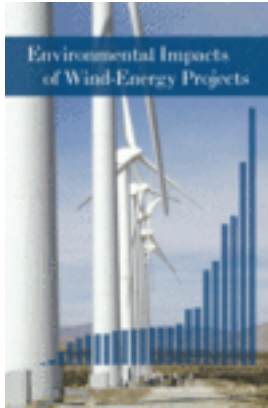


Free Executive Summary



Environmental Impacts of Wind-Energy Projects

Committee on Environmental Impacts of Wind Energy Projects, National Research Council

ISBN: 978-0-309-10830-0, 394 pages, 6 x 9, (2007)

This free executive summary is provided by the National Academies as part of our mission to educate the world on issues of science, engineering, and health. If you are interested in reading the full book, please visit us online at <http://www.nap.edu/catalog/11935.html>. You may browse and search the full, authoritative version for free; you may also purchase a print or electronic version of the book. If you have questions or just want more information about the books published by the National Academies Press, please contact our customer service department toll-free at 888-624-8373.

There has been rapid growth in the construction of wind-powered electricity generating facilities over the past 25 years in the United States. Wind-energy facilities emit no atmospheric pollutants and are driven by a renewable source, addressing multiple environmental concerns such as air quality and climate change. But the expansion of such facilities can carry adverse environmental impacts. As wind energy development continues to expand, federal, state and local agencies should adopt a coordinated approach to evaluating the planning, regulation, and location of wind-energy projects. This National Research Council report provides a framework that can help in evaluating tradeoffs between the benefits of new wind-energy projects and risks of adverse environmental impacts before projects begin.

This executive summary plus thousands more available at www.nap.edu.

Copyright © National Academy of Sciences. All rights reserved. Unless otherwise indicated, all materials in this PDF file are copyrighted by the National Academy of Sciences. Distribution or copying is strictly prohibited without permission of the National Academies Press <http://www.nap.edu/permissions/> Permission is granted for this material to be posted on a secure password-protected Web site. The content may not be posted on a public Web site.

Summary

INTRODUCTION

In recent years, the growth of capacity to generate electricity from wind energy has been rapid, growing from almost none in 1980 to 11,603 megawatts (MW) in 2006 in the United States and about 60,000 MW in 2006 globally. Despite this rapid growth, wind energy amounted to less than 1% of U.S. electricity generation in 2006.

Generation of electricity by wind energy has the potential to reduce environmental impacts caused by use of fossil fuels to generate electricity because, unlike fossil fuels, wind energy does not generate atmospheric contaminants or thermal pollution, thus being attractive to many governments, organizations, and individuals. Others have focused on adverse environmental impacts of wind-energy facilities, which include aesthetic and other impacts on humans and effects on ecosystems, including the killing of wildlife, especially birds and bats. Some environmental effects of wind-energy facilities, especially those from transportation (roads to and from the plant site) and transmission (roads or clearings for transmission lines), are common to all electricity-generating plants; other effects, such as their aesthetic impacts, are specific to wind-energy facilities.

This report provides analyses to help to understand and evaluate positive and negative environmental effects of wind-energy facilities. The committee was not asked to consider, and therefore did not address, non-environmental issues associated with generating electricity from wind energy, such as energy independence, foreign-policy considerations, resource utilization, and the balance of international trade.

Wind energy has a long history, having been used for sailing vessels at least since 3100 BC. Traditionally, windmills were used to lift water and grind grain as early as the 10th century AD. However, significant electricity generation from wind in the United States began only in the 1980s, in California; today, electricity is generated from wind in 36 states, including Alaska and Hawaii.

There has been a rapid evolution of wind-turbine design over the past 25 years. Thus, modern turbines are different in many ways from the turbines that were originally installed in California's three large installations at Altamont Pass, Tehachapi, and San Geronio (Palm Springs). A typical modern generator consists of a pylon about 60 to 90 meters (m) high with a three-bladed rotor about 70 to 90 m in diameter mounted atop it. Larger blades and taller towers are becoming more common. Other support facilities usually include relatively small individual buildings and a substation.

This study is concerned with utility-scale clusters of generators often referred to as "wind farms," not with small turbines used for individual agricultural farms or houses. Some of the installations contain hundreds of turbines; the wind installation at Altamont Pass in California consists of more than 5,000, and those at Tehachapi and Palm Springs contain at least 3,000 each, ranging from older machines as small as 100 kilowatts (kW) to more modern 1.5 MW turbines. The committee that produced this report focused only on installations onshore. There were no offshore wind-energy installations in the United States as of the beginning of 2007.

THE PRESENT STUDY

Statement of Task

The National Research Council was asked to establish an expert committee to carry out a scientific study of the environmental impacts of wind-energy projects, focusing on the Mid-Atlantic Highlands¹ (MAH) as a case example. The study was to consider adverse and beneficial effects, including impacts on landscapes, viewsheds, wildlife, habitats, water resources, air pollution, greenhouse gases, materials-acquisition costs, and other impacts. Using information from wind-energy projects proposed or in place in the MAH and other regions as appropriate, the committee was charged to develop an analytical framework for evaluating those effects to inform siting decisions for wind-energy projects. The study also was to identify major areas of research and development needed to better understand the

¹The MAH refers to elevated regions of Virginia, West Virginia, Maryland, and Pennsylvania.

environmental impacts of wind-energy projects and to reduce or mitigate negative environmental effects.

Current Guidance for Reviewing Wind-Energy Proposals

The United States is in the early stages of learning how to plan for and regulate wind-energy facilities. Federal regulation of wind-energy facilities is minimal if the facility does not have a federal nexus (that is, receive federal funding or require a federal permit), which is the case for most energy development in the United States. The Federal Energy Regulatory Commission regulates the interstate transmission of electricity, oil, and natural gas, but it does not regulate the construction of individual electricity-generation (except for nonfederal hydropower), transmission, or distribution facilities. Apart from Federal Aviation Administration guidelines, federal and state environmental laws protecting birds and bats are the main legal constraints on wind-energy facilities not on federal lands or without a federal nexus.

Wind energy is a recent addition to the energy mix in most areas, and regulation of wind energy is evolving rapidly. In evaluating current regulatory review processes, the committee was struck by the minimal guidance offered to developers, regulators, or the public about (1) the quantity and kinds of information to be provided for review; (2) the degrees of adverse or beneficial effects of proposed wind developments to consider critical for approving or disallowing a proposed project; and (3) the competing costs and benefits of a proposed project to weigh, and how to weigh them, with regard to that single proposal or in comparison with likely alternatives if that project is not built. Such guidance, and technical assistance with gathering and interpreting information needed for decision making, would be enormously useful. This guidance and technical assistance cast at the appropriate jurisdictional level could be developed by state and local governments working with groups composed of wind-energy developers and nongovernmental organizations representing all views of wind energy, in addition to other government agencies. The matrix of government responsibilities and the evaluation guide in Chapter 5 of this report should help the formulation of such guidance.

The committee judges that material in Chapter 5 could be a major step in the direction of an analytic framework for reviewing wind-energy proposals and for evaluating existing installations. If it were followed and adequately documented, it would provide a basis not only for evaluating an individual project but also for comparing two or more proposed projects and for undertaking an assessment of the cumulative effects of other human activities. It also could be used to project the likely cumulative effects of additional wind-energy facilities whose number and placement are identi-

fied in various projections. Finally, following this material would allow for a rational documentation of the most important areas for research.

Environmental Benefits of Wind Energy

The environmental benefits of wind energy accrue through its displacement of electricity generation that uses other energy sources, thereby displacing the adverse environmental effects of those generators. Because the use of wind energy has some adverse impacts, the conclusion that a wind-energy installation has net environmental benefits requires the conclusion that all of its adverse effects are less than the adverse effects of the generation that it displaces. However, this committee's charge was to focus on the use of wind energy; it was not able to evaluate fully the effects of other energy sources. The committee also did not fully evaluate so-called life-cycle effects, those effects caused by the development, manufacture, resource extraction, and other activities affiliated with all energy sources. Thus, in assessing environmental benefits of wind-energy generation of electricity, the committee focused on the degree to which it displaces or renders unnecessary the electricity generated by other sources, and hence on the degree to which it displaces or reduces atmospheric emissions, which include greenhouse gases, mainly carbon dioxide (CO₂); oxides of nitrogen (NO_x); sulfur dioxide (SO₂); and particulate matter. This focus on benefits accruing through reduction of atmospheric emissions, especially of greenhouse-gas emissions, was adopted because those emissions are well characterized and the information is readily available. It also was adopted because much of the public discourse about the environmental benefits of wind energy focuses on its reduction of atmospheric emissions, especially greenhouse-gas emissions. The restricted focus on benefits accruing through reduction of atmospheric emissions also was adopted because the relationships between air emissions and the amount of electricity generated by specified types of electricity-generating sources are well known. However, relationships between incremental changes in electricity generation and other environmental impacts, such as those on wildlife, viewsheds, or landscapes, generally are not known and are unlikely to be proportional. In addition, wind-powered generators of electricity share some kinds of adverse environmental impacts with other types of electricity generators (for example, some clearing of vegetation is required to construct either a wind-energy or a coal-fired power plant and its access roads and transmission lines). Therefore, calculating the extent to which wind energy displaces other sources of electricity generation does not provide clear information on how much, or even whether, those other environmental impacts will be reduced. This report does, however, provide a guide to the methods and information needed to conduct a more comprehensive analysis.

Projections for future wind-energy development, and hence projections for future wind-energy contributions to reduction of air-pollutant emissions in the United States, are highly uncertain. Recent model projections by the U.S. Department of Energy (DOE) for U.S. onshore installed wind-energy capacity in the next 15 years range from 19 to 72 gigawatts, or 2 to 7% of projected U.S. onshore installed electricity-generation capacity. In the same period, wind-energy development is projected to account for 3.5 to 19% of the *increase* in total electricity-generation capacity. If the average wind-turbine size is assumed to be 2 MW (larger than most current turbines), 9,500 to 36,000 wind turbines would be needed to achieve that projected capacity.

Because the wind blows intermittently, wind turbines often produce less electricity than their rated maximum output. On average in the mid-Atlantic region, the capacity factor of turbines—the fraction of their rated maximum output that they produce on average—is about 30% for current technology, and is forecast to improve to nearly 37% by the year 2020. Those are the fractions the committee used in estimating how much wind energy would displace other sources. Other factors, such as how wind energy is integrated into the electrical grid and how quickly other energy sources can be turned on and off, also affect the degree to which wind displaces other energy sources and their emissions. Those other factors probably further reduce the 30% (or projected 37%) figure, but the reduction probably is small, at least for the projected amount of onshore wind development in the United States. The net result in the mid-Atlantic region is unclear. Because the amount of atmospheric pollutants emitted varies from one energy source to another, assumptions must be made about which energy source will be displaced by wind. However, even assuming that all the electricity generation displaced by wind in the mid-Atlantic region is from coal-fired power plants, as one analysis has done, the results do not vary dramatically from those based on the assumption that the average mix of electricity sources in the region is displaced.

In addition to CO₂, coal-fired power plants also are important sources of SO₂ and NO_x emissions. Those two pollutants cause acid deposition and contribute to concentrations of airborne particulate matter. NO_x is an important precursor to ozone pollution in the lower atmosphere. However, because current and upcoming regulatory controls on emissions of NO_x and SO₂ from electricity generation in the eastern United States involve total caps on emissions, the committee concludes that development of wind-powered electricity generation using current technology probably will not result in a significant reduction in total emission of these pollutants from the electricity sector in the mid-Atlantic region.

Conclusions

- Using the future projections of installed U.S. energy capacity by the DOE described above, the committee estimates that wind-energy development probably will contribute to offsets of approximately 4.5% in U.S. emissions of CO₂ from electricity generation by other electricity-generation sources by the year 2020. In 2005, electricity generation produced 39% of all CO₂ emissions in the United States.

- Wind energy will contribute proportionately less to electricity generation in the mid-Atlantic region than in the United States as a whole, because a smaller portion of the region has high-quality² wind resources than the portion of high-quality wind resources in the United States as a whole.

- Electricity generated in the MAH—including wind energy—is used in a regional grid in the larger mid-Atlantic region. Electricity generated from wind energy in the MAH has the potential to displace pollutant emissions, discharges, wastes, and other adverse environmental effects of other sources of electricity generation in the grid. That potential is estimated to be less than 4.5%, and the degree to which its beneficial effects would be realized in the MAH is uncertain.

- If the future were to bring more aggressive renewable-energy-development policies, potential increased energy conservation, and improved technology of wind-energy generation and transmission of electricity, the contribution of wind energy to total electricity production would be greater. This would affect our analysis, including projections for development and associated effects (for example, energy supply, air pollution, and development footprint). On the other hand, if technological advances serve to reduce the emissions and other negative effects of other sources of electricity generation or if fossil-fuel prices fall, the committee's findings might overestimate wind's contribution to electricity production and air-pollution offsets.

- Electricity generated from different sources is largely fungible. Depending on factors such as price, availability, predictability, regulatory and incentive regimes, and local considerations, one source might be preferentially used over others. The importance of the factors changes over varying time scales. As a result, a more complete understanding of the environmental and economic effects of any one energy source depends on a more complete understanding of how that energy source displaces or is displaced by other energy sources, and it depends on a more complete understanding of the environmental and economic effects of all other available

²The quality of a wind resource refers to the amount of wind available for wind-powered generation of electricity.

energy sources. Developing such an understanding would have great value in helping the United States make better-informed choices about energy sources, but that was beyond this committee's charge. Nonetheless, the analyses in this report have value until such time as a more comprehensive understanding is developed.

Ecological Impacts

Wind turbines cause fatalities of birds and bats through collision, most likely with the turbine blades. Species differ in their vulnerability to collision, in the likelihood that fatalities will have large-scale cumulative impacts on biotic communities, and in the extent to which their fatalities are discovered. Probabilities of fatality are a function of both abundance and behavioral characteristics of species. Among bird species, nocturnal, migrating passerines³ are the most common fatalities at wind-energy facilities, probably due to their abundance, although numerous raptor fatalities have been reported, and raptors may be most vulnerable, particularly in the western United States. Among bats, migratory tree-roosting species appear to be the most susceptible. However, the number of fatalities must be considered in relation to the characteristics of the species. For example, fatalities probably have greater detrimental effects on bat and raptor populations than on most bird populations because of the characteristically long life spans and low reproductive rates of bats and raptors and because of the relatively low abundance of raptors.

The type of turbines may influence bird and bat fatalities. Newer, larger turbines appear to cause fewer raptor fatalities than smaller turbines common at the older wind-energy facilities in California, although this observation needs further comparative study to better account for such factors as site-specific differences in raptor abundance and behavior. However, the data are inadequate to assess relative risk to passerines and other small birds. It is possible that as turbines become larger and reach higher, the risk to the more abundant bats and nocturnally migrating passerines at these altitudes will increase. Determining the effect of turbine size on avian risk will require more data from direct comparison of fatalities from a range of turbine types.

The location of turbines within a region or landscape influences fatalities. Turbines placed on ridges, as many are in the MAH, appear to have a higher probability of causing bat fatalities than those at many other sites.

The overall importance of turbine-related deaths for bird populations is unclear. Collisions with wind turbines represent one element of the cumu-

³Passerines are small to medium mainly perching songbirds; about half of all U.S. birds are passerines.

lative anthropogenic impacts on these populations; other impacts include collisions with other structures and vehicles, and other sources of mortality. As discussed in Chapter 3, those other sources kill many more birds than wind turbines, even though precise data on total bird deaths caused by most of these anthropogenic sources are sparser and less reliable than one would wish. Chapter 3 also makes clear that any assessment of the importance of a source of bird mortality requires information and understanding about the species affected and the likely consequences for local populations of those species.

The construction and maintenance of wind-energy facilities also alter ecosystem structure through vegetation clearing, soil disruption and potential for erosion, and noise. Alteration of vegetation, including forest clearing, represents perhaps the most significant potential change through fragmentation and loss of habitat for some species. Such alteration of vegetation is particularly important for forest-dependent species in the MAH. Changes in forest structure and the creation of openings alter microclimate and increase the amount of forest edge. Plants and animals throughout an ecosystem respond differently to these changes. There might also be important interactions between habitat alteration and the risk of fatalities, such as bat foraging behavior near turbines.

Conclusions

- Although the analysis of cumulative effects of anthropogenic energy sources other than wind was beyond the scope of the committee, a better analysis of the cumulative effects of various anthropogenic energy sources, including wind turbines, on bird and bat fatalities is needed, especially given projections of substantial increases in the numbers of wind turbines in coming decades.

- In the MAH, preliminary information indicates that more bats are killed than was expected based on experience with bats in other regions. Not enough information is available to form a reliable judgment on whether the number of bats being killed will have overall effects on populations, but given a general region-wide decline in the populations of several species of bats in the eastern United States, the possibility of population effects, especially with increased numbers of turbines, is significant.

- At the current level of wind-energy development (approximately 11,600 MW of installed capacity in the United States at the end of 2006, including the older California turbines), the committee sees no evidence that fatalities caused by wind turbines result in measurable demographic changes to bird populations in the United States, with the possible exception of raptor fatalities in the Altamont Pass area, although data are lacking for a substantial portion of the operating facilities.

- There is insufficient information available at present to form a reliable judgment on the likely effect of all the proposed or planned wind-energy installations in the mid-Atlantic region on bird and bat populations. To make such a judgment, information would be needed on the future number, size, and placement of those turbines; more information on bird and bat populations, movements, and susceptibility to collisions with turbines would be needed as well. Lack of replication of studies among facilities and across years makes it impossible to evaluate natural variability.

Recommendation

- Standardized studies should be conducted before siting and construction and after construction of wind-energy facilities to evaluate the potential and realized ecological impacts of wind development. Pre-siting studies should evaluate the potential for impacts to occur and the possible cumulative impacts in the context of other sites being developed or proposed. Likely impacts could be evaluated relative to other potentially developable sites or from an absolute perspective. In addition, the studies should evaluate a selected site to determine whether alternative facility designs would reduce potential environmental impacts. Post-construction studies should focus on evaluating impacts, actual versus predicted risk, causal mechanisms of impact, and potential mitigation measures to reduce risk and reclamation of disturbed sites. Additional research is needed to help assess the immediate and long-term impacts of wind-energy facilities on threatened, endangered, and other species at risk. Details of these recommendations, including the frequency and duration of recommended pre-siting, pre-construction, and post-construction studies and the need for replication, are in Chapter 3.

Impacts on Humans

The human impacts considered by the committee include aesthetic impacts; impacts on cultural resources, such as historic, sacred, archeological, and recreation sites; impacts on human health and well-being, specifically from noise and from shadow flicker; economic and fiscal impacts; and the potential for electromagnetic interference with television and radio broadcasting, cellular phones, and radar. This is not an exhaustive list of all possible human impacts from wind-energy projects. For example, the committee did not address potentially significant social impacts on community cohesion, such as cases where proposed wind-energy facilities might cause rifts between those who favor them and those who oppose them. Psychological impacts—positive as well as negative—that can arise in confronting a controversial project also were not addressed.

There has been relatively little dispassionate analysis of the human impacts of wind-energy projects in the United States. In the absence of extensive data, this report focuses mainly on appropriate methods for analysis and assessment and on recommended practices in the face of uncertainty. Chapter 4 contains detailed conclusions and recommendations concerning human impacts, including guides to best practices and descriptions of information needs. General conclusions and recommendations concerning human impacts follow.

Conclusions

- There are systematic and well-established methods for assessing and evaluating human impacts (described in Chapter 4); they allow better-informed and more-enlightened decision making.
- Although aesthetic concerns often are the most-vocalized concerns about proposed wind-energy projects, few decision processes adequately address them. Although methods for assessing aesthetic impacts need to be adapted to the particular characteristics of wind-energy projects, such as their visibility, the basic principles (described in Chapter 4 and Appendix D) of systematically understanding the relationship of a project to surrounding scenic resources apply and can be used to inform siting and regulatory decisions.

Recommendations

- Because relatively little research has been done on the human impacts of wind-energy projects, when wind-energy projects are undertaken, routine documentation should be made of processes that allow for local interactions concerning the impacts that arise during the lifetime of the project, from proposal through decommissioning, as well as processes for addressing the impacts themselves. Such documentation will facilitate future research and therefore improve future siting decisions.
- Human impacts should be considered within the context of the environmental impacts discussed in Chapter 3 and the broader contextual analysis of wind energy—including its electricity-production benefits and limitations—presented in Chapter 2. Moreover, the conclusions and recommendations concerning human impacts presented by topic in Chapter 4 should not be considered in isolation; instead, they should be treated as part of a process. Questions and issues concerning human impacts should be covered in assessments and regulatory reviews of wind-energy projects.

Analyzing Adverse and Beneficial Impacts in Context

The committee's charge included the development of an analytical framework for evaluating environmental and socioeconomic effects of wind-energy developments. As described in Chapter 1, an ideal framework that addressed all effects of wind energy across a variety of spatial and temporal scales would require more information than the committee could gather, given its time and resources, and probably more information than currently exists. In addition, energy development in general, and wind-energy development in particular, are not evaluated and regulated in a comprehensive and comparative way in the United States, and planning for new energy resources also is not conducted in this manner. Instead, planning, regulation, and review usually are done on a project-by-project basis and on local or regional, but not national, scales. In addition, there are few opportunities for full life-cycle analyses or consideration of cumulative effects.

There also are no agreed-on standards for weighting of positive and negative effects of a proposed energy project and for comparing those effects to those of other possible or existing projects. Indeed, the appropriate standards and methods of conducting such comparisons are not obvious, and it is not obvious what the appropriate space and times scales for the comparisons should be. Therefore, a full comparative analysis has not been attempted here.

The committee approached its task—to carry out a scientific study of the adverse and beneficial environmental effects of wind-energy projects—by analyzing the information available and identifying major knowledge gaps. Some of the committee's work was made difficult by a lack of information and by a lack of consistent (or even any) policy guidance at local, state, regional, or national levels about the importance of various factors that need to be considered. In particular, the committee describes in Chapter 1 and Chapter 5 the reasons that led us to stop short of providing a full analytic framework and instead to offer an evaluation guide to aid coordination of regulatory review across levels of government and across spatial scales and to help to ensure that regulatory reviews are comprehensive in addressing the many facets of the human and nonhuman environment that can be affected by wind-energy development.

Framework for Reviewing Wind-Energy Proposals

Conclusion

- A country as large and as geographically diverse as the United States and as wedded to political plurality and private enterprise is un-

likely to plan for wind energy at a national scale in the same way as some European countries are doing. Nevertheless, national-level energy policies (implemented through such mechanisms as incentives, subsidies, research agendas, and federal regulations and guidelines) to enhance the benefits of wind energy while minimizing the negative impacts would help in planning and regulating wind-energy development at smaller scales. Uncertainty about what policy tools will be in force hampers proactive planning for wind-energy development. More-specific conclusions and recommendations follow.

Conclusion

- Because wind energy is new to many state and local governments, the quality of processes for permitting wind-energy developments is uneven in many respects.

Recommendation

- Guidance on planning for wind-energy development, including information requirements and procedures for reviewing wind-energy proposals, as outlined in Chapter 5, should be developed. In addition, technical assistance with gathering and interpreting information needed for decision making should be provided. This guidance and technical assistance, conducted at appropriate jurisdictional levels, could be developed by working groups composed of wind-energy developers; nongovernmental organizations with diverse views of wind-energy development; and local, state, and federal government agencies.

Conclusion

- There is little anticipatory planning for wind-energy projects, and even if it occurred, it is not clear whether mechanisms exist that could incorporate such planning in regulatory decisions.

Recommendation

- Regulatory reviews of individual wind-energy projects should be preceded by coordinated, anticipatory planning whenever possible. Such planning for wind-energy development, coordinated with regulatory review of wind-energy proposals, would benefit developers, regulators, and the public because it would prompt developers to focus proposals on locations and site designs most likely to be successful. This planning could

be implemented at scales ranging from state and regional levels to local levels. Anticipatory planning for wind-energy development also would help researchers to target their efforts where they will be most informative for future wind-development decisions.

Conclusion

- Choosing the level of regulatory authority for reviewing wind-energy proposals carries corresponding implications for how the following issues are addressed:

- (1) cumulative effects of wind-energy development;
- (2) balancing negative and positive environmental and socioeconomic impacts of wind energy; and
- (3) incorporating public opinions into the review process.

Recommendation

- In choosing the levels of regulatory review of wind-energy projects, agencies should review the implication of those choices for all three issues listed above. Decisions about the level of regulatory review should include procedures for ameliorating the disadvantages of a particular choice (for example, enhancing opportunities for local participation in state-level reviews).

Conclusion

- Well-specified, formal procedures for regulatory review enhance predictability, consistency, and accountability for all parties to wind-energy development. However, flexibility and informality also have advantages, such as matching the time and effort expended on review to the complexity and controversy associated with a particular proposal; tailoring decision criteria to the ecological and social contexts of a particular proposal; and fostering creative interactions among developers, regulators, and the public to find solutions to wind-energy dilemmas.

Recommendation

- When consideration is given to formalizing review procedures and specifying thresholds for decision criteria, this consideration should include attention to ways of retaining the advantages of more flexible procedures.

Conclusion

- Using an evaluation guide such as the one recommended in Chapter 5 to organize regulatory review processes can help to achieve comprehensive and consistent regulation coordinated across jurisdictional levels and across types of effects.

Recommendation

- Regulatory agencies should adopt and routinely use an evaluation guide in their reviews of wind-energy projects. The guide should be available to developers and the public.

Conclusion

- The environmental benefits of wind-energy development, mainly reductions in atmospheric pollutants, are enjoyed at wide spatial scales, while the environmental costs, mainly aesthetic impacts and ecological impacts, such as increased mortality of birds and bats, occur at much smaller spatial scales. There are similar, if less dramatic, disparities in the scales of realized economic and other societal benefits and costs. The disparities in scale, although not unique to wind-energy development, complicate the evaluation of tradeoffs.

Recommendation

- Representatives of federal, state, and local governments should work with wind-energy developers, nongovernmental organizations, and other interest groups and experts to develop guidelines for addressing tradeoffs between benefits and costs of wind-energy generation of electricity that occur at widely different scales, including life-cycle effects.

Environmental Impacts of Wind-Energy Projects

Committee on Environmental Impacts of Wind-Energy Projects

Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This project was supported by Contract No. EC25C001 between the National Academy of Sciences and Executive Office of the President, Council on Environmental Quality. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the organizations or agencies that provided support for this project.

International Standard Book Number-13: 978-0-309-10834-8 (Book)

International Standard Book Number-10: 0-309-10834-9 (Book)

International Standard Book Number-13: 978-0-309-10835-5 (PDF)

International Standard Book Number-10: 0-309-10835-7 (PDF)

Library of Congress Control Number 2007931763

Cover design by Liza Hamilton, National Research Council. Photograph of 1.5 mW turbines at San Geronio, CA, by David Policansky, National Research Council. Graph adapted from Figure 1-1, which was reproduced with permission from the American Wind Energy Association.

Additional copies of this report are available from

The National Academies Press
500 Fifth Street, NW
Box 285
Washington, DC 20055

800-624-6242

202-334-3313 (in the Washington metropolitan area)

<http://www.nap.edu>

Copyright 2007 by the National Academy of Sciences. All rights reserved.

Printed in the United States of America.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE ON ENVIRONMENTAL IMPACTS OF WIND-ENERGY PROJECTS

Members

PAUL RISSER (*Chair*), University of Oklahoma, Norman
INGRID BURKE, Colorado State University, Ft. Collins
CHRISTOPHER CLARK, Cornell University, Ithaca, NY
MARY ENGLISH, University of Tennessee, Knoxville
SIDNEY GAUTHREAUX, JR., Clemson University, Clemson, SC
SHERRI GOODMAN, The Center for Naval Analysis, Alexandria, VA
JOHN HAYES, University of Florida, Gainesville
ARPAD HORVATH, University of California, Berkeley
THOMAS H. KUNZ, Boston University, Boston, MA
LYNN MAGUIRE, Duke University, Durham, NC
LANCE MANUEL, University of Texas, Austin
ERIK LUNDTANG PETERSEN, Risø National Laboratory, Frederiksborgvej,
Denmark
DALE STRICKLAND, WEST, Inc., Cheyenne, WY
JEAN VISSERING, Jean Vissering Landscape Architecture, Montpelier, VT
JAMES RODERICK WEBB, University of Virginia, Charlottesville
ROBERT WHITMORE, West Virginia University, Morgantown

Staff

DAVID POLICANSKY, Study Director
RAYMOND WASSEL, Senior Program Officer
JAMES ZUCCHETTO, Director, Board on Energy and Environmental Systems
MIRSADA KARALIC-LONCAREVIC, Manager, Technical Information Center
BRYAN SHIPLEY, Research Associate
JOHN H. BROWN, Program Associate
JORDAN CRAGO, Senior Project Assistant
RADIAH ROSE, Senior Editorial Assistant

Sponsor

EXECUTIVE OFFICE OF THE PRESIDENT, COUNCIL ON ENVIRONMENTAL QUALITY

BOARD ON ENVIRONMENTAL STUDIES AND TOXICOLOGY¹

Members

JONATHAN M. SAMET (*Chair*), Johns Hopkins University, Baltimore, MD
RAMÓN ALVAREZ, Environmental Defense, Austin, TX
JOHN M. BALBUS, Environmental Defense, Washington, DC
DALLAS BURTRAW, Resources for the Future, Washington, DC
JAMES S. BUS, Dow Chemical Company, Midland, MI
COSTEL D. DENSON, University of Delaware, Newark
E. DONALD ELLIOTT, Willkie Farr & Gallagher LLP, Washington, DC
MARY R. ENGLISH, University of Tennessee, Knoxville
J. PAUL GILMAN, Oak Ridge Center for Advanced Studies, Oak Ridge, TN
SHERRI W. GOODMAN, Center for Naval Analyses, Alexandria, VA
JUDITH A. GRAHAM, American Chemistry Council, Arlington, VA
WILLIAM P. HORN, Birch, Horton, Bittner and Cherot, Washington, DC
JAMES H. JOHNSON, JR., Howard University, Washington, DC
WILLIAM M. LEWIS, JR., University of Colorado, Boulder
JUDITH L. MEYER, University of Georgia, Athens
DENNIS D. MURPHY, University of Nevada, Reno
PATRICK Y. O'BRIEN, ChevronTexaco Energy Technology Company,
Richmond, CA
DOROTHY E. PATTON (retired), Chicago, IL
DANNY D. REIBLE, University of Texas, Austin
JOSEPH V. RODRICKS, ENVIRON International Corporation, Arlington, VA
ARMISTEAD G. RUSSELL, Georgia Institute of Technology, Atlanta
ROBERT F. SAWYER, University of California, Berkeley
LISA SPEER, Natural Resources Defense Council, New York, NY
KIMBERLY M. THOMPSON, Massachusetts Institute of Technology,
Cambridge
MONICA G. TURNER, University of Wisconsin, Madison
MARK J. UTELL, University of Rochester Medical Center, Rochester, NY
CHRIS G. WHIPPLE, ENVIRON International Corporation, Emeryville, CA
LAUREN ZEISE, California Environmental Protection Agency, Oakland

Senior Staff

JAMES J. REISA, Director
DAVID J. POLICANSKY, Scholar

¹This study was planned, overseen, and supported by the Board on Environmental Studies and Toxicology.

RAYMOND A. WASSEL, Senior Program Officer for Environmental Sciences
and Engineering

KULBIR BAKSHI, Senior Program Officer for Toxicology

EILEEN N. ABT, Senior Program Officer for Risk Analysis

KARL E. GUSTAVSON, Senior Program Officer

K. JOHN HOLMES, Senior Program Officer

ELLEN K. MANTUS, Senior Program Officer

SUSAN N. J. MARTEL, Senior Program Officer

STEVEN K. GIBB, Program Officer for Strategic Communications

RUTH E. CROSSGROVE, Senior Editor

OTHER REPORTS OF THE BOARD ON ENVIRONMENTAL STUDIES AND TOXICOLOGY

- Scientific Review of the Proposed Risk Assessment Bulletin from the Office of Management and Budget (2007)
- Assessing the Human Health Risks of Trichloroethylene: Key Scientific Issues (2006)
- New Source Review for Stationary Sources of Air Pollution (2006)
- Human Biomonitoring for Environmental Chemicals (2006)
- Health Risks from Dioxin and Related Compounds: Evaluation of the EPA Reassessment (2006)
- Fluoride in Drinking Water: A Scientific Review of EPA's Standards (2006)
- State and Federal Standards for Mobile-Source Emissions (2006)
- Superfund and Mining Megasites—Lessons from the Coeur d'Alene River Basin (2005)
- Health Implications of Perchlorate Ingestion (2005)
- Air Quality Management in the United States (2004)
- Endangered and Threatened Species of the Platte River (2004)
- Atlantic Salmon in Maine (2004)
- Endangered and Threatened Fishes in the Klamath River Basin (2004)
- Cumulative Environmental Effects of Alaska North Slope Oil and Gas Development (2003)
- Estimating the Public Health Benefits of Proposed Air Pollution Regulations (2002)
- Biosolids Applied to Land: Advancing Standards and Practices (2002)
- The Airliner Cabin Environment and Health of Passengers and Crew (2002)
- Arsenic in Drinking Water: 2001 Update (2001)
- Evaluating Vehicle Emissions Inspection and Maintenance Programs (2001)
- Compensating for Wetland Losses Under the Clean Water Act (2001)
- A Risk-Management Strategy for PCB-Contaminated Sediments (2001)
- Acute Exposure Guideline Levels for Selected Airborne Chemicals (five volumes, 2000-2007)
- Toxicological Effects of Methylmercury (2000)
- Strengthening Science at the U.S. Environmental Protection Agency (2000)
- Scientific Frontiers in Developmental Toxicology and Risk Assessment (2000)
- Ecological Indicators for the Nation (2000)
- Waste Incineration and Public Health (2000)
- Hormonally Active Agents in the Environment (1999)
- Research Priorities for Airborne Particulate Matter (four volumes, 1998-2004)
- The National Research Council's Committee on Toxicology: The First 50 Years (1997)
- Carcinogens and Anticarcinogens in the Human Diet (1996)
- Upstream: Salmon and Society in the Pacific Northwest (1996)
- Science and the Endangered Species Act (1995)
- Wetlands: Characteristics and Boundaries (1995)
- Biologic Markers (five volumes, 1989-1995)
- Review of EPA's Environmental Monitoring and Assessment Program (three volumes, 1994-1995)
- Science and Judgment in Risk Assessment (1994)
- Pesticides in the Diets of Infants and Children (1993)
- Dolphins and the Tuna Industry (1992)
- Science and the National Parks (1992)
- Human Exposure Assessment for Airborne Pollutants (1991)
- Rethinking the Ozone Problem in Urban and Regional Air Pollution (1991)
- Decline of the Sea Turtles (1990)

*Copies of these reports may be ordered from the National Academies Press
(800) 624-6242 or (202) 334-3313
www.nap.edu*

Preface

The generation of electricity from wind energy is surprisingly controversial. At first glance, obtaining electricity from a free source of energy—the wind—seems to be an optimum contribution to the nation’s goal of energy independence and to solving the problem of climate warming due to greenhouse gas emissions. As with many first glances, however, a deeper inspection results in a more complicated story. How wind turbines are viewed depends to some degree on the environment and people’s predilections, but not everyone considers them beautiful. Building wind-energy installations with large numbers of turbines can disrupt landscapes and habitats, and the rotating turbine blades sometimes kill birds and bats. Calculating how much wind energy currently displaces other, presumably less-desirable, energy sources is complicated, and predicting future displacements is surrounded by uncertainties.

Although the use of wind energy has grown rapidly in the past 25 years, frequently subsidized by governments at various levels and in many countries eager to promote cleaner alternative energy sources, regulatory systems and planning processes for these projects are relatively immature in the United States. At the national scale, regulation is minimal, unless the project receives federal funding, and the regulations are generic for construction and management projects or are promulgated as guidelines. Regulation at the state and local level is variable among jurisdictions, some with well-developed policies and others with little or no framework, relying on local zoning ordinances. There are virtually no policy or regulatory frameworks at the multistate regional scale, although of course the impacts and benefits of wind-energy installations are not constrained by political boundaries.

This is the complex scientific and policy environment in which the committee worked to address its responsibility to study the environmental impacts of wind energy, including the adverse and beneficial effects. Among the specified considerations were the impacts on landscapes, viewsheds, wildlife, habitats, water resources, air pollution, greenhouse gases, materials-acquisition costs, and other impacts. The committee drew on information from throughout the United States and abroad, but by its charge, focused on the Mid-Atlantic Highlands (a mountainous region in Pennsylvania, Virginia, Maryland, and West Virginia). Using existing information, the committee was able to develop a framework for evaluating those effects; we hope this framework can inform future siting decisions of wind-energy projects. Often, there is insufficient information to provide certainty for these decisions, and thus in the process of its work the committee identified major research needed to improve the assessment of impacts and inform the siting and operational decisions of wind-energy projects.

The committee membership included diverse areas of expertise needed to address the committee's charge. Committee members originated from across the United States, and one hails from Denmark, adding to the international perspective of the study. Members represented the public and private sectors, and numerous natural and social science disciplines. But most important, the committee worked together as a cohesive group in deciding what issues were important and how important, examining issues from multiple perspectives, recognizing and dealing with biases, framing questions and issues in formats that would convey information effectively to decision makers, and considering, respecting, and reconciling differences of opinion, judgment, and interpretation.

The committee broadly defined "environmental" impacts to include traditional environmental measures such as species, habitats, and air and water quality, but attention was also devoted to aesthetic, cultural, recreational, social, and economic impacts. The committee recognized that the planning, policy, and regulatory considerations were paramount if information about impacts was to be translated into informed decision making. Finally, because decision making about wind-energy projects occurs at a variety of geographic and jurisdictional levels, the committee paid careful attention to scale issues as it addressed impacts and benefits.

The benefits of wind energy depend on the degree to which the adverse effects of other energy sources can be reduced by using wind energy instead of the other sources. Assessing those benefits is complicated. The generation of electricity by wind energy can itself have adverse effects, and projecting the amount of wind-generated electricity available in the future is quite uncertain. In addition, the amount of potential displacement of other energy sources depends on characteristics of the energy market, operation of the transmission grid, capacity factor of the wind-energy generators as well

as that of other types of electricity generators, and regulatory policies and practices affecting the production of greenhouse gases. Even if the amount of energy that wind energy displaces is small, it is clear that the nation will depend on multiple energy sources for the foreseeable future and reduction of environmental impacts will thereby require multiple approaches.

The committee began its work expecting that there would be measurable environmental impacts, including biological and socioeconomic impacts, and that there would be inadequate data from which to issue definitive, broadly applicable determinations. Given the complexity of the electric-power industry, the dynamics of energy markets, and the rapidity of technological change, we also expected that predicting the environmental benefits of wind energy would be challenging. On the other hand, the lack of any truly coordinated planning, policy, and regulatory framework at all jurisdictional levels loomed larger than expected throughout our deliberations. Although some predictions about future adverse environmental effects of wind-energy use can be made, the committee recognized gaps in our knowledge and recommended specific monitoring studies that will enable more rigorous siting and operational decisions in the future. Similarly, the report includes descriptions of measures of social impacts of wind-energy development, and recommends studies that would improve our understanding of these impacts.

The complexity of assessing the environmental impacts of wind-energy development can be organized in a three-dimensional action space. These dimensional axes include spatial jurisdictions (local, state/regional, and federal), timing of project stages (pre-project, construction, operational, and post-operational) and environmental and human impacts, each of which include their own time and space considerations. The committee evaluated these issues in offering an evaluation guide for organizing the assessment of environmental impacts. We hope that the results of these deliberations and the evaluations and observations in this report will significantly improve the nation's ability to plan, regulate, and assess the impacts of wind-energy development.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report:

Jan Beyea, Consulting in the Public Interest
Dallas Burtraw, Resources for the Future
Michael Corradini, University of Wisconsin-Madison
Samuel Enfield, PPM Atlantic Renewable
Chris Hendrickson, Carnegie Mellon University
Alan Hicks, New York Department of Environmental Conservation
Mark Jacobson, Stanford University
Kevin Porter, Exeter Associates
Paul Kerlinger, Curry & Kerlinger, LLC
Ronald Larkin, Illinois Natural History Survey
Martin Pasqualetti, Arizona State University
John Sherwell, Maryland Department of Natural Resources
Linda Spiegel, California Energy Commission
James Walker, enXco, Inc.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by the review coordinator, Gordon H. Orians of the University of Washington (emeritus), and the review monitor, Elsa M. Garmire of Dartmouth College. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

The committee gratefully acknowledges the following for making presentations to the committee: Dick Anderson (WEST, Inc.), Edward Arnett (Bat Conservation International), Dinah Bear (Council on Environmental Quality), Gwenda Brewer (Maryland Department of Natural Resources), Daniel Boone (Consultant), Steve Brown (West Virginia Department of Natural Resources), Richard Cowart (The Regulatory Assistance Project), Samuel Enfield (PPM Atlantic Renewable), Ken Hamilton (Whitewater Energy), Alex Hoar (U.S. Fish and Wildlife Service), Judith Holyoke Schoyer Rodd (Friends of the Blackwater), Tom Kerr (U.S. Environmental Protection Agency), Julia Levin (California Audubon), Patricia McClure (Government Accountability Office), The Honorable Alan B. Mollohan (U.S. Representative, WV 1st Congressional District), Kevin Rackstraw (American Wind Energy Association Siting Committee), Dennis Scullion (EnXco, Inc.), John Sherwell (Maryland Department of Natural Resources), Craig Stihler (West Virginia Department of Natural Resources), Robert Thresher (National Renewable Energy Laboratory), James A. Walker (EnXco, Inc.), and Carl Zichella (Sierra Club). In addition, John Reynolds and Joseph Kerecman

of PJM Interconnection and officials of Dominion Resources provided helpful information to the committee through personal communications; Laurie Jodziewicz of the American Wind Energy Association, Nancy Rader of the California Wind Energy Association, and Linda White of the Kern Wind Energy Association provided helpful information and contacts. We also thank Wayne Barwikowski and his colleagues at enXco, Inc. for their informative and helpful tour of the San Geronio (Palm Springs) wind-energy facility.

The committee's work was enhanced in every way by the extraordinary work of the project director, David Policansky, who provided endless sound advice, insightful expertise, and just good sense. The committee offers David its sincere gratitude for his attentive assistance and for his good fellowship throughout the project, which involved five meetings in five different locations with field trips to several wind-energy installations and public hearings. Ray Wassel and James Zucchetto also provided valuable help in framing questions, analyzing literature, and clarifying our thought processes and writings. Bryan Shipley helped to identify relevant literature and to summarize it for the committee. John Brown helped with meeting planning, including arranging field trips and helping to make sure that the committee arrived where it was supposed to be and returned in good condition. Jordan Crago supported the committee in so many ways that I cannot list them all, but they include literature searching and verification (along with Mirsada Karalic-Loncarevic), organizing drafts and committee comments, and keeping the committee housed and fed. Finally, Board Director James Reisa provided his usual wise counsel at difficult times, and his comments have improved the clarity and relevance of this report. We are grateful to them all.

Finally, I want to offer a personal note of appreciation to the committee and the staff. This was an extraordinary group of people, all with outstanding credentials but many points of view, who came together over the past two years to address an important and challenging topic. During this time they listened to each other, helped each other, and worked incredibly hard. It has been an honor to chair the committee, and my life has been enriched by the time and talents of my committee colleagues.

Paul G. Risser, Chair
Committee on Environmental Impacts of
Wind-Energy Projects

Contents

SUMMARY	1
1 INTRODUCTION	15
Generating Electricity from Wind Energy, 17	
The Present Study, 21	
Developing an Analytical Framework, 22	
Temporal and Spatial Scales of Analysis, 24	
Understanding and Assessing Cumulative Environmental Effects, 25	
Organization of the Report, 27	
2 CONTEXT FOR ANALYSIS OF EFFECTS OF WIND-POWERED ELECTRICITY GENERATION IN THE UNITED STATES AND THE MID-ATLANTIC HIGHLANDS	28
Estimating the Environmental Benefits of Generating Electricity from Wind Energy, 28	
Wind Energy Globally, 41	
Quantifying Wind-Energy Benefits in the United States and the Mid-Atlantic Highlands, 42	
Conclusions, 64	
3 ECOLOGICAL EFFECTS OF WIND-ENERGY DEVELOPMENT	67
Chapter Overview, 67	
Introduction, 69	

Bird Deaths in Context, 71	
Turbines Cause Fatalities to Birds and Bats, 72	
Bird and Bat Fatalities, 73	
Wind-Energy Projects Alter Ecosystem Structure, 103	
Projected Cumulative Impacts of Bird and Bat Fatalities: A Working Hypothesis, 122	
Conclusions and Recommendations, 129	
4 IMPACTS OF WIND-ENERGY DEVELOPMENT ON HUMANS	140
Introduction, 140	
Aesthetic Impacts, 141	
Cultural Impacts, 153	
Impacts on Human Health and Well-Being, 156	
Local Economic and Fiscal Impacts, 162	
Electromagnetic Interference, 169	
Conclusions and Recommendations, 173	
General Conclusions and Recommendations, 178	
5 PLANNING FOR AND REGULATING WIND-ENERGY DEVELOPMENT	180
Guidelines for Wind-Energy Planning and Regulation, 181	
Regulation of Wind-Energy Development, 191	
Framework for Reviewing Wind-Energy Proposals, 210	
Conclusions and Recommendations, 213	
REFERENCES	219
APPENDIXES	
A ABOUT THE AUTHORS	269
B EMISSION RATES FOR ELECTRICAL GENERATION	276
C METHODS AND METRICS FOR WILDLIFE STUDIES	279
D A VISUAL IMPACT ASSESSMENT PROCESS FOR EVALUATING WIND-ENERGY PROJECTS	349

Environmental Impacts of Wind-Energy Projects

