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Wind Energy Economics: Production Costs and Additional Impacts

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PRODUCTION COSTS AND ADDITIONAL IMPACTS

WEST MICHIGAN WIND ASSESSMENT ISSUE BRIEF #6

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The West Michigan Wind Assessment is a Michigan Sea Grant-funded project that is analyzing the benefits and challenges of utility-scale wind energy development in coastal West Michigan. More information about the project is available at http://www.gvsu.edu/wind.

Introduction

- *This report puts a dollar amount on the potential indirect impacts of electricity production from wind, coal and natural gas.*

West Michigan's electricity choices—whether conventional sources or alternative sources such as wind energy—have an impact on the local and regional economy. In addition to the cost of building, operating and maintaining an energy facility, electricity production has unintended effects that are rarely incorporated into the cost of electricity; economists call these indirect, unintended effects "externalities". For example, stakeholders in West Michigan are concerned about how wind farms could affect property values, public health and wildlife. Each of these potential impacts, or externalities, is discussed in the following sections and then the best available information is used to assess the value of these impacts in dollars. We then tallied up the costs to build and maintain energy facilities and the unintended effects to estimate the overall production cost for three different types of energy facilities: onshore wind farms, and coal-fired power plants and natural gas power plants.

The potential economic stimulus of building new onshore wind energy facilities is discussed in a companion report, *Wind Energy Economics: Potential Economic Development in West Michigan.* The economic implications of offshore wind energy are explored in a separate factsheet, *Offshore Wind Energy in Michigan: Economic Costs and Benefits*.

Property Values

There is widespread concern that wind farms could decrease nearby residential property values. This section reviews all the available scientific studies about wind turbines and property values. When surveyed, some people would expect a discounted sale price if they were to buy a home with a view of a wind turbine, however, studies of home sales near existing wind farms show no consistent change in sale prices as a result the wind farms.

The West Michigan Wind Assessment project team reviewed all available theses, government reports and peer-reviewed articles published in scientific journals on the effect of wind turbines on property values and compensation. There are a number of other technical reports from appraisers, project developers, activist groups, and others that come to a wide range of conclusions and are excluded from this analysis because their methods are less credible and potentially biased. The 10 scientifically rigorous studies that could be found are summarized in Table 1, revealing very similar findings —no evidence of consistent, measurable property value reductions from constructed wind turbines. These studies can help answer some important questions.

- *Sale prices for homes located more than 3,000 feet from a wind turbine are unaffected by a nearby wind farm. However, it's harder to detect consistent patterns for the few homes located closer than 3,000 feet.*

Do home prices vary depending on their proximity to wind turbines?
Six scientific studies gathered data on home sales at different distances from existing wind turbines and used an economic model called hedonic analysis to look for patterns. For example, a team of scientists from the Lawrence Berkeley National Laboratory analyzed almost 7,500 sales of single family homes located within 10 miles of 24 existing wind facilities in 9 states [1]. The scientists concluded:

"…none of the [property value] models uncover conclusive evidence of the existence of any widespread property value impacts that might be present in communities surrounding wind energy facilities. Specifically, neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, and statistically significant effect on home sales prices" [1, p. iii].

The bulk of scientific research on house values and proximity of wind turbines show little to no effect on home prices located more than 3,000 feet from a turbine. Within 3,000 feet, the number of home sales is not large enough to find statistically meaningful differences in most instances. However, Sims, Dent, and Oskrochi [2] find, depending on conditions, both positive and negative effects inside 2,600 feet. Therefore, the effect within 3,000 feet is probably dependent on multiple factors, including the type of turbine, view of the turbine, topography, and distance.

- *Interestingly, home sale prices seem to drop just after a new wind farm is announced, but once built, prices return to normal.*

How does the announcement of a new wind development affect home prices?
Several studies examined home sales near wind farms over time: before the wind farm was announced; after announcement but before construction; and after construction [1, 3, 4]. Two research teams found some influence on housing prices between 3,000 feet and one mile from a wind turbine. Home prices dropped by 8 percent after the wind farm announcement but before construction. This effect is called "anticipation stigma". Sale prices dropped in anticipation of planned wind farm project. However, in these studies, researchers found that home prices returned to normal after the wind farm was constructed and operating [1, 4].

There are two possible explanations for such a finding. First, the fear of possible problems associated with the turbines could be greater than the reality of the actual problems. Second, some individuals might be strongly and negatively affected by the proximity of a turbine. They sell at a loss early in the construction process, but enough people are comfortable with the nearby turbines that there's a base of buyers and sellers after the initial adjustment.

Authors	Type of Publication	Location	Method	Findings
Grover [5]	Peer reviewed	Washington	Tax assessor interviews	No property value impacts reported, but method is weak.
Hoen [6]	Thesis	New York	Residential property sales (hedonic model)	No measurable effects on price from wind farm.
Sims and Dent [7]	Peer reviewed	Cornwall, UK	Residential property sales (hedonic model)	Data insufficient to draw conclusions.
Sims, Dent, and Oskrochi [2]	Peer reviewed	Cornwall, UK	Residential property sales (hedonic model)	No consistent effect on sales price, views of turbines had both positive and negative effects.
Hoen and others [1]	Govt. report	USA	Residential property sales (hedonic model)	No consistent effect on price from constructed wind farms. Found evidence of "anticipation stigma".
Laposa and Mueller [3]	Peer reviewed	Colorado	Residential property sales (hedonic model)	No evidence of "anticipation stigma." Wind farms not constructed yet.
Hinman [4]	Thesis	Illinois	Residential property sales (hedonic model)	Evidence of "anticipation stigma," but no long-term effect on price of home within three miles of constructed turbines.
Bergmann and others [8]	Peer reviewed	Scotland	Survey (choice experiment)	Participants willing to accept a hypothetical, high-landscape impact wind project if compensated at £19.40 / household / year (about $30 / household / year).
Groothius and others [9]	Peer reviewed	North Carolina	Survey (contingent valuation)	Participants willing to accept a hypothetical wind farm if compensated for lost vista ($23 / household / year).
Bond [10]	Peer reviewed	Australia	Survey	28% of respondents would pay less for a home within about two miles of a wind farm, most 1-9% less.

Table 1: Summary of studies documenting the effects of wind power on housing prices.

Several studies surveyed people to get at this question: How much would a potential buyer expect to save if they purchased a home near a wind turbine? Surveys of hypothetical situations can provide information when direct observations are not possible; however, studies of home sales are seen as more reliable than surveys because they reflect actual consumer behavior. Surveys indicated that, in hypothetical situations, participants were willing to accept compensation for vistas that are

- *In surveys about hypothetical situations, people would accept a small annual compensation for living in view of a wind turbine.*
- *It is likely that some people living very close to turbines are negatively affected by the noise, but there is not enough information to calculate these costs.*

impacted by wind turbines, but the amount of compensation is relatively small ($20 – 30 per household per year) [8, 9]. This suggests that people may prefer to live in a home without a view of wind turbines, but this preference may be too weak to be seen in most home sales.

Some homeowners may have a negative reaction to turbines; however the size of this group seems to be too small to affect overall home prices. It is possible that as more turbines are built in more densely populated places, housing price effects may become more evident.

In order to calculate the total production cost of wind energy, including potential impacts on property values, the West Michigan Wind Assessment took a very conservative approach (see results in Table 4). The authors of this issue brief assumed that wind turbines decrease the value of a house within one mile by 8 percent. This is the largest negative impact found in peer-reviewed literature, although it was only observed temporarily after a wind farm was announced [1]. This analysis assumes that homes within 1 mile of a coal or natural gas power plant also show an 8 percent loss of value, which is consistent with what economists have observed [11]. Disregarding mining and drilling impacts, wind farms cover a much larger geographic area and affect more homes than traditional power plants.

Health Effects

Wind power can replace fossil-fuel electricity generation and its pollutants, which benefits human health. However, some people living in the immediate vicinity of wind turbines have reported health concerns. Studies have shown that most residents living near turbines report no disturbance. For those that do report being disturbed by wind turbines, the most common complaints include insomnia and depression. Although health concerns receive a lot of attention, scientific research to date has not documented a causal link between wind turbines and health complaints. Potential negative health effects associated with wind turbines are not calculated here because there is not enough information about the validity, magnitude or extent of these issues and costs cannot be estimated. One speculative calculation is discussed in the footnote below[1] [12, 13]. Despite the lack of research, it is likely that some individuals living very close to wind turbines are negatively affected by the noise. This is a topic of ongoing scientific investigation and as science progresses, health effects may be documented more fully. For more details on this topic, see the *Wind Power and Human Health* issue brief [14].

[1] Many of the unsubstantiated health claims revolve around increased occurrences of insomnia and depression (Pedersen and Persson Waye [12]). In an attempt to quantify a maximum, assume all people within 0.5 miles acquire insomnia. This assumption is beyond any current scientific or even anecdotal evidence found by the study group. Using numbers from Ozminkowski et al. [13] the cost of insomnia can be estimated. In addition assume that none of these insomnia cases are treated in the first year and after which they are treated. An untreated case of insomnia costs $1,700 on average for the first year and $200 per year after it is treated. So for the first year, the additional 6.4 cases of insomnia per megawatt (MW) of installed capacity would result in an additional external cost of $4.14 per megawatt hour (MWh) after which it would drop only $0.49 per MWh. Therefore, even this *beyond* worst case example shows that the result that wind is competitive with natural gas and less expensive than coal, once externalities are taken into account, still holds.

Wind energy could benefit public health if wind farms replace electricity generation from more polluting fuels such as coal or natural gas. It is well known that the production of electricity using coal and natural gas results in environmentally harmful emissions that affect human health. Emissions from power plants in the four county study area were obtained from the U.S. Environmental Protection Agency and are detailed in Table 3 [15]. The air pollutants include nitrogen oxides (NO_x), and sulfur dioxide (SO_2), which contribute to acid rain, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which contribute to climate change, and mercury (Hg) which accumulates in fish and wildlife and is toxic to humans.

	Nameplate capacity (MW)	Annual production (MWh)	NO_x (tons)	SO_2 (tons)	CO_2 (tons)	CH_4 (lbs)	N_2O (lbs)	Hg (lbs) [2]
Total for all **gas** plants in study area	1,233	952,369	121	6	464,276	18,267	1,837	-
Average for a **gas** plant in study area	176	136,053	17	1	66,325	2,610	262	-
Total for all **coal** plants in study area	2,318	11,144,339	13,563	42,878	11,822,738	276,924	403,030	557
Average for a **coal** plant in study area	463	2,228,868	2,713	8,576	2,364,548	55,385	80,605	139

Table 2: Annual electricity production and air emissions from all power plants (7 gas, 5 coal) in the study area. Data are from the US EPA [15]

Each of the air pollutants associated with fossil fuels has well documented health and/or climate impacts, including asthma, neurological damage and premature death. Each of these health and climate effects can be valued in dollars using a range of methods that, for example, incorporate health care bills and lost productivity due to sick days. Table 3 summarizes four studies that estimated the health and climate costs associated with specific pollutants. The West Michigan Wind Assessment used the estimates in Tables 2 and 3 to calculate the total cost of producing electricity from coal and natural gas (see results in Table 4).

[2] The latest EPA pollution dataset (eGRID2010) did not contain data on mercury emissions. The mercury emissions rate (lbs/GWh) for the coal plants was obtained from the dataset's previous version (eGRID2007) and was applied to the current level of electricity production.

	NO_x ($/ton)	SO_2 ($/ton)	CO_2 ($/ton)	CH_4 ($/lb)	N_2O ($/lb)	Hg ($/lb)
Health and Environmental Cost	$1,066	$1,649	$9.37	$0.06	$0.78	$10,276.48
Data Source	Rive 2010 [16]	Rive 2010[16]	Muller et al. 2011 [17]	Tol 1999 [18]	Tol 1999 [18]	Rezek and Campbell 2007 [19]

Table 3: Health impact costs associated with different air pollutants, reported in dollars per ton or dollars per pound of pollutant released into the air. Data are from four peer-reviewed studies.

Wildlife Effects

Stakeholders in West Michigan have also expressed concerns about potential bird and bat mortality due to wind turbines. The amount of bird and bat kill depends on many things, including the geographic location and the startup wind speed of the turbine. Barclay and colleagues compiled 22 studies of bird and bat fatalities from across the U.S. and Alberta, Canada. They found that, on average, two birds and seven bats were killed each year by a single turbine [20]. However, the extent and causes of bat deaths are poorly understood; observations of bat fatalities vary widely, for example, less than 2 bats were killed annually per turbine in Minnesota, while more than 40 were killed annually in West Virginia. In general, biologists are more concerned and unsure about the impacts of wind turbines on bat populations than birds [21, 22]. Local conditions, including turbine height, season and turbine operational settings will influence fatalities, but on average, the problem is relatively small compared to other sources of bird and bat mortality in West Michigan, including collisions with communication towers and hunting by house cats [23].

- *On average, a single wind turbine kills 2 birds and 7 bats a year, far less than caused by collisions with communication towers or hunting by house cats [23].*

Birds and bats are important components in their ecosystems, and they provide tangible and intangible benefits to humans. Bats eat a huge number of insects, reducing the need for insecticides on farm fields. They also disperse seeds and help pollinate plants in natural and agricultural systems. In an attempt to quantify the cost of killing birds and bats, we focused on one service that bats and some types of birds provide—insect control. This particular benefit seemed to be the least subjective and most well studied.

- *Bats benefit humans by eating pest insects and reducing the need for insecticides on crops.*

Example: Bat Fatalities

A few researchers have estimated the number of insects consumed by the average bat and then calculated the cost of insecticide needed for the same result. For example, one research team found that Brazilian free-tailed bats ate large numbers of cotton bollworm, significantly reducing damage to cotton crops in a four-county region of West Texas [24]. Based on this example of one bat species, one high value crop and one pest insect, they found that a colony of 1.5 million bats produced $121,000 to $1.7 million in annual benefits by reducing crop damage, decreasing the number of needed pesticide applications, and minimizing the environmental costs associated with pesticides. From this, one could estimate that a single Brazilian free-tailed bat in Texas is worth an average $0.49 annually. A typical wind farm (67 turbines) could kill 470 bats a year (assuming 7 bat deaths per turbine, as found by Barclary [20]), costing farmers about $230 annually. Unfortunately bat populations and bat feeding behavior is not as well studied in the Midwest, and it's unlikely that the loss of a few bats would be noticeable. For these reasons, this example from Texas likely provides an overestimate of the cost of bat fatalities from wind turbines in west Michigan, but it is used here to provide a conservative estimate of potential costs associated with wildlife effects.

Impacts from Existing Power Plants

The impact of existing energy sources upon fish and wildlife populations is also an important consideration when evaluating alternative energy impacts. For example, coal and nuclear power require large amounts of water for cooling, and older plants with once-through cooling systems are particularly destructive to fish because fish are sucked into plant intake pipes or caught on screens [25].

- *Older power plants along the Great Lakes shoreline kill fish and cause $2.1 million in losses for commercial and recreational fishing each year.*

There are 67 older thermo-electric power plants along the U.S. Great Lakes shoreline that kill large numbers of fish and reduce potential commercial and recreational fishing harvests. This impact has been valued at about $2.1 million per year for the U.S. side of the Great Lakes [25]. This means that one average-sized, coastal coal plant causes $31,000 in damage to fisheries each year. This corresponds to a relatively small cost per MWh of electricity produced (about $0.013/MWh, Table 6). This estimate does not include non-market effects of power plants, such as the cost of less healthy fish populations for people who don't catch or eat Great Lakes fish, or the cost of mercury emissions that accumulate in fish. Fishery effects are discussed more in the issue brief, *Offshore Wind Energy in Michigan: Implications for the Great Lakes Environment* [26].

Comparing Different Electricity Sources

When comparing different ways to produce electricity, it can be useful to tally up all associated costs— including the cost to build and operate a new facility and the cost of potential impacts on human health, property values and wildlife. In this section we compare the costs associated with new natural gas, coal and onshore wind facilities. The data presented are national averages from the Energy Information Administration's Annual Energy Outlook, our own calculations for West Michigan, and recent figures from the Michigan Public Service Commission. To demonstrate the level of certainty for cost estimates, we presented data from these three sources.

- *Wind projects are generally less expensive to build and operate coal-fired power plants, but more expensive than comparable natural gas plants.*

Construction Costs

How much does it cost to build different types of power plants? The Energy Information Administration (EIA), a division of the U.S. Department of Energy, estimated the capital costs for constructing new electricity-generation facilities [27]. The capital cost is presented in dollars per kilowatt in order to standardize for the size of the project (Table 4). The power plant capacity refers to the maximum electricity-generation potential of the facility. The EIA estimates show that wind projects are less costly to build, however, wind farms usually have a much smaller capacity and they don't generate electricity as consistently as coal or gas-fired plants. Of the three, conventional natural gas plants are the least costly to build when standardized based on their energy production (Table 4).

	Conventional natural gas (combined cycle)	Advanced pulverized coal (single unit)	Onshore wind (67 turbines)
Plant construction cost	$528,120,000	$2,058,550,000	$243,800,000
Power plant capacity (kW)	540,000	650,000	100,000
Standardized cost ($/kW)	$978	$3,167	$2,438

Table 4: Cost to build a typical gas, coal, and onshore wind generation facilities in 2010 dollars. Standardized costs (also called the "overnight capital cost") illustrate what a typical project would cost if it were constructed overnight and each type of plant had the same capacity to generate power. Source: EIA 2010 [26].

Construction and Operation Costs

How do construction and operation costs compare for different electricity sources? The U.S. Energy Information Administration also estimates the price of a unit of electricity produced over the lifetime of an energy facility. This is called the levelized cost of electricity and is measured in dollars per megawatt-hour ($/MWh). In this case, the levelized costs include direct costs such as construction, fuel, and operation and maintenance, but not indirect impacts related to pollution or property values. Table 5 presents a range of cost estimates for different electricity sources coming online in 2017, as reported in the 2012 Annual Energy Outlook[3] [28].

If pollution and other indirect costs are ignored, natural gas is currently the lowest-cost source of electricity. As illustrated in Table 5, wind and coal have similar levelized costs, though wind's cost is more variable. The least expensive wind projects are less costly than the least expensive coal plants. However, the most expensive wind projects cost more to build and operate than the most expensive coal plants (Table 5).

		Conventional natural gas	Advanced coal	Onshore wind
Levelized costs – construction and operation ($/MWh)	Minimum	$61.80	$103.90	$78.20
	Maximum	$88.10	$126.10	$114.10
	Average	$68.60	$112.20	$96.80

Table 5: Estimates of direct costs for various electricity sources, also known as the total system levelized costs in 2010 dollars. The range reflects regional variation in costs, incentives and financing[3]. Source: EIA 2012 [28].

[3] Recently the EIA calculated the total direct costs for various forms of electricity generation (Table 5) [28]. EIA's cost estimates are higher than those in Table 6 because the West Michigan Wind Assessment ignored costs that would be the same for all production types. In addition, EIA's calculation is for 2017 not 2010, so coal costs reflect new regulations and wind energy reflects increased areas of the U.S. approaching the 10 percent wind threshold. Their results do not change the findings of this proect: wind is competitive with the costs of coal generation and more expensive then natural gas when externalities are not addressed.

Indirect and Direct Electricity Costs for West Michigan

How do different types of electricity compare when indirect costs such as pollution are also considered? The project team estimated the total production cost of electricity from wind, coal and natural gas in West Michigan by adding the direct costs of construction, maintenance and fuel costs, as well as the indirect (external) costs associated with pollution, wildlife and property values (Table 6). Costs are presented per unit of electricity produced, in this case dollars per megawatt hour ($/MWh), to provide a clear comparison of different sources of electricity. For reference, a typical household uses about 13 MWh of electricity in a year. The sources and process used for these calculations are discussed in the Appendix. For this analysis, the project team made assumptions that would increase the cost of wind and decrease the cost of traditional sources in order to provide a conservative estimate for the costs of switching to a newer energy source, such as wind.

- *Fuel costs for natural gas and coal plants can fluctuate dramatically over time and most of this spending flows to out-of-state businesses.*

The levelized costs presented above (Table 5) and the West Michigan Wind Assessment's estimates of direct costs (Table 6) are different, in part, because the assessment team used data from actual coal, gas and wind energy facilities in Michigan, rather than national averages. However, the relative costs of different energy types are very similar. Wind energy facilities are generally considered more expensive to build than a natural gas or coal plant when costs are standardized based on their energy production. We assumed that a wind farm will only last 20 years, which is less time than manufacturers advertise, while a coal plant could last longer with adequate upkeep. Fuel costs for coal and natural gas are a significant part of operating a power plant; most of this spending goes to out-of-state businesses and future fuel prices could fluctuate dramatically. In comparison, the cost to maintain a wind farm is relatively low and stable over time.

- *When indirect costs such as air pollution are included, the cost of wind power becomes competitive with natural gas and much cheaper than coal.*

The results presented in Table 6 show that direct production cost estimates for wind power in West Michigan, without accounting for externalities or subsidies, are greater than those for coal. Without subsidies, the direct costs of wind generation are within $10/MWh of coal. Current federal incentives reduce the cost of wind power by $20 /MWh. These costs are only appropriate when wind makes up less than 10 percent of the electric energy mix. If wind power generates more than 10% of a region's electricity, the grid system will need to change to accommodate the fluctuating nature of wind power, creating additional costs that are not considered in this analysis. These issues are discussed in the companion issue brief, *Wind and the Electric Grid* [29].

Once indirect effects such as air pollution are added to the overall direct costs, the cost of wind power becomes competitive with natural gas and much cheaper than coal.[4] This is because coal-fired power plants produce air pollution that harms public health and increases health care expenses—costs which are essentially hidden from electricity users. When indirect costs such as air pollution are included, wind has a production cost of $88.97/megawatt hour (MWh), compared to $82.64/MWh for natural gas and $95.64/MWh for coal (Table 6). This analysis suggests that it would be less costly

[4] The pollution cost is estimated only for the production of electricity not for the construction or maintenance of electrical generating plants.

overall to the people of West Michigan to use wind power than coal over the next 20 years.

		NATURAL GAS	COAL	WIND
Direct costs	*Construction*	$34.63	$43.43	$75.43
	Operation and Maintenance	$14.83	$8.99	$10.68
	Fuel	$28.30	$25.00	$0.00
Total direct costs($/MWh)		**$77.76**	**$77.42**	**$86.11**
Indirect costs	*NO_x*	$0.14	$1.30	0
	SO_2	$0.01	$6.34	0
	CH_4	<$0.01	<$0.01	0
	N_2O	<$0.01	$0.03	0
	Hg	$0.00	$0.51	0
	CO_2	$4.57	$9.94	0
	Housing	$0.13	$0.08	$2.85
	Bats/Birds	$0.00	$0.00	<$0.01
	Fish	<$0.01	$0.01	$0.00
Total indirect costs ($/MWh)		**$4.88**	**$18.22**	**$2.86**
Total costs ($/MWh) (direct + indirect)		**$82.64**	**$95.64**	**$88.97**

Table 6: Estimated direct and indirect production costs for three different types of electricity generation in West Michigan. Costs do not include tax incentives or subsidies. The renewable energy incentives in the U.S. currently would reduce the cost of wind by about $20 per MWh. Pollution cost estimates are explained on pages 4-6 and other calculations are explained in the Appendix.

Electricity Contract Prices in Michigan

To compare electricity costs, we can also look at the actual contracts being negotiated in Michigan for new energy facilities. Electricity contract prices indicate how much a utility company will pay a developer for electricity from a particular facility and are a good indication of actual construction, operation and fuel costs. The Michigan Public Service Commission recently reported that the contract price for a new conventional coal-fired power plant in Michigan is between $107/MWh and $133/MWh, depending on whether a price for carbon emissions is included [30].

The average contract price for new wind energy projects in Michigan is $94.27/MWh [30]. The cost of wind projects continues to fall, with some recent contracts below

$65/MWh. This new information indicates that Michigan-based wind energy is now less expensive to produce that a new conventional coal-fired power plant, even without considering pollution and other indirect impacts.

Summary

1. There is no clear evidence that onshore wind farms produce a lasting change in home values within a mile of a turbine. However, housing values do temporarily drop after the announcement of a new wind farm. In the studies that have documented this, prices fully recovered after construction and operation.
2. The potential negative health effects of wind turbines, such as sleep disruption, have not been well studied but are generally thought to only affect homes very close to a turbine. In contrast, natural gas and coal plants produce air pollution that is known to harm public health and the environment. The cost of these health impacts has been quantified.
3. A typical sized wind farm kills about 470 bats a year, which could increase the need for pesticides with a cost of $230 annually. An old thermo-electric power plant that uses lake water for cooling will kill thousands of fish annually, causing about $31,000 in damages each year to commercial and recreational fisheries.
4. The direct costs associated with building and operating an onshore wind farm are somewhat more expensive than a new natural gas or coal plant, when standardized based on the amount of electricity produced.
5. When the full social cost of electricity production is considered, including impacts to property values, health and wildlife, wind power is less expensive than using coal and is competitive with natural gas.
6. The Michigan Public Service Commission found that new wind projects are able to negotiate a contract price that is lower than that negotiated for a new conventional coal plant.

Appendix: Calculation Notes

Many pieces of information are needed to calculate each part of the total costs presented on page 9 and Table 6. A variety of factors can affect the construction and capital costs of an individual plant, so the results are for a representative plant.

Capital Costs

For these calculations, the overnight capital costs for an average new coal or natural gas plant with current pollution reduction technology are taken from Beck [31] and the costs for an average wind turbine in the Midwest are taken from Barber [32]. The construction costs are annualized by using a 10 percent capital recovery for all plants which is a common capital recovery rate. Amending these assumptions within reasonable bounds did not qualitatively change relative results.

Operation and Maintenance Costs

The operation and maintenance (O&M) costs for coal, natural gas, and wind plants are taken from Beck [31]. A capacity factor of 79 percent was used for coal, 50 percent was used for natural gas, and 30 percent was used for wind. These numbers are based on averages for relatively new plants in Michigan using data from Michigan, Wisconsin, Illinois, and Indiana as reported in eGRID 2010 [14] for coal and natural gas and eGRID 2012 [33] for wind. The eGRID 2010 database was used for coal and natural gas as the data is from 2007, before energy production dropped due to the recession. In addition, the capacity factor for natural gas was revised up to 50 percent from 38 percent to better match use during summer 2012. The capacity factor is important for determining O&M and fuel costs as well as the plant's ability to recoup capital costs. The capacity factors for coal are high since it is a base load source. Natural gas is lower reflecting its peak load role; however, it is possible to run natural gas turbines at higher capacity factors when needed. Wind capacity is governed by wind speed and turbine design and newer wind projects generally report higher energy generation.

Fuel Costs

The costs of coal and natural gas, as well as predictions for the price of coal and natural gas in the future, were obtained from the U.S. Department of Energy [34]

Home Prices

In order to calculate the external costs, the effect on housing needed to be calculated using average housing prices for Oceana, Muskegon, Ottawa, and Allegan counties. This was done by taking the rural housing density gathered from the 2000 Census [35, 36, 37, 38], then calculating the number of houses that would be expected to be located within 1 mile of any given turbine in a 100 MW wind farm assuming 40 acres are needed per turbine. Finally, there are also negative housing effects for proximity to traditional generation facilities [11]. The same procedure used for wind is used for traditional electricity generation facilities. However, the traditional generation facilities cover a much smaller area then a comparable wind farm.

Bird, Bat and Fish Fatality Costs

For this analysis, we used the estimates detailed by Cleveland [24] to calculate the annual value of a single bat in terms of insect pest control using Cleveland's reference case. This is the average value of a bat in a colony (not the marginal value); it is likely that if just a few bats were lost from the colony the other bats would compensate by eating more insects. As such, the value of a bat at $0.49 is likely an overestimate of the cost associated with modest losses from a bat population. We assumed that a single 2.5 MW turbine could kill seven bats in a year based on Barclay's 2007 [20] analysis of fatality data from 21 sites. If a wind turbine operated at a 33 percent capacity, seven bats could be lost while a single turbine generated 6,750 MWh of electricity in a year. A single turbine could generate $3.43 of costs due to bat losses, or a $0.00047 of cost per MWh of electricity produced. Even using the highest estimates of bat mortality from West Virginia (40 deaths per turbine per year), one MWh of electricity production from a wind turbine would result in less than $0.01 of damage to bats. One turbine kills about two birds a year based on Barclay's analysis [20], and the cost of this impact was not quantified.

Fishery impact calculations are based on a 2011 report by the Environmental Protection Agency [25], which calculated the economic costs and benefits of regulating older power plants and manufacturing facilities that currently use 2 million gallons of water each day, partially for cooling purposes (67 facilities on the Great Lakes). The EPA found that in the Great Lakes, older facilities currently cause $1.98 million in damage to recreational fisheries and $80,000 in damage to commercial fisheries. We used the EPA's Emissions & Generation Resource Integrated Database (eGRID) to calculate the average electricity production of a coal fired thermal power plant in Michigan in 2009 [14]. From these two sources, we estimated that an average Great Lakes coal-fired thermal power plant generates $30,800 in damages and produces 2.3 million MWh annually, with a per unit cost of $0.0134/MWh for fisheries.

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