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Research Suggestions for Assessing Ecological and Climatic Environmental Effects of Wind Power Development in China

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Abstract: Until 2017, the cumulative installed capacity of wind power in China ranked first in the world for 8 continuous years. In the future, China's wind power capacity promises to maintain a high growth rate. Under such circumstances, it is crucial to obtain a clear understanding of the impacts of wind power development on the ecological and climatic environment, so as to ensure the sustainable development of wind power. Establishment of a national major research program on basic sciences, to conduct research on the ecological and climatic effects of wind power development, is the need of the hour. This paper suggests that development planning and distribution of wind power in China by 2050 should be undertaken through observational experiments, mechanism analyses, numerical simulations, effect assessments, and adaptation and mitigation measure studies. An assessment method and indicator system for impacts of wind power development on the ecological and climatic environment should be devised and established. An ecological and climatic environment monitoring network should be built across the nation in regions bound to witness wind power development, and it should be connected with all wind farms in China, so as to regularly evaluate the overall and local impacts on the ecological and climatic environment using big data and artificial intelligence technology.

Keywords: wind energy development and utilization; ecological and climatic environmental effects; monitoring network; quantitative evaluation; adaptation and mitigation

1 Introduction

The past decade witnessed the unprecedented exploration of wind energy and a rapid growth in the wind power market in China. By the end of 2017, the cumulative installed capacity in the whole country amounted to about 164 million kilowatts (kW), showing an almost 29-fold increase over that in 2007. China ranked first in the world for the 8th consecutive year for cumulative installed wind power capacity. On-grid wind power contributed 305 700 million kilowatt hours (kWh) in 2017, amounting to about 4.8% of China's total electric power consumption in that year [1]. Wind energy has become the third source of electric power in China. It is a critical part of the country's clean energy transition and presents an important approach to address climate change.

It is predicted that the rapid growth of the wind power industry will continue, making it one of the major contributors of the country's power supply. The National Energy Administration released the *13th Five-Year Plan for Wind Power Development* on November 16, 2016. As per the Plan, China aims to raise its in-

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stalled grid-connected wind power generation system capacity to at least 210 gigawatts (GW) by the end of 2020 and the planned annual energy yield will be at least 4.2×10^{11} kWh, about 6% of the total power yield of the country. According to the *China Wind Energy Development Roadmap 2050*, jointly released by the Energy Research Institute of the National Development and Reform Commission and the International Energy Agency (IEA), the installed wind power capacity will reach 1000 GW in 2050, meeting 17% of domestic demand. Wind power will thus be one of the country's mainstream energy sources.

The *China Wind Energy Development Roadmap 2050* estimates that the total area of the country's wind farms will reach about 500 000 km^2, which is equivalent to the size of Sichuan province, assuming a capacity factor of 2–3 MW/km^2. China's wind energy resources show a highly uneven distribution. Areas with high wind power development capacity are mainly distributed in the northwest, northern, and northeast regions of China. The area available for wind power development in the three regions (including Xinjiang Autonomous Region, Gansu province, Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region, Hebei province, Heilongjiang province, Jilin province, and Liaoning province) amounts to 68% of the country's total. Wind resources on both high ratio of available land for wind farm building and low-speed wind areas are mainly distributed in the North China Plain and Huanghuai Plain. The available areas in Hebei, Henan, Shandong, Anhui, and Jiangsu provinces occupy 40% of the total land area in the 19 provinces of Central, Eastern, and Southern China. This situation raises concerns about the impacts on ecology, climate, and environment resulting from building and operating large wind power farms in the above-mentioned northern region, and the impact of exploiting low-speed wind resources in the densely populated North China Plain and Jianghuai Plain on the ecological and climatic environment and human activities.

In other words, it remains to be seen whether the large-scale, concentrated development of wind power will change the existing ecological and climatic environment and have negative effects on human life. These aspects have become a major concern for academicians at home and abroad as well as policy makers. It is vital to study this topic if China wishes to ensure sustainable development and exploitation of renewable energies.

2 Research on large-scale wind power development and its negative effects on the ecological and climatic environment

International studies on wind power development and its impacts on the regional ecology and climatic environment began nearly a decade ago and continue to make progress [2–4]. Most of the conclusions point to the negative impacts of wind power. Wind farm operations may adversely affect the behavior of birds, bats, and marine creatures, and can generate noises and visual distractions. Building wind farms results in a series of ecological consequences such as deforestation and soil erosion. Wind turbine operations usually raise night surface temperature, possibly leading to climate-related changes. However, more studies are needed to confirm these findings and research on these topics is underway. Currently, similar studies are being conducted in China by scientists based on their personal interests [5–7]. There are no extensive field studies on the influence of wind farm operations on the climate, ecology, and environment, and research on the impacts of regional wind power development on climatic change, atmospheric circulation, and the regions' environmental carrying capacity are lacking. This is also true with regard to assessment methodology and standard systems for analyzing the impacts of wind power projects on the environment.

2.1 Lack of intensive studies on impacts of wind farm operations on the ecological environment

According to existing investigations, wind turbine operations can reduce the activities of winged creatures, such as bats, living on the farms. The noise level of each turbine is about 96–104 dB (A), repelling noise-sensitive animals. In the past ten years, many overseas reports have confirmed the deaths of birds and bats due to collision with rotating wind turbines [8,9]. An American report in 2010 listed 46 wind farms responsible for the deaths of birds after colliding with the wind turbines and noted that the highest and average death rates are 14 and 4 birds per megawatt per year for most wind farms [10]. Many researchers have evaluated the effects of wind turbines on birds and bats based on the changes in their population, habitats, migration routes, and other factors. They found that rotating wind turbines and overhead power lines are potentially responsible for the deaths of birds and bats, and that most of these creatures avoid resting and looking for food near these installations [9,11,12]. Other studies indicated that rotating wind turbines may drive birds away but have little impact on the bird population [13]. The Dafeng Offshore Wind Farm is located in the south of the pilot zone of the national reserve in China's Yancheng city, Jiangsu province. The *Special Report on Evaluating Jiangsu Dafeng (70 MW) Offshore Wind Power Project's Impacts on Ecological Environment* records an accident that occurred from September 4 to September 11, 2008 near the shoal and fish ponds during the first phase of the construction project. The crash caused the deaths of 25 birds. Wind turbine noise hardly affects migratory birds but has a big influence on resident birds. Most birds are sensitive to noise. Rare birds such as the red-crowned crane avoid noisy areas. A family of 4–5 red-crowned cranes resided in the reclamation area that accommodates the Dafeng Wind Power Project, according to a survey conducted in 2005. However, a survey in 2009 showed no trace of them around the wind farm and within a range of 200 m away from it [14].

Few studies have focused on the impacts of offshore wind

farms on the ecology. The wind turbine bases are planted deep into the seabed, much like artificial reefs. They provide havens for fishes, and thus, in theory, fishes will flourish in the area. The noise generated from the running wind turbines, however, could have a negative impact on the activities and reproduction of fishes living in coastal waters. However, these effects vary for different fishes [15].

Moreover, some studies show that building wind power farms can increase the bulk density of soil, pH level, and total porosity of the disturbed land while decreasing its electrical conductivity, soil moisture, and total salt content, thus leading to a decline in soil fertility [7]. However, no study has investigated whether a wind farm has the same impact on soils outside its territory, namely, whether the farm's sphere of influence and strength of its impact extend outside the farm. It is worth noting that a wind farm's influence on the local climate will certainly change the amount of greenhouse gas emissions from soils, which will have serious impact on carbon and nitrogen circulation in soils [16–18]. In addition, a wind farm's impact on rainfall will indirectly change the amount of water absorbed by soils [19]. Some studies hypothesize that wind farms will change the soil water evaporation rate. However, this notion is only an unproved assumption [20]. Usually, soils outside wind farm territory respond slowly to external disturbances. Thus, it may take 20–25 years or longer for these effects to be demonstrated [21].

Studies on wind power development in China and its negative impacts on the ecological environment are ad hoc and unsystematic, and need urgently organized and systematic research.

2.2 Contradictory conclusions of overseas studies versus China's lack of academic insights into national wind farm development and its impacts

Certain researchers have focused on the possible influence of wind power development on climate change and have raised some significant issues. In recent years, there has been an upsurge in studies on the impacts of wind farm operations on the climate. The main methodologies used in these studies are satellite retrieval and numerical simulation. Observational and experimental studies are rare. However, one instance—the surface meteorological observation project implemented at the Black Law Wind Farm in Scotland—stands out [4].

The running of wind turbines can affect the transmission of energy, momentum, mass, and water between land and the atmosphere while transforming wind energy into electric power. According to some studies, if wind power becomes the only source of global energy consumption, it will consume 0.006%–0.008% of the energy held by the atmospheric layer within 1 km above ground level, which is one order of magnitude less than the loss of energy caused by aerosol pollution and urbanization [22]. Some studies show that the inland surface temperature will rise over 10 °C if the world uses wind power to meet 10% of its energy demand [23]. Some studies note that the increase in temperature and rainfall caused by wind farm operations is much milder than the climate change being witnessed in most parts of Europe [24]. Others confirm that wind farm operations will cause local droughts [25]. A study led by the University of Delaware in the US estimated that an offshore wind farm with an installed capacity of over 300 GW can diminish the speed of a hurricane at the sea surface by 25–41 m/s and reduce the rate of occurrence of such events by 6%–79% [26]. There are essentially two reasons for these disparate conclusions. First, we do not know much about the physical mechanism of the impacts of wind farm operations on turbulent energy exchange at the land surface. Second, the impacts of wind power development on climate change are assessed through numerical simulations, but no exact or definite mathematical expression exists in numerical simulations to assess the interplay between running wind turbines and atmospheric turbulence.

Conducting observational experiments is the best way to understand the physical mechanism of the impacts of wind farm operations on the turbulence energy exchange at the surface layer. The Black Law Wind Farm in Scotland was established in 2005 with 54 wind turbines and has a total capacity of 124 000 kW. To detect its effects on climate change, 101 temperature and humidity sensors were set up in the wind farm, which spans an area of 18.6 km^2. In one of the summer months of 2012, the farm remained closed for operations and maintenance management. This provided an opportunity for Armstrong et al [4] to observe and analyze environmental data during a wind farm stoppage and comparing it with the data obtained during its operation. The results showed that when the wind farm was operational, the biggest increase in surface temperature and humidity was 0.18 °C and 0.03 g/m^3, respectively. The effects on temperature and climate decreased logarithmically with the increase in distance. However, the changes in the microclimate at the ground surface were also influenced by factors such as soil temperature, soil carbon concentration, and carbon cycling in the ecological system. Zhou et al [3] analyzed the satellite data from 2003–2011 for central and western Texas, an area accommodating four of the largest wind farms in the world, and found that nighttime temperature during summers was 0.65 °C higher than that of the nearby areas without wind farms. Walsh-Thomas et al [27] adopted Zhou's [3] method to analyze Landsat 5 satellite's retrieval data during 1984–2011 in a study of the impacts on surface temperature within the San Gorgonio Pass Wind Farm in southern California and its nearby areas. The results showed a noticeable increase in surface temperature within the 12 km area located downwind of the wind farm.

Specialists at Tsinghua University and the China Meteorological Administration have started conducting research on the influence of wind power development on the climatic environment,

but no definite conclusions have been reached yet. One example is Chang's [5] study on the impacts of large-scale wind farms in northwestern China's Guazhou county on the environment based on MODIS land surface temperature data using Zhou's [3] method. The study showed that the temperature of the area near the wind farm increased noticeably at nights but the increase was not obvious in daytime. The increase in nighttime temperature peaked in summer (0.51 °C over 8 years), followed by autumn (0.48 °C over 8 years), and was lowest in winter (0.38 °C over 8 years). No apparent increase was observed in spring.

3 Importance of conducting systematic studies on the impacts of wind power development on the ecological and climatic environment in China

3.1 Importance of assessing ecological and climatic effects before initiating large-scale wind farm projects

As mentioned, China's abundant wind energy resources are distributed mainly in the northwest, north, and northeast regions as well as in the southeast coastal area. The cumulative installed capacity of the six wind power bases (Hami city in Xinjiang Autonomous Region, Jiuquan city in Gansu province, eastern and western Inner Mongolia, Zhangbei county in Hebei province, and the eastern part of Jilin province) located in the "Three Norths" occupies about 44% of the country's installed capacity. Though the nation has begun considering the development of low-speed wind resources in the central, eastern, and southern regions, it is still strategically important to build large-scale wind power bases through concentrated development in resource-rich areas to achieve the goal of installing up to 300 GW capacity in 2030 and 1000 GW capacity in 2050. It is crucial to understand how negative impacts on the regional ecology and climate may be avoided or mitigated by formulating scientific development plans. To do so, it is important to first assess the ecological and climatic feasibility of large wind power projects. To do this, organized research on the impacts of large-scale wind power development on the ecological and climatic environment is necessary. These steps will guarantee sustainable wind power development.

3.2 Need for policies and implementation measures pertaining to climate change adaption and mitigation

The widespread utilization of wind energy can reduce greenhouse gas emissions, thus mitigating the greenhouse effect and alleviating global warming. However, the positive effects can be partly offset if the wind farm operations change the nature of soil, terrestrial radiation balance, energy exchange, and atmospheric turbulence, leading to increased surface temperatures. Despite previous efforts, not enough is known about the comprehensive effects of wind farm operations. On the same note, there is an urgent need to provide scientific and persuasive explanations in response to public concerns about wind power development being the source of serious smog events in Beijing.

3.3 Need of the hour to conduct systematic studies on large-scale wind power development and its impacts on the ecology and climate

Except for analyses of satellite data of surface temperature changes, all the existing overseas studies on this topic have focused on theoretical or numerical simulations. A systematic research methodology, including field observations, scientific experiments, drawing conclusions, mathematical modeling, and scenario projection, is lacking in these studies. In reality, scientific field observations and experiments are key to understanding the influencing mechanisms and verifying the study method. China leads the world in installed wind power capacity, with the Jiuquan Wind Power Base being the world's largest wind farm. In addition to continuing the development of the eight largest wind power bases, China is set to make substantial investments in developing scattered wind farms in its central, eastern, and southern regions. The overall scenario thus offers a mature environment for undertaking comparative observations and research on the impacts of the existing wind farms on the surrounding ecology and climate before and after their installation and operation. The Zhangbei Wind Power Test Base and low-speed wind tunnels in some universities and research institutions can also serve as case studies for such experiments. These studies could cover various fields, including aerodynamics, atmospheric boundary layer meteorology, climatology, plant and animal ecology, restoration ecology, and energy systems engineering. A national research strategy on developing the basic science behind this field will enable joint studies by coordinating specialists, academicians, engineers, and technicians in different disciplines and industries.

4 Suggestions

A national basic science research project should be set up and scientists from the fields of aerodynamics, ecology, climatology, environmental protection, and the wind power industry should convene to conduct field observations and lab experiments on the impacts of wind power development on the ecological and climatic environment. Their explorations should include the mechanisms and impacts of wind farm operations on plants, animals, and the atmospheric environment. These efforts should be aimed at establishing parameter-based numerical simulation systems to evaluate the aforementioned impacts, using different climate models, and adaptation and mitigation measures should be proposed. The following recommendations can bring these efforts to fruition.

(1) Proposal of a wind power development strategy by 2050 based on the premise of rapid growth in wind power and a

healthy ecology and environment.

(2) Development of assessment methods and index systems for evaluating the impacts of wind power development on the ecology and environment, and provision of scientific support for making policies and setting measures to protect the ecological and climatic environment during this development.

(3) Evaluation of extensive field observations/experiments, and updation of these data into an ecology and environment monitoring network covering the wind power zones over the long term. The network should monitor the behaviors of animals and birds and the growth of plants within the wind farms and nearby areas, as well as long-term changes in meteorological factors and turbulent fluxes within the atmospheric boundary layer.

(4) Establishment of an effective connection between the above-mentioned monitoring network and wind farm operations across the country, leveraging big data and artificial intelligence technologies, to assess local and regional ecological and environmental status on a regular basis.

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