Renewable Energy 49 (2013) 19–24

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

The avian benefits of wind energy: A 2009 update

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ARTICLE INFO

Article history:
Available online 8 March 2012

Keywords:
Wind power
Avian mortality
Wind turbines

ABSTRACT

This article summarizes the threats that wind farms pose to birds before surveying the recent literature on avian mortality and summarizing common methodological problems with such studies. Based on operating performance in the United States and Europe, the paper then offers a preliminary calculation of the number of birds killed per kilowatt-hour kWh generated for wind electricity, fossil fuel, and nuclear power systems. The study estimates that wind farms and nuclear power stations are responsible each for between 0.3 and 0.4 fatalities per gigawatt-hour (GWh) of electricity while fossil fueled power stations are responsible for about 5.2 fatalities per GWh. Within the uncertainties of the data used, the estimate means that wind farms killed approximately 20,000 birds in the United States in 2009 but nuclear plants killed about 330,000 and fossil fueled power plants more than 14 million. The paper concludes that further study is needed, but also that fossil fueled power stations appear to pose a much greater threat to birds and avian wildlife than wind farms and nuclear power plants.

1. Introduction

Many energy policy studies have noted how wind turbines present direct and indirect hazards to birds, other avian species, and chiropteran species such as bats [1–3]. Birds can directly smash into moving or even stationary turbine blades, crash into towers and nacelles, and collide with local distribution lines. These risks are exacerbated when turbines are placed on ridges and upwind slopes, built close to migration routes, or operated during periods of poor visibility such as fog, rain, and at night. Some species, such as bats, face additional risks from the rapid reduction in air pressure near turbine blades, which can cause internal hemorrhaging through a process known as barotrauma [4].

Concern about avian mortality and wind electricity began to surface in the late 1980s and early 1990s. Thelander and Rugge [5] and Smallwood and Theolander [6] studied raptor mortality at the Altamont Pass Wind Resource Area in California and estimated that as many as 835 were killed each year. Another study examined 64 wind turbines in West Virginia and Pennsylvania and calculated that about 2000 bats were killed during a much shorter 6-week interval [7]. Several additional studies conducted in the Appalachian Mountains (focused on the region from Tennessee to Vermont), Rocky Mountains, Pacific Northwest, and the Midwest have found that large numbers of nocturnal migrants (including bats) are uniquely at risk of colliding with wind turbines [8,9]. Erickson et al. reviewed 31 studies of bird collusions at utility-scale wind farms in the United States and found that 78% of carcasses found at facilities were songbirds protected by the Migratory Bird Treaty Act [10]. Other studies have produced similar findings for European offshore and onshore wind farms [11–13].

This study, however, finds that wind energy is actually beneficial to birds when compared to other sources of electricity, particularly nuclear power and fossil fuels. Through a synthesis of hundreds of studies on avian mortality and energy and electricity production, the study finds that wind farms and nuclear power stations are responsible each for between 0.3 and 0.4 fatalities per gigawatt-hour (GWh) of electricity while fossil fueled power stations are responsible for about 5.2 fatalities per GWh. When put into context for the United States, about 20,000 birds died from wind farms in 2009 but nuclear plants killed about 330,000 and fossil fueled power plants more than 14 million, estimates illustrated by Fig. 1. The Figure also shows how the number of absolute birds killed by wind energy pales in comparison to other causes such as windows and cats. The paper concludes that further study is needed, but also that conventional electricity sources appear to pose a greater danger to birds and avian wildlife than wind farms.

2. Problems with current avian mortality research

The above studies, while useful and important, nonetheless suffer from three common problems: (1) they rarely compare their results with studies of other wind farms to contextualize their estimates; (2) most do not compare the possible avian deaths from

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0960-1481/$ – see front matter © 2012 Published by Elsevier Ltd.
doi:10.1016/j.renene.2012.01.074

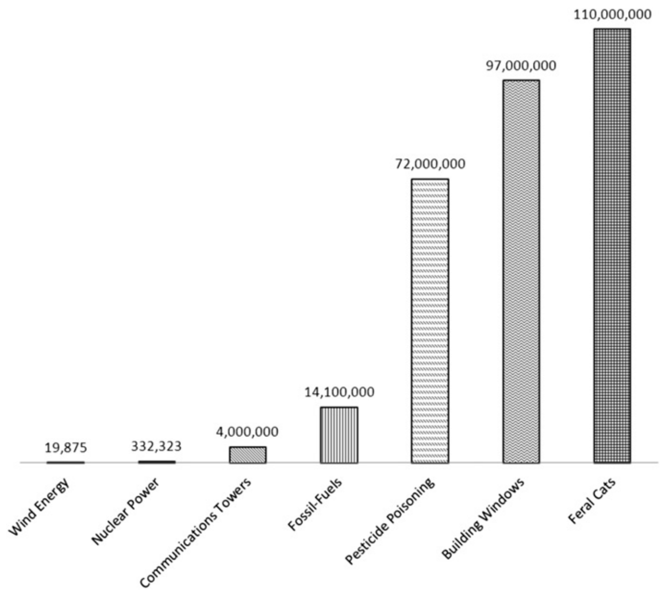

Fig. 1. Avian deaths per year in the United States, 2009. Source [1]: and [34]. When a range of estimates has been given, the figure presents only data for the lowest end of that range.

wind electricity with other sources, and when they do, studies typically do not compare them to other energy sources; and (3) none attempted to calculate the number of avian deaths per kWh from energy sources so that more meaningful comparisons might be made between different forms of electricity supply.

2.1. Variation and small sample size

A majority of studies examined focused on individual wind farms but did not attempt to compare results across many wind farms or larger geographic areas. There are some notable exceptions, many of which are cited in this study. Still, in an evaluation of 616 studies on wind electricity and avian mortality examined by the author, more than 510 (or 80% of the sample) focused only on one or two wind farms. The problem with such narrow sampling is that a great deal of variability in the amount of avian death associated with particular wind farms exists, ranging from 0 to almost 40 deaths per turbine per year.

What explains this great variability? The risk of avian death differs according to weather, layout of the wind farm, type of wind technology, bird migration routes, and topography, along with the specific bird species and number of birds found in the area [14]. A bird's flight performance strongly determines the chances of collision with pylons and power lines. Janss [15] found poor fliers such as ducks, heavy birds such as swans and cranes, and birds that concentrate in flocks are at greater risk. Kunz et al. [16] found that most mortality estimates had to be adjusted upwards or downwards as scavengers were known to remove bird and bat carcasses before researchers could discover them. Human error plays a role as well, as researchers miss carcasses, especially in agricultural landscapes and dense forest ridge tops [2,3].

Avian fatalities are also sensitive to time. Birds sometimes learn to avoid wind farms after their first few years of operation [1]. The type of wind technology can also significantly reduce bird fatalities. Altamont Pass, for example, is located near bird migration routes and has terrain, such as craggy landscapes and various canyons, making it ideal for birds of prey, and it is populated with mostly outdated turbine designs. It takes between 15 and 34 Altamont turbines to produce as much electricity as one modern turbine, and early turbines were mounted on towers at the same level as bird flight paths (60–80 feet in height) [1].

Newer wind farms, however, can produce the same amount of electricity with fewer turbines, and turbines are mounted on towers that typically avoid birds at a height of 200–260 feet. Latest capacities are between 2.5 and 4 MW, the turbines tend to be spaced at a greater distance between each other, and many blades have slower rotational speeds. Newer turbines have gotten more efficient as their capacity factors have improved, and developers have gotten better at siting and installing them. It is standard practice in the Pacific Northwest of the United States for all wind projects to involve habitat mapping, nest surveys, and general avian use surveys with a particular focus on threatened, engendered, or sensitive species. The standards are so strict they often cause developers to significantly modify the layout of wind farms and to abandon risky projects [1].

Death-rates of birds have decreased in recent years as wind power entrepreneurs have installed larger turbine blades that turn more slowly, and have used advanced thermal monitoring and radar tracking to site turbines more carefully. Developers commonly avoid placing wind farms in areas of high nesting or seasonal density of birds, remove potential perches on lattice towers, and utilize micrositing and bird sensitivity mapping to position turbines in ways that minimize intersection with flight paths [18].

A study that focused only on one or two wind farms, therefore, could produce exceptionally high or low estimates of avian mortality as a result of the specific weather, type of wind farm, number of birds in the area, species of birds, quality of researchers collecting carcasses, terrain and siting, and form of wind technology that are not representative for all or even most wind turbines.

2.2. Comparing avian deaths with non-energy related fatalities

Providing comparisons between the avian deaths from wind electricity and other causes is important, but comparisons thus far have only focused on avian fatalities from non-energy sources. Dozens of studies have noted that millions of birds die annually when they strike tall stationary communications towers, get run over by automobiles, or fall victim to stalking cats. After surveying wind development in California, Colorado, Iowa, Minnesota, New Mexico, Oklahoma, Oregon, Texas, Washington, and Wyoming (the 10 states with more than 90% of total installed wind power capacity), the GAO [7] calculated that building windows are by far the largest source of bird morality, accounting for 97 million to 976 million deaths per year. Attacks from domestic and feral cats accounted for 110 million deaths; poisoning from pesticides 72 million; and collisions with communication towers 4 to 50 million [7].

The Canadian Wind Energy Association estimated that more than 10,000 migratory birds die each year in the city of Toronto between 11 pm and 5 am from collisions with brightly lit office towers [19]. A 29-year study of a single television tower in Florida found that it killed more than 44,000 birds of 186 species, and another 38 year study at a communication tower in Wisconsin found even greater deaths amounting to 121,560 birds of 123 species. Yet another study projected that glass windows kill 100 to 900 million birds per year; transmission lines to conventional power plants, 175 million; hunting, more than 100 million; house cats, 100 million; cars and trucks, 50 to 100 million; agriculture, 67 million [21]. The National Academy of Sciences [22] reported that less than 0.003% of anthropogenic bird deaths every year were attributed to wind turbines in four eastern states in the United

States, and confirmed that collisions with buildings and communication towers pose a much greater risk.

However, since house cats and office windows do not yet produce electricity, the comparisons are less relevant than those that assess avian deaths from other sources of electricity generation.

2.3. Failing to quantify avian deaths per unit of electricity generated

Finally, not one of the studies examined produced an estimate of how many birds die from wind electricity correlated with the amount of electricity those wind turbines actually generated [3]. This lack of a quantifiable figure allows opponents of wind power to perhaps unfairly portray it as a threat to birds when the evidence concerning the impacts from conventional sources is completely lacking [3]. Strong advocates of wind power do the same thing, citing low absolute numbers of avian deaths but not admitting that those fatalities would grow significantly as the number of wind farms expanded. Metrics such as fatalities per turbine per year, in other words, do little to clarify or contextualize avian risks compared directly to other sources of energy supply, and make it difficult to properly assess the true threat that wind, conventional, and nuclear electricity technologies pose to birds.

3. Estimating and contextualizing avian mortality

In an attempt to address some of these shortcomings, the author assessed and compared the avian deaths per GWh from three electricity systems: wind farms, fossil-fueled power plants (coal, natural gas, and oil generators), and nuclear power plants.

3.1. Wind electricity

Unlike fossil fuel and nuclear power plants, which spread their avian related impacts across an entire fuel cycle, most of a wind farm's impact occurs in one location. Wind moves but windy locations do not, meaning wind energy differs from coal, oil, gas, and uranium energy sources because fuel cannot be extracted and transported for use at a distant site. To determine an estimate of avian mortality representative of all wind farms, a broad enough area had to be assessed taking into account a variety of species of birds, locations, wind farm configurations, and types of wind technologies. The capacity factor for wind farms is also important, since the amount of electricity a wind farm produces directly influences the amount of avian deaths per GWh.

The author began by determining the average load or capacity factor for a modern wind turbine—that is, the ratio of the actual output of a wind turbine over time compared to its output if it had operated at full capacity. The U.S. Department of Energy [23] conducted a comprehensive assessment of wind turbine performance across a sample of 170 wind projects built between 1983 and 2006 (totaling 91% of nationwide installed capacity in 2006, or 10,564 MW). The DOE found that despite great variations in windiness at each location, the average capacity factor for wind hovered around 22% in 1998 but jumped to 31% in 2003 and 35% in 2006 as turbine technology improved. Out of 58 projects installed between 2004 and 2006, more than one-quarter achieved capacity factors in the low to mid-forties, with average capacity factors for Hawaii reaching 45%, those in the Heartland averaging 40.8%, and those in California averaging 36.9%. Because half of the country's entire wind capacity was installed in the United States in 2007 and wind technology continues to improve, the author presumed that a capacity factor of 33% was an accurate indication of average wind turbine performance.

Next, the author assessed the real world operating performance of six wind projects, each varying according to windiness, size, and location in the United States. Though his numbers may not be the most accurate or accepted given varying searcher efficiency and carcass removal rates [2], using data collected by Erickson [24] avian mortality was quantified per GWh for 339 individual turbines constituting 274 MW of capacity. The thirty-six 660 kW wind turbines comprising the Vansycle Oregon wind farm averaged 10 avian fatalities per year. The sixteen 1.5 MW wind turbines in Klondike, Oregon, were responsible for 8 fatalities per year. The one-hundred-and-thirty-three 600 kW and 750 kW wind turbines at Foot Creek Rim, Wyoming, were responsible for 35 avian deaths per year. The forty-four 1.5 MW wind turbines at the Mountaineer wind farm in West Virginia were responsible for 118 fatalities per year. The thirty-seven 1.3 MW turbines at Nine Canyon, Washington, were responsible for 36 fatalities per year. Finally, the seventy-three 300 kW wind turbines in Buffalo Ridge, Minnesota, were responsible for 14 deaths per year. Averaged out over all six wind farms, and presuming a capacity factor of 33%, those 339 turbines were responsible for 0.279 avian deaths per GWh.

3.2. Coal, oil, and natural gas power plants

Coal-, oil-, and natural gas-fired power plants induce avian deaths at various points throughout their fuel cycle: upstream during coal mining, collision and electrocution with operating plant equipment, and poisoning and death caused by acid rain, mercury pollution, and climate change.

Starting with the upstream impacts, Winegrad [20] estimated that mountain top removal and valley fill operations in just four states—Kentucky, Tennessee, Virginia, and West Virginia—destroyed more than 387,000 acres of mature deciduous forests. Such a loss of forest will result in approximately 191,722 deaths of the global population of Cerulean Warblers, and can be loosely calculated to amount to 0.02 Warbler deaths per GWh.

Avian wildlife also frequently collides with or faces electrocution at power plant equipment. An observation of 500 m of power lines feeding a 400 MW conventional power plant in Spain estimated that it electrocuted 467 birds and killed an additional 52 in collisions with lines and towers over the course of two years (or about 260 per year) (Janss, 2000). Presuming a capacity factor of 85%, and that power plant was responsible for 0.09 deaths per GWh. Similarly, Anderson (1978) observed 300 waterfowl killed each year by colliding into Kincaid Power Plant near Lake Sangchris, Illinois. Presuming that the 1108 MW power station operated at 85% capacity factor, it was responsible for about 0.04 deaths per GWh. The mean for both facilities is 0.07 fatalities per GWh.

Acid rain occurs when sulfur and nitrogen compounds rise into the atmosphere and combine with water to then fall to the earth as rain, snow, mist, and fog. Ecologists, biologists, and ornithologists have shown that the acid rain partly formed from power plant pollution destroys nesting sites for birds, advances stages of forest dieback, thins forest canopies, lessens the amount of available food, alters habitat, and degrades soil. One study concluded that acid rain induced "great impacts on the reproduction and population size of piscivorous birds, forest birds, and insectivorous and granivorous birds" [25]. After taking into account and adjusting for soil and vegetation, habitat alteration, population density, and vegetation cover, an extensive study conducted by the Cornell Laboratory of Ornithology estimated that acid rain annually reduced the population of the wood thrushes in the United States by 2–5% [26]. The upper end of the estimate reflects wood thrushes living at higher elevations and thus subject to greater levels of acid rain found in the Adirondacks, Appalachian Mountains, Great Smokey

Mountains, and the Allegheny Plateau. The results can be used to loosely quantify avian deaths of 0.05 fatalities per GWh.

Acid rain pollution is not the only threat from fossil fueled power plants. A string of scientific studies have confirmed that the emission of mercury, another byproduct of fossil fuel combustion, can be lethal at even relatively low doses to avian fauna. Mercury exposure to albatross, falcons, mallards, terns, gulls and other seabirds, woodstorks, pheasants, and bald eagles has been proven in laboratory studies and biological monitoring of real birds to lead to fewer eggs, fewer produced young, and reduced survival rates. Hallam et al. [27] studied a colony of the endangered woodstork in the Everglades of Florida, at great risk because the birds spend most of their time in water, and observed that methyl mercury poisoning caused tameness, lack of muscle coordination, progressed to inability to fly, and death. They attributed 3–50% reductions in annual colony size to possible mercury poisoning. Burger and Gochfeld [28] found high levels of mercury in the feathers and eggs of many species of birds, and concluded that they caused abnormalities and lowered reproductive success. Relying on the collection of feathers to determine mercury exposure, Burger and Gochfeld discovered that even low levels of mercury exposure (0.5–0.6 ppm wet weight in eggs) was sufficient to cause decreased egg weight, embryo malformations, lowered hatchability, neural shrinkage, and increased mortality. They also noted that mercury contamination was concentrated in the coastal areas of the United States, with mercury accumulating in the bottom of rivers, streams, lakes, and coastal lagoons that many birds rely on for drinking water. While efforts at quantification are highly uncertain, they extrapolated their results to posit that mercury poisoning and contamination were responsible for population declines ranging from 1 to 11% across 14 species of penguins, albatross, ducks, eagles, hawks, terns, gulls, and other birds. These numbers, as well, can be roughly quantified into 0.06 deaths per GWh.

Finally, while perhaps the most difficult to quantify, climate change is already threatening the survival of millions of birds around the world. About 80% of the North American duck population, for example, breeds in the prairie potholes of the northern Great Plains. Climatologists expect that temperature increases of 1 °C could decimate duck populations by about 25% if rainfall remains constant [29]. A more disturbing study conducted by Thomas et al. [30] concluded that climate change was the single greatest long-term threat to birds and other avian wildlife. Looking at the mid-range scenarios in climate change expected by the Intergovernmental Panel on Climate Change, Thomas et al. projected that 15–37% of all species of birds will be committed to extinction by 2050. These numbers, too, can be quantified into 4.98 deaths per GWh.

Adding the avian deaths from coal mining, plant operation, acid rain, mercury, and climate change together result in a total of 5.18 fatalities per GWh.

3.3. Nuclear power plants

The threat to avian wildlife from nuclear power plants can also be divided into upstream and downstream fatalities.

Uranium milling and mining can poison and kill hundreds of birds per facility per year. Indeed, in early 2008 the Cotter Corporation was fined $40,000 for the death of 40 geese and ducks at the Cañon City Uranium Mill in Colorado. The birds apparently ingested contaminated water at one of the settling ponds at the uranium mine [1]. These deaths can be very roughly quantified into 0.006 deaths per GWh. The U.S. Fish and Wildlife Service [31] has also noted that abandoned open pit uranium mines in Wyoming can form pit lakes hazardous to wildlife. Uranium-bearing formations are usually associated with strata containing high concentrations of selenium. It is not uncommon for these pits to kill 300 birds per year. Because those mines operated at about one-tenth the efficiency of Canon City, they would correlate to about 0.45 deaths per GWh. Taking the mean from both uranium mines gets us 0.228 fatalities per GWh.

Like fossil fueled power stations and wind farms, avian fauna can also collide with nuclear power plants. Three thousand birds died in two successive nights in 1982 from collisions with smokestacks and cooling towers at Florida Power Corporation's Crystal River Generating Facility [1]. Given that the power plant now hosts an 838 MW nuclear reactor, and presuming it operated with a capacity factor of 90% and that the 3000 deaths were the only ones throughout the year, the facility was responsible for 0.454 avian deaths per GWh. Ornithologists observed 274 fatal bird collisions with an elevated cooling tower at the Limerick nuclear power plant in Pennsylvania from 1979 to 1980 [32]. Since the Limerick plant has a 1200 MW reactor, and also assuming it operated at a 90% capacity factor, it was responsible for 0.261 deaths per GWh. At the Susquehanna plant in eastern Pennsylvania, 1500 dead birds were collected between 1978 and 1986 for an average of 187 fatalities per year [33]. Assuming that the 2200 MW plant operated at 90% capacity factor, it was responsible for 0.01 deaths per GWh. Extensive surveys for dead birds were also conducted at the Davis-Bess nuclear plant near Lake Erie in Northern Ohio. Ornithologists recorded a total of 1554 bird fatalities or an average of

Table 1
Comparative assessment of avian mortality for fossil fuel, nuclear, and wind power plants in the United States, 2009.

Fuel source	Assumptions	Avian mortality (total per year)	Avian mortality (fatalities per GWh)
Wind Energy	Based on real world operating experience of 339 wind turbines comprising six wind farms constituting 274 MW of installed capacity. Total Avian Mortality per year taken by applying 0.269 fatalities per GWh multiplied by the 73,886 GWh of wind electricity generated in 2009	19,875	0.269
Fossil Fuels	Based on real world operating experience for two coal facilities as well as the indirect damages from mountain top removal coal mining in Appalachia, acid rain pollution on wood thrushes, mercury pollution, and anticipated impacts of climate change. Total Avian Mortality taken by applying the 5.18 fatalities per GWh multiplied by the 2.72 million GWh of electricity produced by the country's fleet of coal-, natural gas-, and oil-fired power stations in 2009	14.1 million	5.18
Nuclear power	Based on real world operating experience at four nuclear power plants and two uranium mines/mills. Total Avian Mortality taken by applying the 0.416 fatalities per GWh multiplied by the 798,855 GWh of electricity produced by the country's nuclear plants in 2009	332,323	0.416

Source: 2009 electricity generation statistics taken from [34].

196 per year from 1972 to 1979 [33]. Given that the power plant hosts an 873 MW reactor, and assuming it operated with a 90% capacity factor, and the plant was responsible for 0.0285 fatalities per GWh. Taking the mean for each of the four power plants results in 0.188 deaths per GWh.

The total avian deaths per GWh for nuclear power plants are therefore about 0.416.

4. Conclusion

The issue of avian mortality and electricity generation is certainly complex. Avian wildlife can perish by striking wind turbines, nuclear power plant cooling structures, transmission and distribution lines, and smokestacks at fossil-fuel fired power stations. Birds can starve to death in forests ravaged by acid rain, ingest hazardous and fatal doses of mercury, drink contaminated water at uranium mines and mills, or die in large numbers as climate change wreaks havoc on migration routes and degrades habitats. Power plants directly and indirectly kill many different types of species, different members of the same species, at different times and in different ways.

For wind turbines, the risk appears to be greatest to birds striking towers or turbine blades. For fossil-fueled power stations, the most significant fatalities come from climate change, which is altering weather patterns and destroying habitats that birds depend on. For nuclear power plants, the risk is almost equally spread across hazardous pollution at uranium mine sites and collisions with draft cooling structures. Yet, taken together, fossil-fueled facilities are about 17 times more dangerous to birds on a per GWh basis than wind and nuclear power stations. In absolute terms, wind turbines may have killed about 20,000 birds in 2009 but fossil fueled stations killed 14 million and nuclear power plants 330,000 (See Table 1).

Three conclusions, however, must be stated when observing the estimates provided by Table 1. First, far more detailed, rigorous, and sophisticated analysis is called for that takes into account the complexities of the wind, fossil-fueled, and nuclear energy fuel cycles. The shortcomings of this preliminary study are as obvious as they are numerous: a focus on bird deaths but not bird births; a small sample size for wind, coal, and nuclear facilities that may not be representative; a focus on individual species such as the wood thrush or waterfowl to produce overall estimates of avian mortality that are definitely not representative (and undoubtedly conservative); a presumption that coal was only mined using mountain top removal (thereby excluding the impacts from other types of coal mining); fatalities that happened on particular days and weeks that were then presumed to be the only ones throughout the year (also resulting in conservative estimates); an assumption that only carbon dioxide emissions from power plants contribute to climate change (again conservative for excluding other greenhouse gases); highly uncertain deaths attributed to climate change that may be prevented if future greenhouse gas emissions are significantly reduced. A study with a larger sample size that focused on a greater number of species across more locations (including migration routes and other important areas) over a longer period of time and encompassing entire part of the fuel cycle for different electricity systems is certainly called for.

Although the rudimentary numbers presented here are intended to provoke further research and discussion, they nonetheless still emphasize the importance of providing estimates of avian mortality per unit of electricity generated. Metrics such as fatalities per turbine, transmission line, or power plant structure per year, as well as estimates of the absolute number of avian deaths attributed to agriculture, communication towers, cats, and automobiles, tell us nothing about the avian fatalities involved with producing a GWh of electricity. Such metrics do not enable meaningful comparison among electricity sources, and are open to abuse from many strong opponents and proponents of wind energy. More than anything else, this study is a call for equal and careful study and observation of the avian mortality associated with other electricity sources besides wind power so that the issue can be properly balanced and contextualized.

Second, while the avian deaths attributed to fossil fuel, wind, and nuclear power plants do vary, they also imply that there is no form of electricity supply completely benign to birds. The best strategy for preserving avian wildlife, therefore, would be to encourage the more efficient use of energy before any type of new power plant or wind farm is constructed.

Third, and perhaps more important, for it applies to many types of assessment beyond the electricity sector, is the lesson that the most visible impacts from a given technology are not always the most egregious. Wind turbines seem to present a significant threat to birds because all of their negative externalities are concentrated in one place, while those from conventional and nuclear fuel cycles are spread across space and time. Avian mortality and wind energy has consequently received far more attention and research than the avian deaths associated with coal, oil, natural gas, and nuclear power generators, even though this study suggests that wind energy may be the least harmful to birds. The first-order estimates of avian mortality per GWh offered here suggest that fossil fuels may be more dangerous to avian wildlife (and nuclear power plants slightly more dangerous) than wind farms, and they remind us that what can sometimes be considered the most obvious consequence of a particular energy system may not always be the most salient.

Acknowledgments

This paper was initially published in [1], and presented at one of the "Energy Policy and Strategy" Sessions of the Eleventh World Renewable Energy Congress and Exhibition at the Armed Forces Officers Club and Hotel, Abu Dhabi, United Arab Emirates, September 25–30, 2010. This version of the article has updated some data to 2009, and it has also incorporated some of the excellent suggestions made by conference participants.

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