Audit Report

Performance Audit of Climate Change Adaptation Actions (CCAA)

Audit Report on Climate Change Adaptation in China's Photovoltaic Industry

SAI: National Audit Office of China

Approved by:________________________

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In accordance with the relevant provisions of the *Audit Law of the People's Republic of China* and the requirements of the cooperative audit project under the INTOSAI Development Initiative, an audit team consisting of the Department of Natural Resources, Ecology and Environment Audit of the National Audit Office of the People's Republic of China and the S Provincial Audit Office, selected S Province as an audit sample and adopted the Five-Step Audit Method (document review, meetings and interviews, on-site inspections, statistical analysis, and professional consultation). The audit objective is to review and investigate whether S Province has effectively implemented the requirements related to adapting to climate change during the planning, construction, operation, decommissioning, and disposal of PV power generation. The audit will also examine the formulation and implementation of relevant plans for photovoltaic power generation, the establishment of industry development safeguards, and the impact and damage to the ecological environment. Moreover, the audit extended its scope to perform necessary tracing and retrospective analysis.

I. General Overview

Climate change is a common challenge for all humankind. As global temperatures continue to rise, the long-term adverse effects and sudden extreme events caused by climate change pose increasingly severe threats to economic and social development as well as the safety of people's production and livelihoods. In response to climate change, China upholds the concept of green development, promotes the transformation of its development model, and engages in extensive international energy cooperation, contributing Chinese efforts into the global energy transition and green development. Relying on continuous technological innovation, a sound industrial and supply chain system, sufficient competition, and super-large-scale market advantages, China has achieved rapid growth in its renewable energy industry, enriched global supply, and contributed to international efforts to combat climate change and improve human well-being.

China is located in a climate-sensitive area, with a fragile ecological environment susceptible to climate change. To advance climate adaptation efforts, China issued the *National Climate Adaptation Strategy* in 2013, raising climate adaptation to the level of a national strategy for the first time to promote proactive adaptation actions in key sectors including energy and industry. The *National Climate Adaptation Strategy 2035*, released in 2022, proposed enhancing climate resilience in the energy sector. Impact and risk assessment of climate change on the production, transport, storage, and distribution of energy should be conducted focusing on extreme weather and climate events such as heatwaves, freezing, and rainstorms. Energy structure and land use layout should be optimized according to changes in climate resources and energy demand. The protection and emergency dispatch of power transmission and distribution systems should be strengthened in the event of extreme weather, with enhanced monitoring, inspection, and maintenance of power equipment. The application of technologies such as energy storage, smart grids, and digitalization should be promoted. The emergency response planning system should be improved to enhance the ability of power infrastructure to predict and warn of security risks, implement defensive measures, and recover quickly. The *Guidelines to Comprehensively Promote the Development of a Beautiful China*, released in 2024, underscores the importance of safeguarding the bottom line of building a Beautiful China, effectively addressing the impacts and risks brought by climate change, and basically building a climate-resilient society by 2035.

The PV industry serves as a key driver in China's energy transformation and optimizing the energy structure. Since the 14^{th} Five-Year Plan, China's PV industry has accelerated its capacity expansion, making PV the second-largest source of power generation after coal, with the largest installed capacity and fastest growth rate among renewable energy sources. Since 2013, China's newly added installed renewable energy capacity has accounted for over 40% of the world's total. In 2023, it accounted for more than half. According to *Renewables 2023* released by the International Energy Agency (IEA), China was recognized as the global leader in renewable energy and the primary driving force behind the rapid, massive expansion in the sector. From 2014 to 2023, the share of non-fossil energy consumption globally rose from 13.6% to 18.5%, with China contributing 45.2% of the incremental increase. The *Renewables 2024* emphasizes that China contributes the most to the rapid development of the global renewables, projecting that by 2030, about 60% of the world's expansion will come from China and its PV production capacity growth will lead globally. As of the end of 2024, China's total installed PV capacity reached 886 GW, with distributed PV installations reaching over 375 GW, representing more than 42% of the total PV capacity. The PV components and wind power equipment manufactured by Chinese enterprises have enabled the widespread and economical utilization in more and more countries. According to the International Renewable Energy Agency (IRENA), in the past decade, the global levelized costs of energy (LCOE) for wind and solar power projects have declined by over 60% and 80% respectively, with China playing a significant role.

With the development of PV and other renewable energy sources, the power system has experienced profound transformations, with the technological pathway shifting from a singular focus on large-scale centralized generation to a dual approach combining both centralized and distributed generation. This means that new energy power generation, in addition to adopting large-scale centralized generation models in large bases, also employs distributed generation models including rooftop and wall-mounted PV systems, as well as decentralized wind power. The grid structure has also evolved, developing from a traditional centralized large grid model to a hybrid system integrating large grids, regional grids, and microgrids. With the extensive integration of high-proportion renewable energy sources and electronic devices, as well as the emergence of distributed PV systems, small new energy power stations, and microgrids, the transmission and distribution network is transitioning from a stable grid to a resilient grid.

Currently, extreme weather events are increasingly frequent worldwide. Extreme heatwaves and heavy rainfall in summer and blizzards and cold waves in winter all pose severe challenges to the stable supply of electricity. The impact on the power grid primarily falls into two areas. First, climate change induced disasters directly interfere with and damage power grid infrastructure and its essential auxiliary equipment, resulting in partial functional failure of the grid.

Second, climate change causes fluctuations in power generation and grid load, increasing disturbances across the entire power grid system and affecting its operational stability and security. In the context of PV projects, strong winds may cause PV modules to be dislodged or damaged; hailstorms may cause cracks and damage to the surface, or even completely shatter the PV panels, leading to short circuits within the modules, potentially triggering fires; heavy snow and rainfall significantly reduce power generation, while melting snow can form icicles, damaging PV modules and support structures; extreme heatwaves may cause inverters to shut down and accelerate aging of electronic components, reducing operating efficiency and decreasing power generation capacity. Moreover, the construction of PV generation facilities can also have a certain impact on the ecological environment. Ecosystems from the surface to underground and underwater may be affected by PV panels, and decommissioned PV modules also pose potential environmental risks.

II. Audit Evaluation and Conclusion

In recent years, China's climate conditions have been worsened, characterized by warm and dry climate patterns and frequent flood and drought disasters. During the flood season, heavy rainfall has demonstrated high disaster-causing potential, while regional and periodic droughts are evident. In central and eastern China, high-temperature weather occurs earlier with a wide impact and strong extremity, while in northern China, sandstorms are frequent, occurring earlier with greater severity. Regarding the sample province, the annual total solar radiation of S Province is approximately 1,500 kWh per square meter, which is a solar resource zone II (high amount of solar energy), with the annual average sunshine duration ranging from 2,290 to 2,890 hours. From 1960 to 2024, the average temperature has warmed at an average rate of 0.31°C per decade, with an accelerated warming trend since 2000, reaching 0.4°C per decade. In addition to extreme weather, climate change has also triggered severe meteorological disasters. Since 2000, the annual direct economic losses caused by meteorological disasters in S Province have averaged 1.7% of GDP, with major disasters including storms, drought, lightning, strong winds, hailstorm, heatwaves, typhoons, cold waves, and snowstorms.

As of 2024, the PV power generation of S Province reached 76.13 GW, ranking first in China with a share of 8.6%. The S Provincial government places great emphasis on PV industry development, implementing a series of policy measures to encourage technological innovation and industrial growth. Since 2021, the provincial and municipal governments have introduced 78 policies across various dimensions, including government planning, land use security, financial support, and healthy industrial development, creating a favorable environment for PV industry development. Currently, S Province's PV industry is expanding rapidly, forming a relatively complete industrial chain that spans upstream raw material production, midstream component manufacturing, and downstream system integration and application.

Audit Conclusion: Based on the audit results, S Province has not yet fully and effectively integrated the policy requirements for adapting to climate change into the entire life cycle management of PV power generation. Key issues identified include the lack of effective planning and guidance in some areas, an incomplete industry development safeguard system, and the risk of ecological and environmental impact and damage.

3. Major Issues Spotted in the Audit

(1) The government lacks effective planning and guidance, and climate adaptability of PV facilities in rural areas needs improvement.

First, PV development and power grid development are not coordinated, reducing climate adaptability of the grid under high load. Distributed PV systems have been widely integrated into the grid in China's rural areas, complementing large-scale centralized PV facilities due to their decentralized setup and flexible adjustment. Grid construction typically requires three to five years, whereas PV power station construction generally takes two years, leading to a mismatch in development timelines. Overall, the rapid growth of installed PV capacity has posed challenges to the stability, regulation, and consumption capacity of the grid, with distributed PV facilities installed in rural areas significantly impacting rural power grids. The audit found that due to inadequate maintenance of some PV power generation access equipment, some distributed PV facilities in rural areas, such as rooftop and floating solar installations, have experienced issues including aging equipment, slow grid capacity expansion and voltage boosting, and a long-term lack of high-load safety assessments for the power grid.

Second, PV construction occupies farmland and river channels, reducing climate adaptability. Apart from desertified regions, densely populated and economically developed areas face conflicts between PV industry expansion and the occupation of high-quality farmland. The audit revealed that inadequate government planning and guidance have resulted in some rural areas allowing PV facility construction on idle farmland, where concrete foundations damage soil arable layers and hinder the use of agricultural machinery, ultimately reducing grain production. In some cases, local governments have prioritized rapid PV development, leading to PV power stations being built on riverbeds, lake shores, and reservoir areas, posing safety risks. For example, a PV project with an investment of RMB 190 million was built in river channels, illegally occupying shorelines. Ultimately, it had to be dismantled due to its encroachment on the river, impact on flood discharge, and threats to ecological security.

(2) The PV industry development protection system is not well-established, leading to insufficient climate resilience.

First, the industry standards for PV design and construction are not fully developed. The long-term healthy development of the PV industry requires a full-chain industry standard covering design, construction, and acceptance processes to enhance safety assurance capabilities. The audit found that the current universal design standards for PV power systems are based on the power supply security and investment economics of traditional power systems. These standards cannot meet the requirements of new power systems characterized by a high proportion of renewable energy, frequent extreme weather events, and high-cost power outages. Although some regions have introduced design and construction standards from the perspective of PV risk control, a more comprehensive and mandatory national standard system is still in the process of being formulated. In particular, there are still gaps in specialized control standards for PV facilities to enhance their capability to withstand extreme weather conditions such as rain, snow, typhoons, and heatwaves. The absence of design and construction standards has also affected the introduction of safe recycling and reuse standards for PV panels and other components.

Second, a cross-industry early warning system has not yet been established. Efficient responses to extreme weather events require accurate forecasting from the meteorological department. PV power generation authorities should establish an effective coordinated early warning system with meteorological departments to ensure timely responses and the implementation of effective disaster prevention and mitigation measures. The audit found that in some remote rural areas, an effective coordinated early warning system has not yet been established. There is a disconnect between warnings of meteorological departments and the response of PV power generation authorities. Some PV power companies rely solely on public meteorological forecasts to take precautionary measures, which has resulted in shortcomings in effectively preventing hailstorms, typhoons, and snowstorms.

(3) The impact and damage to the ecological environment still persist, posing challenges to sustainable development.

First, a recycling industry chain has not yet been formed. Due to factors such as market scale, technological limitations, and funding shortages, a standardized and well-developed PV component recycling and reuse industry chain has not yet been formed nationwide. Some decommissioned PV components are illegally dismantled, posing high environmental pollution risks. The audit found that the absence of effective industry regulations and guidance has caused some decommissioned PV components to have been sent to small dismantling enterprises that lack qualifications and technical expertise. These enterprises employ simple dismantling, incineration, and landfill disposal methods, leading to the destruction and waste of recyclable parts, thus resulting in low recycling efficiency.

Second, an ecological security assessment system has not yet been established. In some regions, the construction of PV facilities have occupied lakes, wetlands, forests and other biodiversity hotspots. Due to the lack of a comprehensive ecological security assessment system and the absence of evaluation standards, some PV power projects have not undergone rigorous ecological security assessments. The audit found some regions have constructed large-scale PV power facilities on lakes and wetland surfaces, which affected the water ecosystem's access to solar energy, disrupted the ecological balance of aquatic flora and fauna, and reduced the habitat for birds and mammals that rely on water surfaces for survival.

IV. Audit Recommendation

(1) Further strengthen government planning and guidance, with a focus on improving the climate adaptability of PV facilities in rural areas. The government should scientifically plan and guide the coordinated development of the PV industry and the power grid, laying stress on strengthening the integration of rural PV power generation facilities into the grid. Authorities should conduct assessments of the ability of distributed PV systems in rural areas to withstand extreme weather conditions. Investments should be increased in the maintenance and renovation of aging facilities to enhance grid stability and security, thereby reducing power waste caused by poor coordination. Scientific planning should be implemented to coordinate PV project construction with land use

conflicts involving farmland and wetlands. Measures must be taken to strictly prevent damage to soil arable layers caused by PV construction. Additionally, PV projects built in river channels and lakes should be designed to enhance their resilience against floods, storms, and geological disasters.

(2) Further improve the support system for the development of the PV industry to enhance climate resilience. The government should establish a comprehensive industry standard covering the entire chain of photovoltaic design, construction, acceptance, and recycling, and develop specialized standards for the PV power generation industry that are more adaptable to climate change. These standards should serve as a guideline to enhance resilience against extreme weather events. The government should also strengthen the construction of a coordinated cross-industry early warning system, promote the establishment of a timely and effective early warning mechanism between relevant PV power generation authorities and meteorological departments, and especially strengthen the construction of early warning infrastructure in rural areas to ensure comprehensive coverage, timely warnings, and effective prevention, enhancing adaptability and reducing losses.

(3) Further reduce the impact on and damage to the ecological environment to enhance sustainable development capacity. The government should establish a nationwide recycling and reuse industry chain for PV facilities, introduce mandatory environmental impact standards, explore the establishment of a recycling industry fund, encourage large-scale dismantling and recycling by market-based approaches, strengthen control and management of illegal dismantling by small enterprises, and strictly control heavy metal pollution resulting from the dismantling process. It should also advance the development of an ecological security assessment system to make ecological impact a prerequisite for the feasibility study of PV projects, comprehensively enhancing the sustainable development capabilities of the PV industry and the ecosystem.