exchange restrictions. A financing guarantee was provided by the guaranteed company and the photovoltaic energy efficiency insurance by the commercial insurance company to ensure efficient power generation for the project. The financing party thus changed from the Bank of Punjab to the Import–Export Bank of China, China Development Bank, etc., which provided syndicated loans. Furthermore, the construction and development model of the Quaid-e-Azam Solar Park has gradually been promoted in other regions in Pakistan, being adopted and considered by companies and organizations such as Baluchistan, FATA, and NESCOM.

3.2. Economic Performance of Photovoltaic Power Stations

To alleviate the domestic energy crisis, Pakistan adopted a cost + return mode in the development policies on renewable energy sources. An electricity price favorable for the IPP was set as the electricity price for the project. The electricity price can be negotiated according to the investment costs of the various investors. Regarding the cost + return mode, assuming investors could recover reasonable construction costs and operating costs, the internal rate of return on the capital was allowed to reach 15~17%. During the project construction, the shareholders' funds by debt financing were generally recovered through the income after taxes of new energy projects and residual claims.

In early 2014, the government of Pakistan implemented the subsidy policy of feed-in tariffs for photovoltaic power station projects. Afterward, the National Electric Power Regulatory Authority (NEPRA) of Pakistan approved the transmission electricity price of solar power stations of 17.85 Rupees per kWh in the northern regions and 17.12 Rupees per kWh in the southern regions. The implementation period was limited to 25 years after the start of commercial operation of the power stations, which did not apply to power stations with an installed capacity of more than 50 MW. Taking the first stage of the 100 MW of photovoltaic power station project in Quaid-e-Azam Solar Park as an example, the total investment in the project was USD 215 million, including USD 131 million in the EPC stage and USD 73 million in the O&M stage. With a life expectancy of the project as 25 years and the solar panels supplying power for the National Grid 8~10 h daily, this project has an estimated profit of about USD 21.95 million over the whole life cycle.

Although the governments of Pakistan and Punjab introduced a series of measures to encourage the promotion of renewable energy projects, there are often conflicts between various policies. In the contract period of the project, TBEA Xinjiang Sunoasis Co., Ltd. obtained a 25-year power generation license from NEPRA of Pakistan, and both parties agreed that the solar energy generated by the power plant would be sold to the power grid for USD 0.1497 per kWh. In December 2015, on the grounds of the price reduction of solar light panels and related equipment, NEPRA of Pakistan reduced the feed-in tariffs of photovoltaic power from USD 0.1415 to USD 0.1135~0.1153 per kWh in the northern region and USD 0.1072~0.1089 per kWh in the southern region. The new price came into effect in January 2016 for six months. In 2018, the photovoltaic project in Pakistan was changed to be governed by a tariff-based auction. Table 2 presents the preferential tariff policies for photovoltaic power stations. Although each country granted tax exemptions in different fields with different ratios for solar products, the increase in the tax rate and the decrease in the electricity price would significantly increase the construction cost of photovoltaic projects and reduce the revenue of electricity generation, thereby creating some obstacles to the government's photovoltaic power generation plan.

Table 2. Preferential tariff policies for photovoltaic power stations.

Category	Description
Upfront tariff	The upfront tariff released in 2015 was to promote the development and utilization of Pakistan's renewable energy sources. Under the policy, NEPRA would announce the feed-in tariff and levelized tariff during the effective period of the power purchase agreement (PPA) to serve as a reference for Pakistan Electric Power Company (PEPCO) and local IPPs.
Tariff-based auction	In March 2017, NEPRA released an official document numbered NEPRA/LA(Leg.)/NCBT-01/6072 to confirm the implementation of the tariff-based auction system.
Net-metering scheme	In September 2015, NEPRA released the net-metering policy for covers power plants with an installed capacity between 1 kW and 1 MW. Owners of power plants may deduct excess electricity generated off their utility bills or sell it to distribution companies (DISCOs) by region.

Source: NEPRA.

3.3. Emission Reduction Potentials of Photovoltaic Power Stations

Based on the data from World Bank, Pakistan's carbon emissions showed a trend of a sharp increase after the 1980s, with an annual growth rate of about 6%. After 2005, the growth rate decreased but remained above the average global level, reaching 432.50 million tons (Mt) of CO_2-eq in 2019 [6,43]. As an essential component of renewable energy, photovoltaic power stations have huge carbon emission reduction and environmental improvement effects, with relatively less impacts on the ecological environment. In order to measure the carbon emission reduction from photovoltaic power investment, this study adopts the calculation method of marginal carbon emission in the United Nations Framework Convention on Climate Change (UNFCCC) [44] and obtains the corresponding photovoltaic power project construction and operation data from the China–Pakistan Economic Corridor Energy Priority Project. The potential emission factors are derived from IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy and Approved Baseline and Monitoring Methodologies for Large Scale CDM Project Activities [45]. It should be noted that photovoltaic power generation is also affected by solar radiation, terrain elevation, power curve, operating time, etc. The operation period of the above photovoltaic power projects is mostly designed to be 25 years. As for the electricity demands in Pakistan, the cumulative electricity generation of the case photovoltaic power priority project during the operation period can reach nearly 40.09 billion kWh, which can be used by more than 200,000 local households. Combining the power generation and marginal carbon emission factors of each photovoltaic power project, the average annual carbon emission reduction of photovoltaic power priority projects could reach 23.82 Mt CO_2-eq. Based on the 25-year operation time, the cumulative carbon emission reduction could reach 23,819.42 kt CO_2-eq. Table 3 lists the cumulative installed capacity, electricity generation, and carbon emission reduction of China's photovoltaic power investment in Pakistan based on the case stations.

Table 3. Cumulative carbon emission reduction of photovoltaic power stations in Pakistan.

No.	2020	2025	2030	Operation
Cumulative installed capacity (MW)	400	1000	1000	1000
Cumulative power generation (GWh)	3183.69	8254.08	13,979.93	40,086.54
Cumulative emission reduction potential (kt CO_2-eq)	1891.75	5361.36	11,284.00	23,819.42

Source: estimated by the author.

As for the overall energy structure, the proportion of solar energy in Pakistan's energy structure is relatively small, but the development of photovoltaic power stations shows huge potentials. In the Pakistan Vision 2030, the government has planned for renewable energy power generation, and further formulated renewable energy power generation policies and strategies for small hydropower (not exceeding 50,000 kilowatts), wind power, and solar power plants. The Pakistani government proposed accelerating the development of renewable energy power represented by wind power, hydropower, and photovoltaics, and accelerating the construction of nuclear power plants to meet the rapid growth of electricity demand due to economic growth. As one of the countries with the most abundant sunshine in the world, Pakistan has a solar power reserve of 100,000 MW, giving great potentials to the development of solar energy projects. In most parts of Pakistan, especially Sindh Province, Balochistan Province, and southern parts of Punjab, the annual sunshine hours exceed 3000 h, and the radiation of the sun is as strong as 2 MWh/m^2. The importance of vigorously developing renewable energy is beginning to reveal, which will gradually become a key driver for the rapid development of Pakistan's photovoltaic projects.

4. Discussion and Policy Implications

4.1. Pakistan's Renewable Energy Policy Evolution

Overall, the unsustainable energy mix and over-dependence on imported energy fuels urged policymakers to diversify the energy mix by utilizing both traditional and modern energy resources, achieve self-reliance in the power sector as well as sustainable socioeconomic development. For this purpose, a task force was established in 1993 to assess the electricity generation system and submit a complete report to the Prime Minister. As a result, a comprehensive energy policy was introduced in 1994, mostly adopting the features of the report of the Prime Minister's task force on energy. The policy aimed at attracting private and foreign investment in the power sector, since the power sector entirely liberalized and the electricity shortage exceeded 2000 MW. Various generous and lucrative packages and incentives were offered to seek private investors. The policy adopted the cost-plus tariffs formula and offered interested investors USD 0.065 per kWh. Afterward, a new institution, the Private Power and Infrastructure Board (PPIB), was established to implement and monitor policy. One of the most critical features of the policy was bulk power tariffs, assuming a 60% calculated capacity factor. The policy attracted USD 3 billion of foreign investment in the power sector. Almost 19 companies invested and added 3500 MW to the national grid by the end of 2001. The power policies of 1994 and 1998 mainly focused on thermal power generation. There was a need to revisit policies which would lead to the restructuring the power sector and find a solution to expensive electricity. In this context, Power Policy 2002 was announced to promote the idea of a private–public partnership utilizing indigenous renewable energy resources. The target of 1500 MW of renewable electricity was set to be added to the national grid by 2020. However, the prime focus of retrospective national energy policies remained the exploitation of thermal and small hydro resources. Renewable energy resources, particularly solar, wind, biofuel, and geothermal, remained untapped to diversify the energy mix.

The country introduced its first-ever renewable energy policy in 2006 to harness wind and solar potential utilizing renewable energy technologies. The power policy of 2006 focused on harnessing renewable energy potentials in three stages [15]. The policy also allowed the construction of unlicensed and deregulated small solar and hydropower plants to reduce costs and avoid greenhouse gas (GHG) emissions. The government announced another renewable energy policy in 2011, carrying quite similar objectives to the power policy of 2006. The prime focus of this policy was also to tap alternative energy resources and to encourage the private sector in meeting increasing energy demands, adding a 5% share of renewable energy by 2025 [16]. The government introduced another ambitious power policy in 2013 to reduce the huge demand and supply gap of more than 5000 MW [46]. The policy primarily aimed to provide cheap electricity, decreasing costs from 0.12 to USD 0.10 per kWh, increasing the revenue of the power sector by 85–95% by 2017. Furthermore, the policy was directed toward the promotion of efficient energy production, the reduction of fuel pilferage, the renovation of transmission of infrastructure, and the reduction of distribution losses from 25% to 16% by 2017. Minimizing deficiencies in the power distribution sector was set as a priority. Another energy policy was announced in 2015 to attract international and local investors. Better incentives and lucrative business opportunities were offered to shrink the generation–supply gap [47]. The up-front tariffs formula was offered for thermal, hydro, wind, and solar power generation on public–private partnerships. The newest Alternative and Renewable Energy Policy was released in 2019, announcing the intention to have at least 20% of its generation capacity as Alternative and Renewable Energy technologies by 2025 and 30% by 2030 [48]. According to the National Electricity Policy released in 2021, the generation mix for the sector shall gradually reduce reliance on imported fuels and shall move toward optimal utilization of local resources such as coal, hydro, renewable sources, local gas, and nuclear energy.

4.2. Potentials and Constraints of Photovoltaic Power Stations

Pakistan is one of the ten countries most severely affected by climate change [49]. According to the evaluation by the National Disaster Management Authority (NDMA) in Pakistan, the annual average economic loss to Pakistan caused by extreme climatic events from 1994 to 2013 was nearly USD 4 billion. From the early 1980s, Chinese enterprises started to cooperate extensively with the power sectors in Pakistan, laying a solid foundation for future cooperation in renewable energy between the two countries. Meanwhile, the development and utilization of renewable energy contributed to alleviating the long-standing power shortage, severely restricting Pakistan's economic growth and the people's livelihood. Based on the construction and development model, photovoltaic development in Pakistan has gradually been promoted. The renewable energy cooperation in CPEC, especially the cooperation in solar energy and wind power projects, slowly showed broad prospects.

Generally, the development and structure of the photovoltaic power stations in the solar park and their implementation and grid connection are usually affected by multi-scale impacts at the global, national, local, and energy park levels. On a global scale, tackling climate change and renewable energy transition has become a priority and is taken into account when designing the energy strategies of each country. In the nationally determined contributions (NDCs) proposed by each country, specified goals have been set for development needs, which are also one of the main constraints for low-carbon development transformation in various countries [50]. Generally, the host country can attract advanced technology and capital at home and abroad, perfect its industrial policies, and raise its technology level under its unique advantages (such as resource endowment) to realize a leapfrog development of the clean energy industry. However, the infrastructure in some developing countries is underdeveloped, and the government cannot invest large amounts in infrastructure construction. In addition, project implementation and grid connection are influenced by many factors, such as capital and technology. The transition and development of renewable energy represented by photovoltaic power stations are subject to the constraints of elements such as resource endowments, production relations, development planning, and the policies and systems of the host country at different scales. In this context, the renewable energy development model with photovoltaic power stations in Quaid-e-Azam Solar Park as a representative project helps to solve the problems related to land, plants, electric power, and roads in a centralized manner, which contributes to the simultaneous investment of labor, funds, and technology, the optimization of a cooperation model among government departments, and the creation of a more significant agglomeration effect.

Currently, the photovoltaic enterprises in China are beginning to explore emerging markets successively, with Pakistan becoming one of their newly developing investment areas for solar energy. Meanwhile, China and Pakistan's energy power stations gradually provided a powerful impetus for economic development in the country. However, photovoltaic power development and cooperation in Pakistan still have good development prospects:

(1) Photovoltaic projects are geographically scattered, small in scale, and relatively difficult to manage comprehensively in terms of operation and management. The model of photovoltaic power stations in the Quaid-e-Azam Solar Park assists in promoting the large-scale construction of photovoltaic projects. To date, the development model of photovoltaic power stations has been gradually enabled in other areas of Pakistan. Baluchistan, FATA, NESCOM, and other institutions have successively sought relevant guidance to construct solar parks. On this basis, Chinese enterprises can actively promote the progress in constructing relevant solar parks and take this opportunity to promote the development of photovoltaic projects.

(2) As a large-scale photovoltaic power station in Pakistan with an O&M period of 25 years, the photovoltaic power station in Quaid-e-Azam Solar Park laid the foundation for developing photovoltaic power stations in the public and private sector,

which is expected to create a scale effect in the construction of solar power stations in Pakistan. Chinese enterprises will gradually be able to improve industry standards and promote the joint development of industries, which could lead to the improvement of the employment level in Pakistan and the implementation of the target of self-imposed emission reduction contributions.

(3) China has made huge technological advances in the development of photovoltaic power, which are conducive to promoting the demonstration and technology transfer of the solar energy industry in Pakistan. Supported by the geographical advantages and the diplomatic foundations of China and Pakistan, most Chinese photovoltaic enterprises currently active in Pakistan, which means Chinese enterprises have the potentials to further develop markets and promote the photovoltaic industry in Pakistan.

(4) The relatively small scale of photovoltaic power generation in Pakistan presents huge development potential under the framework of CPEC. Compared with coal or hydropower projects, photovoltaic power stations, wind power stations, and other renewable energy projects showed the advantages of fast construction speed, short cycle, and decreasing cost. Between 2010 and 2021, the levelized price per kWh of electricity generated by solar photovoltaic power was reduced by 88% from USD 0.417 to 0.048 per kWh [51]. With continuous cost reduction, photovoltaic power generation displays increasingly potentials.

Meanwhile, there are still issues to be resolved in developing and managing the photovoltaic power stations in Quaid-e-Azam Solar Park. Pakistan's electricity shortage is shrinking and even becoming a surplus, resulting in increasingly fierce competition in Pakistan's renewable energy market, which also increased the entry barriers into the market [28,52]. In addition, credit insurance for renewable energy projects remains weak, and the competition between traditional and renewable energy projects is still obvious.

As for investing in Pakistan, enterprises still need to focus on the macroeconomic situation and policies as well as the timely resolution of cost increases due to unfavorable factors, such as policy changes or inflation, to ensure smooth project implementation. In terms of financing, the related work involves a series of studies such as designing the financing credit structure, the signing of the power purchase agreement and the concession agreement, followed by the loan agreement and the signing of the mortgage pledge agreement. All those situations require adequate preparation as well as familiarity with the related policies and regulations of the target country. The strengthening of communication with different departments and hierarchies, the accurate control of the time nodes of the project, and the realization of the rational division of labor and cooperation of the team are necessary.

In terms of cost–benefit control, investors need to comprehensively consider factors such as resources, geology, immigration, grid connectivity, transportation, and construction. They also need to adopt appropriate technical teams to avoid project technical program risks and to ensure that wind turbines can guarantee high-temperature full-power operation. In terms of determining the electricity price, investors had to keep up with the latest grid connection policies and measure the actual wind speed each month, which can thus ensure the representativeness and integrity of the early-stage wind and meteorological data, as well as the accuracy of wind resource forecasting, to try and avoid the risk of fluctuations in the on-grid price.

4.3. Policy Implications

To cope with climate change, Pakistan submitted the NDCs, which listed a quantitative emission reduction target [50]. Based on the NDCs of Pakistan and the carbon emission trends, the GHG emissions by Pakistan are expected to be 1.603 billion tons CO_2-eq, with carbon dioxide emissions of about 721 million tons. Among them, the energy-related carbon emissions accounted for about 56%, far higher than those related to other categories, such as agriculture, industry, and land use change. According to the NDCs, Pakistan will need about USD 5.5 billion (the current price) to reduce GHG emissions by 10% and about USD 40 billion to reduce them by 20%.

Given the geographical proximity and diplomatic relations between China and Pakistan, Chinese enterprises are actively engaged in Pakistan's photovoltaic projects, e.g., HSSAAE, TBEA., ET Solar, China Three Gorges Renewables (Group) Co., Ltd., (Beijing, China) Canadian Solar, Zonergy, Hanergy, and Powerway Renewable Energy Co., Ltd., Foshan, China. In addition, China's photovoltaic technology can help promote the project demonstration and technology transfer of photovoltaic industries in Pakistan. Compared with coal-fired power plants or hydropower projects, the development of solar and wind power stations is characterized by high construction speed and continually decreasing costs. With the gradually decreasing costs, the potential of photovoltaic power generation also significantly increased.

Meanwhile, there are still blind investment behaviors in the processes of China's outward investment. Regarding the investment in renewable energy projects overseas, it is necessary to consider local investment markets, policies, laws, resources, and environmental protection policies. Based on China's experience investing in solar power in Pakistan, the development of deep-level renewable energy cooperation between China and Pakistan to address electricity shortages and achieve sustainable development is expected. Some aspects that need to be considered are the following:

(1) Since the launch of CPEC in 2013, several energy and electric power projects have started operating in Pakistan. The hydropower, wind power, solar energy, and other renewable energy cooperation fields have gradually been expanded. A development model with diversified investment and various participating parties covering the whole industrial chain has initially been formed and achieved good social and economic benefits. Based on the Belt and Road Initiative, Chinese enterprises could further promote the construction and development model of photovoltaic power stations in Quaid-e-Azam Solar Park as an example to promote the large-scale construction of renewable energy projects and build a large-scale demonstration project connected to the grid.
(2) Affected by the change in purchase price policy, the 900 MW photovoltaic power stations in Punjab province, Pakistan, which received an investment of USD 1.5 billion from Zonergy Solar Technology Co., Ltd., was scheduled to be completed in June 2016. However, the 600 MW of solar energy generation is still in the construction stage. Although the development and utilization of renewable energy in Pakistan are still in the exploration stage, the relevant institutions in Pakistan still need to urgently agree on a unified and stable electricity price policy, change the current case negotiation strategy on electricity purchase, and encourage private investors to enter the renewable energy field in an open, fair, transparent, and competitive but orderly environment.
(3) The finance and investment of China in photovoltaic power stations still follow the traditional loan approach applied to thermal power and hydropower projects. Meanwhile, the evaluation of renewable energy's green and low-carbon attributes is insufficient, and the support of credit insurance institutions for renewable energy is still weak. In the underwriting policy, the advantages of renewable energy projects in terms of underwriting limit, insurance period, insurance rate, etc., have not been fully exploited. In the future financing and investing processes, the principal investors' need to combine renewable energy characteristics of a low-carbon and green economy with controllable construction will optimize the layout of energy projects in CPEC and will create the right conditions to explore the project financing and structured financing with limited recourses.
(4) With the increased participation of Chinese enterprises in photovoltaic power stations in Pakistan, the investment and market shares of Chinese enterprises are growing, and the gap in demand for electricity in Pakistan is shrinking or even turning around. The solar power market in Pakistan faced increasingly competitive, and the project

profit space has been continuously compressed. The above situation not only impacts the existing business management model and investment profit but also places higher requirements on the energy utilization efficiency and carbon emission reduction efficiency of Chinese-funded renewable energy power stations.

5. Conclusions

As far as photovoltaic power station projects in Pakistan are concerned, the project construction process, the development model, the economic performance, the environmental benefits, and the energy policy evolution were considered, with a summary of the possibilities and challenges faced by the photovoltaic power stations. The construction and development processes of Quaid-e-Azam Solar Park were divided into three stages, with different actors involved in the development and construction, including TBEA Xinjiang Sunoasis Co. and Zonergy Solar Technology Co., Ltd. The continuous participation of Chinese enterprises could be witnessed in the construction and development model of photovoltaic power stations transformed from the EPC + O&M mode to the BOO mode. Note that the successful implementation and grid-connection of renewable energy sources such as photovoltaic power stations depend on multi-scale reguations that covers global, national, local, and park levels. It has also been affected by factors such as resource endowment, policy system, development planning, technological level, and financial guarantees by the host country. In this context, the construction and development of the photovoltaic power stations can provide references for the improvement of institutional energy systems, the fulfillment of carbon reduction commitments, and the mitigation of global climate change, which is expected to provide quantified support and possible implications for renewable energy development and low-carbon transition in Pakistan.

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