Exploring the Ecological Impact of Wind Farm Development

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

With the looming threat of global warming and climate change on the horizon, the need to utilize renewable sources of energy becomes increasingly pressing. One of the most widely used clean energies sources is wind power. Energy is harnessed from the wind using turbines that typically have 3 blades that spin when air flows past them. The kinetic energy from the rotating blades is converted into electrical energy with a generator that is housed in the nacelle of the turbine. The amount of energy generated is directly related to the swept area of the blades of the turbine. To maximize the amount of energy created by a single turbine, the wind industry has been gradually increasing the size of the rotors. These massive turbines are reaching heights of 90 meters, which is about the height of the Statue of Liberty (EERE, 2021). A typical turbine has the ability to power hundreds of homes. Due to this, wind farms are gaining popularity as a clean energy source and there were over 58,000 turbines recorded by the United States (US) Wind Turbine Database at the beginning of 2019 (Inspire Clean Energy, 2020). That year it was also recorded that wind energy made up 42% of the renewable energy produced in the US, but only 7% of all of the energy produced in the country.

Due to the increasing demand for wind energy and the decreasing amount of land on which facilities can be placed, wind farm development is now moving offshore. Construction of these wind farms is gaining popularity and has been pushed by President Biden to help boost the amount of energy currently being produced by wind. Over the next couple years there are plans to build both on and offshore wind farms to help the country reach its renewable energy goals. Producing energy in a way that does not emit carbon will help not only the country, but benefit the world as a whole in the long run by helping alleviate the effects of climate change.

With all of the positive implications that come with switching to a non-carbon emitting energy source, it is hard to see how wind power could pose harm to the environment. It is nearly impossible to create an energy production system that is entirely perfect and there are flaws associated with all renewable energy sources. This thesis explores the negative environmental implications of windfarm development.

Case context

Despite wind being viewed as one of the cleanest forms of energy there are a few negative environmental effects brought about by construction of wind farms. The most widely known problem is the danger that the rotating blades pose to bird and bat populations around at the wind farm site. The blades have an extremely large swept area and the tips of the blades reach speeds of over 100 mph. Birds and bats can get hit flying by these rotating blades or fly into them when they are not moving. Thousands of birds and bats are killed by turbines each year. There are several methods that have been tested to try to prevent animals from flying in the path of the blades. One of these involved painting one of the blades of the turbine black. While this reduces the number of fatalities, there is still no full proof way to prevent it from occurring.

Offshore wind farms not only have the ability to affect the avian community but also the aquatic community. In order to keep the turbines vertical in the water stabilization structures are placed at the base of the turbine under the water. The type of structure that is used is dependent on the depth of the water and type of ground at the site. These different types of structures have different shapes and sizes so they all impact the surrounding differently. Some of these different types have been shown to promote coral and underwater plant growth. An upside to this is the

possibility for an increase in the biodiversity of the community. Conversely it could also cause invasive species to spread and take over the surrounding area. Placing manmade objects in natural habits is bound to change certain aspects of that environment, so it is important to understand these changes.

Onshore wind farms have the ability to alter the environment in which they are built. These include changes in ground and air temperature (Luo, 2021). In order for the US to be powered entirely by wind energy, millions of turbines would need to be produced and would have to occupy a very large area of land. It was estimated that construction of that many turbines would actually cause a 0.24-degree Celsius temperature increase of the entire United States (Burrows). This would be directly adding to a problem that wind turbines are designed to help alleviate. The increase in temperature caused by their construction could be essential in preventing further increase in temperature for the planet as a whole.

It is important to understand all effects that an energy production source will have on the environment. They can be used to assess whether the climactic benefits of its production outweigh the less favorable climactic impacts that it might have. This paper dives deeper into these possible impacts and focuses on changes that have been observed at the sites of wind farm development.

Responsible Innovation and the Wind Industry

Innovation within the wind industry promotes further development of wind farms. The remainder of this paper will focus on exploring the ecological implications of this development. To do this I approached this topic using the framework of Responsible Innovation. More

specifically I explored the topic through the sustainability and humility lenses using a paper written by Leidy Klotz, Elke Weber, Eric Johnson, Tripp Shealy, Morela Hernandez, and Bethany Gordon (2018) and another paper written by Sarah Hartley, Froydis Gillund, Lilian van Hove, and Fern Wickson (2016). Responsible Innovation focuses on the importance of morality and accountability when it comes to the innovation and design process.

Within engineering there is an unspoken standard that must be upheld to maintain trust between society and innovators. This standard implies the need for sustainable practices. Klotz defines sustainable design practices as those without outcomes that "improve the well-being of current generations without compromising the well-being of future generations and the environments on which we all rely" (Klotz, 2018, p. 225). To assess how sustainability plays a role in innovation, the design process is broken down into general steps that include: identifying needs, defining a problem, creating concepts, selecting a concept, developing the details, and implementing and evaluating. Within each of these there are obstacles and opportunities to make environmentally conscious decisions. An example of this falls within the "Identifying Needs" step of the design process. This obstacle is possibility for there to be too much emotional empathy. Klotz highlights that too much emotional empathy can "mislead designers through user perspectives that discount the needs of future others" (Klotz, 2018, p. 226). There needs to be an evaluation of whether the issue at hand is more dire than a problem that it could cause later. This is important in the context of renewable energy sources. One of the main ecological concerns surrounding wind farms is the amount of bird and bat fatalities that their operation directly causes. Wind turbines have been estimated to kill over 140,00 birds every year in just the US (Hogan, 2020). While this is an unfortunate circumstance there are many other manmade objects that cause greater harm to the avian community. It comes down to whether the lives of future

generations that will be directly affected by climate change outweigh the lives of the birds and bats that are being hurt now.

Another important aspect of responsible innovation is humility. Sarah Hartley's paper, "Essential Features of Responsible Governance of Agricultural Biotechnology," dissects the ways that responsibility should be incorporated into the governance of biotechnology. While this paper is not focused on the same scientific topic, many of her points are applicable across a wide range of scientific fields of study. Governance of scientific knowledge should be held to the same standards to maintain levels of trust between innovators, scientists, and stakeholders. Hartley breaks down this responsibility into five essential features:

1. commitment to candor
2. recognition of underlying values and assumptions
3. involvement of a broad range of knowledges and actors
4. consideration of a range of alternatives
5. preparedness to respond.

She highlights the need for candor and humility within science and engineering and that "candidly recognizing and truthfully representing scientific uncertainties and the full range of concerns at stake does not reflect a lack of competence" (Hartley, 2016, p. 3). Knowing the limits to a design does not make it less innovative or ingenious.

Within the wind industry there is the notion that bigger is better. Larger rotors produce more energy but there are factors that limit the size that rotors can reach. As stated earlier there is a lack of viable transportation for the blades and tower components to the build sites (Allen, 2020). Larger blades also reach great speeds at the tips and have a greater swept area increasing the likelihood an animal will be hit when flying through wind farms (EERE, 2021). The

increased speed also puts greater stress which could lead to more breakages and a greater need for maintenance.

Due to the fact that wind technology is consistently improving, wind turbines are being outfitted with new blades at half of their expected operating lifespan of 25 years (Martin, 2020). The blades that are being replaced end up in landfills as there are very few programs in place to recycle them. The wind industry continually changing the blade design has improved the power output of turbines but has also caused a waste of blades. Assessing the positive and negative benefits to constant improvement of turbine design could shed light on why so many blades meet this fate.

Research Question and Methods

This thesis explores ways that wind turbines impact their surrounding environments and attempts to answer the question: What are the ecological implications of further windfarm development? There are many ways in which wind farm development can affect and alter the surrounding environment and its inhabitants. Both the positive and negative implications of the continued installation and operation of wind farms are explored.

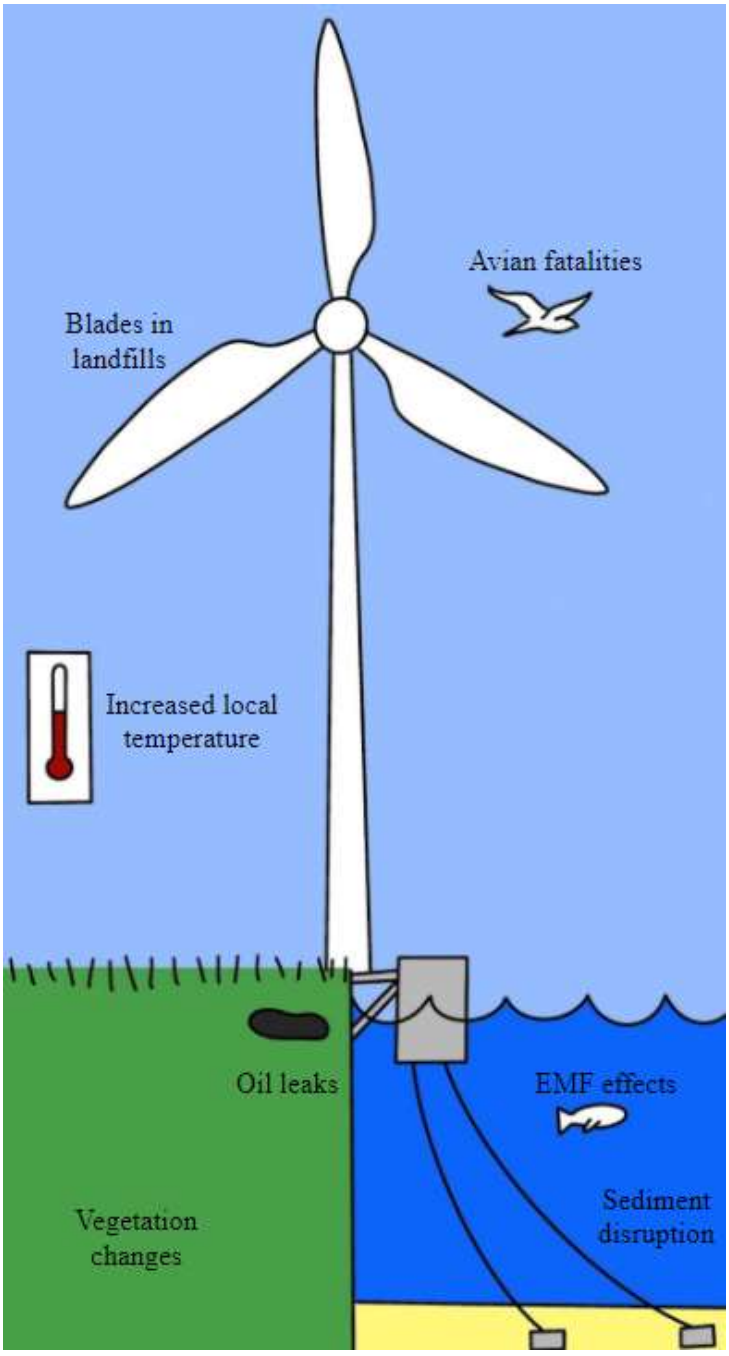
The research focuses on cases studies where a change in the environment post-installation was observed. This includes a study done at an onshore wind facility in North China observing environmental factors before and after construction of the farm (Luo, 2021) and a review summarizing studies of observed effects of offshore wind farms (Farr, 2021). Another source that is assessed are statistics and studies regarding bird and bat deaths caused by wind farms and other manmade structures for comparison. Specifically, this includes a study conducted by

Western Ecosystems Technology that compares the number of bird fatalities caused by anthropogenic factors (Erickson, 2003). Other sources examined includes literature on the effects of offshore wind turbines on the aquatic community, plans for future wind farms, and documents detailing how development sites are chosen. The Responsible Innovation framework is used to evaluate the findings from the research. Specifically, looking at the sustainability of the wind farm development process and how the benefits of switching to wind energy weigh against the environmental effects that were previously discussed. The role of humility within the wind industry is examined, focusing on the limitations associated with the expansion of wind power.

Results

Wind farm development has the ability to affect multiple aspects of the environment in which it is built, which includes the local climate and surrounding animals, vegetation, and land. In two case studies observed changes in the local climate occurred throughout the installation and operation of wind farms, such as changes in land surface temperature, soil changes, wind pattern changes, and harming avian life. Additionally, a scientific review of possible effects of offshore wind farms provided strong evidence supporting the possibility of climactic and biological effects from construction of deep-water wind farms. These included effects like disrupted sediment, changes in air temperature, and disruption of local wildlife. To evaluate the findings the results section is split into three categories: climactic impacts, animal and vegetation effects, and limitations of wind farm development. I chose to split them this way due to the fact that each of the studies had different focuses and wanted to be able to compare the common data from each.

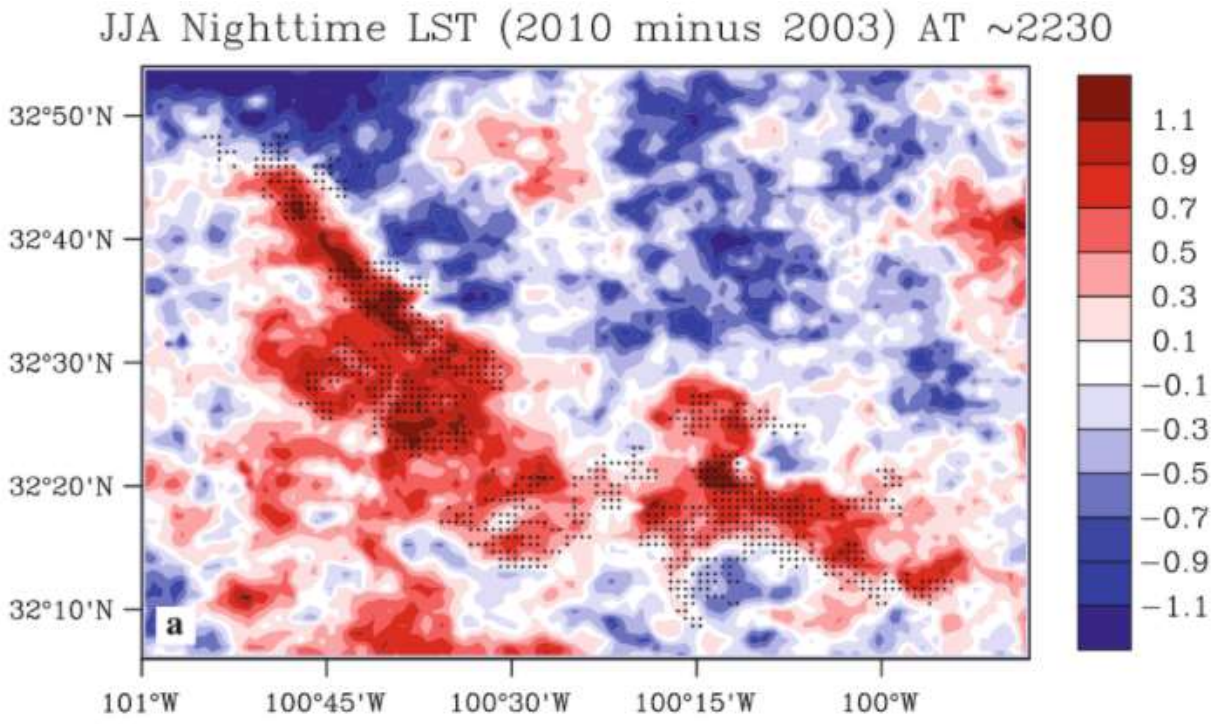
Figure 2. Adverse Effects of Wind Turbines Onshore and Offshore.



Climactic Impacts

For understanding the climactic impacts of building more wind farms two case studies focusing on certain environmental factors were examined for onshore wind farms. The first study, "Diurnal and seasonal variations of wind farm impacts on land surface temperature over western Texas," used imaging from a satellite to record the temperature of the region for the period of 2003-2011 (Zhou, 2012). It focused on differences in the land surface temperature (LST) changes throughout the period, focusing on certain day and night times across different seasons. This information was gathered from Moderate resolution Imaging Spectroradiometer (MODIS) data obtained from satellites. The study attempted to isolate the warming effects from the wind farm by using "spatial and temporal averaging." Through the study it observed that the areas with turbines and adjacent to turbines were warmer than areas lacking the,. The warming trend that was noted over the 8-year period was determined to be strongest at night with an increase of 0.31 to 0.67 degrees Celsius. The season where the observed warming was strongest was summer. While it was acknowledged that this observed warming could be attributed to the mixing of air laterally, the study provided evidence that the warming effect was due to the development of the wind farm. One of these pieces of evidence was that the "spatial pattern of the warming resembles the geographic distribution of wind turbines" (Zhou, 2012). This can be seen in Figure 1 below, where the red areas represent the places with the greatest temperature changes. These red areas greatly match the distribution of the turbines across the farm which are represented by small black dots in the figure. As farms like this expand and become more prevalent the warming effects could be more significant.

Figure 2. *Nighttime LST change Between 2003 and 2010 for June, July, and August (Zhou, 2012)*



The second case study observed, "Local climatic and environmental effects of an onshore wind farm in North China," focused on more than just the LST for the area. To assess how the environment changed before and after construction of a windfarm in Shangyi County, China the researchers examined the wind air temperature (T_a), ground surface temperature (T_s), evapotranspiration, and normalized vegetation index in addition to the LST. This study also used information obtained from the MODIS database as well as local data from installed and existing weather towers. This study took data from 1981 to 2019 to fully understand the climate trends before and after the turbines were installed. Through the study it was found that "after the construction of the studied wind farm the annual wind speed tended to decrease, T_a and T_s

showed increasing trends and evapotranspiration showed a significant increasing trend" (LUO, 2021). This indicates that wind farms have measurable impact on multiple parts of the local climate. Wind farms on a larger scale could cause a more sizable change in an area's climate as they continue to grow in area and amount.

The final piece of literature examined for impacts to the climate is a review titled "Potential environment effects of deepwater floating offshore wind facilities" (Farr, 2021). Due to the fact that deepwater wind farms are a relatively new technology, there is no literature directly studying them. Because of this, the review used previous knowledge from other types of offshore wind farms and data from sources that were deemed analogous. The study identifies the potential implications of the development of these farms and then determined the severity of the impact of these implications on a scale of: negligible, minor, moderate, or major. The review determined from past literature that offshore wind farms could change the atmospheric and ocean dynamics. While there are predicted adverse effects, they were determined to be only minor to moderate threats due to the fact that the effects would be averaged over a very large geographic region.

From a sustainability standpoint it is interesting to take all of the observed and predicted impacts into perspective. A truly sustainable innovation by Klotz's definition will cause no harm to the environment or pose any issues to be resolved by future generations. With the wind industry it is important to weigh current impacts with the impending effects of climate change. For example, the wind farm in Texas caused a 0.31 to 0.67°C over 8 years for that region. It is important to note that the US as a whole, excluding Hawaii and Alaska, has increased 0.22 to 0.3°C per decade since the 1970's (EPA, 2021). Looking at these numbers it may seem that wind farm installation is counterintuitive. Clean energy is meant to stop global warming, not add to it.

Although the change in regional temperature is greater than the change over the US as a whole, these wind farms could mitigate the more drastic changes in the continental US temperature and the global temperature. Sustainability takes into account the present impacts while also accounting for what is beneficial for future generations.

Animal and Vegetation Effects

One of the most publicly known ecological concerns is the death of birds and bats caused by collisions with wind turbines. When looking at the annual fatalities for wind turbines independently, the values seem staggering. Wind turbines are not the only technology with this issue so it is important to compare these numbers to bird and bat deaths caused by other manmade objects. In order to gain some perspective on the true human impact on bird mortality a summary of bird mortality due to anthropogenic causes was assessed. Due to the age of the findings in the summary, I recalculated the value for the wind turbine fatalities based off of today's turbine total using the calculation methods presented in the study. The information included in the summary, collected by Wallace Erikson, Gregory Johnson, and David Young Jr., focuses mainly on fatalities caused by collisions with manmade objects like vehicles, buildings, power lines, communication towers, and wind turbines. The annual estimated fatality values in the US for each collision type are included in Table 1 below.

Table 1. Bird Fatalities Caused by Manmade Structures (Erickson, 2003)

Manmade object	**Estimate for 2003**
Vehicles	Cars: 80 million Airplanes: 25,000
Buildings and Windows	97.6-976 million
Powerlines	130 million
Communication Towers	4-5 million (conservative estimate)
Wind Turbines	20,000

As stated in the study, "the average number of avian collision fatalities per turbine and per MW (Megawatt) are 2.11 and 3.04 per year, respectively" (Erickson, 2003). Using this criterion, the value calculated for a 2022 estimate came out to 372,293 birds (WINDExchange, 2020). This number is still significantly less than the estimate of for deaths caused by collisions with buildings from 19 years. These numbers don't even include other ways that humans cause harm to birds. While many people are horrified by the way that turbines affect birds, it is hard to be squeamish about this number when humans are already a large detriment to the avian community in many other ways. Additionally, there is continual research being done to find ways to mitigate this issue. Some of these include painting one of the turbine blades black or playing an ambient noise to deter the animals.

Both on and off shore wind farms pose a threat to birds and bats, but stabilization of offshore wind farms presents a new way in which turbines and farms interact with animals. There are many types of stabilization structures used for offshore farms and they are dependent on the depth and type of sea floor over which they are situated. Some are attached directly to the

ground and some stabilize the floating structure on which the turbine sits with long cables that are anchored to the ocean floor. From the review previously mentioned summarizing possible adverse effects of deepwater offshore wind farms, it is highlighted that there are ways in which these structures could interact with marine life. These include "electromagnetic (EMF) effects on marine species, habitat alterations to benthic and pelagic fish and invertebrate communities, underwater noise effects on marine species, structural impediments to wildlife and changes to water quality" (Farr, 2021). Through the review's assessment, these harms were deemed to be minimal to moderate, using the same scale explained above. It is important to note though that this review did not include possible effects from the installation or possible failure of these deepwater offshore wind farms.

The movement of sediment during installation can disrupt the ecosystem and cause harm to animals residing on the ocean floor. Another possible source of issue rises from the oil that is needed to lubricate turbines to maintain smooth rotation of the rotor. When the rotor or turbine is not operating properly the oil can leak out of the turbine and accumulate at the base or leak onto the blades and be flicked into to surrounding areas by their rotation. This presents an issue for animals and the cleanliness of the ocean as a whole.

Klotz's does not explicitly mention the interaction of humans and animals within her definition of sustainability, but it can be inferred that animals are part of the "environments on which we all rely" (Klotz, 2018). It is hard to determine where the line must be drawn when it comes to the impact that turbines have on surrounding wildlife. This conflict is where it is possible for too much emotional empathy to arise. While many are horrified by the fact that a supposedly "clean" technology could affect animals like this, it is important to understand that clean energy does not benefit just humans. Climate change has taken a toll on many species.

Slowing and reversing its effects would be in the best interest of these other species. Checking that empathy is not misplaced or too prevalent ensures that progress can be made towards these sustainability goals.

Humility in the Wind Industry

With all innovation and science, there comes a limit. There is always a limitation to one factor of an innovation, be it size or depth of understanding. When it comes to wind power, its limiting factors are size, land availability, and disposability. Wind turbines are constantly growing in height and rotor radius. With this continual growth, transportation of parts becomes increasingly difficult. It is important to acknowledge that reaching this barrier does not diminish the technology or the good that its doing. Hartley highlights the need for engineers and scientists need to be open and honest about these limitations. This concept also applies to the continual update of turbines blades and the disposal of blades. while it is important to maximize the efficiency of existing turbines there needs to be a better way to dispose of blades. So many of them are ending up in landfills before the end of their lifespan. Maximizing the life of blades to prevent this and understanding the limitations associated with the expansion of wind power would show humility. Energy production and efficiency can be maximized in innovative ways that produce less waste and embrace humility.

Limitations and Future Work

While there are a number of case studies available that detail the effects of wind turbines, the information could be more accurate and in depth. It should also be more readily available so that

proper research is able to be done and the effects can be completely assessed. Without access to this knowledge, it is hard to make solid conclusions about the impacts and what can be done to mitigate them. Due to the more recent development of offshore wind energy facilities and the current lack of operational deepwater wind farms, the review used in this analysis was mostly speculative. While they drew their conclusions from current information about offshore turbines and found cases that are seemingly analogous, the full environmental effects and the true magnitude of those effects cannot be fully understood until they are physically observed.

For future work I would pull information from a greater number of case studies to broaden the scope of research. It would be interesting to compare how these effects differ between ecosystems and whether they are observed at the same prevalence across these different habitats. It would also probably wise to narrow in on one specific effect to truly understand if it is caused by wind farms as a whole or if it was just observed in one or two instances. Overall, more knowledge and a better understanding of wind power and its effects are needed to properly use it to ameliorate climate change consequences.

Conclusion

This research emphasizes the fact that the possible harmful ecological effects of wind farms are outweighed by the good that their operation will do for future generations. There needs to be continued installation and improvement of renewable energy facilities to help ameliorate the damage that humans have inflicted on the earth throughout history. Within these facilities it is important to fully understand the way that they interact with their environment so that steps can be taken to prevent any unintended harm. As wind power expands as a clean energy source its

negative impacts will be made up for with the good that it strives to achieve. Wind power is essential in lessening the impending effects of climate change and ensuring a safe future for mankind.

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