

**STRATEGIC HEALTH IMPACT ASSESSMENT ON  
WIND ENERGY DEVELOPMENT IN OREGON**

March 2013

Prepared By:  
Public Health Division  
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## **Final Report**

This Health Impact Assessment report was released for public comment on January 3, 2012. During the 90-day comment period, the Oregon Health Authority's Public Health Division (PHD) received more than 1,000 pages of comments and reference materials. PHD revised this report based on comments received during the public comment period. PHD produced a "Response to comments" report which provides additional information on our revision process, the revisions made in this documents, and responses to other comments.

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**Acknowledgements:**

We would like to thank the members of this project's Steering Committee for their time, expertise, and participation in this HIA. The Steering Committee members are:

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We would like to thank Mark Bastasch, P.E., INCE (CH2M HILL) and Kerrie Standlee, P.E. (Daly-Standlee & Associates) for reviewing a draft of the noise section of this report. We also would like to acknowledge Dan Rubado, MPH and Mandy Green, MPH, for their technical review of an earlier draft of this report, and Sandra Healy, Jill Brackenbrough, and Susan Dietz for their assistance throughout this project.

Finally, we thank this project's funders, the Association of State and Territorial Health Officials and the Centers for Disease Control and Prevention, for their continued support to build state and local capacity to conduct Health Impact Assessment in Oregon.

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# Foreword

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Wind Energy is an important area of renewable energy development for the Pacific Northwest and for the United States. As a key area of energy and economic development, wind energy has positive contributions to offer to Oregon and to the communities that host and are served by wind energy projects. In response to ever-growing energy demand and concerns over environmental and health impacts of petroleum and coal-based energy production, many states have enacted laws and policies requiring that increasing portions of their energy portfolios be derived from sustainable energy production, such as hydro, wind, solar, geo-thermal and wave sources. In 2007, Oregon's Legislature enacted one of the most aggressive sustainable energy plans among other states in the U.S. by passing a renewable energy bill that requires large utilities to obtain at least 25% of their retail electricity portfolio from renewable sources by 2025.

There is little doubt that sustainable energy development is here to stay, but some who live and work in locations where this development is occurring are expressing mixed reactions to the projects being built in their backyards. As these developments are sited near more communities around the state, there are questions and concerns about the potential impacts these projects have on nearby communities

Health Impact Assessment (HIA) is a tool that is being used with increasing frequency around the world. Developed in the European Union in the 1990's and ratified by consensus of the World Health Organization, HIA is "a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population."<sup>1</sup> HIAs are guided by the World Health Organization's definition of health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."<sup>2</sup>

An HIA, as endorsed by the World Health Organization, aims to ensure that:

- people can meaningfully participate in a transparent process for the formulation, implementation and evaluation of policies that affect their health, both directly and through elected political decision makers,
- both positive and negative impacts are shared equitably across a community,
- both short term and long term impacts are considered in the decision-making process, and
- different scientific disciplines and methodologies are used as needed to get as comprehensive an assessment as possible.

This Health Impact Assessment was conducted as a "strategic HIA", as differentiated from a site-specific HIA. A site-specific HIA is designed primarily to answer questions about the health impact of a specific project. In contrast, this HIA is a more general assessment of the ways that wind energy developments in Oregon might affect the health of individuals and communities where they are built and maintained. It is

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<sup>1</sup> World Health Organization Gothenburg consensus paper (1999). Available from: <http://www.apho.org.uk/resource/item.aspx?RID=44163>. Accessed November 16, 2011.

<sup>2</sup> Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946. Available from: <http://www.who.int/about/definition/en/print.html>. Accessed November 16, 2011.

designed to provide both a framework and relevant reference material for future HIAs that may be conducted on proposed wind energy installations. It is intended for use in Oregon, but we recognize that there are communities outside of Oregon where wind energy is being proposed and developed who may also find this a useful framework.

All development projects have both advocates and opponents, and the passions around wind energy developments in Oregon were running high when this HIA was conceived and executed. So it is not at all surprising that this HIA engendered some controversy. I want to recognize the staff that worked on this HIA, particularly the project lead, Dr. Jae Douglas, and thank them for their willingness to guide this project through those choppy waters, and maintain their professionalism and commitment to the goals of this project. Similarly, I want to recognize and thank the members of the project Steering Committee for their extremely constructive engagement with us, despite the passions which this work may have aroused.

Sometimes in the heat of controversy about development projects, economic development and health protection get portrayed as in opposition to one another. But this is a false dichotomy. A robust economy is a powerful driver of good health, just as healthy workers are a critical ingredient to a sustainably robust economy. Both are needed for a truly healthy community. While individual decisions related to a specific development project may of necessity involve compromising one of these goals in favor of another, the long-term public interest is best served when the interdependence of these goals is recognized and balanced through a process that empowers people to shape their lives and communities. It is my hope that this HIA will be a useful tool to do just that for future wind energy development projects in Oregon.

Mel Kohn, MD, MPH  
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# I. Key Findings and Recommendations

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Wind energy  
in Oregon

Wind is a renewable source of energy that increasingly is used to generate electricity in the U.S. and globally. In the U.S., the total installed wind energy capacity grew from 2,472 MW in 1999 to 40,180 MW in 2010 [1]. In the same time period, the total installed generating capacity in Oregon grew from 25 MW to 2,104 MW, and accounted for 7.1% of Oregon's net electricity generation in 2010 [2]. As of 2011, most of Oregon's wind energy development has taken place in north-central and northeastern areas of Oregon, with some development planned in central Oregon.

The growth in wind energy development in Oregon has been influenced by state and national initiatives to reduce greenhouse gas emissions, increase energy security, and promote economic growth in rural areas [3]. One such initiative is the Oregon Legislature's enactment of a Renewable Portfolio Standard (RPS) in 2007. This standard requires electric utilities in Oregon to provide a certain percentage of electricity sold to retail customers from renewable energy sources by 2025; this percentage ranges from 25% for the largest utilities to 5% for the smallest utilities [4]. Wind energy development is expected to continue in the near future because of the RPS, growing energy demand in the Northwest, and the relative cost-effectiveness of wind energy compared to other sources of renewable energy [5].

HIA Purpose,  
Objectives  
and Methods

The Oregon Health Authority's Public Health Division (PHD) conducted this strategic Health Impact Assessment (HIA) in response to a convergence of questions about potential health impacts from wind energy facilities in Oregon. HIA is "a structured process that uses scientific data, professional expertise, and stakeholder input to identify and evaluate public health consequences of proposals [or projects] and suggests actions that could be taken to minimize adverse health impacts and optimize beneficial ones" [6]. This strategic HIA is intended to assist stakeholders to understand and respond to health-related questions at new wind energy developments in Oregon, and provides a framework to guide assessments and decisions for specific projects. This HIA was conducted by PHD and was funded under grants from the Association of State and Territorial Health Officials and Centers for Disease Control and Prevention to build capacity in state health departments for conducting HIAs.

The objectives of this HIA were to:

- Identify community questions and concerns about any potential health impacts from wind energy facilities, and assess the available evidence for health impacts of highest priority for stakeholders in Oregon.
- Develop evidence-based recommendations for elected officials, the Oregon Department of Energy (ODOE), the Energy Facility Siting Council (EFSC), public health officials, the wind energy industry and community members to consider in future wind energy facility siting decisions.
- Engage community members in the HIA process, and provide them and other stakeholders with timely and useful information.
- Increase awareness of and knowledge about HIA and assess its use for specific wind farm siting decisions.

Methods

To establish the scope of this HIA, PHD collected information on questions, issues and concerns about potential health impacts from wind energy facilities in Oregon during three community listening sessions and an online questionnaire. Based on these data, PHD identified five domains, or areas of study, to assess in this HIA: noise, visual impacts, air pollution, economic effects, and community conflict. For each domain, PHD identified key research questions and conducted a literature review. The review focused on research and publications in peer-reviewed public health, engineering, social science, and other journals; reports and studies by state, federal and international governmental agencies; and information published by industry groups, community members, and non-profit organizations. PHD included baseline data on current conditions in Oregon when available and appropriate.

Steering Committee

For this HIA, PHD convened and consulted with a steering committee that included representatives from ODOE, EFSC, county elected officials, a county public health director, a city community development director, community members, the wind energy industry, and private wind energy developers. The Steering Committee met four times from December 2010 to July 2011. During these meetings, the committee helped PHD define the HIA's objectives, scope and research questions, and identify research studies and resources for the assessment. The Steering Committee served in an advisory role only and did not write or provide final approval for this report.

How to use this HIA

This strategic HIA does not replace the need for and value of site-specific assessments on individual wind energy developments in local communities. As noted in several places in this report, it is difficult to generalize about health and other impacts without specific information about a proposed facility and the impacted community. Further, local communities may have health-related questions not addressed in this report. Therefore, this report serves as a starting point for stakeholders to understand potential health impacts from wind energy developments, and assess the need and scope for site-specific assessments for future developments in Oregon.

The findings and recommendations in this strategic HIA reflect an intensive effort by PHD staff and management to review, assess, and synthesize the best available scientific and other credible literature on these topics. Despite our best efforts, we acknowledge that our review was constrained by limited scientific information on some topics, and limited staff time and resources to conduct an exhaustive review on these issues. Given the evolving scientific evidence on how environmental, social, and economic factors influence health, the findings and recommendations in this report may need to be revisited as new information becomes available.

This report is organized by the five areas of study: noise, visual impacts, air pollution, economic effects and community conflict. The Supporting Documentation section has detailed information from our assessment of these five domains, and the Appendix contains detailed information on our methods and process.

## Noise:

### Key Findings

- Environmental noise in community settings is linked to sleep disturbance, annoyance, stress, and decreased cognitive performance [7-9]. These effects, undesirable in their own right, can in turn adversely affect physical health. Chronic sleep disturbance and stress from environmental noise exposures may increase risks for cardiovascular disease, decreased immune function, endocrine disorders, mental illness, and other effects [7, 9-12].
- Objective measures of sound do not necessarily correlate with subjective experiences of noise. When comparing similar sounds, a 3 dB increase correlates to a doubling in sound energy levels, but is considered the threshold of perceivable difference in loudness [10, 13]. A 10 dB increase equates to a 10-fold increase in sound energy, but is perceived as a doubling in loudness [10].
- The perception of sound as noise is a subjective response that is influenced by factors related to the noise, the person, and the social/environmental setting. These factors result in considerable variability in how people perceive and respond to noise at the individual and community level [8, 14]. Factors that are consistently associated with negative community response are changes in noise exposure (i.e., the introduction of a new noise, or a noticeable change in noise loudness or quality), and increases in human-generated noise [14].
- A small number of epidemiological studies have linked wind turbine noise to increased annoyance, feelings of stress and irritation, sleep disturbance, and decreased quality of life [15-18]. These studies have not identified positive associations between wind turbine noise and hypertension, cardiovascular disease, or other diseases. In studies from Europe, annoyance from wind turbine noise was more likely when levels exceeded 35-40 dBA [15, 16].
- There is some evidence that wind turbine noise is more noticeable, annoying and disturbing than other community or industrial noise at the same level of loudness [15, 16, 18-20]. This may be because:
  - wind turbines produce noise that fluctuates in loudness and “type” (i.e., swishing vs. pulsing amplitude-modulated noise) [19-21]. Since fluctuating noise is generally considered more annoying than steady or constant noise, wind turbine noise may be perceived as more annoying than other environmental noise;
  - unlike other sources of community noise, wind turbine noise levels may not decrease predictably at night, and could be perceived as more noticeable and louder at night than during the day. This could result in sleep disturbance in nearby residences [15, 19, 22].
- Factors unrelated to noise may explain some of the annoyance reported in the few epidemiological studies of wind turbine noise. These factors include being able to see wind turbines from home, having a negative opinion about turbines, and self-reported sensitivity to noise [16, 17, 20, 22].
- Wind turbine-generated infrasound (frequencies below 20 Hz) is below levels that can be perceived by humans [23-26].

Oregon Noise  
Standard for  
Wind Energy  
Facilities

- Some field studies have found that in some locations near wind turbine facilities, low frequency noise (frequencies between 10 and 200 Hz) may be near or at levels that can be heard by humans [24-26]. However, there is insufficient evidence to determine if low frequency noise from wind turbines is associated with increased annoyance, disturbance or other health effects [26].
- People with greater exposure to noise from wind turbines, such as those that live nearby, are more likely to experience negative health effects than those with lower levels of exposure to noise. The extent of that impact depends on many site-specific variables, such as distance from the facility, local topography and water bodies, weather patterns, background noise levels, etc.
- In Oregon, a developer must demonstrate that a new wind energy facility complies with an ambient degradation noise standard and a maximum allowable noise standard. These standards are defined in rule by the Oregon Department of Environmental Quality. The ambient degradation standard states that a wind energy development cannot increase the median background noise levels by more than 10 dBA. Developers can either measure actual background noise levels or assume an hourly median ( $L_{50}$ ) noise level of 26 dBA. Based on the assumed background level of 26 dBA, the maximum  $L_{50}$  allowed under the ambient degradation standard is 36 dBA. Under the maximum allowable standard, a wind energy facility may not contribute more than 50 dBA of the noise measured outside of any residence. A landowner can waive the ambient degradation standard, in which case the facility must still comply with the maximum allowable noise standard [27, 28].
- For landowners who do not waive Oregon's noise standard, a new wind energy facility cannot increase outdoor median noise levels by more than 10 dBA. If the background  $L_{50}$  level is assumed to be 26 dBA, the maximum outdoor  $L_{50}$  level allowed under Oregon's ambient degradation standard is 36 dBA.
  - When compared to WHO and USEPA health-based guidelines, an outdoor  $L_{50}$  of 36 dBA is not expected to result in sleep disturbance, disturbance of communication, or annoyance in the general population.
  - Landowners who do not waive Oregon's standard could experience up to a 10 dBA increase in outdoor hourly median noise levels. Given that a 10 dBA increase in noise levels is generally perceived as a doubling in loudness [10] and that wind turbine noise may be more noticeable than other forms of community noise [16], a 10 dBA increase could represent a noticeable change in outdoor noise levels. However, the resulting noise levels are below the WHO and USEPA's recommended guidelines for outdoor noise.

- For landowners who waive Oregon’s ambient degradation standard, a wind energy facility can contribute up to 50 dBA to outdoor ambient L<sub>50</sub> noise levels under Oregon’s maximum allowable standard. The total outdoor L<sub>50</sub> level could exceed 50 dBA if noise from other sources contributes more than 41 dBA to the outdoor L<sub>50</sub>.
  - When compared to WHO and USEPA health-based guidelines, an outdoor L<sub>50</sub> of 50 dBA (or higher) could result in sleep disturbance or serious annoyance. This may be especially true in rural areas, where ambient noise levels are relatively low compared to urbanized areas.
  - Landowners who waive Oregon’s ambient degradation standard could experience a substantial change in outdoor noise levels if the total L<sub>50</sub> reaches or exceeds 50 dBA. An L<sub>50</sub> of 50 dBA could be perceived as approximately four times louder than 26 dBA. Typically, an increase in long-term noise levels of this magnitude (over 20 dBA) is expected to cause widespread annoyance, complaints and possibly threats of legal action [10]. The actual change in long-term noise levels from a wind energy facility will likely be less than 20 dBA since the facility is not expected to continually operate at levels that will result in the maximum L<sub>50</sub> allowed by Oregon law. Further, landowners who waive Oregon’s ambient degradation standard may perceive and respond differently (potentially more favorably) to the new noise levels, particularly if they benefit from the facility or have good relations with the developer [10, 15].
- The Oregon Department of Energy is responsible for responding to noise complaints related to large energy facilities sited through the EFSC process. To date, there have been no complaints related to operating wind energy facilities sited through the EFSC process [29].

## Conclusions

1. Given the current scientific evidence, Oregon’s ambient degradation standard of 36 dBA for wind energy facilities is not expected to result in annoyance, sleep disturbance or other health effects in the general population, and is protective of public health. However, the 10 dBA change allowed under this standard could result in a noticeable change in outdoor noise levels at impacted residences.
2. Landowners who waive Oregon’s ambient degradation standard could experience outdoor L<sub>50</sub> noise levels up to 50 dBA from an operating facility under Oregon’s maximum allowable standard. This could represent a substantial change in outdoor noise levels and possibly result in sleep disturbance and moderate to serious annoyance. The likelihood and magnitude of any impacts will depend on a number of factors, including time of day, characteristics of the noise, and people’s perceptions of the noise source.

Recommendations

3. The major source of uncertainty in our assessment is related to the subjective nature of response to noise, and variability in how people perceive, respond to, and cope with noise. Additional uncertainty is due to moderate or limited evidence in the following areas:
    - a. Epidemiological studies on wind turbine noise
    - b. Amplitude modulation of wind turbine noise
    - c. Indoor low frequency noise impacts from wind turbines
  4. The Oregon Department of Energy is responsible for responding to noise complaints related to large energy facilities sited through the EFSC process. To date, there have been no complaints related to operating wind energy facilities sited through the EFSC process [29]. However, there does not appear to be a systematic process for responding to complaints from county-sited facilities. While PHD has anecdotal evidence of noise complaints and reported health impacts from a few operating facilities in Oregon, we currently lack the data needed to evaluate the frequency or magnitude of any noise-related impacts from existing facilities in the state.
1. To reduce the potential for health effects from wind turbine noise, planners and developers should evaluate and implement strategies to minimize noise generation when outdoor levels exceed Oregon's standards for wind turbine noise. These strategies could include the following:
    - a. During the planning phase, consider site-specific factors that may influence noise propagation and perceived loudness wind turbine noise, particularly factors that may influence actual or perceived noise levels at night.
    - b. Continue to evaluate scientific evidence on how local conditions could change the propagation and character of wind turbine noise (e.g., the effects of wind shear on amplitude modulation and noise generation at night).
  2. The level of annoyance or disturbance experienced by people hearing wind turbine noise is influenced by individuals' perceptions of other aspects of wind energy facilities, such as turbine visibility, visual impacts, trust, fairness and equity, and the level of community engagement during the planning process. By explicitly and aggressively addressing these and other community concerns as part of the wind facility siting process, developers and planners may reduce the health impact from noise produced by wind turbines.
  3. Developers, planners and regulatory agencies should ensure that residents living near wind energy facilities understand the potential risks and benefits associated with a development, and are aware (and able) to report health issues and concerns if they choose.

**Visual  
Impacts:**

Key Findings

- Shadow flicker refers to the alternating levels of light intensity produced when rotating turbine blades cast shadows on nearby buildings or receptors [30]. Most modern large wind turbines produce shadow flicker at frequencies between 0.3 and 1 Hz [30].
- Wind turbines produce shadow flicker at certain times, locations, and under certain conditions. In the continental U.S., shadow flicker impacts are relatively lower compared to locations at higher latitudes, are more likely to occur at sunrise or sunset, and affect a butterfly-shaped area to the northeast and northwest of a wind turbine [30, 31].
- There is insufficient evidence to determine if the “looming effect” (i.e., psychological reactions from feeling “enclosed” by a tall building or object) could have negative impacts on people’s quality of life and well-being. Urban planning guidelines that recommend a 4:1 distance-to-height ratio to minimize negative psychological reactions from feeling “enclosed” by a tall building or object may not be applicable to wind turbines in rural environments [32].
- Some Oregonians voiced concern that wind turbines could distract drivers and result in traffic crashes. However, the very few research studies on this issue did not find any increase in crash rates after the construction of the wind energy facilities [33].

Conclusions

1. Shadow flicker from wind turbines in Oregon is unlikely to cause adverse health impacts in the general population. The low flicker rate from wind turbines is unlikely to trigger seizures in people with photosensitive epilepsy. Further, the available evidence suggests that very few individuals will be annoyed by the low flicker frequencies expected from most modern wind turbines [30, 31, 34].
2. While Oregon does not have specific guidelines for shadow flicker, the setback distances (i.e., the distances between turbines and other structures) required to meet Oregon’s noise standard should be sufficient to minimize shadow flicker impacts in most cases.

Recommendations

1. In cases where the conditions at a particular site make shadow flicker a potential issue, planners and developers should consider the distance, orientation and placement of turbines relative to homes and buildings, and the use of visual obstructions to block flicker.
2. If shadow flicker negatively affects people after a wind turbine is installed, strategies such as planting vegetation as visual barriers or installing blinds on affected buildings may be needed [30].
3. While aesthetic impacts are unlikely to directly affect health, they may play an important role in peoples’ perceptions and acceptance of wind energy developments near their communities [34]. Planners should consider evaluating these impacts if they emerge as an important community concern.



**Air  
Pollution:**

Key Findings

- Direct exposure to air pollutants is associated with short and long-term health effects that include respiratory irritation, asthma, cardiovascular disease, cancer, and premature death [35, 36]. Greenhouse gas (GHG) emissions indirectly impact public health through their contribution to global climate change [36]. Children, the elderly, and those with pre-existing respiratory problems are particularly vulnerable to the health effects from air pollution.
- The major sources of air pollution in Oregon and the U.S. are the combustion of fossil fuels for electricity, transportation and other uses; industrial processes; agricultural practices; wildfires; and construction sites and equipment.
- Wind energy facilities do not generate air emissions from electricity production, and could reduce air pollution if they displace electricity generated from gas, coal, and other fossil fuels [36, 37]. The magnitude of any reductions in air pollutant emissions will depend on the type and amount of fossil fuel units replaced, technological changes, and the effect of policies aimed at reducing air emissions from power plants [36]. The available evidence suggests that the largest air pollution reductions will occur by first replacing energy from coal-fired sources, followed by replacement of oil and natural gas.
- Wind energy could contribute to air pollution through the burning of fossil fuels in vehicles and equipment used for construction and maintenance of wind energy developments. However, the construction-related impacts on local air quality are likely to be short-term and relatively small in magnitude.
- It is unlikely that new or improved access roads will result in substantial increases in vehicular traffic or appreciable changes in local air quality.

Conclusions

1. Wind energy facilities in Oregon could indirectly result in positive health impacts if they reduce regional emissions of GHGs, criteria air pollutants and hazardous air pollutants.
2. Communities near fossil-fuel based power plants that are displaced by wind energy could experience reduced risks for respiratory illness, cardiovascular diseases, cancer, and premature death.
3. The health benefits from any reductions in GHG emissions depend on the extent to which these reductions prevent or lessen the severity of future climate change impacts in Oregon.

Recommendations

1. To reduce the health effects from air pollution, mechanisms that link the development and integration of wind energy for electricity consumption to reductions in fossil fuel use should be implemented (if such mechanisms are available and can be feasibly implemented).
2. While construction-related air pollution is expected to have minimal health impacts, planners and developers should consider strategies to reduce diesel emissions from non-road construction equipment. Some effective strategies include reducing idling time, using cleaner fuels, retrofitting engines, and developing environmental management strategies for operations. The EPA's Clean Construction USA program<sup>3</sup> and Oregon DEQ's Clean Diesel Initiative<sup>4</sup> offer resources, technical assistance, and in some cases, tax credits and grant funding to assist in implementing these strategies.

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<sup>3</sup> U.S. Environmental Protection Agency. National Clean Diesel Campaign. Available from: <http://www.epa.gov/cleandiesel/index.htm>. Accessed November 16, 2011.

<sup>4</sup> Oregon Department of Environmental Quality. Oregon Clean Diesel Initiative. Available from: <http://www.deq.state.or.us/aq/diesel/initiative.htm>. Accessed November 16, 2011.

## Economic Effects:

### Key Findings

- Socioeconomic status (measured by income, education and employment) is a strong predictor of life expectancy and overall health at each stage of life [38, 39]. While the links between SES and health are complex and difficult to measure [40], public health studies have found that as SES increases, the risks for premature mortality, disease, disability, and unhealthy behaviors decrease.
- Higher levels of income inequality are associated with poorer health outcomes [41].
- Data from Oregon indicate that personal income and employment levels in the state are lower compared to the U.S., though educational attainment levels in the state are higher compared to the nation as a whole [42, 43]. Within Oregon, there are noticeable disparities in SES between urban and non-urban areas. Compared to urban areas of the state, non-urban areas have relatively lower levels of personal income, lower wages, and higher rates of unemployment [42, 44].
- Wind energy facilities could result in positive local economic impacts if they increase local jobs, personal income, and local tax revenue. Some evidence suggests that community owned wind projects may have relatively larger economic benefits for local communities compared to absentee-owned projects.
- Decreased property values are often an issue of community concern. Economic studies have not found an association between nearby wind energy facilities and changes in long-term property values [45, 46]. However, because property values are influenced by many factors, and it is difficult to generalize these findings to individual or local changes in property values near a given facility [34].
- Data from Oregon indicate that wind energy facilities have increased employment in Oregon's renewable energy sector and the economy as a whole [47, 48]. Wind energy facilities increased personal income for landowners who obtain lease payments and for workers employed by wind energy facilities [47], and increased tax revenue for local government through property taxes and other fees [34, 49].

### Conclusions

1. Wind energy developments could indirectly result in positive health impacts in Oregon communities if they increase local employment, personal income, and community-wide income and revenue. However, these positive effects may be diminished if there are real or perceived increases in income inequality, or an uneven distribution of costs and benefits, within a community.

### Recommendations

1. Local officials, decision-makers and other stakeholders should consider strategies to increase community-wide economic benefits from wind energy developments. These strategies may include:
  - provisions or incentives for hiring local labor, purchasing goods and supplies from local or state businesses, and investing in training programs to prepare local workers for jobs in the wind energy sector;
  - investing tax revenue in public services (e.g., education and health-care);
  - disbursing regular cash payments to local residents;
  - considering the feasibility of community ownership models in which a wind energy project is partially or wholly owned by community members.

**Community  
Conflict:**  
Key Findings  
and  
Conclusions

1. Community conflicts over wind energy developments have many similarities to conflicts over other controversial siting or natural resource decisions in rural communities [50, 51]. These similarities include: tensions between local risks vs. global benefits, mistrust of developers or owners, and limited opportunities for community members to influence the decision-making process [50, 51].
2. Long-term stress from real or perceived environmental threats can increase risks for cardiovascular disease, endocrine disorders, reduced immune function, mental illness, and other negative health effects [52, 53]. Community conflict over controversial siting or environmental decisions may contribute to or exacerbate this stress, and thus increase risks of these negative health effects [53].
3. Rural communities may be disproportionately impacted by community-level conflicts because these conflicts may erode traditional sources of social and interactional support that community members rely on [54].
4. Based on experiences from other controversial environmental and siting decisions, public participation that is inclusive, collaborative, and transparent is an effective strategy to improve the quality, legitimacy and acceptance of environmental and siting decisions [50, 51, 55, 56].

Recommendations

1. Planners, developers, decision-makers, and government agencies involved in wind facility siting decisions should consider and use strategies to anticipate, understand, and manage conflict and stress in communities near proposed developments. If done well, public participation and community consultation are strategies that can minimize negative and maximize positive impacts (health and otherwise) for local communities, decision-makers, developers, and other stakeholders.

## II. Supporting Documentation

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- A. Wind Energy Development in Oregon
- B. Noise
- C. Visual Impacts
- D. Air Pollution
- E. Economic Effects
- F. Community Conflict

## A. Wind Energy Development in Oregon

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1. Policies related to Wind Energy Development
2. Trends in Generating Capacity
3. Energy Facility Siting in Oregon

## 1. Key Policies related to Wind Energy Development

Several state policies and programs have influenced the growth of wind energy developments in Oregon, including the following:

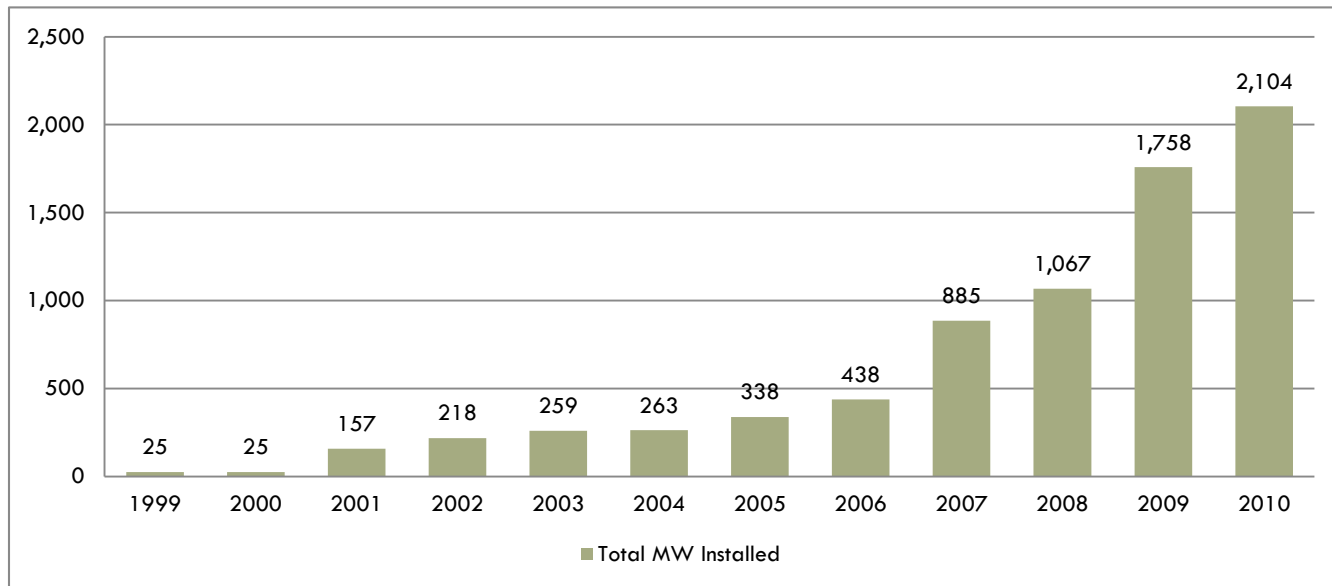
- Greenhouse gas (GHG) emission targets: House Bill 3543 (passed in 2007) set goals to reduce Oregon's GHG emissions and prepare state and local jurisdictions for the effects of climate change. Oregon's goals are to begin reversing growth in GHG emissions by 2010, decrease emissions to 10% below 1990 levels by 2020, and decrease emissions to at least 75% below 1990 levels by 2050 [57].
- Renewable Portfolio Standard (RPS): Oregon's RPS was enacted by Senate Bill 838 in 2007. The RPS requires electric utilities in Oregon to provide a certain percentage of electricity sold to retail customers from renewable energy sources by 2025; this percentage ranges from 25% for the largest utilities to 5% for the smallest utilities [4]. Utilities can meet these requirements by building or operating eligible renewable energy facilities, or buying power or renewable energy certificates from eligible facilities within the Western Electricity Coordinating Council [58]. RPS-eligible sources of renewable energy include biomass, geothermal, hydropower, ocean thermal, solar, tidal, wave, wind and hydrogen [58].
- Business Energy Tax Credit (BETC): Oregon's BETC was enacted in 1979 and modified several times to change the credit's eligibility requirements and caps. In 2007, the BETC was amended to increase the tax credit for renewable energy facilities (including wind) to 50% of the total cost of the project, with a cap of \$10 million. This cap was reduced to \$2.5 million in 2010 [59]. In June 2011, the Oregon legislature sunset the BETC; however, renewable energy projects may be eligible for grants up to \$250,000 or 35% of project costs that are funded through tax credit auctions, taxpayer contributions, or direct appropriations from the legislature [60].

Federal programs that support wind energy development include investment and production tax credits, research and development through the National Renewable Energy Laboratory, and the Wind Powering America initiative.

## 2. Trends in Generating Capacity

The percentage of Oregon's electricity generated by wind increased from 1.5% in 2005 to 7.1% in 2010 [2, 61]. At the end of the second quarter in 2011, Oregon was ranked seventh in the nation for total installed wind energy generating capacity. The total installed generating capacity in Oregon grew from 25 MW in 1999 to 2,305 MW by July 2011 [2]. At the end of 2011, an additional 2,431 MW of generating capacity was approved or under construction (Table 1).

Figure 1: Installed wind capacity in Oregon, 1999-2010.



Data source: US Department of Energy. *U.S. Installed Wind Capacity and Wind Project Locations*. Wind Powering America 2011 [cited 3/6/2011]; Available from: [http://www.windpoweringamerica.gov/wind\\_installed\\_capacity.asp](http://www.windpoweringamerica.gov/wind_installed_capacity.asp).

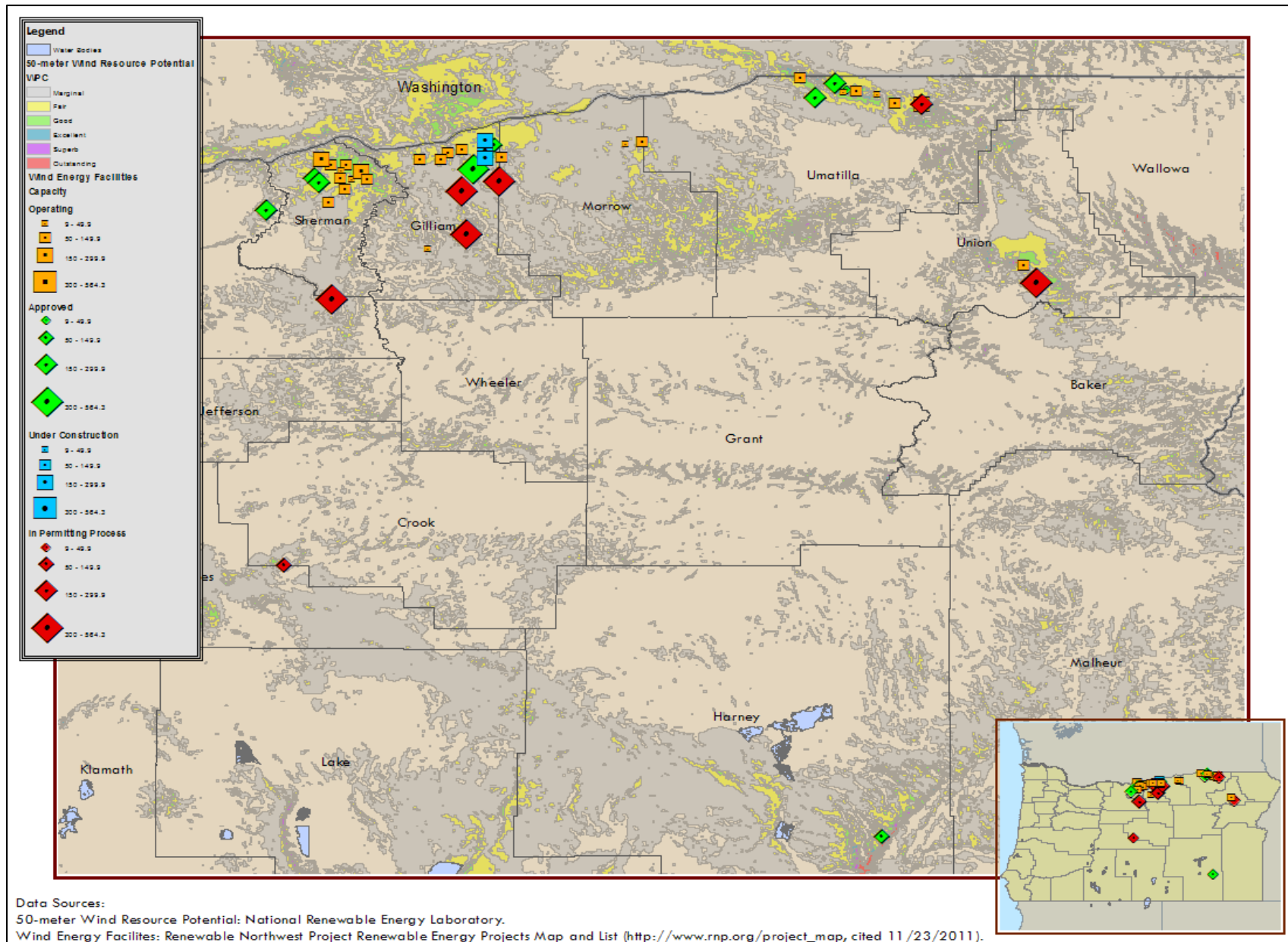
Table 1: Wind generating capacity by status and county as of November 2011.

	Operating	Under Construction	Approved	In Permitting Process	Proposed	Total
Crook				104		104
Gilliam	650.1	265	482	1050		2447.1
Gilliam & Morrow	72	580		564.3		1216.3
Harney			100		104	204
Morrow	9.9					9.9
Morrow & Umatilla	64.5					64.5
Sherman	1057.3		400			1457.3
Umatilla	350.8		404	199.5		954.3
Union	100.7			300		400.7
Wasco			200			200
Wasco & Sherman				500		500
<b>Total</b>	<b>2305.3</b>	<b>845</b>	<b>1586</b>	<b>2717.8</b>	<b>104</b>	<b>7558.1</b>

Data Source: Renewable Northwest Project. Renewable Energy Projects Map and List. [cited 11/23/2011]; Available from: [http://www.rnp.org/project\\_map](http://www.rnp.org/project_map).



Figure 2. Locations of wind energy developments in Oregon, 2011.



Locations of wind energy development in Oregon

As of 2011, most of Oregon's wind energy development has occurred in north-central and northeastern areas of the state. Several facilities are located on the Oregon and Washington sides of the Columbia River Gorge. Figure 2 shows the approximate locations of facilities in operation, under construction, approved, and in the permitting process as of November 2011. At this time, Sherman County has the most wind energy generating capacity in operation, though Gilliam County may soon lead the state in generating capacity as new facilities are approved and constructed (Table 1). There are a few facilities proposed in southern Oregon (Crook and Harney counties), which represents a new area for development.

Future development in Oregon

Wind energy development is expected to continue in order to meet growing regional electricity demand, and satisfy the state's GHG emission goals and the RPS [5, 62]. The population of the Pacific Northwest is expected to grow by more than 28% by 2030; this growth is expected to increase demand for electricity by 1.4% per year through 2030 [5]. While the Northwest Power and Conservation Council has set a goal to meet 85% of regional load growth with conservation measures, the remaining electricity demand will require new generating facilities [62].

There are constraints on increasing electricity production from Oregon's "traditional" sources of energy. Oregon law effectively prohibits constructing new coal-based power plants in the state [62], and the state's only operating coal-based plant is slated to close by 2020 [63]. Hydroelectric generation is constrained by requirements to protect fish and wildlife and is not expected to contribute to increases in load growth in the next 20 years [5]. Finally, in addition to Oregon's GHG emission goals and the RPS, there may be future state and federal policies to reduce carbon and air pollutant emissions. These factors, and wind energy's relative cost-effectiveness compared to other regional renewable energy sources, indicate growth will continue in the near future.

### 3. Energy Facility Siting in Oregon

Prior to building a new energy facility in Oregon, a developer must demonstrate that the facility complies with local, state and federal regulations by obtaining permits from the appropriate government agencies. These regulations are intended to ensure that "the siting, construction and operation of energy facilities [are] accomplished in a manner consistent with protection of the public health and safety and in compliance with the energy policy and air, water, solid waste, land use and other environmental protection policies of this state" [28]. In keeping with this policy, a developer must demonstrate that the facility complies with local, state and federal regulations by obtaining permits prior to the construction of a new energy facility.

A developer can obtain permits through either a local or a state-level siting process [64]. Small facilities (with a peak operating capacity less than 105 MW) can obtain permits through either the state or local process. In the local-level process, a developer applies to all the appropriate state and local-level agencies for the needed permits and approvals. Ultimately, local officials make the final decision for small facilities based on whether the facility complies with a local jurisdiction’s land-use ordinances, which vary across counties, cities and tribal lands.

Large facilities with a peak operating capacity of 105 MW or more are required to go through the state-level siting process. The state-level process provides a streamlined and standardized approach to siting [64]. In this process, a developer applies to one agency (ODOE) to obtain all the necessary permits, and must meet standard requirements that apply to all large energy facilities in Oregon. The Energy Facility Siting Council, a Governor-appointed body of citizens, makes the final determination to issue a site certificate that allows a developer to build and operate a facility. Table 2 shows a comparison of the state and local energy siting processes. As of 2010, approximately 75% of current operational wind farms in Oregon had capacities less than 105 MW and were sited through the local-level process [62].

Table 2: Comparison of state and local energy facility siting processes in Oregon.

	State-level	Local-Level
Facility size	Required for 105 MW or higher; optional for smaller facilities	Less than 105 MW
Process to obtain local/state/federal permits	Consolidated: developer applies to Oregon DOE for site certificate (covers all state-level permits), and to DEQ for federal air/water permits	Unconsolidated: developer applies to local agency to obtain a conditional land-use permit, and then applies to each state/federal authority to obtain necessary permits
Additional requirements	Standardized for all large energy facilities	Dependent on local ordinances
Opportunity for public comment	Defined in site certificate process	Dependent on local requirements
Decision-making body	Energy Facility Siting Council	Local Governments
Entities bound by decision	EFSC decision is binding on all state and local governments	Conditional use permit is binding on local government only
Options to appeal decision	Oregon Supreme Court	Land Use Board of Appeals Oregon Court of Appeals Oregon Supreme Court

MW = Megawatts; DOE = Oregon Department of Energy; DEQ = Oregon Department of Environmental Quality; EFSC = Energy Facility Siting Council

Local  
experience  
with wind  
energy siting

As wind energy development has expanded in some parts of Oregon, developers, decision-makers and community members have gained experience in evaluating the impacts associated with these facilities. This experience has led to the development of policies and processes to guide the siting of future facilities. Some examples include the passage of local ordinances for wind energy facilities, the use of strategic investment plans to guide tax payments and revenue from a facility, and the development of guidelines <sup>5</sup> for counties involved in permitting decisions. These policies and guidelines may be useful for counties that are considering or are new to the siting of wind energy facilities.

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<sup>5</sup> Association of Oregon Counties. Wind Energy Task Force 2009 Report and Recommendations. Available at: <http://www.aocweb.org/aoc/Portals/0/Committees/December%2014%20Report.pdf>. Accessed January 9, 2013.

## B. Noise

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1. Introduction
2. Overview of Sound, Noise and Health
3. Wind Turbine Noise
4. Wind Turbine Noise and Health
5. Oregon Standard for Wind Turbine Noise
6. Conclusions and Recommendations

## **1. Introduction**

Community or environmental noise is unwanted sound from man-made sources and activities outside of the workplace [7]. Community noise is widely recognized as a public health issue that affects people's health and quality of life [7, 14]. Some common sources of community noise include traffic, construction, industry, agriculture, recreation, ventilation systems, and appliances [7].

Wind energy developments represent a relatively new source of noise in Oregon. As new facilities are proposed and built, there are questions about the potential health impacts of wind turbine noise on nearby communities [62]. This section begins with an overview of sound, noise, the impacts of noise on human health, and methods to measure and assess community noise. We then describe the types of noise produced by wind turbines, summarize the available evidence on the effects of wind turbine noise on human health, and examine Oregon's standard for wind turbine noise. This section concludes with our findings and recommendations for wind turbine noise.

## 2. Overview of Sound, Noise and Health

### 2.1. Sound

Sound is a mechanical wave vibration that travels through the air and causes changes in air pressure. Sound frequency is measured in Hertz (Hz), and sound intensity (also known as sound pressure level, or SPL) is typically measured in decibels or dB.

Human perception of sound

Humans with normal hearing can perceive sounds within a certain frequency range depending on the sound's intensity. The human ear can generally hear sound frequencies that range from 20 to 20,000 Hz <sup>6</sup>, and is particularly attuned to frequencies between 1,000 and 6,000 Hz [65]. Sounds with content below 250 Hz are typically characterized as low frequency sound; within this low frequency range, sounds with content below 20 Hz are called infrasound and are not audible by humans. Sounds with content above 1000 Hz are considered to be in the high frequency region, and high frequency sounds above 20,000 Hz (known as ultrasound) are not audible by the human ear. Sounds at lower frequencies must be louder (i.e., have higher SPLs) in order to be heard by humans. For example, the median hearing threshold <sup>7</sup> at 8 Hz is 100 dB, at 20 Hz is 80 dB, and at 200 Hz is 14 dB [66].

Sound propagation

In general, SPLs will decrease (or attenuate) as sound waves move away from the source and through the environment. The major factors that affect how sound propagates and decays through the environment are [10, 13]:

- Geometric spreading from a point, line or plane source. Sound from line or plane sources have the same rate of attenuation as sound from point sources; however, they appear to have lower rates of attenuation because of the contribution of sound from multiple sources.
- atmospheric attenuation, which is the absorption and scattering of sound waves as they move through the atmosphere. Atmospheric attenuation is affected by air temperature, humidity, barometric pressure, and wind speed and direction.
- the sound's frequency content. Lower frequency sounds are less attenuated (or dampened) by the atmosphere than sounds at higher frequencies. Therefore, as the distance from a sound source increases, the sound's lower frequency components will have relatively higher SPLs than the sound's higher frequency components.
- ground characteristics. Hard ground (e.g., pavement or water) tends to reflect more sound, while more porous ground surfaces will absorb some sound.
- terrain profile, obstructions, and other features that act as barriers to sound wave propagation.

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<sup>6</sup> Adults generally are not able to hear sounds at the lower and higher ends of this frequency range.

<sup>7</sup> The hearing threshold is the median SPL that can be heard by young adults with normal hearing; 50% of people have a more sensitive hearing threshold (hear at a lower SPL) and 50% of people have a less sensitive hearing threshold (hear at a higher SPL).

Sound levels  
at a receptor

There also are physical or environmental factors that affect how sound levels at a particular location are perceived. These include [10, 13]:

- distance and position relative to the sound source. Sound levels typically decrease as distance increases. Given the same distance, the sound levels downwind of a source are often louder than levels upwind.
- the presence of barriers, insulation or reflective surfaces. These can include walls, buildings, materials used in a building, etc.
- the sound's frequency content. In general, lower frequency sounds are less attenuated by building materials than sounds at higher frequencies.
- background sounds (from natural or man-made sources) that mask or interfere with sounds from a particular source. Background sound levels vary depending on location, time of day and season, and are generally lower at night-time and in rural areas.

Sound  
measurement

Environmental sound is typically measured and reported as a frequency-weighted decibel level. The dB(A) scale correlates well with human response to sound, and is used to measure moderately loud broadband sounds [67]. The dB(C) scale was developed to evaluate relatively loud sounds (over 70 dB), impulsive sounds, and low frequency sounds [67]. Decibels are measured on a logarithmic scale; therefore, a 3 dB increase in SPLs correlates to a doubling in sound energy, and a 10 dB increase correlates to a 10-fold increase in sound energy [22]. When comparing similar sounds (e.g., comparing one traffic level to another traffic sound level), a 3 dB increase is considered the threshold of perceivable difference.

Investigators use frequency or spectrum analysis when they need additional information on a sound's frequency content. This type of analysis is used to assess sounds with distinct tones, or to examine a sound's frequency components. Spectrum analysis uses filters to separate out a sound's frequency components into bands, and then measure the SPLs within these bands. Frequency analyzers can use "fine" filters that provide very detailed information (narrow-band filters) or relatively "coarse" filters that provide fewer data points (1/3 octave and octave band filters). The type of filter used depends on the goals and resources of the investigation [67].



## 2.2. Noise and Health

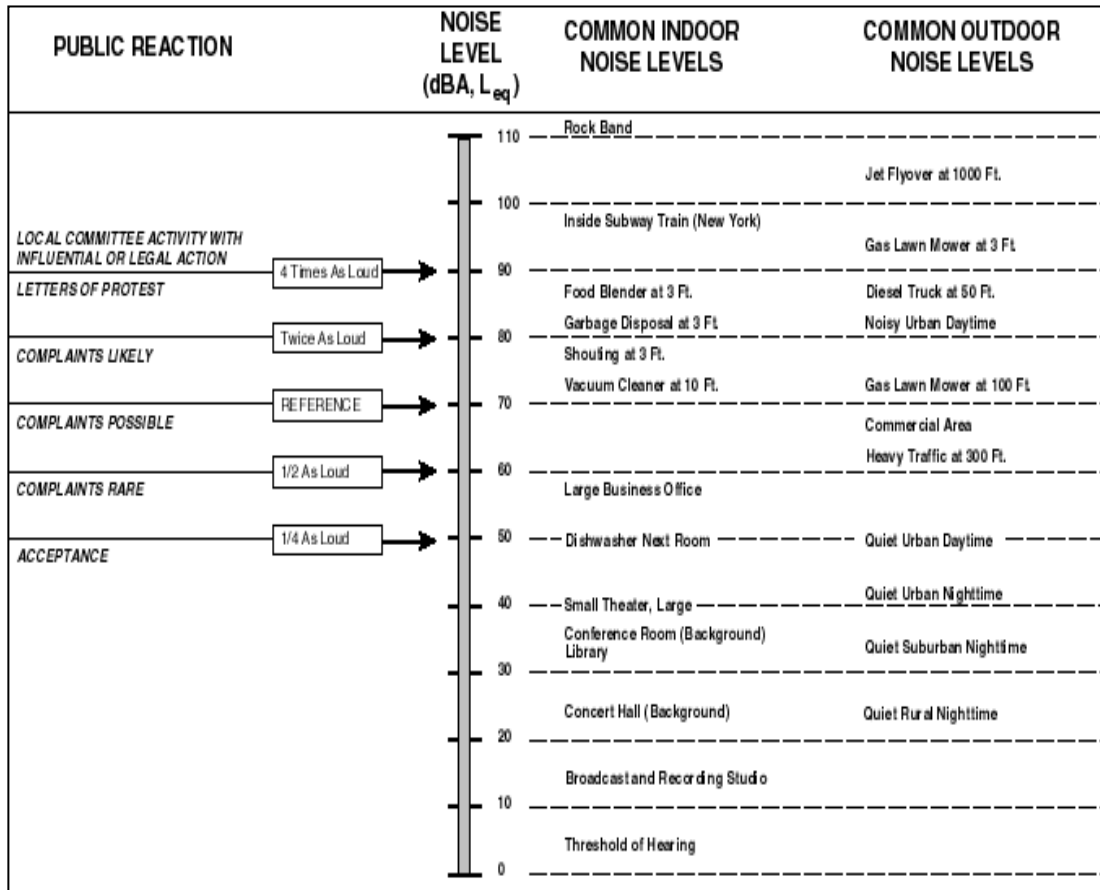
Noise is sound that is perceived as unwanted, annoying, or disturbing [8].

Environmental or community noise is unwanted sound from man-made sources and activities outside of the workplace [7]. Some common sources of community noise include traffic, construction, industry, agriculture, recreation, ventilation systems, and appliances [7].

Noise levels found in community settings

Community noise levels vary across different community settings, types of land use, and population density. In general, man-made noise is expected to be higher in urban areas, near transportation corridors (including highways, airports/air routes, and railways), and in industrial and commercial areas. Noise levels are expected to be relatively lower in wilderness/natural settings, rural areas <sup>8</sup>, and residential areas [7, 68]. Figure 3 shows some examples of indoor and outdoor noise levels.

Figure 3: Examples of common indoor and outdoor noise levels\*.



Source: California Public Utilities Commission. [cited 12/4/2011]. Available from: [http://www.cpuc.ca.gov/Environment/info/esa/divest-pge-one/newpge/chap4\\_10.htm](http://www.cpuc.ca.gov/Environment/info/esa/divest-pge-one/newpge/chap4_10.htm).

\*Note: This figure is shown as an example only. Actual indoor and outdoor noise levels and public reaction depend on noise and community characteristics.

<sup>8</sup> While rural areas typically have lower noise levels than urban/suburban areas, agricultural, manufacturing and transportation activities can impact sound levels in these settings.

Health effects from environmental noise

Scientists have identified three broad categories of health effects from exposure to noise: 1) subjective effects such as annoyance; 2) disturbance of sleep, communication, concentration and other activities; and 3) physiological effects such as anxiety, hearing loss and tinnitus [69]. These effects are often related; for example, disturbance of communication or sleep can lead to annoyance, or vice versa.

Annoyance from noise

"Annoyance" from noise encompasses a wide range of human reactions. People may become annoyed with a noise because it actually interferes with activities or sleep, or because it is simply perceived as being out of place [70]. Suter (1991) provides some context for the use of annoyance in scientific noise surveys:

"Annoyance" has been the term used to describe the community's collective feelings about noise ever since the early noise surveys in the 1950s and 1960s, although some have suggested that this term tends to minimize the impact. While "aversion" or "distress" might be more appropriate descriptors, their use would make comparisons to previous research difficult. It should be clear, however, that annoyance can connote more than a slight irritation; it can mean a significant degradation in the quality of life. This represents a degradation of health in accordance with the WHO's definition of health, meaning total physical and mental well-being, as well as the absence of disease [71].

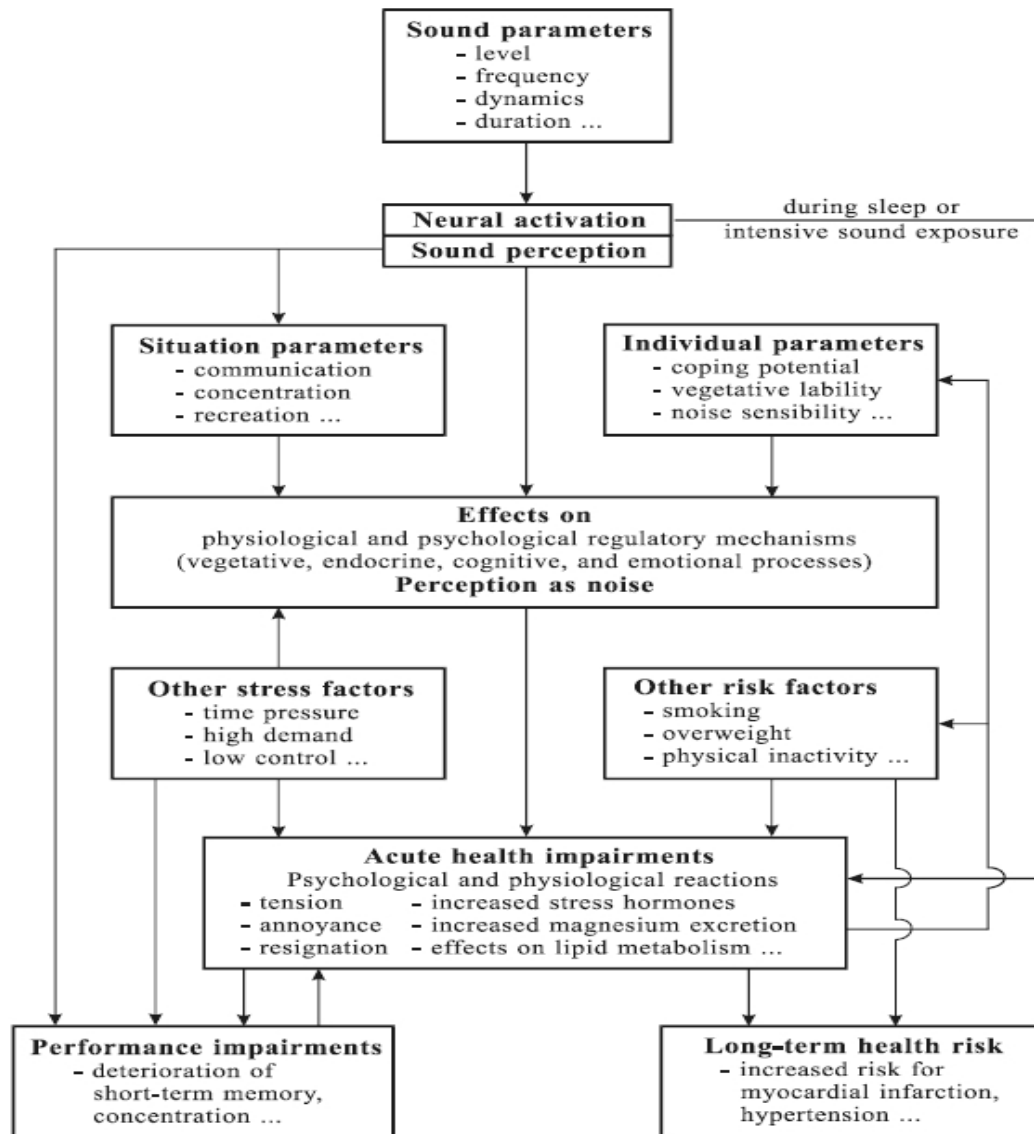
Impacts from environmental noise

At the levels usually found in community settings, environmental noise is most strongly associated with annoyance, sleep disturbance and decreased cognitive performance [8, 9]. The long-term average day-time noise levels associated with increased annoyance are 50 to 55 dBA for outdoor noise, and 35 dBA for indoor noise (measured as  $L_{eq}$ ) [7, 8]. The indoor night-time noise levels associated with sleep disturbance are 30 to 35 dBA (measured as  $L_{eq,8}$ ) [7, 8]. The lowest average night-time outdoor noise levels associated with changes in sleep patterns or self-reported sleep disturbance are between 30 to 40 dBA (measured as  $L_{night, outside}$ ) [69]. Community noise rarely reaches levels that cause hearing loss or decreased hearing sensitivity; these effects occur at levels above 85 dB for long-term or continuous exposures, and at levels beginning at 120 dB for short-term exposures [8, 9].

A limited but growing body of evidence has linked environmental noise to small increased risks for hypertension and cardiovascular disease [8, 72]; this evidence is from European community noise studies focused on aircraft and traffic noise. The increased risks for hypertension and cardiovascular disease were observed at higher noise levels compared to the levels associated with increased annoyance and sleep disturbance. Scientists have not established a threshold or dose-response relationship for these effects [8]. Laboratory studies have documented short-term changes in blood pressure and stress hormones following noise exposure; however, these studies have not established if these physiological changes persist after the noise exposure stops.

Scientists do not completely understand the complex mechanism by which noise produces health effects in humans. Figure 4 shows one possible model for how noise produces health effects through direct and indirect pathways. In the direct pathway, noise exposure activates the nervous and endocrine systems and results in short-term physiological stress response. In the indirect pathway, a person perceives sound as noise and becomes annoyed, which triggers a short-term physiological stress response. The physiological response in both the direct and indirect pathways involves short-term changes in stress hormone levels, heart rate, blood pressure and other factors; these changes resolve when the noise exposure ends. In cases of chronic or long-term noise exposures, people may become habituated to regular noise sources or develop coping mechanisms that reduce their stress response. If this does not occur, the continued stress response to noise may contribute to long-term health risks for cardiovascular disease [8, 73]. As mentioned previously, scientists have not identified a threshold level of exposure for the more harmful effects of noise exposure.

Figure 4: One model to explain effects of low-level noise exposures on health[73].



Factors that affect annoyance or disturbance from noise

At the individual and group levels, the perception of sound as noise is influenced by characteristics related to the noise, the person, and the social/environmental setting (Table 3). The available evidence on noise suggests the following:

- There is considerable variability in how people respond to noise [8]. A particular noise, noise source or noise level may elicit a range of responses within a community. Further, the response seen in one community may be very different than the response in another community [14].
- In addition to loudness or intensity, noise quality (particularly frequency content and temporal distribution) can influence community response [12]. For example, research studies have found that given the same intensity, aircraft noise is more annoying than road traffic noise, which in turn is more annoying than railway noise [7, 14, 70].
- Factors that are consistently associated with negative community response are:
  - a person’s fear of a noise source, and noise sensitivity [7, 74];
  - changes in noise exposure (i.e., the introduction of a new noise, or a noticeable change in noise loudness or quality) [14];
  - increases in man-made noise [14].

Table 3: Factors that influence human perception of sound as noise.

Noise characteristics	<ul style="list-style-type: none"> <li>• Loudness or intensity [7, 9, 14]</li> <li>• Frequency content [7, 9]</li> <li>• Continuous noise vs. discrete noise “events” [14]</li> <li>• Impulsive or fluctuating noise (loudness that varies over time) [7]</li> <li>• Noise accompanied by vibrations [7, 9]</li> <li>• Predictability of noise [22]</li> </ul>
Personal characteristics, attitudes and beliefs	<ul style="list-style-type: none"> <li>• Sensitivity to noise [7, 74]</li> <li>• Ability to control or cope with noise [7]</li> <li>• Fear of danger or harm from noise source [7, 74]</li> <li>• Annoyance with other (non-noise) aspects of source [74]</li> <li>• Beliefs about benefits and importance of source [7, 74]</li> <li>• Expectations about the types and levels of noise appropriate for community [10]</li> </ul>
Social and environmental characteristics	<ul style="list-style-type: none"> <li>• Ability to insulate or isolate from noise [74]</li> <li>• Background noise levels [7]</li> <li>• Community setting and characteristics (i.e., rural, suburban, urban) [10, 75]</li> </ul>

## 2.3. Assessing noise exposure and response

The complex and subjective nature of human response to noise has made it difficult to develop dose-response models to predict the noise levels that result in annoyance, sleep disturbance, and other health effects [7, 8, 14, 70]. This contributes to the challenge of determining the levels of community noise that are “acceptable” or constitute a “significant” impact. In this section, we briefly describe some metrics and guidelines used to assess and evaluate community noise.

Metrics for  
community  
noise levels

Table 4 shows some common metrics used to measure environmental noise. Equivalent noise levels describe the amount of energy present in noise that varies in intensity over time. The equivalent measures  $L_{dn}$  and  $L_{eq}$  are considered the most appropriate metrics to describe long-term average noise levels in a community [7, 10], in part because they have been shown to correlate well with annoyance [7, 13]. While these metrics are useful for evaluating continuous or predictable sources of noise, they are not good measures of impulsive noise or noise events [10]. Further,  $L_{dn}$  and other long-term/annualized metrics may be difficult to use for enforcement purposes because they require long-term measurements of community noise levels [10].

Statistical noise measures are also used to describe community noise levels during a specified measurement interval. Typical measurement durations for statistical noise levels vary from 10 minutes to one hour. Some common statistical descriptors are  $L_{10}$ ,  $L_{50}$  and  $L_{90}$ . During a given measurement interval,  $L_{10}$  represents the loudest 10% of the measurement interval,  $L_{50}$  represents the median noise level, and  $L_{90}$  represents the quietest 90% of the measurement interval [10, 13].

Table 4: Common metrics used to measure community noise.

Metric	Definition	Uses	Notes
$L_{eq, T}$	The level of a hypothetical constant noise with the same energy as the actual noise over a specified time period. Can be thought of as the "average" noise energy level over a time period.	Used for general descriptions of community noise [8]  Appropriate for most continuous sources of noise (e.g., road-way or continuous industrial noise) [7]  Considered a good predictor of community response to community noise [7]	Equivalent noise descriptor  Does not account for noise characteristics that may cause annoyance (e.g., time variation, pulsing, noise "events") [7, 8]
$L_{dn}/L_{den}$	Similar to $L_{eq, 24}$ with penalties (10dB and 5 dB respectively) for night-time and/or evening hours to account for increased noise sensitivity	Describes cumulative outdoor noise  Correlates well with overall community response to noise, especially in residential areas [8, 68]  Often used to describe long-term average noise levels	Equivalent noise descriptor  Penalties not intended to protect from sleep disturbance [7]
$L_{max}$	Maximum noise level during a measurement period	Useful for measuring noise "events" (e.g., aircraft or railway noise) [7, 8]	
$L_{night}$	Similar to $L_{eq}$ for night-time hours (11 pm – 7 am)	Often used to describe long-term average noise levels	Equivalent noise descriptor
$L_{10}$	Loudest 10% of the measurement interval * (90% of the interval duration is below this level)	Sometimes used to evaluate noise "events"	Statistical noise descriptor
$L_{50}$	Median noise level (50% of the measurement interval* is above this level, 50% is below)		Statistical noise descriptor
$L_{90}$	Quietest 10% of the measurement interval* (90% of the measurement interval is above this level)	Used to determine background noise levels	Statistical noise descriptor

SPL = sound pressure level

\*Typical measurement intervals for statistical descriptors range from 10 minutes to 1 hour.

The U.S. EPA's 1972 Federal Noise Control Act provide federal recommendations for environmental noise exposures. The WHO's Guidelines for Community Noise provide more recent and comprehensive guidelines to protect human health from noise exposures. These guidelines (see Table 5 for a subset) identify the indoor and outdoor noise levels that are expected to protect the general population from sleep disturbance, annoyance, hearing impairment and other effects. Some key recommendations for residential areas are as follows:

- For indoor residential areas, the WHO recommends a maximum noise level ( $L_{max}$ ) of 45 dBA. During the day-time or waking hours, an indoor level ( $L_{eq, 16}$ ) of 35 dBA will protect from disturbance of speech communication, while a level of 30 dBA will protect from sleep disturbance during night-time hours [7].
- The WHO recommends day-time outdoor  $L_{eq}$  levels of 50 dBA and 55 dBA to protect from moderate and serious annoyance, respectively [7].
- The U.S. EPA recommends a yearly outdoor  $L_{dn}$  of 55 dBA to protect from disturbance of speech communication. This level will “provide an indoor  $L_{dn}$ <sup>9</sup> of approximately 40 dBA with windows partly open for ventilation. The nighttime portion of this  $L_{dn}$  will be approximately 32 dBA, which should in most cases, protect against sleep interference” [68].
- The U.S. EPA recommends a yearly indoor  $L_{dn}$  of 45 dBA to permit communication in the home [68].
- For residential areas, the WHO and EPA recommend a  $L_{eq, 24}$  of 70 dBA to protect against hearing impairment [7, 68]. Note that the recommended occupational limit for workplace noise exposures is 85 dBA for eight hours ( $L_{eq, 8} = 85$  dBA) [76].
- In 2009, the World Health Organization released a report on the health impacts of night-time noise which included recommendations for night-time noise levels in Europe [72]. In this report, the WHO recommended an annual night-time level of 40 dBA for noise measured outside the facade of a building ( $L_{night, outside}$ ) [72]. This recommendation is based on the lowest noise levels at which adverse health effects (body movements, awakening, self-reported sleep disturbance and arousals) have been observed, even among vulnerable groups. The WHO also established an interim night-time noise target of 55 dBA  $L_{night, outside}$  for jurisdictions unable to achieve the 40 dBA guideline in the near term. The WHO notes that the interim target is not health-based and does not protect vulnerable groups, and recommends its use as “as a feasibility-based intermediate target which can be temporarily considered by policy-makers for exceptional local situations”[72]. Table 6 provides a summary WHO's major findings on night-time noise exposures in Europe.

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<sup>9</sup> While the U.S. EPA assumed an outdoor to indoor noise reduction of 15 dBA (with partly opened windows), the actual reduction will vary depending on the noise source, condition of home and windows, and other factors.

Table 5: Selected WHO and EPA guidelines for community noise[7, 68].

	Health Effects	Environment	Noise level in dBA
WHO Guidelines for Community Noise (1999)	Sleep disturbance	Indoor Dwelling	$L_{eq,T} = 30$ (8) $L_{max} = 45$
	Sleep disturbance	Outside bedroom, window open	$L_{eq,T} = 45$ (8) $L_{max} = 60$
	Speech intelligibility, moderate annoyance	Indoor Dwelling	$L_{eq,T} = 35$ (16) $L_{max} = 45$
	Moderate annoyance	Outdoor living areas	$L_{eq,T} = 50$ (16)
	Serious annoyance	Outdoor living areas	$L_{eq,T} = 55$ (16)
	Speech intelligibility, learning disturbance, message communication	Indoor schools	$L_{eq,T} = 35$ (class time)
	Hearing impairment	Industrial/ commercial/ traffic areas	$L_{eq,T} = 70$ (24)
US EPA - 1972 Federal Noise Control Act	Annoyance and activity disturbance (outdoor speech communication, sleep disturbance indoors at night-time)	Outdoor living areas	$L_{dn} \leq 55^*$
	Annoyance and activity disturbance (indoor speech communication)	Indoor living areas	$L_{dn} \leq 45$
	Hearing impairment	All areas	$L_{eq,T} = 70$ (24)

WHO = World Health Organization, EPA = Environmental Protection Agency, dBA = A-weighted decibels,  $L_{eq,T}$  = equivalent noise energy in dB(A) over time period T (hours),  $L_{max}$  = maximum noise level,  $L_{dn}$  = yearly day-night equivalent noise levels

\*An outdoor  $L_{dn}$  of 55 dBA will provide an indoor  $L_{dn}$  of approximately 40 dBA with windows partly open for ventilation. The nighttime portion of this  $L_{dn}$  will be approximately 32 dBA, which should in most cases, protect against sleep interference[68].

Table 6: Effects of different night-time noise levels on population health [72].

Annual night-time noise level ( $L_{night, outside}$ )	Health effects observed in the population
Up to 30 dBA	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night, outside}$ of 30 dBA is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40 dBA	A number of effects on sleep are observed in this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (e.g, children, the chronically ill, the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night, outside}$ of 40 dBA is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40 to 55 dBA	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dBA	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.



The "absolute" guidelines discussed above address noise intensity and (for  $L_{dn}/L_{night}$ ) time of day, but do not account for the many other factors that influence community response to noise. For example, there is evidence that noticeable changes in long-term noise levels may result in community response, even if the new levels fall below the guidelines noted above [10, 12]. The EPA and WHO suggest that long-term increases of 5 dBA or greater may result in community noise impacts [7, 68]. Other guidelines suggest that an increase of 5-10 dBA may be perceived as intrusive, an increase of 10-15 dBA may be noticeable, and increases over 15 dBA may be objectionable or intolerable [11].

In order to improve community noise impact assessments, the EPA proposed a method that adjusts (or normalizes) increases in long-term noise levels by noise characteristics (e.g., impulsivity, the presence of distinct tones), background noise levels, community characteristics and attitudes, and other factors [12, 68]. For example, in a community with no previous experience with intrusive noise, the noise level from a new source may be adjusted by +5 dBA. However, if a community has previous experience with intrusive noise or good relations with the source's operator, the "new" noise level may be adjusted by -5 dBA. After making these adjustments, the guidelines in Table 7 are used to predict the community's reaction.

EPA's method is based on changes in the  $L_{dn}$ , which is a measure of long-term community noise levels, and may not be appropriate for evaluating short-term changes in noise. A 5 or 10 dBA increase in average 24-hour noise levels will have a different (and likely greater) impact on nearby communities than short-term increases of 5 or 10 dBA.

Table 7: Expected community reaction due to changes in  $L_{dn}$  [10].

Normalized change in $L_{dn}$ (dBA)	Expected community reaction
-5	None
0	Sporadic complaints
+5	Widespread complaints
+14	Threats of legal action
+21	Vigorous action

$L_{dn}$  = day-night noise level; dBA = A-weighted decibels

The guidelines in Tables 5 and 6 can be considered ideal community noise levels. Both the absolute and relative guidelines discussed in this section are intended as starting points for decision makers to address and evaluate environmental noise in their communities and jurisdictions [7, 8, 68, 70]. Further:

- These guidelines address noise exposures and response in the general population, and are not intended as measures of individual or small communities' responses to noise. Exceeding a recommended noise level will not necessarily result in health impacts. Similarly, people may have adverse health impacts at noise levels below these guidelines [7, 8, 68, 70].
- These guidelines address the effects of long-term exposures to environmental noise (as measured by  $L_{eq}$ ,  $L_{dn}$ ,  $L_{night}$ ), and may not be appropriate for assessing impacts from short-term exposures (as measured by  $L_{10}$ ,  $L_{50}$ ,  $L_{90}$ , etc.) [10].
- These guidelines are based, in large part, on evidence from studies of transportation and other noise sources in urban/suburban areas. Therefore, they may not reflect the exposures, context or responses of rural or small communities [7, 68].
- The guidelines do not take into account the cost and feasibility of meeting the recommended levels [7, 8, 68, 70].

### 3. Wind Turbine Noise

#### 3.1. Mechanical and Aerodynamic Noise

Mechanical  
Noise

The major sources of noise from wind turbines are mechanical noise and aerodynamic noise. Mechanical noise is generated by the mechanical components of the wind turbine such as the gearbox, cooling fans, and generator [23]. The amount of mechanical noise generated depends on the turbine's size, materials and design, and on the engineering practices used to construct and maintain the turbine. Modern turbines use a number of design factors to reduce mechanical noise [23].

Aerodynamic  
Noise

Aerodynamic noise is usually the most noticeable source of noise from wind turbines [23, 77, 78]. One type of aerodynamic noise from wind turbines is the repetitive "swishing" sound often associated with moving turbine blades [79]. Wind turbine-generated aerodynamic noise is broadband in nature, which means that it is distributed over a wide frequency spectrum that ranges from infrasound to ultrasound (<20 Hz to >20 kHz) [80], and typically does not have distinct tonal components [77]. Some studies have found that most of the audible noise from wind turbines is in the 500-1,000 frequency range [77, 81]. Recent assessments of large wind turbines indicate that at residences near wind turbines, the dominant frequency range for outdoor noise is 200-2000 Hz [25, 26].

Design  
features  
that affect  
aerodynamic  
noise

Wind turbines generate noise (and electrical energy) when there is sufficient wind to move the turbine blades. In general, as the size and maximum power output of turbines increase, the amount of aerodynamic noise generated also increases [25]. Wind turbines will generate their maximum noise levels in high wind speed conditions. This is because at higher wind speeds, the interaction between a turbine's blade and the wind is more turbulent, which results in more noise generation [77, 78, 82]. Wind turbines will generate lower levels of noise (or no noise) in calmer wind conditions.<sup>10</sup>

Some modern wind turbines have features to minimize turbulence (e.g., fixed speed designs, or blade pitch control), though these features also reduce power output [23]. Factors that can increase turbulence and noise generation are inefficient angles of attack (angle the blade tilts into the wind), rough blade surface conditions, and rotors that are located downwind of the turbine tower [77]. The amount of noise generated by wind turbines of the same size can vary considerably between makes, models, and individual turbines of the same model [25, 26].

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<sup>10</sup> The noise levels generated by wind turbines may not reflect how wind turbine noise is perceived at a receptor. During periods of maximum noise generation, the higher levels of wind turbine noise may be masked by noise from high wind speeds. On the other hand, noise generated in calmer wind conditions may be more noticeable because of less masking from wind or other noise sources [19].

## 3.2. Amplitude Modulated Aerodynamic Noise

Definition

Amplitude modulation refers to fluctuations in the loudness of aerodynamic noise.

“Swish” sound

One form of amplitude-modulated noise is the characteristic “swish” sound associated with wind turbines [21]. This noise, which occurs approximately once every second, is from an increase in SPLs as turbine blades move downward [78]. This noise is most noticeable near a turbine. At a distance, the “swish” sound becomes less distinguishable, and may be perceived as a “churning” noise or the sound of an airplane overhead [79].

“Pulsing”  
sound

In certain conditions, wind turbines may also generate “pulsing”, “thumping”, or “beating” sounds that are different from the “swishing” sound [29]. This type of amplitude modulated noise is hypothesized to be generated when there is wind shear, or “layers” of wind speeds at different heights above ground [19, 22]. In these conditions, a turbine blade passes through different layers of wind along its path, with higher winds at the top of a blade’s path and lower winds near the ground. This may result in varying angles of attack at different points on a blade’s path, which could result in fluctuations in the loudness of aerodynamic noise from the turbine [19].

There is a relatively limited body of evidence on the causes of the “pulsing” form of amplitude modulated wind turbine noise. Therefore, it is difficult to predict the conditions that result in amplitude modulation, or determine how common this phenomenon is at wind turbine facilities [22, 83]. The available evidence suggests the following:

- The pulsing form of amplitude modulated wind turbine noise is hypothesized to occur in stable atmospheric conditions, when overall wind speeds are relatively low and the wind shear effect is more pronounced [19].
- When it occurs, the pulsing noise from individual wind turbines may be louder and more noticeable than expected by planners or receptors. Further, it has been hypothesized that stable wind conditions may increase the likelihood of multiple turbines producing the pulsing noise “in sync”, which results in compounded noise levels that are higher than expected at a receptor [82]. Finally, at night or in stable atmospheric conditions, receptors may perceive the pulsing noise as being louder, since there may be less background noise to mask noise from wind turbines [19].
- There is evidence from laboratory and field studies that amplitude modulated noise (from wind turbines and other sources) is more annoying than unmodulated noise with the same frequency and intensity [22].

### 3.3. Low Frequency Noise

Low frequency noise is usually defined as noise with content below 250 Hz. Low frequency noise with content below 20 Hz is called infrasound, and is generally not audible by humans. Compared to higher frequency noise, noise at lower frequencies must be louder in order to be heard by people with normal hearing. For example, the median human hearing threshold at 8 Hz is 100 dB, at 20 Hz is 80 dB, and at 200 Hz is 14 dB [66]. Noise with lower frequency content is less attenuated by the atmosphere and building materials than noise with higher frequency noise [13].

Field studies  
of low  
frequency  
noise

There are a limited, but growing, number of field studies that have measured levels of infrasound and low frequency noise generated by wind turbine facilities [24, 25, 80]. These studies vary in their methods and design, and their findings are not representative of all wind turbine facilities [26]. We noted the following findings from our review of some low frequency noise assessments and other literature:

- There is strong evidence that upwind turbines (rotors upwind of the tower) do not produce infrasound at levels that are perceptible to humans [22-26].
- There is evidence that as wind turbines increase in size and power, they may produce higher levels of low frequency noise per-MW [25, 26].
- Some assessments found that the indoor low frequency noise levels at locations near wind energy facilities were near or slightly above the threshold of human perception [24-26]. In both the Epsilon (2009) and Madsen and Pedersen (2010) assessments, the researchers concluded that while low frequency noise could be audible in these locations, it was below thresholds for annoyance [25, 26]. On the other hand, Møeller and Pedersen (2011) concluded that while the low frequency noise levels found in their assessment were relatively low, they could still cause some people to be annoyed [26]. An important limitation to these assessments is that they did not evaluate whether people at the measurement locations reported annoyance, disturbance or other health effects.
- In a 2011 self-published field study in Falmouth, MA (a community with three operational turbines), two investigators measured indoor and outdoor low frequency noise levels in one home, and documented the health effects they experienced during the three-day study (e.g., nausea, headache, anxiety) [84]. The investigators determined that their symptoms occurred when the turbines were operating under moderate to high wind speeds. Citing research by Salt and Hullar (2010), the researchers suggest that their symptoms were caused by the stimulation of their vestibular system by inaudible low frequency noise emissions from the wind turbines. Given the limitations in how the health and exposure data were collected (i.e., self-reported symptoms from the two investigators) and interpreted, and the theoretical nature of Salt and Hullar's research on inner ear responses to infrasound [85], it is difficult to determine the public health significance of this study's findings.

## 4. Wind Turbine Noise and Health

In this section, we summarize our review of studies on wind turbine noise and human health. These studies fall into three major categories: cross-sectional studies; case-series reports; and other reviews, white papers, and assessments.

### 4.1. Cross-Sectional Studies

In epidemiology, cross-sectional studies are used to measure the prevalence of a characteristic in a population at a single point in time [86]. These studies provide a “snapshot” of how many people in a population have a disease, exposure, or risk factor at a particular time.

European studies of wind turbine noise

Most of the epidemiological evidence on wind turbine noise comes from three cross-sectional studies conducted in Sweden and the Netherlands between 2000 and 2007. The overarching objectives of these studies were to: a) evaluate the prevalence of perception and annoyance due to wind turbine noise; b) examine population, environmental and noise -related characteristics that influenced associations between noise and perception/annoyance; and c) examine the possibility of a dose-response relationship for wind turbine noise and annoyance [16, 17]. Another cross-sectional study examined the association between health-related quality of life and proximity to a wind energy facility in a semirural area of New Zealand [18].

Methods

The three European studies estimated exposure to wind turbine noise using modeled A-weighted sound pressure levels at respondents’ homes. The noise exposures ranged from approximately 30 dBA – 40 dBA in the Swedish studies, and from 24 dBA – 54 dBA in the Dutch study [22]. A mail-in questionnaire was used to collect data on health effects (measured as annoyance, sleep disturbance, stress, and self-reported clinical disease) and potential moderating variables. Subsequent analyses of the three studies’ combined data evaluated the relationship between wind turbine noise and adverse health effects [15], and compare a dose-response relationship between annoyance and wind turbine noise to annoyance from other sources of community noise [20].

The New Zealand study compared health-related quality of life between two communities with similar demographic, socio-economic and geographic characteristics, but different proximities to a wind turbine facility [18]. The study compared a “Turbine” group located less than 2 km from a wind turbine to a “Comparison” group located more than 8 km from a wind turbine. A mail-in questionnaire was used to collect data on physical, psychological, social, environmental and general health, neighborhood amenity, annoyance, and demographic information. In order to reduce response bias, the researchers masked the intent of the study by giving the questionnaire a generic title and including distracter questions.

## Key Findings

The European studies found the following:

- Annoyance with wind turbine noise increased with A-weighted sound pressure levels [15-17]. The studies found that people were more likely to be annoyed when noise levels exceeded 35-40 dBA [16, 17].
- The following personal factors appeared to increase the odds of being annoyed by wind turbine noise [16, 17, 20, 22]:
  - Being able to see wind turbines from home
  - Having a negative opinion about the visual impact of turbines on the landscape, or a negative opinion about turbines in general
  - Self-reported sensitivity to noise
  - Economic benefit (only examined in the Netherlands study) decreased the likelihood of annoyance from wind turbine noise.
- In the analysis of combined data, the researchers found that people who reported annoyance outdoors were more likely to report sleep interruption, feeling tense and stressed, and feeling irritable. Annoyance indoors was positively associated with sleep interruption [15]. The researchers observed that the impact of noise on sleep interruption “did not increase gradually with noise levels”; instead, the rates of reported sleep interruption were stable at lower noise levels, and increased at 40 dB in the Swedish study and at 45 dB in the Dutch study [16].
- In the analysis of combined data, the researchers did not find statistically significant associations between annoyance (indoors or outdoors) and other self-reported health outcomes included in the study (including diabetes, high blood pressure, cardiovascular disease, tinnitus, and other outcomes)[15].
- The researchers concluded that wind turbine noise is different, and possibly more annoying, than other sources of community noise at similar levels [16, 17].
  - The Netherlands study found that below 50 dBA ( $L_{den}$ ), wind turbine noise was more annoying than similar levels of noise from aircraft, general industry, road traffic and railways, and less annoying than shunting yards [16].
  - A 2011 analysis of the studies’ combined data compared an exposure-response relationship for wind turbine noise to exposure-response relationships for stationary industrial and transportation noise.<sup>11</sup> The researchers found that a higher percentage of people were annoyed indoors by wind turbine noise compared to the percentage annoyed by similar levels of industrial, aircraft, roadway, and railroad noise [20]. The exposure-response curve for wind turbine noise was steeper compared to those for industrial and transportation noise [20].

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<sup>11</sup> The exposure-response model excluded people who benefitted financially from wind turbines.

Cross-sectional studies:  
Key Findings continued

- The researchers suggest that the relatively high levels of annoyance observed in these studies may be explained in part by amplitude modulation of wind turbine noise [15, 20].
- Some key limitations include the use of self-reported responses to measure health effects and moderating factors, the use of modeled (versus measured) noise levels outdoors to estimate exposure, possible reporting bias from relatively low response rates (37%, 57.6% and 68.4% for the Netherlands, 2007 Sweden and 2004 Sweden studies respectively), and the omission of potential personal or situational factors in their questionnaire and analysis (e.g., type of housing) [15-17, 20]. Further, the exposure response relationship described by the researchers were developed using data from a small number of field studies [20].

In the New Zealand study, respondents from the "Turbine" group had lower average scores compared to respondents living farther away in the following domains: overall quality of life, amenity (i.e., satisfaction with neighborhood/living environment) and physical and environmental health-related quality of life [18]. When examining specific factors in the physical and environmental domains, the respondents in the "Turbine" group had lower average scores in self-reported perceived sleep quality, energy levels, how healthy they perceived their environment to be, and their satisfaction with their living conditions. There was no difference between the two groups for social, psychological and general health-related quality of life, or for annoyance from traffic or neighborhood noise. However, 23 of the 39 respondents in the "Turbine" group independently identified wind turbines as an "other" source of noise annoyance, and rated turbine noise as highly annoying. Some limitations of this study were small sample sizes (39 and 158 respondents in the Turbine and Comparison groups respectively), the use of self-reported outcome measures, lack of noise measurements in the turbine and comparison areas, and limited information on respondents' attitudes about wind turbines[18].



## 4.2. Case Series Reports

Case series or case reports are the most basic type of observational study in which investigators describe the symptoms, outcomes, and other characteristics of one or more individuals with health problems. These studies are often used to describe unusual or new health symptoms, and may provide a basis for further epidemiological studies.

Case series reports on wind turbine noise

A number of case investigations and case reports on health effects associated with wind turbine noise have been conducted and self-published by medical doctors, community groups, and others. We reviewed case series reports by Harry (2007), Phipps (2007), Pierpont (2009), and Nissenbaum (2009), Ambrose and Rand (2011) and also reviewed summaries and critiques of these and other investigations [77, 81, 87]. Most of the case series reports we considered are not peer-reviewed in the traditional sense of the scholarly peer review process. However, these and other case reports have been cited in a number of journal articles, including several articles on wind turbine noise impacts in a 2011 issue of the *Bulletin of Science, Technology & Society*.

Methods

The reports we reviewed are quite similar in their methodology and major findings. Some investigators (Harry 2007, Pierpont 2009) selected the individuals to include in their case reports; usually, these cases had previously contacted the investigator about health issues they believed were related to nearby wind turbines. Other investigators (Phipps, Wind VOiCe) utilized a self-select self-report method by sending or making a survey available to individuals within a certain geographic area. The investigators collected data using surveys or questionnaires that included one or more of the following topic areas:

- Demographic information (age, sex, occupation);
- Place of residence (location, time in home, distance from nearest wind turbine or facility);
- Health conditions/prescription use before and after wind turbine installation;
- Checklist of various health symptoms/diagnoses;
- Perception of wind turbines (visual/noise/environmental aspects)
- Changes in quality of life

Some investigators asked if the cases had seen a medical doctor about their health issues, and at least one reviewed a handful of cases' medical records. None of the investigations appeared to include independent medical examinations. With the exception of the Ambrose and Rand (2011) field study [84], none of these reports

include exposure data on noise levels (or other measures); however, some investigators used distance to the nearest wind turbine as a proxy measure for exposure.

## Key Findings

The case reports' findings and conclusions have some similarities:

- The investigators found that people living near wind turbines experienced new or worsening health symptoms after the turbines began operating. The most common symptoms reported are sleep disturbance, headache/migraines, stress, depression, anxiety, and feelings of anger and hopelessness. At least one investigator (Pierpont) has developed a case definition for these symptoms called "wind turbine syndrome"[88].
- Some investigators documented an increase in prescription drug use (offers by doctors and/or acceptance by patients).
- Many cases reported decreased quality of life, and some reported that they had or were considering moving from their home/area.
- Some investigators have hypothesized that cases' symptoms are caused by low frequency noise or infrasound, which affects people's health by disturbing the vestibular system [84, 88].

## Limitations

Case series investigations are the most basic type of epidemiological study. In addition to the inherent limitations of these types of studies, the investigations on wind turbine noise had the following limitations:

- Cases were either self-selected (e.g., chose/initiated participation in study) or selected by investigator
- Lack of controls
- Reliance on self-reported information
- Limited review of medical records, and no independent clinical exams
- Data on "pre-exposure" health status collected retrospectively
- Lack of exposure information (i.e., noise measurements), and no identified "threshold levels"

### 4.3. Reviews, White Papers, and HIAs

There are several evidence reviews, white papers, and at least two HIAs on the health impacts from wind turbine noise. These evidence reviews have been conducted or commissioned by public health agencies [69, 87], industry groups [77], non-profit organizations [89], and consultants to community groups and developers.

Similarities  
and  
Differences

For the most part, these reviews draw on the same body of evidence. They may differ on how they define health and health effects; some reports use a relatively narrow and clinical definition that emphasizes direct health effects (e.g., hearing impairment), while others use broader definitions that consider overall impacts to health, quality of life, and well-being.

Key Findings

Overall, these reviews tend to have similar conclusions:

- Wind turbines do not produce noise at levels that could cause hearing impairment [34, 69, 77, 87, 90].
- Annoyance and impacts on quality of life are the most common effects found in epidemiological studies of wind turbines [69, 77, 90, 91]. The available evidence suggests that these effects are from audible levels of amplitude-modulated noise [77, 87, 89].
- A number of case reports have found that some people living near wind energy facilities have reported symptoms such as dizziness, headaches, sleep disturbance, stress and anxiety. However, there have not been epidemiological analyses to determine if these symptoms are or are not associated with wind turbine noise [77, 87, 90].
- Some key data gaps in exposure assessment include limited noise measurements or monitoring data on actual noise levels near wind turbine facilities, and the need for noise models that account for local conditions and aerodynamic modulation [34, 77, 87, 89].
- People's attitudes and concerns about potential health impacts from wind turbine facilities may be influenced by: the visibility and visual impacts of turbines; concerns about fairness and equity; values and interests of community members; and the level of community engagement during the planning process [69, 87, 89-91].

## 5. Oregon Standard for Wind Turbine Noise

New wind energy developments in Oregon are subject to the Noise Control Regulations for Industry and Commerce (OAR 340-035-0035), which were developed by the Oregon Environmental Quality Commission for new industrial and commercial noise sources on previously unused sites. The Department of Environmental Quality (DEQ) implemented a noise control program in Oregon until funding for the program was eliminated in 1991 [92]. In 2004, Oregon’s noise control regulations were amended to include specific provisions for commercial wind energy facilities.

Under DEQ’s noise regulations, wind energy facilities in Oregon must meet two standards: an ambient degradation standard and a maximum allowable standard [27]. The ambient degradation standard specifies that a wind energy facility cannot increase the  $L_{10}$  or  $L_{50}$  ambient noise level at a residence by more than 10 dBA. A developer can either measure the actual ambient background noise levels or assume a background  $L_{50}$  of 26 dBA. Under the assumed background  $L_{50}$  of 26 dBA, the facility must be designed so that the resulting ambient noise levels at a residence do not exceed 36 dBA (26 dBA plus the 10 dBA allowed by the ambient degradation standard). The facility may result in ambient noise levels above 36 dBA if the developer measures ambient noise levels and finds that the background  $L_{50}$  is greater than 26 dBA. The maximum allowable standard requires wind energy facilities to meet DEQ’s “Table 8” limits for general industrial and commercial noise sources in Oregon. Under this rule, a wind energy facility must not contribute more than 50 dBA to the noise measured outside of any residence. The maximum allowable rule only applies to noise generated by a facility and does not consider the background noise level or the contribution of other noise sources.

Table 8: Summary of noise limits for wind turbine facilities in Oregon.

	Ambient Degradation Standard	Maximum Allowable Standard*	
Landowner does not waive ambient degradation standard	$L_{50} = 36$ dBA (background + 10 dBA)	Daytime $L_{50}$ : 55 dBA $L_{10}$ : 60 dBA	Evening $L_{50}$ : 50 dBA $L_{10}$ : 55 dBA
Landowner waives ambient degradation standard	N/A	$L_1$ : 75 dBA	$L_1$ : 60 dBA

\*In practice, EFSC determines compliance with the maximum allowable standard based on the lowest level from Table 8, which is 50 dBA.

Landowners in Oregon have the option to waive the ambient degradation standard. In these cases, the developer must still comply with the maximum allowable standard and ensure that the facility does not contribute more than 50 dBA to outdoor ambient L<sub>50</sub> noise levels.

During the siting of a proposed facility, a developer must demonstrate compliance with the ambient degradation and maximum allowable standards by modeling the anticipated noise levels at a receptor. These models must assume that all of the facility's turbines are operating between cut-in speed (the minimum speed at which a wind turbine will generate energy) and the wind speed that produces the maximum sound power level (i.e., the "worst-case scenario" in terms of noise levels). In practice, projects evaluate compliance with Oregon's noise standard based on the maximum warranted SPL, which is typically + 2 dBA over the levels that manufacturers expect the turbine will produce. OAR 340-035-0035 has additional details on the methods and procedures for modeling noise from wind energy facilities in Oregon.

## 5.1. Comparison of Oregon Standard to health guidelines

There are some difficulties in comparing Oregon's noise standard to the WHO and EPA guidelines discussed in Section B.2.3. Oregon's standard is based on hourly statistical levels, while the WHO and EPA guidelines are equivalent noise levels ( $L_{eq}$  and  $L_{dn}$ ) over longer time periods. Therefore, Oregon's standard cannot be directly compared to WHO or EPA guidelines. In the absence of comparable metrics, we assumed that for a wind turbine, the hourly  $L_{50}$  level is roughly equivalent to the hourly  $L_{eq}$ . This is a conservative assumption that may overestimate the  $L_{eq}$  depending on the character of the noise.<sup>12</sup>  $L_{50}$  tends to be lower than  $L_{eq}$  since it is less influenced by noise events [93].

Another limitation is that without site-specific information, we can only draw general conclusions about changes in noise levels, and are unable to address issues related to changes in noise patterns or quality (e.g., whether wind turbine noise at a site is relatively constant, characterized by noise events, or varies with time of day).

Re-cap  
WHO/EPA  
Guidelines

- The WHO recommends that outdoor noise levels not exceed  $L_{eq} = 45$  dBA at night to protect from sleep disturbance, 50 dBA during the day to protect from moderate annoyance, and 55 dBA during the day to protect from serious annoyance [7].
- The EPA recommends a yearly outdoor  $L_{dn}$  of 55 dBA to prevent serious annoyance and activity disturbance during the day and sleep disturbance at night [68].
- The WHO and EPA suggest a 5 dBA or greater increase over "typical" long-term noise levels could result in significant community noise impacts [7, 68]. Depending on characteristics related to the noise and community, a 10 dBA or greater increase in community noise levels could be perceived as intrusive or noticeable, and increases above 15 dBA may be objectionable or intolerable [10-12]. These guidelines address changes in long-term community noise levels and are based on equivalent noise metrics ( $L_{eq}/L_{dn}$ ). A 5 or 10 dBA increase in  $L_{eq}$  will likely be greater (louder) than a 5 or 10 dBA increase in  $L_{50}$ .

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<sup>12</sup>  $L_{eq}$  is approximately equivalent to  $L_{50}$  for noise that is steady (i.e., does not fluctuate too much). For noise with larger fluctuations,  $L_{10}$  may be a more appropriate approximation; for intermittent noise events, the  $L_{eq}$  may be some value between  $L_{90}$  and  $L_{50}$ .

Potential  
Impacts

For landowners who do not waive Oregon's noise standard, a new wind energy facility cannot increase outdoor median noise levels by more than 10 dBA. If the background  $L_{50}$  level is assumed to be 26 dBA, the maximum outdoor  $L_{50}$  level allowed under Oregon's ambient degradation standard is 36 dBA.

- When compared to absolute health-based guidelines, an outdoor  $L_{50}$  of 36 dBA is not expected to result in sleep disturbance, disturbance of communication, or annoyance in the general population.
- Landowners who do not waive Oregon's standard could experience up to a 10 dBA increase in outdoor hourly median noise levels. Given that a 10 dBA increase in noise levels is generally perceived as a doubling in loudness [10] and that wind turbine noise may be more noticeable than other forms of community noise [16], a 10 dBA increase could represent a noticeable change in outdoor noise levels.

For landowners who waive Oregon's ambient degradation standard, a wind energy facility can contribute up to 50 dBA to outdoor ambient  $L_{50}$  noise levels under Oregon's maximum allowable standard. The total outdoor  $L_{50}$  level could exceed 50 dBA if noise from other sources contributes more than 40 dBA to the outdoor  $L_{50}$ .<sup>13</sup>

- When compared to absolute health-based guidelines, an outdoor  $L_{50}$  of 50 dBA or more could result in sleep disturbance or serious annoyance. This may be especially true in rural areas, where ambient noise levels are relatively low compared to urbanized areas.
- Landowners who waive Oregon's ambient degradation standard could experience a substantial change in outdoor noise levels at times when the  $L_{50}$  reaches or exceeds 50 dBA. An  $L_{50}$  of 50 dBA could be perceived as approximately four times louder than 26 dBA. Typically, an increase in long-term noise levels of this magnitude (over 20 dBA) is expected to cause widespread annoyance, complaints and possibly threats of legal action [10]. The actual change in long-term noise levels from a wind energy facility may be less than 20 dBA, since the facility is not expected to continually operate at levels that will result in the maximum  $L_{50}$  allowed by Oregon law. Landowners who waive Oregon's ambient degradation standard may perceive and respond differently (potentially more favorably) to the new noise levels, particularly if they benefit from the facility or have good relations with the developer [10, 15].

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<sup>13</sup> Noise levels are measured on a logarithmic scale and cannot be added or subtracted in the "typical" arithmetic way. For example, 50 dBA + 50 dBA = 53 dBA (not 100 dBA). If the difference between two noise levels exceeds 10 dBA, the resulting noise level will be the "louder" of the two noise levels. In other words, adding 50 dBA to a background of 26 dBA will result in a total noise level of 50 dBA.

The Oregon Department of Energy is responsible for responding to noise complaints related to large energy facilities sited through the EFSC process. To date, there have been no complaints related to operating wind energy facilities sited through the EFSC process [29].



## 6. Conclusions and Recommendations

- Environmental noise in community settings is linked to sleep disturbance, annoyance, stress, and decreased cognitive performance [7-9]. These effects, undesirable in their own right, can in turn adversely affect physical health. Chronic sleep disturbance and stress from environmental noise exposures may increase risks for cardiovascular disease, decreased immune function, endocrine disorders, mental illness, and other effects [7, 9-12].
- Objective measures of sound do not necessarily correlate with subjective experiences of noise. When comparing similar sounds, a 3 dB increase correlates to a doubling in objective sound energy levels, but is considered the threshold of perceivable difference in loudness [10, 13]. A 10 dB increase equates to a 10-fold increase in sound energy, but is perceived as a doubling in loudness [10].
- The perception of sound as noise is a subjective response that is influenced by factors related to the noise, the person, and the social/environmental setting. These factors result in considerable variability in how people perceive and respond to noise at the individual and community level [8, 14]. Factors that are consistently associated with negative community response are changes in noise exposure (i.e., the introduction of a new noise, or a noticeable change in noise loudness or quality), and increases in human-generated noise [14].
- A small number of epidemiological studies have linked wind turbine noise to increased annoyance, feelings of stress and irritation, sleep disturbance, and decreased quality of life [15-18]. These studies have not identified positive associations between wind turbine noise and hypertension, cardiovascular disease, or other diseases. In studies from Europe, annoyance from wind turbine noise was more likely when levels exceeded 35-40 dBA [15, 16].
- There is some evidence that wind turbine noise is more noticeable, annoying and disturbing than other community or industrial noise at the same level of loudness [15, 16, 18-20]. This may be because:
  - wind turbines produce noise that fluctuates in loudness and “type” (i.e., swishing vs. pulsing amplitude-modulated noise) [19-21]. Since fluctuating noise is generally considered more annoying than steady or constant noise, wind turbine noise may be perceived as more annoying than other environmental noise;
  - unlike other sources of community noise, wind turbine noise levels may not decrease predictably at night, and could be perceived as more noticeable and louder at night than during the day. This could result in sleep disturbance in nearby residences [15, 19, 22].

Oregon Noise  
Standard for  
Wind Energy  
Facilities

- Factors unrelated to noise may explain some of the annoyance reported in the few epidemiological studies of wind turbine noise. These factors include being able to see wind turbines from home, having a negative opinion about turbines, and self-reported sensitivity to noise [16, 17, 20, 22].
- Wind turbine-generated infrasound (frequencies below 20 Hz) is below levels that can be perceived by humans [23-26].
- Some field studies have found that in some locations near wind turbine facilities, low frequency noise (frequencies between 10 and 200 Hz) may be near or at levels that can be heard by humans [24-26]. However, there is insufficient evidence to determine if low frequency noise from wind turbines is associated with increased annoyance, disturbance or other health effects [26].
- People with greater exposure to noise from wind turbines, such as those that live nearby, are more likely to experience negative health effects than those with lower levels of exposure to noise. The extent of that impact depends on many site-specific variables, such as distance from the facility, local topography and water bodies, weather patterns, background noise levels, etc.
- In Oregon, a developer must demonstrate that a new wind energy facility complies with an ambient degradation noise standard and a maximum allowable noise standard. These standards are defined in rule by the Oregon Department of Environmental Quality. The ambient degradation standard states that a wind energy development cannot increase the median background noise levels by more than 10 dBA. Developers can either measure the actual background noise levels or assume an hourly median ( $L_{50}$ ) noise level of 26 dBA. Based on the assumed background level of 26 dBA, the maximum  $L_{50}$  allowed under the ambient degradation standard is 36 dBA. Under the maximum allowable standard, a wind energy facility may not contribute more than 50 dBA of the noise measured outside of any residence. A landowner can waive the ambient degradation standard, in which case the facility must still comply with the maximum allowable noise standard [27, 28].
- For landowners who do not waive Oregon's noise standard, a new wind energy facility cannot increase outdoor median noise levels by more than 10 dBA. If the background  $L_{50}$  level is assumed to be 26 dBA, the maximum outdoor  $L_{50}$  level allowed under Oregon's ambient degradation standard is 36 dBA.
  - When compared to WHO and USEPA health-based guidelines, an outdoor  $L_{50}$  of 36 dBA is not expected to result in sleep disturbance, disturbance of communication, or annoyance in the general population.

- Landowners who do not waive Oregon's standard could experience up to a 10 dBA increase in outdoor hourly median noise levels. Given that a 10 dBA increase in noise levels is generally perceived as a doubling in loudness [10] and that wind turbine noise may be more noticeable than other forms of community noise [16], a 10 dBA increase could represent a noticeable change in outdoor noise levels. However, the resulting noise levels are below the WHO and USEPA's recommended guidelines for outdoor noise.
- For landowners who waive Oregon's ambient degradation standard, a wind energy facility can contribute up to 50 dBA to outdoor ambient L<sub>50</sub> noise levels under Oregon's maximum allowable standard. The total outdoor L<sub>50</sub> level could exceed 50 dBA if noise from other sources contributes more than 41 dBA to the outdoor L<sub>50</sub>.
  - When compared to WHO and USEPA health-based guidelines, an outdoor L<sub>50</sub> of 50 dBA (or higher) could result in sleep disturbance or serious annoyance. This may be especially true in rural areas, where ambient noise levels are relatively low compared to urbanized areas.
  - Landowners who waive Oregon's ambient degradation standard could experience a substantial change in outdoor noise levels if the total L<sub>50</sub> reaches or exceeds 50 dBA. An L<sub>50</sub> of 50 dBA could be perceived as approximately four times louder than 26 dBA. Typically, an increase in long-term noise levels of this magnitude (over 20 dBA) is expected to cause widespread annoyance, complaints and possibly threats of legal action [10]. The actual change in long-term noise levels from a wind energy facility will likely be less than 20 dBA, since the facility is not expected to continually operate at levels that will result in the maximum L<sub>50</sub> allowed by Oregon law. Further, landowners who waive Oregon's ambient degradation standard may perceive and respond differently (potentially more favorably) to the new noise levels, particularly if they benefit from the facility or have good relations with the developer [10, 15].
- The Oregon Department of Energy is responsible for responding to noise complaints related to large energy facilities sited through the EFSC process. To date, there have been no complaints related to operating wind energy facilities sited through the EFSC process [29].

## Conclusions

1. Given the current scientific evidence, Oregon's ambient degradation standard of 36 dBA for wind energy facilities is not expected to result in annoyance, sleep disturbance or other health effects in the general population, and is protective of public health. However, the 10 dBA change allowed under this standard could result in a noticeable change in outdoor noise levels at impacted residences.
2. Landowners who waive Oregon's ambient degradation standard could experience outdoor L<sub>50</sub> noise levels up to 50 dBA from an operating facility under Oregon's maximum allowable standard. This could represent a substantial change in outdoor noise levels and possibly result in sleep disturbance and moderate to serious annoyance. The likelihood and magnitude of any impacts will depend on a number of factors, including time of day, characteristics of the noise, and the receptors' perceptions of the noise source.
3. The major source of uncertainty in our assessment is related to the subjective nature of response to noise, and variability in how people perceive, respond to, and cope with noise. Additional uncertainty is due to moderate or limited evidence in the following areas:
  - a. Epidemiological studies on wind turbine noise
  - b. Amplitude modulation of wind turbine noise
  - c. Indoor low frequency noise impacts from wind turbines
4. The Oregon Department of Energy is responsible for responding to noise complaints related to large energy facilities sited through the EFSC process. To date, there have been no complaints related to operating wind energy facilities sited through the EFSC process [29]. However, there does not appear to be a systematic process for responding to complaints from county-sited facilities. While PHD has anecdotal evidence of noise complaints and reported health impacts from a few operating facilities in Oregon, we currently lack the data needed to evaluate the frequency or magnitude of any noise-related impacts from existing facilities in the state.

## Recommendations

1. To reduce the potential for health effects from wind turbine noise, planners and developers should evaluate and implement strategies to minimize noise generation when outdoor levels exceed Oregon's standards for wind turbine noise. These strategies could include the following:
  - a. During the planning phase, consider site-specific factors that may influence noise propagation and perceived loudness wind turbine noise, particularly factors that may influence actual or perceived noise levels at night.
  - b. Continue to evaluate scientific evidence on how local conditions could change the propagation and character of wind turbine noise (e.g., the effects of wind shear on amplitude modulation and noise generation at night).

2. The level of annoyance or disturbance experienced by people hearing wind turbine noise is influenced by individuals' perceptions of other aspects of wind energy facilities, such as turbine visibility, visual impacts, trust, fairness and equity, and the level of community engagement during the planning process. By explicitly and aggressively addressing these and other community concerns as part of the wind facility siting process, developer and planners may reduce the health impact from noise produced by wind turbines.
3. Ensure that residents living near wind energy facilities understand the potential risks and benefits associated with a development, and are aware (and able) to report health issues and concerns if they choose.

## 6.1. Additional Recommendations

Based on the available evidence, the dBA scale appears to be the most appropriate scale for measuring noise from wind turbine facilities [16, 79]. The dBA scale is appropriate for measuring broadband frequency noise with moderate SPLs. This is a fairly accurate description of the typical noise profile from wind turbines. Further, most of the public health evidence and guidelines for noise exposures are based on studies that have used A-weighted noise measurements. Therefore, measurement in the dBA scale would provide data that could be compared public health guidelines or studies.

In cases where low frequency noise is a concern, some public health authorities have recommended comparing simultaneous measurements in the dBC and dBA scales, and considering more in-depth analyses if the difference in measurements (dBC-dBA) is greater than 10 dBA [7, 87]. Historically, the dBC-dBA difference has been used to evaluate low frequency noise sources with tonal components (e.g., diesel engines, aircraft, compressors) [94]. The dBC-dBA comparison is intended as an initial screen to determine the need for additional evaluations, and is not intended as method to determine if low frequency noise levels are problematic at a particular site [94]. In cases where conditions at a site indicate the need for additional noise measurement and analysis, it may be appropriate to conduct an in-depth frequency or spectrum analysis (discussed in Section B.2.1) [7].

At this time, there is limited guidance for measuring and evaluating amplitude modulated noise generated by wind turbine facilities. As more is known about the causes of this phenomenon, the frequency of its occurrence, and its impacts on nearby communities, there may be additional guidance on assessing and mitigating potential impacts from amplitude modulated wind turbine noise.

Planners and developers can consider several strategies to ensure that nearby residents and communities are not adversely affected by noise generated from wind turbines. These strategies could include:

1. Use iterative noise modeling to plan facilities boundaries and turbine locations [79]. In the early phases of planning, developers can use baseline modeling techniques to establish the initial boundaries of a project. Once these boundaries are defined, developers can identify residences or receptors within or near the facility, and use more refined and location-specific modeling techniques to plan and site turbines at appropriate distances from these sensitive areas.

Strategies during the operations phase

2. Ensure that the measurements and models used during the siting process are up-to-date and reflect the current state of science.
3. Ensure that nearby residents understand the potential health implications associated with a development (wind energy or otherwise). Further, residents should receive information on how to report health-based issues or concerns during the operations phase, and information on the developer's noise mitigations plans (if any).

In cases where noise levels from a facility exceed local regulations, or result in complaints from nearby community members, government agencies, planners and developers, and other stakeholders may need to implement noise mitigation strategies. These could include the following:

1. Develop systems and protocols for systematically documenting, responding to, and evaluating complaints. This complaint-based system may include noise monitoring at affected residences, documentation of residents' symptoms (e.g., a symptom log), or other measures. Ideally, this system would allow for the collection of complaints across multiple sites in order to track issues and trends over time.
2. Use noise mitigation strategies, such as operating the facility in a low-noise operating mode (usually achieved by reducing the rotational speed of turbines). Developers should outline and communicate their proposed mitigation strategies to nearby residents, government agencies, and other stakeholders.

## C. Visual Impacts

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1. Introduction
2. Overview of Shadow Flicker
3. Shadow Flicker and Health
4. Other Visual Impacts
5. Conclusions and Recommendations



## 1. Introduction

A common community concern about wind energy developments in the U.S. and other countries is their visual impact on the surrounding landscape and viewshed [34, 62, 95]. Some potential reasons for these concerns are [34]:

- wind energy developments are a relatively new type of development, and often are built in rural or remote areas that historically were not considered for industrial development;
- a wind energy facility's project area can extend over a very large geographic area;
- wind turbines are highly visible due to their height, moving blades (or blinking lights), and sometimes due to their location at higher elevations (e.g., on mountain tops or ridges).

In this HIA, we focused our assessment of visual impacts on shadow flicker, and briefly discuss the available evidence on distraction to drivers and looming. We did not address aesthetic impacts on the landscape and viewshed. However, aesthetic impacts may play an important role in peoples' perceptions and acceptance of wind energy developments near their communities [22, 34]. Further, these perceptions may play a role in other pathways examined in this HIA, particularly in the noise and community conflict domains. Therefore, we believe it is important for planners to consider and evaluate the aesthetic impacts of these developments on nearby communities and viewsheds.

## 2. Overview of Shadow Flicker

### Definition

Shadow flicker refers to the alternating levels of light intensity produced when rotating turbine blades cast shadows on nearby buildings or receptors [30]. Shadow flicker is most noticeable indoors when shadows are cast through windows or other openings, and is generally not considered an issue outdoors [30].

### Factors that affect people's experience of shadow flicker

Wind turbines only produce shadow flicker at certain times and locations. Factors that influence the magnitude and likelihood of shadow flicker impacts include the following [30, 31, 34]:

- **Geographic location:** Shadow flicker impacts are relatively lower in the continental U.S. compared to countries at higher (or more northern) latitudes. This is because at higher latitudes, the sun has a lower position in the sky, which results in longer shadows.
- **Distance:** The likelihood and magnitude of shadow flicker impacts decrease with increasing distance from a turbine.
- **Location relative to turbine:** The shadow flicker effect occurs in a butterfly-shaped area around a turbine. In the northern hemisphere, this area extends in directions east-northeast and west-northwest of a turbine, and does not affect receptors located to the south of a turbine.
- **Time of day/year:** Shadow flicker is more likely to occur when the sun's position is low in the horizon. Therefore, shadow flicker impacts are more likely to occur at either sunrise or sunset, and may be greater during winter months compared to summer.
- **Intensity of light:** Shadow flicker occurs in sunny clear weather, and is unlikely to be an issue in cloudy conditions.
- **Turbine design, wind speed and direction:** In variable speed turbines, increasing wind speed will increase shadow flicker speed or frequency. In turbines that rotate on their axis, wind direction will affect the direction that blades cast their shadows.
- **Presence of visual obstructions:** Visual obstructions such as trees and buildings may reduce the amount of shadow flicker at a location.

### Measurement of Shadow Flicker

Shadow flicker is measured in Hertz (Hz), or flashes per second, which is determined by the rotational speed of wind turbine blades. For example, a three-blade turbine with a speed of 20 rotations per minute (rpm) produces shadow flicker at a rate of 1 Hz. Most modern large wind turbines produce shadow flicker at frequencies between 0.3 and 1 Hz [30]. Chronic or long-term exposures to shadow flicker are measured in minutes/hours of flicker per day/year [31].

### 3. Shadow Flicker and Health

There is limited epidemiological evidence on the health risks associated with shadow flicker from wind turbines. The health effects that have received the most attention are photosensitive epilepsy (PSE) and nuisance.

#### 3.1. Photosensitive epilepsy (PSE)

Epilepsy affects approximately 2 million people in the U.S., or 0.6% of the U.S. population [96]. PSE is a form of epilepsy in which seizures are triggered by exposure to flashing lights at certain intensities, or certain types of visual patterns. Approximately 3% of people with epilepsy have PSE [97]. People with PSE may have increased seizure risks at flicker levels that range from 3 Hz [98] to 30 Hz [97]. This flicker can come from many potential sources, including television, video games, strobe lights, or natural light that flickers in the environment [97].

Evidence on turbine-generated flicker and PSE

Only a handful of published research studies have examined the risks of PSE from turbine-generated shadow flicker. These studies examine the issue from theoretical or risk assessment perspectives, and are not based on epidemiological data. Harding et al. (2008) outlines the conditions where shadow flicker from wind turbines could theoretically exceed a 3 Hz risk level (thereby increasing seizure risks in people with PSE), and recommends that wind turbines have rotational speeds less than 60 rpm [98]. The authors mention "two examples of seizures induced by wind turbines on small wind turbine farms in the UK... reported to the authors in 2007", but do not give any specifics on the nature of exposure or any clinical evaluations of these individuals.

In 2007, the UK-based organization Epilepsy Action collaborated with Dr. Harding on an online survey to identify people affected by shadow flicker from wind turbines. The survey had a low response rate, and the organization could not conclusively identify any cases of seizures triggered by wind turbines. The organization stated that it "...does not challenge the theory that wind turbines may create circumstances where photosensitive seizures can be triggered. However from our experience and that of our members and website users it does appear that this risk is minimal [99]."

Another study used a model to assess the risk of epileptic seizures under different meteorological conditions in land and marine environments. The researchers concluded that because of their relatively slow rotational speed, large turbines are unlikely to pose risks for seizures. For the various meteorological conditions considered, the study found minimal risks at distances more than nine times the maximum height of a turbine's blade [100]. We did not identify any self-published or self-reported cases of seizures or epilepsy associated with shadow flicker from wind turbines.

## 3.2. Nuisance

Nuisance or annoyance is a subjective measure of a person's reaction to an exposure or stimulus. Annoyance can range from a feeling of irritation to a "significant degradation in the quality of life" (Suter 1999).

A 2010 evidence review on shadow flicker found that approximately 10% of adults and between 15-30% of children in the general population may be disturbed by light fluctuations at 15-20 Hz from any source. Children are more likely than adults to be annoyed by light fluctuations, and may be more severely impacted if this annoyance disrupts their concentration or work activities [30]. The report also notes that very few people are annoyed at frequencies below 2.5 Hz [30].

## 3.3. Guidelines for shadow flicker

Oregon does not have any specific guidance or requirements for shadow flicker from commercial wind turbines. However, the setback distances required to meet Oregon's noise standard may also minimize any impacts from shadow flicker, though there may be sites or conditions where this is not true.

A few European countries have regulations or guidelines on the maximum number of hours of shadow flicker per year allowed at a receptor. For example, Germany has a maximum worst-case limit of 30 hours of flicker per year or 30 minutes a day, while Denmark recommends no more than 10 hours per year for people who experience shadow flicker [30, 34]. However, it is not clear if these are health-based recommendations.

## 3.4. Summary

The available evidence indicates that shadow flicker from properly sited wind turbines in Oregon are unlikely to cause PSE or nuisance. The risks for PSE or nuisance are minimal at flicker levels below 2.5 Hz, and most modern wind turbines produce flicker at frequencies between 0.3 and 1 Hz. Further, because shadow flicker only occurs under certain conditions, any impacts will be limited in time and location. In the majority of cases, the setback distances required to meet Oregon's noise standard are expected to minimize shadow flicker impacts.

## 4. Other Visual Impacts

### 4.1. Distraction while driving

Theoretically, wind turbines could be an external source of distraction for drivers because of their moving blades, blinking lights, size, and because they may be a “novel” object in the landscape. However, there is very limited data to evaluate if wind turbines have increased accident rates due to driver distraction. There have been one or two research studies on this issue, which did not find any increase in accident rates before and after the construction of the wind energy facilities [33]. We did not identify any health-based recommendations that address driver distraction from wind energy facilities.

### 4.2. Visual looming effect

The "looming effect" refers to the phenomenon of large wind turbines towering or looming over nearby residents. This effect could theoretically have negative impacts on people's quality of life and well-being. The looming effect was raised as an issue of concern in Oregon, and was addressed during the siting of at least one wind energy development in Washington. The analysis conducted for the Washington site is the only reference we were able to identify on the visual looming effect from wind turbines [32]. In their paper, the authors provide background on the visual looming effect in science and architecture, and describe field tests to assess the potential for the visual looming effect at an existing wind energy development. The authors conclude that looming will not cause negative effects at a 4:1 distance to height ratio (i.e., the setback distance from a receptor should be four times the height of a wind turbine). This finding is based on urban planning guidelines, which suggest that a 4:1 distance-to-height ratio will minimize any negative psychological reactions from feeling "enclosed" by a tall building or object. It should be noted that this is not a health-based guideline. Further, it is not clear if this guideline also applies to wind turbines built at higher elevations (e.g., on a ridge or mountaintop).

## 5. Conclusions and Recommendations

### Key Findings

- Shadow flicker refers to the alternating levels of light intensity produced when rotating turbine blades cast shadows on nearby buildings or receptors [30]. Most modern large wind turbines produce shadow flicker at frequencies between 0.3 and 1 Hz [30].
- Wind turbines produce shadow flicker at certain times, locations, and under certain conditions. In the continental U.S., shadow flicker impacts are relatively lower compared to locations at higher latitudes, are more likely to occur at sunrise or sunset, and affect a butterfly-shaped area to the northeast and northwest of a wind turbine [30, 31].
- There is insufficient evidence to determine if the “looming effect” (i.e., psychological reactions from feeling “enclosed” by a tall building or object) could have negative impacts on people’s quality of life and well-being. Urban planning guidelines that recommend a 4:1 distance-to-height ratio to minimize negative psychological reactions from feeling “enclosed” by a tall building or object may not be applicable to wind turbines in rural environments [32].
- Some Oregonians voiced concern that wind turbines could distract drivers and result in traffic crashes. However, the very few research studies on this issue did not find any increase in crash rates after the construction of the wind energy facilities [33].

### Conclusions

1. Shadow flicker from wind turbines in Oregon is unlikely to cause adverse health impacts in the general population. The low flicker rate from wind turbines is unlikely to trigger seizures in people with photosensitive epilepsy. Further, the available evidence suggests that very few individuals will be annoyed by the low flicker frequencies expected from most modern wind turbines [30, 31, 34].
2. While Oregon does not have specific guidelines for shadow flicker, the setback distances (i.e., the distances between turbines and other structures) required to meet Oregon’s noise standard should be sufficient to minimize shadow flicker impacts in most cases.

### Recommendations

1. In cases where the conditions at a particular site make shadow flicker a potential issue, planners and developers should consider the distance, orientation and placement turbines relative to homes and buildings, and the use of visual obstructions to block flicker.
2. If shadow flicker negatively affects people after a wind turbine is installed, strategies such as planting vegetation as visual barriers or installing blinds on affected buildings may be needed [30].
3. While aesthetic impacts are unlikely to directly affect health, they may play an important role in peoples’ perceptions and acceptance of wind energy developments near their communities [34]. Planners should consider evaluating these impacts if they emerge as an important community concern.

## D. Air Pollution

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1. Introduction
2. Overview of Air Pollution and Health
3. Wind Energy and Air Pollution
4. Conclusions and Recommendations

## 1. Introduction

Air pollution is a complex mixture of chemicals, particles, gases and other materials in the atmosphere that can harm human health and damage the environment. There are natural and man-made sources of air pollution. The primary man-made sources of air pollution in Oregon and the U.S. include emissions from power plants, industrial facilities, cars and other transportation sources, and chemicals used in everyday activities [101]. One important source of air pollution is from power plants that burn fossil fuels to produce electricity. While most of Oregon's electricity production is from renewable sources, more than 30% of electricity generated in the state from 2005-2009 years was from coal and natural gas [61, 102].

Direct exposure to the most common air pollutants in the U.S. is associated with short and long-term health effects that include respiratory irritation, asthma, cardiovascular disease, cancer, and premature death [35, 36]. Some air pollutants have indirect effects on human health; for example, greenhouse gas emissions accumulate in the atmosphere and contribute to climate change, while persistent pollutants like mercury can deposit on soil and water, and accumulate in our food chain [36]. The risks from air pollution depend on several factors, including: 1) the type and toxicity of pollutants; 2) synergistic effects between pollutants; 3) routes and levels of exposure; and 4) whether there are vulnerable or susceptible people in the exposed population.

The process of generating electricity from wind energy does not produce air pollution [37]. However, there are other ways that wind energy development can impact local and regional air emissions. In this section, we begin with an overview of the major types of air pollution and their effects on human health. We then evaluate how wind energy facilities could change local air pollution levels through three pathways: 1) the replacement of gas/coal-fired units in the state; b) construction equipment and vehicular traffic during construction and operation and maintenance phases; and c) changes in road conditions/infrastructure in local communities.



## 2. Air Pollution: Types, sources, and health impacts

### 2.1. Greenhouse gases

Greenhouse gases (GHGs) trap heat in the atmosphere, and are produced from natural and human sources. Increases in GHGs from human activities are the cause of rising global surface temperatures, changes in precipitation patterns, changes in ocean temperatures and sea levels, and other changes in the Earth's climate [103].

The main greenhouse gases generated from human activity are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and fluorinated gases. The major sources of GHGs in the U.S. are: the combustion of fossil fuels for energy; the extraction, processing and transport of fossil fuels; livestock and agricultural practices; and industrial processes [104]. From 1990 to 2009, total U.S. emissions of greenhouse gases increased by 7.3% [104]. Oregon accounts for 1% of U.S. GHG emissions [105]. Transportation and electricity generation are the major sources of GHG emissions in the state, and agriculture, waste management and industrial processes also contribute smaller amounts of GHGs [106].

Table 9: Greenhouse gas emissions in the U.S. and Oregon [104, 106].

Gas	% total US GHG emissions (2009)	% total OR GHG emissions (2008)	Major Sources
CO <sub>2</sub>	83%	83.5%	Fossil Fuel Combustion Non-energy use of fuels Iron/steel/coke production
Methane	10.3%	8.5%	Natural gas production Enteric fermentation Landfills
N <sub>2</sub> O	4.5%	4.7%	Agricultural soil management Mobile combustion Manure management
Fluorinated gases Hydrofluorocarbons (HFCs) Perfluorocarbons (PFCs) Sulfur hexafluoride (SF <sub>6</sub> )	2.2%	3.3%	Substitution of ozone depleting chemicals Electricity transmission and distribution Production of HCFC-22

Sources and Trends

Health effects

GHG emissions have indirect impacts on public health through their contribution to global climate change [36]. These health impacts are long-term and global in scale, and include: increased morbidity and mortality from extreme heat and weather-related; increased incidence of respiratory illnesses, cardiovascular diseases and cancer; increased risks for food-, vector- and water-borne diseases; increased mental health and stress disorders; and food insecurity and malnutrition from disruptions in agricultural systems [107].

Climate change poses some specific challenges for the Pacific Northwest in the near and long-term, including the following [105]:

- Average annual temperatures are expected to increase by 0.2-1 °F per decade
- Summers will be warmer and drier
- Extreme precipitation events may increase
- Global sea levels may increase

These changes may result in the following health impacts [105]:

- Injuries and deaths due to heat waves, flooding and other extreme weather events
- Altered infectious disease patterns due to changes in disease vectors, water and food quality, and environmental/weather conditions that influence disease transmission
- Changes in incidence and severity of respiratory illnesses (e.g., asthma, hay fever)
- Cardiovascular diseases and stroke from changes in heat and air pollution
- Mental health and stress

GHG emission goals

Global GHG emissions must be reduced by 60-80% below 1990 levels to avoid serious changes in the climate system [108]. In 2007, the Oregon Legislature established state goals to reduce GHG emissions and prepare for the impacts of climate change. These goals represent Oregon's "fair share" of the global emissions reductions needed to avoid "dangerous interference with the climate system" [108]. Oregon's GHG reduction goals are to begin reversing growth in GHG emissions by 2010, decrease emissions to 10% below 1990 levels by 2020, and decrease emissions to at least 75% below 1990 levels by 2050 [108].

## 2.2. Criteria Air Pollutants

The U.S. EPA enforces national air quality standards for six criteria air pollutants: ground-level ozone ( $O_3$ ), particulate matter ( $PM_{10}$  and  $PM_{2.5}$ ), nitrogen oxides ( $NO_x$ ), sulfur dioxide ( $SO_2$ ), carbon monoxide (CO) and lead [35]. CO,  $SO_2$ , lead and  $PM_{10}$  are emitted directly into the atmosphere from fuel combustion, construction sites and equipment, wildfires, and industrial sources. Ozone,  $PM_{2.5}$ , and  $NO_x$  are formed indirectly during complex chemical reactions in the atmosphere.

Health effects

The criteria air pollutants are the most common air pollutants in the U.S., and account for most of the public health burden from air pollution [35]. These pollutants have direct and near-term health impacts at the local and regional levels. Ozone and fine particulate matter are the most harmful of these pollutants. Short-term exposures to criteria air pollutants are associated with increased respiratory symptoms (coughing, wheezing, difficulty breathing), inflammation of airways, irregular heartbeat, aggravation of asthma, bronchitis, and other respiratory illness, non-fatal heart attacks, and increased risk for death [35]. In the long-term, higher levels of exposure to these pollutants can cause increased risks for chronic lung and heart disease, cancer, and premature death [35].

Health-based guidelines

The EPA's National Ambient Air Quality Standards (NAAQS) and the Air Quality Index are health-based standards for the criteria air pollutants (Table 10). These standards are a useful guide to determine when local levels of these pollutants pose risks to public health. It is important to note that these thresholds are for air pollution from all local sources, and cannot be used to determine if emissions from a single source are "safe" or unacceptable.

Oregon data

The Oregon DEQ and the Lane Regional Air Pollution Agency (LRAPA) monitor and report on air quality in Oregon. In 2010, most areas in Oregon met EPA's air quality standards for the criteria air pollutants; the exceptions were Klamath Falls, Oakridge and Lakeview, which did not meet the daily  $PM_{2.5}$  standard [109]. The levels of  $NO_x$  and  $SO_2$  in Oregon have been below national standards for decades, and  $PM_{10}$  and CO levels have been below these standards since the mid-1990s. While ozone levels in the state are near the NAAQS, they are on a downward trend due to ozone reduction efforts in metropolitan areas [109].

Table 10: Sources and air quality standards for criteria air pollutants.

Pollutant	Sources	NAAQS
Ground-level Ozone (O <sub>3</sub> )	Formed indirectly by reactions between sunlight, NO <sub>x</sub> and other chemicals	75 ppb (8-hour average)
Particulate matter (PM)	PM <sub>10</sub> (coarse particulate matter): emitted directly from construction sites, unpaved roads, fires, and smokestacks	PM <sub>10</sub> : 150 µg/m <sup>3</sup> (24-hour average)
	PM <sub>2.5</sub> (fine particulate matter): formed indirectly by chemical reactions in the atmosphere	PM <sub>2.5</sub> : 35 µg/m <sup>3</sup> (24-hour average) PM <sub>2.5</sub> : 15 µg/m <sup>3</sup> (annual average)
NO <sub>x</sub> (NO <sub>2</sub> and other nitrogen oxides)	Formed from emissions of motor vehicles, power plants, construction equipment  Contributes to formation of ozone and fine particulate matter	100 ppb (1-hour average) 53 ppb (Annual average)
SO <sub>2</sub>	Primary source is power plants that use fossil fuels (73% of all emissions); also formed from non-road equipment Contributes to formation of fine PM	140 ppb (24-hour average)
CO	Formed during combustion of fuels; primary source is from mobile sources	9000 ppb (8-hour average) 35000 ppb (1-hour average)
Lead	Primary sources are lead smelters, leaded aviation gasoline and other industrial sources	0.15 µg/m <sup>3</sup> (3-month rolling average)

NAAQS = EPA National Air Quality Standards, ppb = parts per billion; µg/m<sup>3</sup> = micrograms per meter cubed

### 2.3. Hazardous Air Pollutants

The EPA currently regulates 188 air toxics in the U.S. [110], and has designated 33 of these chemicals as air toxics of national concern [109]. Power plants, diesel engines and motor vehicles are all sources of hazardous air pollutants. The amount and type of air pollutants emitted by these sources vary depending on the fuel, chemicals and technology and processes used.

Health effects

Hazardous air pollutants (or air toxics) can cause serious illnesses in people who are exposed to unsafe levels of these chemicals. Exposure to these chemicals may cause increased risks for cancer, neurological problems, developmental issues, and damage to the immune, respiratory, and reproductive systems [110]. These pollutants enter the environment through air emissions, but may eventually deposit in soil or water, or be taken up into plants, fish, milk and other foods. Therefore, people can be exposed to these pollutants by breathing in contaminated air; swallowing pollutants in water, soil or dust; absorbing chemicals through the skin; or eating fish, plants, or other foods that are contaminated with these chemicals [110].

Health-based guidelines

Health-based thresholds (if any) for hazardous air pollutants depend on the toxicity and other properties of each individual contaminant. Currently, there are no federal health-based standards for this class of pollutants. However, the Oregon DEQ has developed ambient benchmark concentration for 52 contaminants in order to prioritize pollution reduction efforts in the state [111]. Information on these benchmarks is available at: <http://www.deq.state.or.us/aa/toxics/benchmark.htm>.

## 2.4. Vulnerable Populations

In general, children, the elderly, and people with existing respiratory or cardiovascular illnesses may be more vulnerable to the effects of air pollution [35, 110]. People who live or work near a pollutant source may be at higher risk for exposure to air pollution.

### 3. Wind Energy Facilities' Impacts on Air Pollution

#### 3.1. Pathway 1: Displacement of fossil-fuel generated electricity in Oregon

Wind energy facilities do not generate air emissions from electricity production, and could reduce regional air pollution levels if they displace electricity generated from gas, coal, and other fossil fuels [36, 37]. In order to quantify reductions in air emissions, researchers must consider the following factors [34, 36]:

- The sources and amounts of fossil-fuel energy displaced by wind energy
- The types and amounts (per unit energy) of air pollutants emitted by the displaced energy source
- Current and future demographic, technological and policy changes that will affect electricity consumption and air emissions

Estimating the impacts of wind energy facilities on local air emissions is a complex process that is outside of the scope of this report. Reports by the National Research Council (NRC) and EPA provide more in-depth information on calculating a development's impact on air pollution [34, 36]. In this section, we provide some basic information on electricity production in Oregon and the air emissions impacted by electricity generation in the state.

##### 3.1.a. Electricity Production in Oregon

Electricity demand varies by time of day and season. The “base load” demand (demand that stays relatively constant over time) is met using electricity from the lowest-cost power plants. The remaining demand is met by dispatching power plants based on availability and cost, with the highest-cost sources utilized last to meet periods of peak electricity demand [36].

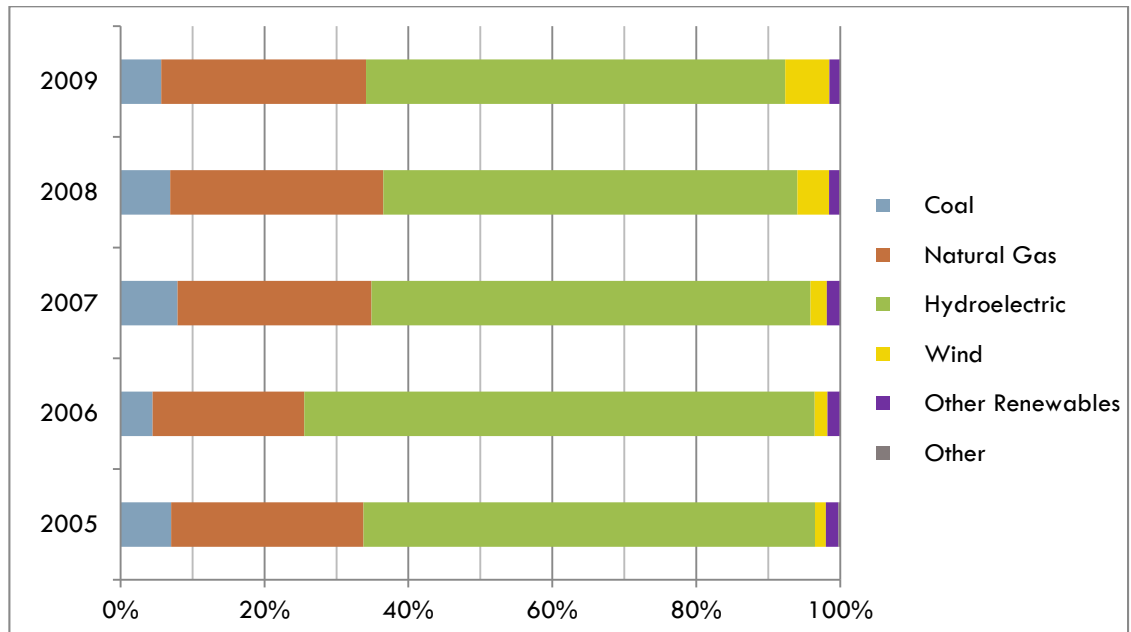
In the U.S., electricity is bought and sold on a regional level. Therefore, a power plant in a particular locale or state may generate electricity that is ultimately consumed in another locale or state [36, 112]. Most of the electricity consumed in Oregon comes from a network of utilities that serve Oregon, Washington, Utah and parts of California, Nevada, Wyoming and Montana [112].

Basic  
information on  
electricity  
production

## Electricity generation in Oregon

Hydroelectricity is the largest source of electric power generation in Oregon, followed by coal and natural gas (Figure 5) [61, 102]. The proportion of the state's electricity generated from wind energy grew from 1.5% in 2005 [61] to 7.1% in 2010 [2].

Figure 5: Sources of electricity generated in Oregon, 2005-2009.



Data source: U.S. Energy Information Administration. Oregon Renewable Electricity Profile 2009, Tables 4 and 5. Available at: [http://www.eia.gov/cneaf/solar.renewables/page/state\\_profiles/oregon.html](http://www.eia.gov/cneaf/solar.renewables/page/state_profiles/oregon.html).

Factors that will affect future electricity production in Oregon include:

- **Population and electricity load growth:** The population of the Pacific Northwest is expected to grow by more than 28% by 2030 [5], and regional electricity demand is expected to increase by 7000 average MW between 2009 and 2030, or by 1.4% per year [5].
- **Phase-out of coal-based power plants:** Oregon law effectively prohibits constructing new coal-based power plants in the state [62], and the state's only operating coal-based plant is slated to close by 2020 [63].
- **Constraints on hydroelectricity:** Hydroelectric generation is constrained by fish and wildlife protections and other environmental considerations. Hydroelectric output in the region is unlikely to change in the next 20 years and is not considered an option to meet growing load demand [5].
- **Current and future policies related to climate change, environmental quality, and energy:** These policies include renewable portfolio standards, GHG goals, restrictions on air pollutant emissions, and carbon reduction strategies.
- **Electricity costs:** The costs of producing electricity any source depends on future demand, fuel prices, technological changes in production and transmission systems, and a host of other factors.

### 3.1.b. Changes in air emissions

To estimate changes in air emissions due to wind energy developments, we need information on the following factors:

- The source and amount of fossil-fuel energy displaced by wind energy
- The type and amount of air pollutants emitted by the displaced energy source per unit energy
- Current or future technological and policy changes that affect air emissions from fossil fuels

Energy displacement refers to the amount of fossil-fuel generated electricity that wind energy replaces in a particular region. Energy displacement depends on many factors, including those shown in Table 11.

Table 11: Factors that influence energy displacement.

Displacement factor	Modifiers/Supporting information
The amount of energy actually generated by wind energy facilities	Currently, commercial wind energy facilities in the U.S. are estimated to have an average generating capacity that is 30% of their nameplate capacity[34]. For example, a 20 MW facility with a 30% average generating capacity will produce 52,560 MW-hours of electricity in a year.
The amount of wind energy integrated into the regional electrical grid	Wind energy is considered an intermittent source of energy because it depends on having adequate wind speeds to produce electricity. The extent to which intermittent energy sources are integrated into electrical grids depends on the accuracy of supply/demand forecasts, mix of available energy sources, the grid's ability to accommodate variations in demand and output, and other factors.
The electric energy source(s) that wind energy displaces (e.g., coal, natural gas, nuclear, hydroelectric), and the amount of displacement that occurs	Electric grid operators respond to changes in electricity demand by dispatching power plants based on cost and availability. Because of its variability, wind energy is typically not used to meet peak energy demand. The types of energy sources displaced by wind energy (in both the near and long-term) will depend on the relative costs of each energy source.

Energy  
Displacement



Air Pollutants from fossil fuels

Fossil fuel-based power plants contribute to the following atmospheric air emissions [101, 113]:

- Greenhouse gases, including CO<sub>2</sub>
- Criteria air pollutants: NO<sub>x</sub>, SO<sub>2</sub> and coarse particulate matter are directly released to the atmosphere, while ozone and fine particulate matter are indirectly formed during reactions involving NO<sub>x</sub>, SO<sub>2</sub>, ammonia, and other chemicals in the atmosphere
- Hazardous air pollutants, including volatile organic compounds (VOCs), mercury (from coal), heavy metals, polycyclic aromatic hydrocarbons (PAHs), and dioxins/furans

The type and amount of air pollutants produced by fossil fuel combustion depend on the fuel, technology and emission controls used at a particular plant. Table 12 compares the average emission rates (expressed in pounds per megawatt-hour electricity generated) of four pollutants from the combustion of natural gas, coal, and fossil fuels in general. The available data indicate that natural gas produces lower levels of air pollutants per unit energy than coal or oil [114, 115].

Table 12: Average emission rates of NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub>, and mercury by fuel-type\*, 2005.

	NO <sub>x</sub> (lb/MWh)		SO <sub>2</sub> (lb/MWh)		CO <sub>2</sub> (lb/MWh)		Mercury (lb/GWh)	
	OR	US	OR	US	OR	US	OR	US
Coal	4.8	3.4	6.9	9.7	2306.3	2135.9	0.05	0.05
Natural Gas	0.25	0.54	0.008	0.11	870.9	966.3	-	-
Fossil Fuels <sup>^</sup>	1.2	2.59	1.5	7.1	1171.4	1797.6	0.01	0.04

\*Data for oil is not shown since it is not major fuel source in Oregon. U.S. data shown for comparison.

<sup>^</sup>Represents the average emission rate for fossil fuels in general.

Data source: US EPA. eGRIDweb database. Available from: <http://cfpub.epa.gov/eGRIDweb/index.cfm>. Accessed: May 5, 2011.

Effects of technological and policy changes

Technological changes, environmental regulations, and policies to improve air quality affect local and regional emissions from power plants. The Clean Air Act, Clean Air Interstate Rule, and Clean Air Market programs are examples of federal-level initiatives to regulate air emissions from utilities and other regional pollutant sources. From 1970 to 2003, these regulations reduced emissions of SO<sub>2</sub> and NO<sub>x</sub> from electric generating plants in the U.S. by 37% and 9% respectively [34]. As new federal and state regulations and policies are implemented, it is likely that air pollutant emissions from electric utilities will continue to decline. However, these programs (particularly market-based cap and trade programs) add additional complexity in estimating the impacts of renewable energy on air pollution [36].

Pathway 1: Summary

In summary, wind energy facilities could reduce state-wide emissions of greenhouse gases, criteria air pollutants, and hazardous air pollutants if they displace fossil-fuel based power plants in Oregon. The magnitude of any reductions in air pollutant emissions will depend on the type and amount of fossil fuel units replaced, technological changes, and the effect of policies aimed at reducing air emissions from power plants. The available evidence suggests that the largest air pollution reductions will occur by first replacing energy from coal-fired sources, followed by replacement of oil and natural gas.

### 3.2. Pathway 2: Emissions from construction and vehicular traffic

Any industrial development will generate some amount of air and other environmental pollution during construction, operations and maintenance (O&M), and decommissioning activities. Wind energy facilities have some unique characteristics that may affect the emission and impacts of air pollution during these phases:

- Wind energy facilities are usually built in rural areas with low population density. Compared to construction projects in urban areas, there may be fewer people directly impacted by pollutants from these sites.
- Some large facilities have a large project area, with turbines spread over tens of thousands of acres. This means that air pollution sources at these sites (mostly construction and maintenance equipment) will not be centralized, but spread across a large geographic region.
- Local transportation infrastructure may be inadequate for transporting parts and equipment because of the size and weight of rotors and towers [116]. These factors may result in more intensive construction activities (e.g., building more access roads, or fortifying and improving existing bridges and roads) or more vehicular traffic to transport parts and equipment.

Sources of air pollution

The major sources of air pollution at wind facility sites are equipment and vehicles that run on diesel or other fuel [116]. The equipment and materials needed during the construction phase are typical of those used in most road construction projects. This equipment includes: concrete mixers and water tank trucks; heavy-duty trucks (flatbed/goose-neck trailers); cranes; trenching/augering equipment; line trucks; and light or medium-duty vehicles [116]. During the O&M phase, the equipment typically includes light or medium-duty vehicles.

Diesel and other emissions

Diesel engines release particulate matter, greenhouse gases, carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs), sulfur compounds and other chemicals into the atmosphere. Other air pollutants from construction activities are dust and silicate; vapors from paints, cleaning solvents and degreasing chemicals; and pesticides and herbicides. The level of air emissions from these activities depends on the size, scale, timeline and other facility-specific factors [116].

Potential for exposure

The amount of exposure to construction-related air pollution depends on a person's proximity to the pollutant source, amount of time exposed, and personal or environmental factors that increase or decrease contact with these air pollutants. In general, construction and on-site workers are expected to have the highest amount of exposure, followed by residents living close to construction sites, workers involved with transporting equipment and parts, and community members who live or work near transportation corridors.

Applicable Regulations

There are a number of state and federal requirements to protect environmental quality, public health, and worker safety at construction sites in Oregon [117] which include provisions to limit air pollution and dust generation at these sites.

Pathway 2: Summary

Given that construction activities at wind energy facilities are relatively short-lived, and that these facilities are built in sparsely populated areas of Oregon, the expected health impacts from construction-related air pollution are short-term and minimal.

### 3.3. Pathway 3: Changes in road conditions and infrastructure

As mentioned previously, wind turbine facilities sometimes require new access roads or improvement to existing roads and bridges. These roads are used by facility workers, and may be used by landowners and residents living near the facility. This section examines if changes in local road infrastructure (e.g., new access roads) or road surface conditions (e.g., pavement or gravel caps) could have a measurable impact on local air quality.

Increased road capacity

Increased road capacity (measured as new miles of roadway) is associated with increased driving (measured as vehicle miles traveled, or VMT) in both urban and rural areas [118]. An increase in VMT will result in increased emissions of particulate matter, NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub>, CO, hydrocarbons and hazardous air pollutants. It is likely O&M activities at a facility will increase VMT at the local level, though this may not significantly change local air pollutant emissions. It is less certain if new or improved roads will increase VMT by local residents or visitors in an area. If new or improved road capacity does not substantially change residents' driving habits, there will not be a measurable change in VMT-related air emissions. However, if the roads improve access to nearby recreational or tourist areas, there may be an increase in emissions due to increased traffic in an area. The human health significance of any changes in air emissions changes will depend on the number and characteristics of people who exposed these air pollutants.

Road conditions and air quality

We found limited information on the air pollution impacts of paved versus unpaved roads. The most comprehensive analysis was from a 2002 report on the environmental and socioeconomic impacts of paved versus unpaved roads in Alaska [119]. The study authors found the following:

- Unpaved roads generate a significant amount of dust and coarse particulate matter from blowing wind and vehicles traveling across the road surface. Paved roads also generate dust and particulate matter, but at much lower levels compared to unpaved or gravel roads.

- The amount of airborne dust decreases with increasing distance from roads. The main impact is usually within 100 ft of a road.
- Paving is an effective dust control strategy that is estimated to control up to 99% of coarse air particles.
- Other strategies to suppress dust include traffic control, and using water or chemicals to stabilize the road surface. Some chemical stabilizers may cause air and other environmental impacts, depending on the toxicity, persistence and amount of chemicals used.
- There is little information on non-dust emissions from vehicles on paved versus unpaved roads.

Other environmental and public health impacts

There are other environmental and public health issues related to building and improving road conditions. Paved roads generate less air pollution, but may cause other negative environmental and ecological effects, including water and soil pollution, disruption of local habitats, and killing local wildlife. In terms of safety, there is mixed evidence on whether unpaved roads are more or less dangerous than paved roads. On the one hand, unpaved roads may reduce accident rates because they force reduced vehicle speeds and have less volume; on the other hand, they could pose more dangers because of decreased visibility and narrower right-of-ways. Lastly, road conditions affect other safety and quality of life measures in rural communities, including speed, ease and cost of travel for local residents, and improved access for emergency vehicles.

Pathway 3: Summary

It is unlikely that changes in local road conditions and infrastructure will result in air quality-related health impacts.

## 4. Conclusions and Recommendations

### Key Findings

- Direct exposure to air pollutants is associated with short and long-term health effects that include respiratory irritation, asthma, cardiovascular disease, cancer, and premature death [35, 36]. Greenhouse gas (GHG) emissions indirectly impact public health through their contribution to global climate change [36]. Children, the elderly, and those with pre-existing respiratory problems are particularly vulnerable to the health effects from air pollution.
- The major sources of air pollution in Oregon and the U.S. are the combustion of fossil fuels for electricity, transportation and other uses; industrial processes; agricultural practices; wildfires; and construction sites and equipment.
- Wind energy facilities do not generate air emissions from electricity production, and could reduce air pollution if they displace electricity generated from gas, coal, and other fossil fuels [36, 37]. The magnitude of any reductions in air pollutant emissions will depend on the type and amount of fossil fuel units replaced, technological changes, and the effect of policies aimed at reducing air emissions from power plants [36]. The available evidence suggests that the largest air pollution reductions will occur by first replacing energy from coal-fired sources, followed by replacement of oil and natural gas.
- Wind energy could contribute to air pollution through the burning of fossil fuels in vehicles and equipment used for construction and maintenance of wind energy developments. However, the construction-related impacts on local air quality are likely to be short-term and relatively small in magnitude.
- It is unlikely that new or improved access roads will result in substantial increases in vehicular traffic or appreciable changes in local air quality.

### Conclusions

1. Wind energy facilities in Oregon could indirectly result in positive health impacts if they reduce regional emissions of GHGs, criteria air pollutants and hazardous air pollutants.
2. Communities near fossil-fuel based power plants that are displaced by wind energy could experience reduced risks for respiratory illness, cardiovascular diseases, cancer, and premature death.
3. The health benefits from any reductions in GHG emissions depend on the extent to which these reductions prevent or lessen the severity of future climate change impacts in Oregon.

1. To reduce the health effects from air pollution, mechanisms that link the development and integration of wind energy for electricity consumption to reductions in fossil fuel use should be implemented (if such mechanisms are available and can be feasibly implemented).
2. While construction-related air pollution is expected to have minimal health impacts, planners and developers should consider strategies to reduce diesel emissions from non-road construction equipment. Some effective strategies include reducing idling time, using cleaner fuels, retrofitting engines, and developing environmental management strategies for operations. The EPA's Clean Construction USA program<sup>14</sup> and Oregon DEQ's Clean Diesel Initiative<sup>15</sup> offer resources, technical assistance, and in some cases, tax credits and grant funding to assist in implementing these strategies.

#### 4.1. Additional Recommendations for Site-Specific Assessments

1. Given time and resources, an assessment of impacts from air pollution could range from a qualitative or descriptive analysis to a fairly sophisticated quantitative analysis. There are a number of tools and resources that can be used to predict potential health impacts if there is sufficient site-specific information. Impact assessment tools such as EPA's Co-Benefits Risk Assessment (COBRA) model and BenMAP use concentration-response models to predict the health impacts of air pollution. Planners can use these tools to estimate how local air pollution levels may affect the health of their communities. It is important to note that these tools may use different concentration-response functions depending on the tool's purpose and the quality and availability of evidence. They also vary in terms of their sophistication, input data requirements, and software platforms. As with any modeled data, there are a number of uncertainties and limitations in the estimates from these tools. One notable limitation is that most epidemiological studies of air pollution are conducted in urban areas. There will be more uncertainties in applying concentration-functions from these studies to rural areas with lower population densities, and different air pollution levels.
2. A description of baseline conditions should include any available information on local air pollutant levels, particularly if the site is in a maintenance or non-attainment area for a particular criteria air pollutant. For a list of these areas, see the Oregon Department of Environmental Quality's website:  
<http://www.deq.state.or.us/aq/planning/index.htm>.

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<sup>14</sup> U.S. Environmental Protection Agency. National Clean Diesel Campaign. Available from: <http://www.epa.gov/cleandiesel/index.htm>. Accessed November 16, 2011.

<sup>15</sup> Oregon Department of Environmental Quality. Oregon Clean Diesel Initiative. Available from: <http://www.deq.state.or.us/aq/diesel/initiative.htm>. Accessed November 16, 2011.

## E. Economic Effects

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1. Introduction
2. Overview of Socioeconomic Factors and Health
3. Economic Effects from Wind Energy Facilities
4. Conclusions and Recommendations



## 1. Introduction

At the local level, wind energy facilities can impact personal income, the availability and quality of local jobs, and local jurisdictions' revenue for education, healthcare, public safety, and other public services. These factors (particularly income, employment and education) are indicators of individual and community-level socioeconomic status (SES), which are strong predictors of health and disease [39, 120].

This section begins with a brief overview of the associations between major socioeconomic factors and health. We then describe our findings on how wind energy developments could affect the following economic factors in local communities: a) personal income and assets; b) jobs, employment and local business; and c) revenue and liability for local and state jurisdictions, including education and other districts. This section concludes with our key findings and recommendations on potential health impacts from the local economic effects of wind energy developments.

## 2. Socioeconomic status and health

Links between  
SES and  
health and  
mortality risks

In the U.S. and throughout the world, SES predicts both life expectancy and overall health at each stage of life [38, 39]. In the U.S., people with the lowest SES have over three times the risk of dying prematurely (before the age of 65) than those with the highest SES, while people in the middle have up to twice the risk of premature death than those at the top [120]. Researchers have found a similar gradient in the relationship between SES and the relative risks for infectious and chronic diseases, disability, and unhealthy behaviors across the lifespan [39, 120]. Public health researchers have identified at least four pathways to explain why health and mortality risks appear to increase as SES decreases. People with lower SES are believed to:

- have poorer access to quality health care;
- be more likely to live and work in unhealthy or toxic environments;
- be more likely to have behaviors and lifestyles that increase their health risks;
- have more sources and higher levels of chronic stress [38, 121].

Public health  
studies on  
SES and  
health

In public health studies, SES is often measured by income level, educational attainment, or employment status. Public health researchers note that the links between these indicators and health are complex and difficult to measure [40]. For one, income, employment, and education are often related to each other, but may not be interchangeable because they influence health to different degrees and through different mechanisms [38]. Second, race, ethnicity, and other factors are strongly associated with both socioeconomic status and health, which makes it difficult to isolate the effects of SES [40]. Further, just as income or education can affect a person's health, health can affect a person's socioeconomic opportunities and outcomes [122]. Finally, researchers have observed that both individual and community-level SES play an important role in health; for example, both absolute income (i.e., a person's net worth) and relative income (i.e., a person's net worth relative to other community members) affect disease and mortality risks [39, 122].

In the follow section, we summarize the current evidence on the links between SES (income, education and employment) with health and mortality risks. When available, we provide Oregon-specific data on these SES measures.

## Income

- As income increases, people are less likely to die prematurely [121], and more likely to report better health [123]. People with the lowest income have the largest gains in health and lifespan as income increases. For example, an increase from \$10,000 to \$20,000 in income is correlated with a more dramatic increase in health and lifespan than an increase from \$80,000 to \$90,000 [121].
- Compared to those with higher incomes, people with lower incomes have increased risks for giving birth to low-birth weight babies, for suffering injuries or violence [120, 124], and for developing chronic conditions such as obesity, diabetes and hypertension [120, 125].
- Even after accounting for race, ethnicity and gender, income and wealth affect the likelihood of developing a chronic condition (such as diabetes, heart disease or hypertension), and how well a person functions once they have a chronic illness [126].
- Children are especially vulnerable to the effects of poverty. Children living in poverty have higher risks of injury-related morbidity and mortality, less access to health care, and higher risks of cognitive and developmental delays [127].
- In addition to absolute income levels, income distribution and inequality may result in health disparities. Studies at the state and national level have found that higher levels of income inequality within a population are associated with higher age-adjusted mortality rates [41]. For example, one study found that individuals living in states with high levels of income inequality had up to a 12% increased mortality risk [128]. Further, there is some evidence that perceived income inequality is more strongly associated with poor self-reported health than absolute income levels [129].

## Data on income in Oregon

Personal income in Oregon is lower compared to the U.S. In 2009, the median household income in Oregon was \$48,325 (compared to \$50,221 in the U.S.) [130], and per-capita personal income<sup>16</sup> in the state was \$35,571 (compared to \$38,46 in the U.S.) [44]. Personal income in rural areas of Oregon is lower compared to urbanized areas of the state. In 2009, per-capita personal income in non-metro<sup>17</sup> counties was \$6,986 (23%) lower than in metro counties; this is largely due to an average \$9,920 difference in wages between metro and non-metro workers [44].

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<sup>16</sup> Per-capita personal income is the total amount of income earned in a geographic area divided by the population in that area. This measure takes into account income from wages, pensions, dividends, interest, rent, and benefits from retirement, Medicare and unemployment insurance.

<sup>17</sup> The 11 metro counties in Oregon have (or are closely connected to) cities with more than 50,000 people [45].

## Education

- Education is positively linked to health. Education leads to better employment outcomes, higher income, improved access to health care, and higher levels of health literacy, which are all associated with improved health outcomes [131].
- Some studies have found that even after controlling for income and access to health insurance, education remains a strong independent predictor of health [132]. Educational attainment may be a stronger predictor of health risks, outcomes and disparities than income or occupation [133, 134].
- People with lower educational attainment have relatively higher risks for premature death. Even after controlling for income and other demographic variables, people with less than 12 years of education have higher mortality risks than high school or college graduate [121].
- In an analysis of data from the National Health Interview Survey and the National Death Index, Cutler and Lleras-Muney (2006) observed the following health gains for every four additional years of education [132]:
  - a 1.8% decrease (or -1.8%) in risk for death within five years;
  - lowered risks for heart disease (-2.2%), diabetes (-1.3%), and self-reported poor health (-6%);
  - decreased likelihood of smoking (-11%), being overweight or obese (-5%), or using illegal drugs (-0.6%);
  - an increased likelihood of positive health behaviors such as obtaining flu shots (+7%), wearing seat belts (+12%), and having a smoke detector in home (+10.8%)[132].
- Some research suggests that educational attainment is a stronger predictor of health risks, outcomes and disparities than income or occupation [133, 134].

## Data on educational attainment levels in Oregon

Adults in Oregon have higher levels of educational attainment compared to adults in the U.S. Among Oregonians over the age of 25, 88.3% were high school graduates (compared to 84.6% in the U.S.) and 28.3% had a bachelor's degree or higher (compared to 27.5% in the U.S.) [43]. While the high-school graduation rates in non-metro and metro areas of Oregon are similar (76% and 78% respectively), a higher percentage of adults in metro areas have some secondary education (64% compared to 54% in non-metro areas) [135].

## Employment

- Employment is linked to overall better health and to slower declines in health over time. People who are employed have more access to resources to maintain and improve their health [136].
- Unemployment, underemployment and uncertain employment have been shown to have negative effects on health [137].
- Compared to people who are employed, the unemployed are more likely to die prematurely, have poor mental health, report chronic illnesses (particular cardiovascular diseases) and lower self-rated health, and have higher rates of smoking, poor nutrition and other health risk factors [138]. Overall, these risks appear to be higher for men than women [138], though some evidence suggests that women in blue-collar occupations have poorer health outcomes than men in the same occupations [137].
- Studies have found that workers who receive low incomes and workers who are overqualified for their jobs reported higher levels of depression symptoms and worse health than consistently employed workers [139, 140].
- Workers with lower occupational status (i.e., blue-collar or hourly-wage workers) have higher risks for chronic illnesses, injury, and death compared to workers with higher occupational status (white-collar or salaried workers) [137].

## Data on employment in Oregon

Oregon's unemployment rate has historically been higher than the national rate, and this trend has continued in recent years. During the recent recession, Oregon's unemployment rate peaked at 11.6% in the summer of 2009. At the end of 2011, the seasonally adjusted unemployment rates in Oregon and the U.S. were 9.5% and 9% respectively [42].

In recent years, non-metro counties have had unemployment rates that were 1-2 percentage points higher than metro counties [44]. Urban and rural areas of Oregon are different in terms of industry major sectors and wages paid to workers [47]. Metro counties in Oregon tend to have higher shares of employment in higher paying industries such as information, financial and business services, while non-metro counties have higher employment shares in lower-paying sectors like agriculture and hospitality. Further, workers in metro counties have higher wages compared to non-metro workers in the same industry.

### 3. Economic Effects from Wind Energy Facilities

#### 3.1. Overview of economic impacts

Types of economic impacts

Wind energy developments can affect local economies through direct, indirect and induced impacts [141]. Direct impacts are the most immediate or obvious effects from a development. These impacts can include [36]:

- short-term jobs during the construction phase for on-site workers, managers, and driver,
- long-term jobs in operations and maintenance,
- purchases from local suppliers,
- land lease payments to local landowners, and
- property tax payments.

Indirect impacts include changes in jobs, income or revenue from businesses or sectors that support activities and workers at a development [36]. For example, hotels and restaurants may see an increase in business during the construction phase as outside workers come into the area. Induced economic effects are from changes in household, business and government income and spending in a local community [36].

Studies of economic impacts

There are relatively limited data on the actual impacts of wind energy developments on jobs, income and other economic indicators. Most of the available economic impact studies use models to determine the impacts of these facilities at the local and state levels. These studies, and the models on which they are based, have some important limitations. For example, one commonly used model (the Jobs and Economic Development Impact Model, or JEDI) provides predictions on the gross impacts of a facility on a handful of economic variables. While the JEDI model provides approximate values for the magnitude of economic impacts, it does not provide estimates of net impacts (e.g., does not account for losses due to increased electricity rates, displaced economic activity, or reduced tax revenue), and is a static model that does not account for changes in energy demand, costs or production [142].

Relative impacts during construction and operations phases

Most of the studies in our review examined economic effects during three phases of a development: manufacturing, construction, and operations. Local communities are most likely to be impacted during the construction and operation phases of a development. On average, the construction phase of a wind energy development lasts approximately one year, while the operations phase can last between 20 to 30 years [143]. During the construction phase, local economies can experience a large short-term increase in demand for labor, supplies, and services [34, 143]. On an annual basis, these demands are substantially greater in the construction phase compared to the operations phase; however, the total economic impacts from operations over the lifetime of a facility are greater than short-term construction-related impacts [143].

### 3.1.a. Employment

#### Jobs

Wind energy developments require a relatively large number of workers during the construction phase, and fewer workers during the operations phase [144]. The number of new jobs created depends largely on a facility's size, and the number of jobs filled by local workers depends on whether the local labor force has the needed skills and experience [144]. Further, local businesses may hire more workers if the development increases demand for local goods and services (especially during the construction phase); however, there could also be short or long-term drops in employment if the development has a negative effect on certain sectors (e.g., tourism or recreation) [34].

Lantz and Tegen (2009) reviewed several county and state-level economic impact assessments on community and absentee wind energy projects [145].<sup>18</sup> The authors found that community and absentee projects had similar employment impacts during the construction phase. In the county-level analyses, the short-term employment impacts ranged from 0.15 – 2.58 jobs per-MW, while the state-level analyses projected 2.8-4.2 jobs per-MW.<sup>19</sup> For the operations phase, the projected annual employment impacts ranged from 0.8-1.4 jobs per-MW in county-level analyses, and 0.45-0.92 jobs per-MW in state-level analyses. The analysis also found that community wind projects had greater county and state level impacts on employment than absentee projects. Most of the studies found that community projects' impacts were 1.5-3.4 times higher than absentee projects [145].

#### Wages and compensation

Jobs in the wind energy sector may require specialized skills and training, which could translate to higher wages and compensation compared to other jobs in rural economies. One study from Iowa reported that wages from wind-related jobs were in the 80th percentile statewide [146]. However, currently there are limited data to determine if wind energy jobs provide workers with living or family wages.<sup>20</sup>

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<sup>18</sup> Community wind projects are partially or wholly owned by individuals and/or businesses in the state or area where the wind energy development is located. Absentee wind projects are owned by entities who are from outside the local community and state [80].

<sup>19</sup> The measure of employment impacts (jobs per-MW) indicates the number of jobs created in a geographic region for every MW of installed capacity. Therefore, the projected number of construction jobs from a 50 MW wind energy facility would be between 7.5 and 129 at the county level, or between 140 and 210 at the state level.

<sup>20</sup> Living or family wages provide enough income to meet the basic needs of an individual or family, which include food, shelter, clothing, transportation, etc.

Data from  
Oregon

Oregon's RPS legislation requires Oregon DOE to assess the impact of the standard on employment in Oregon. ODOE's employment assessment and recent data from the Oregon Employment Department indicate the following trends:

- RPS eligible facilities have increased employment and job training programs in Oregon's renewable energy sector [48]. Fourth-quarter employment in the renewable energy sector grew by 208 jobs (2%) between 2005 and 2010, while Oregon's overall employment decreased by 5% during the same time period [47].
- The wind energy industry accounts for most of the state's employment in renewable energy. These jobs have been concentrated in construction, operations and sales and marketing [48].
- The available data indicate that wind energy facilities in Oregon employ a large number of workers during the construction phase, and smaller number of permanent employees during the operations phase [48].
  - Records from three operating facilities under EFSC jurisdiction indicate an increase of 30-40 permanent jobs and 350-370 construction jobs since 2007.
  - At the time of the report's release, records from nine facilities in the planning, approval and construction phases suggested an increase of approximately 182-221 permanent jobs and 2,600 construction jobs [48]. This works out to approximately 4-5 permanent jobs and 58 construction jobs per 100 MW installed capacity.
  - Another survey found conducted in 2009 found that Oregon wind energy facilities employed 225 technicians and a small number of supervisory personnel [48].
  - There are limited data on wages at Oregon wind energy facilities. However, recent data indicate that median hourly wages are relatively higher in the renewable energy sector [47]. Eighty-two percent of renewable energy workers in the state earned at least \$20/hour, compared to 41% of workers across all sectors in Oregon [47].



### 3.1.b. Personal Income

Income from  
land leases

The lease payments that landowners receive from wind energy developers vary quite widely across states [34]. One report found that typical lease payments are in the range of \$2700-\$2900 per-MW of generating capacity [144]. These payments may far exceed the typical revenue a landowner generates from agriculture on these lands, and may represent a significant change for rural economies [143]. According to industry sources, wind energy developers make over \$6 million in land lease payments a year in Oregon [2].

Property  
values

Another potential impact to personal income or wealth is changes in property value. Land lease payments can significantly increase property values for some landowners. However, community members with properties adjacent to land leased for wind turbines or within sight of these facilities may have concerns that a facility near their home will result in a decline in their property values. Changes in property value can have a substantial impact on personal income, since residential property or land may account for a large portion of a person's or family's financial assets. To date, there have been few studies to evaluate the impacts of wind energy facilities on property values, and it is difficult to draw conclusions from this body of evidence because of methodological differences between studies and methodological limitations within studies [46]. Perhaps the most comprehensive study conducted to date is a 2009 analysis that examined whether concerns about area, scenic vistas, or nuisance affected property values at various distances and stages during a facility's development. The study analyzed 7,459 residential sales transactions near 24 existing facilities in nine states [46]. The 2009 analysis did not find evidence that post-construction property values were consistently or significantly affected by "either the view of wind facilities or the distance of the home to those facilities" [46]. The authors did find evidence that property values for homes closest to the facility decreased during the period after the facility was announced but before construction; they also found that the values of these homes increased after construction was completed. Other analyses have also found a decrease in property values during the time period between the approval and operation of a facility, and a subsequent recovery in value after the facility is in operation [45, 147].

While the studies reviewed for this report did not find an association between nearby facilities and long-term property values, this does not mean that property values near a facility have not or will not be impacted. Given the many factors that affect local property values, it is difficult to generalize these studies' findings to individual or local changes in property values at a given facility[34].

Distribution of income benefits and losses

The distribution of positive or negative impacts to personal income is an issue of concern at many wind energy facilities. Landowners who lease their land to developers may accrue substantial economic benefits through increases in personal income or property values. However, landowners who do not lease their land will not directly experience these benefits, and may experience negative impacts if their property values decrease, or if they are adversely affected by unwanted noise, visual impacts, air pollution during construction, and other impacts.

3.1.c. Tax Revenue

Wind energy developments may generate property tax revenue for local governments. Governments often invest tax revenue from wind energy developments in schools, emergency services, health care, or public infrastructure, and sometimes provide direct payments to households in a jurisdiction [148]. However, the revenue generated from property taxes may be reduced if governments provide developers with tax breaks or credits to promote development in their region. The national average tax revenue from wind energy developments is estimated at \$8700/MW, though this amount varies across states and local jurisdictions [144].

By the end of 2010, wind energy facilities in Oregon had paid over \$55 million in property taxes to counties and the state [49]. Several facilities have entered into strategic investment plans (SIPs) with host counties. SIPs allow developers to pay a community service fee in lieu of property taxes on the full value of the project.<sup>21</sup> SIP agreements are a mechanism to attract new development while allowing local governments to direct funds to programs and services that meet communities' needs.

The revenue from property taxes and SIPs is invested differently across counties; to date, there has not been a comprehensive assessment of how these payments are directed at the local level. One case example is Sherman County, which has collected over \$17 million in tax revenue, SIP fees, and lease payments from wind energy facilities in nine years [148]. The county has spent this revenue by [149]:

- disbursing yearly \$590 payments to each of the county's 706 households;
- making \$100,000 annual payments to the county's four towns;
- investing in capital projects and education;
- expanding government services.

To our knowledge, Sherman County is the county in Oregon that shares revenue in this way.

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<sup>21</sup> In rural areas, the community service fee equals 25% (or a maximum of \$500,000 per year) of taxes that would have been paid on a project's value over \$25 million. SIP agreements expire after 15 years, after which taxes are paid on the full value of the project.

### 3.1.d. Ownership

Some studies have examined the effects of ownership on local economic impacts. A review several county and state-level economic impact assessments found that community wind projects had 1.5 to 3.4 times the impact of absentee-owned projects. One model used by researchers in Minnesota predicted that local ownership would result in county-level economic benefits that were 3.1 to 4.5 times higher compared non-local ownership, and local employment increases that were 2.5 to 3.5 times greater [150]. Another analysis predicted that compared to wholly corporate owned projects, a 100% locally owned development would result in 164% greater annual economic benefits during the operation phase, while a project with 51% local ownership would result in a 79% more annual benefits [144]. Lantz and Tegen (2009) suggest that community-owned projects may increase acceptance and decrease opposition to wind energy development [145], though it is not clear if this based on observational information.

It is important to note that these assessments have a number of caveats and limitations. For one, most of these assessments are based on modeled predictions instead of observational data. While many of these models use site-specific information, they also incorporate assumptions on a number of factors (e.g., expected returns on investment, how returns and invested, etc.).

## 4. Conclusions and Recommendations

### Key Findings

- Socioeconomic status (measured by income, education and employment) is a strong predictor of life expectancy and overall health at each stage of life [38, 39]. While the links between SES and health are complex and difficult to measure [40], public health studies have found that as SES increases, the risks for premature mortality, disease, disability, and unhealthful behaviors decrease.
- Higher levels of income inequality are associated with poorer health outcomes [41].
- Data from Oregon indicate that personal income and employment levels in the state are lower compared to the U.S., though educational attainment levels in the state are higher compared to the nation as a whole [42, 43]. Within Oregon, there are noticeable disparities in SES between urban and non-urban areas. Compared to urban areas of the state, non-urban areas have relatively lower levels of personal income, lower wages, and higher rates of unemployment [42, 44].
- Wind energy facilities could result in positive local economic impacts if they increase local jobs, personal income, and local tax revenue. Some evidence suggests that community owned wind projects may have relatively larger economic benefits for local communities compared to absentee-owned projects.
- Decreased property values are often an issue of community concern. Economic studies have not found an association between nearby wind energy facilities and changes in long-term property values [45, 46]. However, because property values are influenced by many factors, and it is difficult to generalize these findings to individual or local changes in property values near a given facility [34].
- Data from Oregon indicate that wind energy facilities have increased employment in Oregon's renewable energy sector and the economy as a whole [47, 48]. Wind energy facilities increased personal income for landowners who obtain lease payments and for workers employed by wind energy facilities [47], and increased tax revenue for local government through property taxes and other fees [34, 49].

### Conclusions

1. Wind energy developments could indirectly result in positive health impacts in Oregon communities if they increase local employment, personal income, and community-wide income and revenue. However, these positive effects may be diminished if there are real or perceived increases in income inequality, or an uneven distribution of costs and benefits, within a community.

Recommendations

1. Local officials, decision-makers and other stakeholders should consider strategies to increase community-wide economic benefits from wind energy developments. These strategies may include:
  - provisions or incentives for hiring local labor, purchasing goods and supplies from local or state businesses, and investing in training programs to prepare local workers for jobs in the wind energy sector;
  - investing tax revenue in public services (e.g., education and health-care);
  - disbursing regular cash payments to local residents;
  - considering the feasibility of community ownership models in which a wind energy project is partially or wholly owned by community members.

## F. Community Conflict

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1. Introduction
2. Community Conflict from Siting and Environmental Decisions
3. Health Effects from Community Conflict
4. Summary
5. Conclusions and Recommendations

## 1. Introduction

While wind energy developments often have support from the general public, there are numerous accounts of projects in the U.S. and around the world that have faced strong local opposition [50, 51, 151-153]. For example, a 2010 public opinion poll found that 78% of Oregon respondents in rural areas and 82% of respondents in urban areas would support having wind turbines erected within sight of their homes or near their communities, with nearly 50% of these respondents expressing strong support [154]. However, during three community listening sessions in central and eastern Oregon, PHD staff heard first-hand accounts of the conflict in some (though not all) communities due to the development of wind energy facilities. One of these sessions was held in a county where voters appeared to be almost evenly divided in their support for a proposed wind energy development. [155].

A few researchers have noted that conflicts over wind energy developments are similar to those seen during the siting of cell phone towers, transmission lines, pipelines, concentrated animal feeding operations, and other facilities [50, 51, 95]. This section describes the similarities between conflicts over wind energy facilities and other environmental/natural resource decisions in rural communities. We then present information stress-related health effects from community-level conflict. This section concludes with suggested strategies to mitigate potentially negative impacts from community conflict.

## 2. Community Conflict from Siting or Environmental Decisions

Community conflicts over siting or environmental decisions often stem from the following issues and concerns [156, 157]:

- tension between regional/national priorities and local interests and values;
- uncertainty or differing views about risks and benefits;
- concerns about fairness and the distribution of risks and benefits in a community;
- type-casting of project opponents as “NIMBY”s (Not-In-My-Backyard);
- feelings of mistrust in developers and decision-makers;
- feelings of powerlessness, and perception that there are limited opportunities to influence decisions;
- involvement of a wide range of stakeholders, interests and perspectives from within and outside the community.

Conflict in rural areas

Rural communities may be disproportionately impacted by community-level conflicts [54]. Urban populations tend to have better access to governmental and other resources to solve environmental issues or problems, and may be less reliant on geographically defined communities for social support. Residents in rural communities may rely more heavily on community interactions, resources and support to address environmental and other challenges. Therefore, conflicts in small communities may be more disruptive if they erode traditional sources of social and interactional support [54].

### 2.1. Controversies at renewable energy facilities

Siting controversies over renewable energy facilities have some unique characteristics compared to “traditional” siting conflicts. For one, renewable energy has broad support from the public, government, industry and environmental groups, who view these developments as a sustainable and clean source of energy, a necessary step towards energy independence and security, and as a source of local economic investment and benefits [158]. Because of these positive aspects of renewable energy facilities, people who oppose a local development are likely to be type-casted as NIMBYs by project proponents within and outside a community [50]. However, local opponents to a project may support renewable energy development, but have genuine concerns about the local effects of a project, the motives of the developer, and the planning process [51, 158].



Haggett (2004) and other researchers have highlighted some recurring themes in local conflicts and opposition to wind energy development [50, 51, 158]:

- Local risks vs. global benefits: For people living near wind energy developments, the potential risks are more tangible and apparent than long-term or global benefits. For example, residents' concerns about global climate change may be far outweighed by concerns about property values or impacts to health and the environment.
- Ownership and perception of developer: Community members may be more likely to oppose wind energy facilities that are wholly owned by "outsiders", in part because of suspicions of exploitation or profiteering at the community's expense.
- Place and identity: People's sense of individual and community identity is shaped by an area's social, cultural, historical and environmental characteristics. Wind energy developments may be perceived as "large-scale technologies that intrude, spatially and culturally, on accustomed ways of life", and threaten community identity [51, 159].
- Landscape impacts: As noted by many researchers, visual and landscape impacts from wind energy facilities are a concern for many communities. This often has little to do with the visual aspects of turbines themselves. Instead, it is related to how people value and identify with the local viewshed and landscape, and whether they feel that a wind energy facility will disrupt or damage an important community resource. This issue overlaps with concerns about wildlife impacts (particularly killing of local and migratory birds).
- Degree of consultation: The nature and extent of community consultation and participation in a decision-making process may affect both the outcome of the decision, and the likelihood of opposition from the community. Community consultation is important for decisions about individual projects, and for long-term planning decisions about the direction and development of the community.

### 3. Stress from community conflict <sup>22</sup>

Primary and secondary stress

Stress is a potential health impact in communities involved in environmental or natural resource disputes [52, 53]. There are at least two sources of stress that act at the individual and community levels. Primary stress is caused by real or perceived risks from environmental hazards, while secondary stress is caused by social and community responses to a site or incident [53].

Health effects from chronic stress

Scientists also distinguish between acute and chronic stress. Acute stress occurs in response to sudden or catastrophic events, and is commonly known as the "fight or flight" response. Chronic stress occurs when there is long-term or repeated activation of the normal stress response [52, 160]. Scientists believe that chronic stress occurs from persistent feelings of anxiety and lack of control, or from repeated exposures to stressful situations or environments [160]. Over time, prolonged stress responses can wear down the organs and systems of the body, and compromise its ability to respond to environmental threats. Clinical studies have found that chronic stress decreases immune function, increases risks for cardiovascular disease and endocrine disorders, and affects how the brain and body age. Further, it impairs cognitive functions such as memory and concentration, and can trigger or worsen mental illnesses such as anxiety disorders and depression [52, 160].

Indirect effects of chronic stress

Chronic stress also has indirect effects on health. Stress can increase people's vulnerability or sensitivity to environmental stressors, and lower people's response thresholds to stressors like noise and pollution [52, 53]. Chronic stress may increase risks for unhealthy behaviors such as smoking, excessive alcohol consumption, drug abuse, and overeating [52, 160]. Finally, stress can erode a person's sources of familial and social support, and limit their engagement with their community. This can amplify the effects of primary stress, and worsen secondary stress at the individual and community levels.

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<sup>22</sup> See Appendix E for more detail on stress and health.

## 4. Summary

In summary, community conflict over wind energy facility siting decisions may stem from: concerns about the distribution of risks and benefits (local risks vs. global benefits); mistrust of developers and regulatory authorities; the importance and value of “place” and landscape for local identity; the degree of consultation and participation in the decision-making process [51]. Community conflict over wind energy developments could potentially result in individual and community-level stress. If this stress is long-term, it could result in adverse physical and mental health effects, which include decreased immune function, increased risks for cardiovascular disease and endocrine disorders, mental illness, increased vulnerability to environmental stressors, and increased risks for unhealthy behaviors.

### 4.1. Strategies to address community conflict

While there may be uncertainty about health impacts, community conflict can have a number of other negative impacts that affect community members, planners, decision-makers, developers, and other stakeholders. Since the degree of consultation has been identified as a potential cause of conflict, strategies centered on public participation and consultation are often recommended to facilitate siting deliberations and decisions [50, 51, 69, 95]. These strategies are relevant in the context of this report for the following reasons:

- Meaningful community engagement and participation in decision-making processes is an underlying value of HIA [161, 162];
- Effective public participation has been shown to improve the quality, legitimacy and acceptance of environmental decisions [56];
- Public participation is a recommended strategy to reduce community members’ stress by giving people a sense of control [53], and this may indirectly affect people’s perceptions and response to noise and visual effects from wind turbines;
- Public participation and involvement were identified as a need by Oregonians who attended PHD’s community listening sessions, or responded to the online questionnaire.

Dietz and Stern (2008) note that there is no single strategy, technique, or tool to ensure meaningful public participation in a decision or process. However, they note that any process should be based on: “inclusiveness of participation, collaborative problem formulation and process design, transparency of the process, and good faith communication [56].”

Resources for public participation

Dietz and Stern's book for the National Research Council entitled *Public Participation in Environmental Assessment and Decision-Making* provides a useful guide for planning and implementing public participation in environmental assessment and decision-making [56]. There also are examples of community consultation and involvement processes that have been implemented in communities near wind energy developments in the U.S. One example is an effort by the Oregon Consensus Program to assess and recommend a mediation process for an Eastern Oregon community that was divided between supporters and opponents of a proposed wind energy development [163]. Other examples were highlighted in a 2011 workshop on "Facilitating Wind Energy Siting"; the workshop's presentations and guidelines for public involvement in wind energy facility siting are available online [55].

## 5. Conclusions and Recommendations

Key Findings and Conclusions

1. Community conflicts over wind energy developments have many similarities to conflicts over other controversial siting or natural resource decisions in rural communities [50, 51]. These similarities include: tensions between local risks vs. global benefits, mistrust of developers or owners, and limited opportunities for community members to influence the decision-making process [50, 51].
2. Long-term stress from real or perceived environmental threats can increase risks for cardiovascular disease, endocrine disorders, reduced immune function, mental illness, and other negative health effects [52, 53]. Community conflict over controversial siting or environmental decisions may contribute to or exacerbate this stress, and thus increase risks of these negative health effects [53].
3. Rural communities may be disproportionately impacted by community-level conflicts because these conflicts may erode traditional sources of social and interactional support that community members rely on [54].
4. Based on experiences from other controversial environmental and siting decisions, public participation that is inclusive, collaborative, and transparent is an effective strategy to improve the quality, legitimacy and acceptance of environmental and siting decisions [50, 51, 55, 56].

Recommendations

1. Planners, developers, decision-makers, and government agencies involved in wind facility siting decisions should consider and use strategies to anticipate, understand, and manage conflict and stress in communities near proposed developments. If done well, public participation and community consultation are strategies that can minimize negative and maximize positive impacts (health and otherwise) for local communities, decision-makers, developers, and other stakeholders.

### III. Appendices

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- A. Additional Information on Health Impact Assessment
- B. Methods
- C. Research Questions
- D. Data from Community Listening Sessions and Questionnaire
- E. Additional Information on Stress and Health

## Appendix A. Additional Information on Health Impact Assessment

*HIA* HIA is "a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA provides recommendations on monitoring and managing those effects" [6]. HIA is a prospective assessment that predicts how a plan, project or policy could affect a community's health in positive and negative ways, and recommends measures to maximize beneficial and minimize harmful effects [6, 164].

*Health and Health Determinants* The World Health Organization (WHO) defines health as: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."<sup>23</sup> This holistic definition recognizes that health and health inequalities are influenced by interactions between individual, environmental and social factors [6, 164]. These factors, or "health determinants", include personal lifestyle, income, education, employment, housing, and access to health care and public services (Figure 6).

Figure 6: Determinants of Health [161].

Fixed Individual Factors	Individual Health Behaviors	Public Services and Infrastructure	Environmental Conditions	Social, Economic, and Political Factors
Genetic Makeup	Diet	Education	Housing Adequacy	Poverty
Gender	Physical Activity	Public Transportation	Air, Soil and Water Quality	Inequality
Age	Addictions	Health Care	Community Noise	Social Cohesion & Inclusion
Existing Health conditions and Disabilities	Coping Transportation	Parks Community Centers Economic Development	Disease vectors	Political Participation

<sup>23</sup> Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946. Available from: <http://www.who.int/about/definition/en/print.html>. Accessed November 16, 2011.

Why conduct HIA?

HIA is a tool to help decision-makers understand the root causes of health and ill-health in a population, identify how a specific policy, program or project could affect these causes, and take action to avoid adverse and promote positive health consequences [6]. HIA is based on the premise that “all public decisions should consider and account for their consequences to human health” [161]. HIA is a tool that can inform and improve planning and policy decisions, especially in "non-health" sectors like energy, transportation, land-use, and agriculture [164]. HIA can provide decision-makers with information to [161, 164]:

- identify potential health risks and health benefits from a project or proposal, and how these will be distributed in a population
- identify alternatives and strategies to prevent or reduce any identified health risks, and promote or enhance potential health benefits
- identify alternatives or strategies to minimize health inequalities from the unequal distribution of risks and benefits
- identify and address potential social, environmental and economic impacts from a project that could directly or indirectly affect health

Features of HIA

HIAs are similar to other types of impact or risk assessments in that they: 1) evaluate a proposed action, and usually one or more alternatives; 2) follow a defined process; 3) identify positive and negative impacts; and 4) provide evidence-based recommendations. However, HIA has some distinct characteristics and functions [161, 162]:

- **HIA has a broad and holistic view of health**, and considers impacts to physical, mental and social well-being. In addition, to evaluating the risks from specific hazards, HIA considers how a project's social, economic, and environmental impacts could indirectly affect health.
- **HIA has an explicit focus on equity**, and examines if certain populations are particularly vulnerable or disproportionately affected by a development's impacts.
- **HIA supports inclusive, transparent and democratic decision-making**. HIA seeks to engage communities in the decisions that affect them, and increase dialogue, cooperation, and partnerships among stakeholders with different backgrounds and interests.
- **HIA is evidence-based, structured, and impartial**. While an HIA may draw on draws on information and methods from different disciplines, any findings and recommendations should reflect the best available evidence.
- **HIA is usually conducted on a specific project, plan or policy**. This ensures that any evaluation of health impacts is site and community-specific, and that the assessment addresses the priorities and realities of the communities and stakeholders involved.

## Strategic HIA

In some cases, decision-makers need a broad evaluation of the impacts of a policy or development, and general guidance to manage these impacts at individual sites or projects. In these cases, a “strategic” or “programmatic” assessment can provide a framework to guide subsequent assessments and decisions for individual projects. Strategic assessments are usually conducted early in the implementation of a policy or process that affects multiple sites or communities.

One advantage of this approach is that the findings and recommendations from a strategic assessment “cascade” down to project-level decisions; this reduces redundancy and improves consistency between projects [165]. A disadvantage of strategic assessments is that they lack the site-specific information and context needed to evaluate and address the potential impacts of a project on a specific community. Therefore, strategic HIAs do not replace or diminish the value of a project-level HIA.



## Appendix B. Methods

HIA is a structured process that typically involves five steps. In this section, we state each step's objective, and briefly outline PHD's activities and major outcomes for this strategic HIA.

### Screening

The objective of screening is to decide if a HIA is feasible, timely and will add value to a decision-making process.

The screening step for this HIA took place in several stages, beginning with a convergence of requests to examine the potential health impacts from wind energy facilities. PHD evaluated several strategies to address these concerns, including a limited health consultation on noise and health, a site-specific HIA on a proposed development, and a strategic HIA. After consulting with internal and external stakeholders, PHD determined that a strategic HIA was the best mechanism to respond to these requests.

### Scoping

The objective of the scoping step is “to create a plan and timeline for conducting a HIA that defines priority issues, research questions and methods, and participant roles” [161]. The major activities for scoping this HIA were to: 1) identify the potential health impacts and health concerns related to wind energy developments; 2) convene a steering committee, and establish roles and responsibilities; 3) establish objectives of the HIA; and 4) develop research questions for the HIA, and identify methods and data sources.

#### 1. Identification of potential health impacts and concerns, and major domains

To identify as many health-related questions, issues and concerns related to wind energy in Oregon as possible, PHD gathered community data and feedback during three community listening sessions in Eastern Oregon, and through an online questionnaire (see Appendix D). A literature search was used to identify potential health issues reported in research studies, reports, and other sources.

Scoping  
contd.

## 2. Convening of steering committee

PHD convened a steering committee to help define the objectives, scope, and research questions for this HIA, identify research studies and resources for the assessment phase, and review and provide input on the HIA report. The steering committee, whose members are listed in Table 13, met four times from December 2010 to July 2011.

Table 13: Wind Energy HIA Steering Committee members.

<b>Name</b>	<b>Organization/Affiliation</b>
John Audley	Renewables Northwest Project
Casey Beard	Community Member
Barry Beyeler	EFSC Member; City of Boardman Community Development Director
Jae Douglas (Facilitator)	Research and Education Services Section Manager, Oregon Office of Environmental Public Health
Charles Gillis	Community Member; Friends of the Grande Ronde Valley
Scott Hege	Wasco County Commissioner
Laura Madison	Community Member; Private Wind Energy Developer
Brendan McCarthy	Portland General Electric
Doris Penwell	Association of Oregon Counties
Leann Rea	Morrow County Commissioner
Gail R. Shibley*	Administrator, Oregon Office of Environmental Public Health
Tom Stoops	Oregon Department of Energy
Teri Thalhofer	North Central Public Health District
Steve White	Oregon Public Health Institute

\*Ex-officio member

### 3. Wind HIA objectives and Definition of Health

The steering committee approved the following objectives and definitions for the Wind HIA on February 3<sup>rd</sup>, 2011, and agreed that changes or additions could be made, if needed, in the future:

1. Identify community questions and concerns about the health impacts from wind energy facilities, and assess the available evidence for priority health impacts.
2. Develop evidence-based recommendations for elected officials, ODOE, EFSC, PHD, and community members in the consideration and assessment of health in future wind energy facility siting decisions.
3. Invite community members to participate in the HIA process, and provide community members and other stakeholders with timely and useful information.
4. Increase awareness and knowledge about HIA among community and government stakeholders, and assess its use for specific wind farm siting decisions

The steering committee agreed to adopt the World Health Organization's definition of health for this HIA: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."<sup>24</sup>

### 4. Research questions, data and resources

During February and March 2011, Oregon Office of Environmental Public Health staff and the steering committee developed and refined research questions for five domains assessed in this HIA: noise, air pollution, visual impacts, economic effects, and community conflict. Each steering committee member independently provided a list of potential research questions for domain. PHD staff compiled these questions, and narrowed the list using the following filter questions:

- 1) Does this question focus on local health impacts?
- 2) Is this question answerable with available resources?
- 3) Will answering this question now help state and local decision-makers with future siting processes?
- 4) Does this question reflect input or concerns from members of the public?

The final list of research questions was finalized on March 11, 2011. See Appendix C for the full list of questions.

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<sup>24</sup> Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948. Available from: <http://www.who.int/about/definition/en/print.html>. Accessed November 16, 2011.

Assessment

The objective of assessment is to “provide a profile of existing conditions data, an evaluation of potential health impacts, and evidence-based recommendations to mitigate negative and maximize positive health impacts” [161]. PHD included baseline data on current conditions and existing policies when available and appropriate. To evaluate potential health impacts and identify recommendations, we conducted a literature review of evidence from a number of sources. This review focused on research and publications in peer-reviewed public health, engineering, social science, and other journals, and on reports and studies by state, federal and international governmental agencies. In addition, we considered information published by industry groups, community members, and non-profit agencies. We used the “hierarchy of evidence” shown in Table 14 to prioritize our information sources.

Table 14: Hierarchy of evidence used in Wind Energy Strategic HIA.

Weight	Study Type	Measurements	Source
<p style="text-align: center;"><b>More</b></p> <p style="text-align: center;">↑</p> <p style="text-align: center;">↓</p> <p style="text-align: center;"><b>Less</b></p>	Population-based	Measured	Peer-review Journals
	Risk assessment	Validated model	Public health/medical reports
	Case series/ case reports	Non-validated model	Publications by public health authorities
	Animal studies		Publications by other groups (Industry, community members)
			Other: Web sites, news articles, opinions, etc.

Reporting

The objective of reporting is to develop a HIA report, and communicate findings and recommendations to decision-makers and other stakeholders [161]. For the reporting phase, PHD will release an initial draft of the report to the public, and accept comments on the report public for up to 90 days. We will use this feedback to make appropriate revisions for a final version of the HIA report. In addition to the report, we will identify other venues to discuss the HIA’s process, findings and recommendations. These venues may include public meetings, community availability sessions, and presentations to county or state level agencies.

Monitoring and Evaluation

The objective of monitoring is to “track the impacts of the HIA on the decision-making process...and the impacts of the decision on health determinants” [161]. PHD will monitor the impacts of this HIA by tracking whether, how, and how often decision-makers use the HIA in specific siting decisions. Some potential measures are: 1) the number of site-specific HIAs conducted for new wind energy developments in Oregon; and 2) the number of siting decisions in which health was explicitly considered, or public health representatives were involved during the decision-making process.

In summer 2011, PHD's Program Design and Evaluation Services completed a process evaluation of PHD's effectiveness in meeting the Wind HIA objectives and engaging and communicating with our stakeholders during the screening, scoping and assessment phases of the HIA. PHD will use this information to improve our strategy, communications and activities for future state-led HIAs.

Communications

Throughout the HIA process, PHD communicated with stakeholders about our activities and progress using the methods and venues shown in Table 15.

Table 15: Communication methods for Wind Energy Strategic HIA.

Venue	Audience	Communications
Press	General Public	Announcement of meetings, report release
Website	General Public	Description of process, announcement of meetings, updates, invitations to provide feedback, links to electronic versions of report
Public meetings	General Public in North Central/ Eastern Oregon	Opportunity for community members to share thoughts, questions, concerns
General Listserv	Interested parties	Announcement of meetings, survey, progress updates, report release
Steering Committee Listserv	Steering committee	Meeting logistics, announcement of meetings, training opportunities, information sharing
Personal Communications	Interested parties	Response to individual calls, emails, and letters

## Appendix C. Wind Energy HIA Research Questions (3/7/2011)

### Domain: Noise

- 1) What types of noise do wind turbines generate, and how do they compare to other sources of community noise?
  - a) What are the sources of noise from wind turbines, what types of noise are they, and how does wind turbine design affect noise generation?
  - b) How does noise from wind turbines compare to other types of noise (e.g., noise from other industrial facilities, typical sources of noise in rural/urban environments)?
  - c) What factors, if any, affect how wind turbine noise propagates through the environment?
  - d) What factors, if any, affect how people experience or perceive noise from wind turbines (e.g., background noise levels, distance from turbines, living in rural vs. urban environments, ability to see turbines, etc.)?
  - e) Which metrics can best measure noise generated by wind turbines?
- 2) What is the current scientific evidence on the health impacts from noise of the type and nature generated by wind turbines?
  - a) What health effects, if any, have been identified or reported in the literature?
  - b) At what thresholds (level of magnitude, duration, etc.) do these effects occur?
  - c) Which populations or groups, if any, has the literature identified as being potentially more vulnerable or likely to be affected by the noise signatures generated by wind turbines?
  - d) What are data gaps/uncertainties/limitations in the current literature?
- 3) What are health-based recommendations to prevent, reduce, or mitigate noise exposures that could cause adverse health effects?
  - a) What levels or thresholds, if any, do state, federal or international public health organizations recommend to protect human health from noise exposures (including vulnerable groups)?
  - b) How applicable are these guidance levels for evaluating noise generated by wind turbines?
  - c) What factors or strategies, if any, are effective to reduce or mitigate noise exposures from wind turbines?

### **What methods or data sources could help answer the research questions? What agencies might provide access to this data?**

- Literature on health effects from noise (in general) and noise generated by turbines

**Domain:  
Visual  
Impacts**

- Subject-matter experts on noise and noise generated by wind turbines; suggestions from steering committee:
  - a. Jim Cowan and Mark Storm, URS Corporation, Acoustics and Noise Control
  - b. Kerrie Standlee, PE
  - c. Mark Bastasch, PE
  - d. Jim Cummings, Acoustic Ecology Institute
  - e. George Kamperman and Richard James
  - f. Others (PGE technical staff, turbine manufacturers)
- Health-based guidelines from state/federal/international organizations (e.g., CDC, EPA, WHO)
- The Noise Manual (ISBN:0-931504-02-4)

- 1) What is shadow flicker from wind turbines?
  - a) What factors, if any, affect whether or how people experience shadow flicker from wind turbines?
  - b) Which metrics, if any, can be used to measure shadow flicker from wind turbines?
- 2) What is the current scientific evidence on the health impacts from shadow flicker from wind turbines?
  - a) What health effects, if any, have been identified or reported in the literature?
  - b) At what thresholds (level of magnitude, duration, etc.) do these effects occur?
  - c) Which populations or groups, if any, has the literature identified as being potentially more vulnerable or likely to be affected by shadow flicker from wind turbines?
  - d) What are data gaps/uncertainties/limitations in the current literature?
- 3) What are health-based recommendations to prevent, reduce, or mitigate exposure to shadow flicker that could cause adverse health effects?
  - a) What levels or thresholds, if any, do state, federal or international public health organizations recommend to protect human health from shadow flicker (including vulnerable groups)?
  - b) What factors or strategies, if any, are effective to reduce or mitigate potentially harmful exposure to shadow flicker from wind turbines?

**What methods or data sources could help answer the research questions? What agencies might provide access to this data?**

- Research literature on shadow flicker

**Domain: Air  
Pollution**

- 1) What is the current scientific evidence, if any, on how wind turbine developments affect emissions of air pollutants in local communities? Specific pathways to evaluate include: a) replacement of gas/coal-fired units in the state; b) construction equipment and vehicular traffic during construction and operation and maintenance phases; c) changes in road conditions/infrastructure in local communities.
  - a) Which air pollutants, if any, would be measurably changed in each pathway?
  - b) What information is available on the magnitude and direction of these changes, if any, in local communities?
  
- 2) What is the current scientific evidence on the health impacts from changes in air pollutant levels, if any, due to wind energy development?
  - a) What health risks and effects, if any, are associated with air pollutants of interest?
  - b) At what thresholds (air concentrations, duration of exposure) do these effects occur?
  - c) Based on the available evidence, what impacts, if any, would estimated changes in air pollutant levels have on human health?
  - d) Which populations or groups, if any, has the literature identified as being potentially more vulnerable or more likely to be affected by changes in these air pollutants?
  - e) What are the data gaps/uncertainties/limitations in the current literature?
  
- 3) What strategies have been identified in the literature to maximize positive and mitigate potentially negative health impacts from changes in air pollutant levels in local communities?

**What methods or data sources could help answer the research questions? What agencies might provide access to this data?**

- Literature on impacts of wind energy developments on air pollution (focus on replacement of gas/coal-fired energy sources, construction/vehicle-related impacts, changes in road conditions)
- Environmental impact assessments from existing developments (identified with assistance from DOE/other steering committee members)
- Literature on human health risks/effects from identified air pollutants
- Subject matter experts



**Domain:  
Community  
Livability/  
Cohesion**

- 1) What factors related to community livability and social cohesion, if any, are known to be linked to human health outcomes (particularly in rural areas)?
- 2) What information is known about how wind energy developments (or similar development projects) measurably affect these identified factors in local communities in the short and long-term, and how could these changes, if any, impact human health?
- 3) What factors or strategies have been identified in the literature to maximize positive and mitigate potentially negative impacts from changes in community livability/cohesion due to development projects?

**What methods or data sources could help answer the research questions? What agencies might provide access to this data?**

- Research literature on community livability, cohesion and health
- Data from PHD community listening sessions/survey
- Data from local/regional polls, surveys, reports
- Assessments of the impacts of other wind energy projects or similar development projects on community cohesion

**Domain:  
Economic  
Effects**

- 1) What is the evidence, if any, on the links between human health and the following priority economic factors: <sup>25</sup>
  - a) Personal income and assets
  - b) Jobs, employment, and local business
  - c) Revenue and liability for local and state jurisdictions (including education and other districts)
- 2) What information is known about how wind energy facilities (or similar projects) affect these factors in local communities in the short and long-term, and how could these changes, if any, affect human health?
- 3) What strategies have been identified in the body of evidence to maximize positive and mitigate potentially negative health impacts from economic changes in local communities due to development projects?

**What methods or data sources could help answer the research questions? What agencies might provide access to this data?**

- Literature on economic determinants of health
- Labor statistics/data on economic trends (Oregon Employment Department/other state and federal resources)
- Key informant interviews/survey (local economic development depts., county officials, chambers of commerce, developers)

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<sup>25</sup> Priority economic factors were identified during community listening sessions/literature review

- Financial information and reports from city/county/state governments
- Data from Strategic Investment Plan
- Private land owner turbine projects
- Land owners (public and private) who economically benefit from wind turbine developments
- Project data on employment from Oregon Dept. of Energy

**Parking Lot**

1. Impact on darkness from flashing lights
2. Looming
3. Scale of developments

## Appendix D. Community Data

This section provides a brief summary of the methods and data PHD collected during three community listening sessions and an online questionnaire. There are some important limitations in the information collected from community members. Due to time and resource constraints, PHD did not collect data that are representative of the state of Oregon. The community listening sessions were held in geographic areas where wind energy development is concentrated (the Columbia River Gorge and north central/northeast Oregon), while the questionnaire was open to anyone in the state. The data are qualitative in nature, and reflect the opinions and views of the respondents. Because these data were not collected in a systematic way, we did not analyze, quantify or rank responses.

### Methods

We gathered community data and feedback during semi-structured listening sessions in three communities in Eastern Oregon, and through an online questionnaire. The listening sessions were held on November 3<sup>rd</sup> and 4<sup>th</sup>, 2010, in LaGrande, Pendleton, and Arlington; the LaGrande and Arlington meetings lasted 1.5 hours and were held in the evening, while the Pendleton meeting lasted one hour and was held in the afternoon. The goals of the sessions were to:

1. Provide a meeting format that helps community members feel heard;
2. Gain an understanding of the experiences, questions, and concerns in communities that are living with and developing wind energy facilities;
3. Explain the Public Health Division's process and timeline.

The meetings began with introductions, a brief overview of the purpose of the listening sessions, and an overview of our agenda. The meeting participants broke into small groups, with one or more PHD staff as group facilitators. In the small groups, participants were asked to answer the following questions:

1. Why do you live where you live? (*Prompting questions: What are some things you value about the place you live? What are some of your community's strengths?*)
2. What are some challenges your community is facing?
3. What are some ways that wind farms impact a community? (*Prompting questions: What are some positive changes wind farms can bring to your community? What are some challenges wind farms can create in your community?*)
4. What specific questions, comments, or experiences do you have about the potential health impacts of wind turbines?
5. What else do you think we should consider?

PHD staff documented participants' answers on large easel pad papers and posted these around the room. Participants could also write their responses on handouts and returning these to the group facilitators. Each participant was given three stickers and asked to read other groups' responses. Each participant used their stickers to "vote" on their top three priorities or issues. PHD staff closed the meeting by reconvening the large group and asking if participants wanted to share or communicate anything else. After receiving information on PHD's next steps and contact information, participants were asked to complete a meeting evaluation.

Online  
questionnaire

PHD used an online questionnaire to provide a second opportunity for community members to share information, questions, and concerns. Respondents were asked for information on their county of residence and zip code, and their responses to the following open-ended questions:

1. What do you value most about the place you live?
2. What do you see as the challenges your community is facing right now?
3. In general, what are the major impacts a wind farm can have on a community?
4. What are the major issues, questions or concerns you have about the health impacts from wind energy facilities?
5. What else should we consider?
6. Is there anything else you would like to share with us?

### *Summary of Community Responses*

*Why do you  
live where  
you live?*

Some common responses to "Why do you live where you live?" included: rural, wide open spaces; solitude; small towns; slow pace of life; and the peace and quiet. Respondents emphasized the ways in which rural areas differed from urban parts of the state. People reported that they valued the beautiful landscapes, starry skies, and having easy access to outdoor recreational activities. Many people live in the region because of its nonindustrial, agricultural base. Several people mentioned freedom, property rights, property value, and low cost of living. Many respondents were born in the area they live, and continue to live in the region because of their relationships to their families, friends and neighbors. People felt their community is a wonderful place to raise a family because of low crime and strong ties and support from family, neighbors and friends.

*What are the challenges your community is facing right now?*

The major challenge in respondents' communities is the economy. Respondents noted that rural Oregon has historically faced a number of economic challenges (e.g., loss/decline of logging and other industries, limited support for local businesses), the rural economies have been hit particularly hard by the recent recession. Further, people reported that there is a severe lack of family wage jobs, and limited funds for basic services like schools and infrastructure. Respondents felt that economic and other challenges have contributed to a declining population in their communities. Young adults in particular are leaving in large numbers because of a lack of educational and work opportunities. Social issues, such as an aging population, drug use, and child abuse were noted as issues of concern in respondents' communities.

*What are the major impacts a wind energy facility can have on a community?*

Respondents noted both positive and negative impacts from wind energy facilities in their communities. Some respondents felt that wind energy development have a positive economic impact from the creation of family wage jobs, increased tax income for the counties, and land lease payments for some community members. People said that increased money in the community could benefit local businesses, increase local hiring, and improve a community's infrastructure and services. Many respondents noted that wind energy is a clean and sustainable source of energy that could improve local and regional environmental quality and help to address climate change.

On the other hand, some community members felt that wind energy facilities won't have the level of economic benefits promised. These respondents had concerns that new jobs would go to outsiders, tax revenues will be less than promised, and that the community would ultimately bear the costs of expanded infrastructure and public services. Some respondents worried that local property values will be negatively impacted. There also were concerns that not everyone will benefit equally, and that some community members will bear a greater burden than others. Some respondents questioned the environmental benefits and reliability of electricity from wind energy facilities.

Most respondents acknowledged that wind energy development come with some level of disruption during construction and an aesthetic cost; however, there were differing views on the relative importance of impacts to the landscape and viewshed. Some people expressed concerns that these developments could negatively impact local tourism and harm birds, bats and other wildlife.

Wind energy development was mentioned as a challenge to community cohesion, and there was a shared concern about the negative feelings and stress in some communities divided by proposed or existing development. Several people felt that a major component to these conflicts is a lack of participation and influence in the decision-making and siting process. Other people mentioned that siting decisions could potentially create winners and losers. Several people mentioned that they fear a loss of quality of life because of the wind development.

*What questions, issues, or concerns do you have about health?*

Respondents were divided on whether or not there are health impacts from wind turbines, although people on both sides of the issue had concerns about the lack of data and scientific studies on potential health impacts. Some specific health issues related to wind turbines included the following: noise, low frequency noise, inaudible noise, sleep disturbance, fatigue, shadow flicker, dizziness, migraines, vibration, blinking lights, and mental health impacts including depression, anxiety, and stress. Some people mentioned the potential for 24-hour exposures and had questions about cumulative impacts from multiple facilities and effects on vulnerable populations such as elders, children, and people with pre-existing conditions. Some people expressed concerns about worker safety during the construction phase and during regular maintenance. There was a shared concern about the impact of community conflict and stress on health.

Many respondents noted that wind energy can have positive health impacts from improved environmental quality and improved economic outcomes. Some people said that any negative health impacts from wind energy are small and less severe than those from coal and other fossil-fuel based plants. Several people had no questions, issues or concerns about health.

*What else should we consider?*

PHD received many responses to this question. Many of the responses fell into the following topic areas:

- Need for more local consultation and involvement in siting process and decisions
- Accurate consideration of local conditions
- Strategies to reduce visual impacts on landscape
- Need for more studies of health and other impacts from wind energy developments in local communities
- Cost-benefit comparisons with other energy sources, and assessments of how risks and benefits are distributed in a community
- Decommissioning wind energy facilities
- Concerns about quality of life and rural lifestyle

Many people expressed some level of distrust with “outsiders”; these outsiders included developers, government agencies, people from urban areas of Oregon, etc. This distrust extends to this office, and several respondents asked the Oregon Public Health Division to stay out of local development decisions. Others, however, were appreciative of PHD’s intent to conduct a HIA on wind energy development in the state, and asked to be kept informed throughout the process.

## Appendix E. Additional information on stress and community conflict

### Definition

A clinical definition of stress is "a state of activation of physical and psychological readiness to act in order to help an organism survive external threats" [52]. This definition highlights the important role of stress in maintaining physical and mental health, and in surviving challenges encountered in everyday life. However, public health research on the health effects of stress tends to focus on a more everyday definition - "a state of physical or psychological strain or tension" [53].

### Primary stress

Researchers who study stress related to environmental risks or hazards have identified at least two types of stress that act at the individual and community levels. Primary stress is caused by real or perceived risks from environmental hazards. Primary stress is influenced by characteristics of the individuals or groups exposed, and the circumstances of the exposure. Individual or group characteristics that affect primary stress response include age, place and length of residence, proximity to the hazard, socioeconomic status, pre-existing physical and mental health status, the presence of other life stressors (e.g., stress related to income, employment, family/neighborhood stability, discrimination), and ability to cope with stress [53]. Exposure-related factors that appear to increase negative responses and stress are exposures that are [52, 53]:

- involuntary vs. voluntary
- manmade vs. natural
- new or poorly studied vs. familiar and well-understood
- catastrophic and acute vs. slow-moving and chronic
- life or health-threatening vs. relatively benign
- controlled by others vs. individually controlled
- unequally distributed vs. fairly distributed
- sources of information untrustworthy/biased vs. sources that are trustworthy/unbiased
- decision or response process that is unresponsive/exclusive vs. responsive/inclusive

Secondary Stress

Secondary stress is caused by social and community responses to a site or incident. Researchers have found that secondary stress may result in the splintering of some communities into different factions, while in other communities, it may result in community-wide mobilization and response [53]. As with individual responses to stress, each community's response is unique and influenced by a number of factors. These include:

- the social, historical and cultural context of a community, which influences how people value and relate to each other, their community, their surroundings, and to people or interests from outside the community;
- availability of social support, information and resources;
- presence of community-wide stressors (e.g., poor or lagging economy, crime, existing sources of environmental stigma or blight);
- levels of pre-existing divisions, disparities or marginalized groups within a community;
- the level of dependence on government or outsiders for information or assistance;
- level of trust within community, and with government/outside entities;
- implementation of strategies that disrupt or preserve existing social norms or structures.

Acute stress response

Researchers and clinicians distinguish between acute and chronic stress responses. Acute stress usually occurs in response to sudden or catastrophic events, and is commonly known as the "fight or flight" response. This reaction activates the endocrine and sympathetic nervous systems, which release adrenaline, noradrenaline, cortisol, glucocorticoids, and other hormones. These hormones cause physiologic changes that include increased heart and lung function, constriction of blood vessels in some parts of the body, dilation of blood vessels to the muscles, increased availability of glucose to the muscles, dilation of pupils, slowing of digestion, and increased awareness or vigilance [52, 53]. Acute stress reactions tend to resolve within hours of removing a stressor.

Chronic stress response

Chronic stress occurs when there is long-term or repeated activation of the normal stress response. Scientists believe that chronic stress occurs from persistent feelings of anxiety and lack of control, or from repeated exposures to stressful situations or environments [160]. Over time, prolonged stress responses can wear down the organs and systems of the body, and compromise its ability to respond to environmental threats. Clinical studies have found that chronic stress decreases immune function, increases risks for cardiovascular disease and endocrine disorders, and affects how the brain and body age. Further, it impairs cognitive functions such as memory and concentration, and can trigger or worsen mental illnesses such as anxiety disorders and depression [160].



In addition to directly causing or exacerbating physical or mental illnesses, stress affects health indirectly. Environmental epidemiologists have found that stress can increase people's vulnerability to environmental stressors. With chemical exposures, people may "take in" more chemicals from the environment because of increases in respiration, perspiration or consumption, or have lowered abilities to counteract harmful effects from these exposures [52]. Chronic stress may also lower people's response thresholds and ability to cope with stressors such as noise and air pollution. Chronic stress may increase risks for unhealthy behaviors such as smoking, excessive alcohol consumption, drug abuse, and overeating [52, 160]. Finally, stress can erode a person's sources of familial and social support, and limit their engagement with their community. This can amplify the effects of primary stress, and worsen secondary stress at the individual and community levels.

#### *Epidemiological studies of stress from environmental hazards*

A few epidemiological studies have examined the health effects of chronic stress in communities affected by environmental incidents or contamination. Researchers have found that residents near these sites had increased biological and psychological indicators of stress compared to control groups. These included psychological distress, anxiety, depression, difficulties concentrating, increased blood pressure, and higher levels of cortisol and other stress hormones in urine [53]. Many of these studies have focused on large or relatively high-profile incidents, such as the Three Mile Island accident or the Love Canal Superfund site. However, researchers have found these effects in communities where an environmental threat was perceived, but not real [52]. These studies do not appear to distinguish between primary and secondary stress. Therefore, we cannot determine the relative importance of stress from community-level conflict compared to stress from perceived or real exposures.

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