

Why GAO did this study

Wind energy is one of the fastest-growing renewable energy sources globally. Onshore and offshore wind energy provide an abundant source of electricity with significant environmental benefits, including lower atmospheric greenhouse gas emissions during electricity generation. However, the increases in the development of wind energy facilities increases the potential environmental effects of these facilities, including greater use of natural resources like critical materials and steel, decommissioning and recycling difficulties, and ecological effects such as wildlife harm.

This report discusses (1) technologies or approaches to help reduce the potential environmental effects related to the life cycle of utility-scale wind energy projects, (2) challenges that might hinder implementation of these technologies or approaches, and (3) policy options to help address these challenges.

To conduct this technology assessment, GAO reviewed evidence, including articles and other reports; interviewed government, industry, and academic stakeholders; conducted a site visit; and convened an expert meeting with the assistance of the National Academies of Sciences, Engineering, and Medicine. GAO is identifying policy options in this report.

View [GAO-24-106687](#). For more information, contact Karen L. Howard, PhD, at (202) 512-6888 or HowardK@gao.gov.

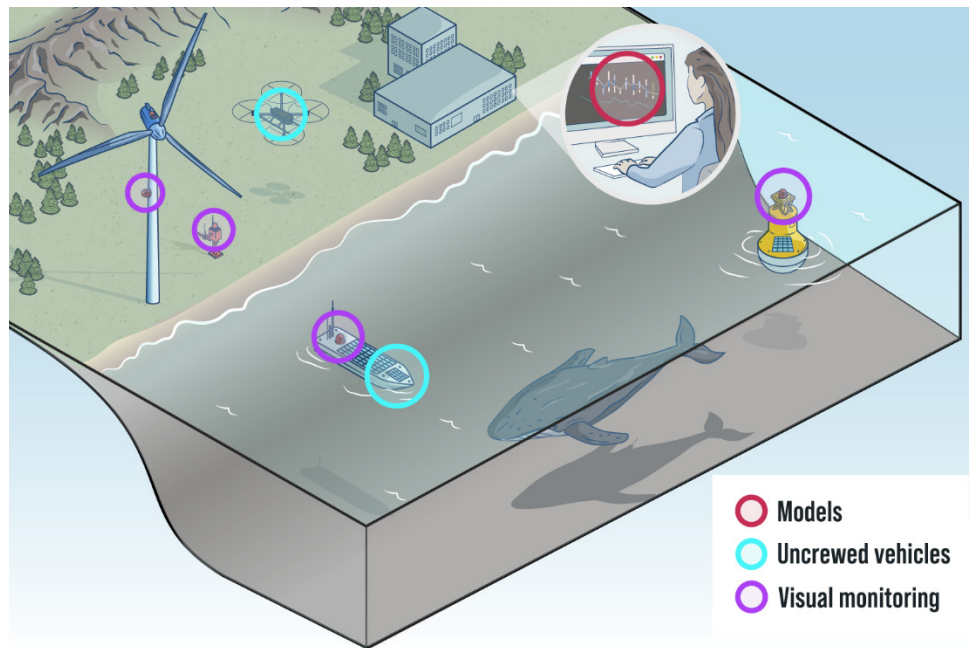
Wind Energy

Technologies and Approaches to Help Address Environmental Effects

What GAO found

Total annual U.S. electricity generation from onshore and offshore wind energy increased from about 6 billion kilowatt-hours (kWh) in 2000 to about 430 billion kWh in 2023, an increase of over 7,000 percent and resulting in wind energy generation providing about 10.2 percent of the electricity in the United States in 2023. Because a continued scale-up in deployment of wind energy facilities could increase the potential environmental effects of these facilities, GAO identified technologies and approaches to address potential effects of wind energy to the physical environment, animals, or humans across a facility's life cycle. These technologies and approaches can be used individually or in combination to address environmental effects. For example, visual monitoring technologies can be placed on uncrewed vehicles to gather data on animal presence and abundance in challenging environments.

Select technologies or approaches in use or under development to help support data collection to address environmental effects



Source: GAO (analysis and illustrations). | GAO-24-106687

However, challenges may limit the use of technologies and approaches to address environmental effects. Some technologies and approaches may incur additional direct costs for a wind energy developer, potentially creating a barrier for use by making the facility's electricity less cost-competitive in the electricity marketplace. Technologies and approaches have to maintain quality assurance during the operation and lifetime of a turbine. Meanwhile, knowledge gaps about projects can make it difficult to determine how to most effectively use technologies and approaches to address challenging effects. Further, some technologies and approaches such as machine learning and modeling require large amounts of data and energy, and barriers to data access may limit the effectiveness of a technology or an approach.

GAO identified five policy options that could help address these challenges or enhance the benefits to technologies and approaches for addressing potential environmental effects of wind energy. These policy options identify possible actions by policymakers, which include Congress, federal agencies, state and local governments, academia, research institutions, and industry. See below for a summary of the policy options and relevant opportunities and considerations.

Policy Options to Help Enhance Benefits or Address Challenges

Policy Option	Opportunities	Considerations
<p>Status quo (report p. 25). Policymakers could take no further intervention, allowing current activities to continue.</p>	<ul style="list-style-type: none"> • Current efforts may address some of the challenges identified in this report without additional resources beyond those that have already been allocated. • Resources and time that may be required in other policy options could instead be used for other priorities. 	<ul style="list-style-type: none"> • Some challenges may remain unresolved or may take longer to resolve than with intervention. • Maintaining the status quo may not be responsive to the wind industry or executive and legislative priorities and may not address unresolved environmental effects.
<p>Encourage innovation and research (report p. 25). Policymakers, such as Congress, academic institutions, industry organizations, or others, could encourage research and development of technologies and approaches to address potential environmental effects.</p>	<ul style="list-style-type: none"> • Additional research could help to better understand wind energy facility sites and inform appropriate and necessary technologies and approaches to address potential environmental effects. • Policymaker communication during research and development can reduce costs and improve access to information and resources. 	<ul style="list-style-type: none"> • Innovation and research can require additional time, personnel, cost, and communication among policymakers.
<p>Data sharing (report p. 26). Academic institutions or other policymakers could facilitate improved data sharing about potential environmental effects, technologies, and approaches.</p>	<ul style="list-style-type: none"> • Having data in a central database may encourage collaboration among policymakers who otherwise might not interact. • Databases could also store other types of information about research alongside the raw data that may not otherwise be accessible. 	<ul style="list-style-type: none"> • Establishing new or trusted data-sharing mechanisms may require additional maintenance, time, personnel, and other resources. • Sharing research that includes proprietary or sensitive data may require investing in data security or removing the proprietary or sensitive information from the data.
<p>Establish consistent methodologies (report p. 27). Policymakers such as academic institutions or industry could encourage the use of consistent methodologies to study wind energy facility sites and to address data and research limitations.</p>	<ul style="list-style-type: none"> • Consistent data collection methods could help establish uniformity in data. • The adaptive management process can encourage use of technologies and approaches to address potential environmental effects while researchers fill knowledge gaps. 	<ul style="list-style-type: none"> • Policymakers may not easily accept voluntary methodologies that were developed by other groups.
<p>Incentives (report p. 28). Policymakers such as government entities could consider incentivizing the use of technologies and approaches to address environmental effects.</p>	<ul style="list-style-type: none"> • Incentives can help operators and companies collaborate to develop and use approaches to address environmental effects that may not be economically viable otherwise. 	<ul style="list-style-type: none"> • Incentives could lead to unintended outcomes for governing authorities or developers. • Environmental and social costs and benefits could be difficult to quantify, making it challenging to set the appropriate level of incentives.