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LETTER

Vertically staggered layouts of wind farms effectively mitigate energy-induced land use security

Mengyao Han,[1,*] Siyuan Liu,[2] Lijuan Chen,[2,*] Keyi Liu,[3] Xinwang Zhang,[4] and Chao Ai[2,*]
[1]Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[2]State Key Laboratory of Crane Technology, Yanshan University, Qinhuangdao 066004, China
[3]Xinjiang Institute of Enginering, Urumqi 830023, China
[4]Urumqi Jinfeng Tianyi Wind Power Co., Ltd, Urumqi 830037, China
*Correspondence: hanmy@igsnrr.ac.cn(M. H.); chenlj@ysu.edu.cn(L. C.); aichao@ysu.edu.cn(C. A.)
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Dear Editor,

Onshore wind power technology, one of the most promising renewable energy technologies, holds the potential to optimize the energy mix and mitigate climate change worldwide. However, the deployment of onshore wind power is complicated by aging wind turbine fleets, increasing land use constraints, and the growing relevance of various social factors, all of which further contribute to land use scarcity. Despite adopting strategies such as differentiated management and multi-modal acquisition for the land utilized by wind power facilities, the occupation of land areas for wind power has become a potential concern due to extensive land area requirements. In this study, the original turbine layout was rehabilitated by interspersing higher wind turbines within the original shorter turbines to increase land use efficiency per unit of wind power generation, and the limited land resources are expected to be effectively solved while mitigating climate change and achieving sustainable development goals worldwide.

INTRODUCTION

Energy decarbonization has been recognized as a crucial measure in addressing the challenge of global climate change, which makes the low-carbon transition strategies from production to consumption sides crucial.[1] Wind energy is a form of renewable energy, typically powered by the movement of wind turbines, making it provide renewable electricity free from greenhouse gas emissions.[2,3] Since a rapid increase could be witnessed in the installed capacity of wind power generation worldwide, optimal siting and sizing of wind farms have gradually drawn due attention, making it possible to vertically utilize wind power density in different terrain conditions.[4,5]

Onshore wind power technology, one of the most promising renewable energy technologies, holds the potential to optimize the energy mix and mitigate climate change worldwide. However, the deployment of onshore wind power is complicated by aging wind turbine fleets, increasing land use constraints, and the growing relevance of various social factors, all of which further contribute to land use scarcity.[6] Onshore wind resources are limited due to the increased wind speeds with height, however, wind resources at high altitudes remain poorly utilized, which can be exploited much more thoroughly by increasing wind turbine towers' height or the unit's power ratings.[7]

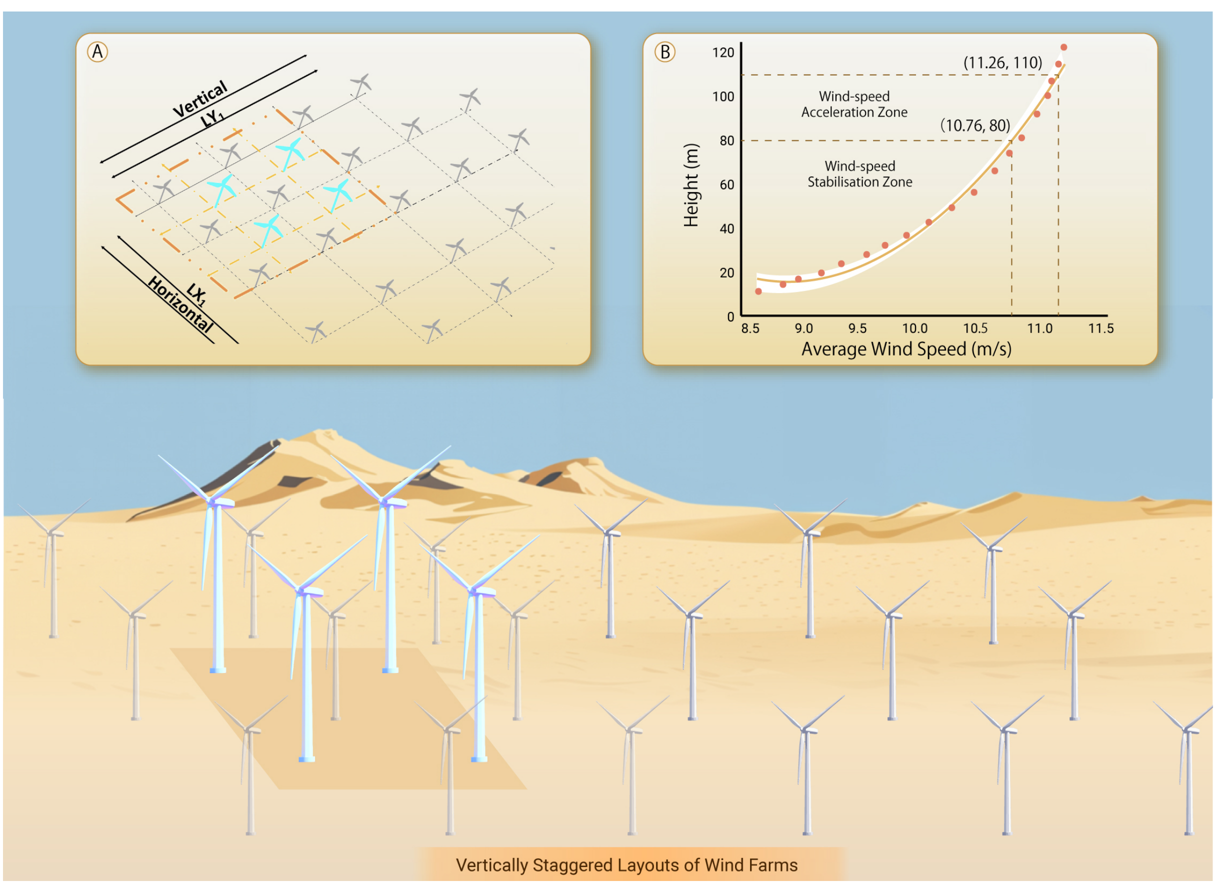

Figure 1. The staggered layout of wind farms with wind speed distribution with different heights. Note: the grey wind turbines represent the original lower wind turbines, and the light blue wind turbines represent the newly installed higher wind turbines (A); The dots in the figure represent the wind speeds at a lower height (80 m) and a higher height (110 m), respectively (B).

Despite adopting strategies such as differentiated management and multimodal acquisition for the land utilized by wind power facilities, the occupation of land areas for wind power has become a potential concern due to extensive land area requirements. Other noteworthy phenomena include the fact that some wind turbines removed could not meet the land use requirements, and the thresholds for land approval become progressively higher.[8] Concerning the above aspects, it is practical to enhance wind power efficiency by developing a vertically staggered layout of wind farms, which has a more vital ability to leverage wind resources, increase land use density, and effectively deploy wind turbines.

VERTICALLY STAGGERED LAYOUTS OF WIND FARMS

Taking the Darbancheng wind farms located in Xinjiang, China as a case, it is the earliest experimental field for wind power deployment, also known as the Wind Valley in China. The potentials of the proposed solutions could be fully utilized, with higher wind turbines limiting the land utilization density as well as increasing wind energy efficiency at the vertical scale. The narrow tube effect makes the number of windy periods more than 160 days in one year, with an annual average wind speed of 6.2 m/s. Before the rehabilitation of wind farms, the geographical layout of the wind turbine was depicted in Figure 1A, where the single power level was generally 2.5 MW, the height of the wind turbine was 80 m, and the number of wind turbine utilization hours was 17 hours/day. To solve the energy-induced land scarcity issues, the original turbine layout was rehabilitated by interspersing higher wind turbines (110 m) within the original lower turbines (80 m) to increase land use efficiency per unit of wind power generation. Comparing the wind farms before and after the rehabilitation, the newly installed capacity of the new standalone power plants is 6 MW, with the height of the new turbines at 110 m and the wind power utilization hour of the wind farms reaching 21 hours/day.

From a macroscopic perspective, renewable energy technologies such as off-shore wind power, wave energy, and hydrogen gradually attracted global attention as emerging renewable technologies,[9,10] which may mitigate onshore land use to a certain extent. Meanwhile, the wake effect will still affect the stand-alone wind power generation, that is, affecting the wind speed of the existing wind turbines and the wind power utilization hours at different heights (see Figure 1B). Note that, wind power utilization rate can be fully reflected in an increasing geographical marginal cost-effectiveness, i.e., a relatively higher vertical density of wind power utilization per unit of land area. However, after the re-interspersion of wind farms, the wind power capacities of this area increased from 6.5 to 14.0 W/m^2, and the wind power generation increased from 23.1 to 32.4 kWh/year/m^2. By empirical comparisons, the utilization hours of the newly installed wind turbine could increase by 21%, and the wind utilization rate of the whole wind farm could improve by 48%, enabling the entire wind farm to operate at a higher efficiency level.

LOCAL PRACTICE AND POLICY IMPLICATIONS

To solve energy-induced land scarcity issues, the original turbine layout of wind farms was suggested to be rehabilitated by interspersing higher wind turbines within original lower turbines to increase land use efficiency per unit of wind power generation, which could propose implications and strategies for the implementation of land-intensive wind farms as follows: (1) Under the restraints of environmental assessment and high-altitude restraint, additional consideration can be given to wind farms in regions with greater access to high altitudes to enhance the utilization rate of wind resources. (2) To reduce the wake effect impact on wind power generation, in combination with utilizing wind farms in regions with abundant wind resources and considering the layout of existing wind turbines, the rational distribution of different heights of new wind turbines can be implemented. (3) To realize the deployment of high-power wind turbines and alleviate the land security of wind turbines, it is necessary to enhance the design and manufacturing of essential components, including blades, bearings, and gearboxes of high-power wind turbines, control technologies, and endurance materials. (4) The layout schemes of wind turbines could address land use constraints of wind turbines in conjunction with recently promising offshore wind farms and large-scale wind power bases. By relaying wind turbines to make full use of wind resources at different heights, the limited land resources can be effectively solved while mitigating climate change and achieving sustainable development goals worldwide.

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AUTHOR CONTRIBUTIONS

Initiation and conceptualization: M.H. and S.L. Investigation: M.H., L.C., and S.L. Methodology and experiment design: M.H., L.C. and S.L. Project administration: K.L. and X.Z. Writing - original draft: M.H. and L.C., Writing - review and editing: S.L. and C.A. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.

LEAD CONTACT WEBSITE

Mengyao Han
https://people.ucas.ac.cn/~hanmy?language=en
https://www.ceenrg.landecon.cam.ac.uk/people/mengyao_han