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A Comparison of Modern Power: Environmental Impacts

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A COMPARISON OF MODERN POWER: ENVIRONMENTAL IMPACTS

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Abstract

There are many aspects of environmental influences that must be considered when evaluating power production methods. Over the course of a six-month literature review this study covered the environmental impact and sustainability of four different power production methods: coal, solar, wind, and nuclear. This study then used the information gathered to create a set of criteria by which each would be evaluated. The goal of this study was to determine the power production method that would deliver the most energy with the least amount of environmental impact. Further, the scope of this study is limited to the midwestern states of the USA. This is important because in the current environmental situation it is crucial that the power that our cities run on comes from a source that is doing as little damage to the environment as possible, essentially lengthening the life of our resources and ultimately our planet. By comparing the pollution created, land required, maintenance required, average annual power production, and miscellaneous other environmental impacts of the considered methods, it was determined that the nuclear power plant provided the most power with the least amount of environmental impact.

Introduction

In the 21st century there has been enormous progress in the area of environmental awareness. Individuals have begun taking a look at their personal lives and making a change to better protect the planet's natural resources and begin the path to true sustainability (Palmer, 1998). However, one aspect of everyone's daily life that is managed well in an individual level but not on a broader level is power production. Society has become aware that their usage of electricity is not unbalanced, still there is little regard for how this electricity is produced. This study is focused on the Great Plains region of the USA, specifically the states of North Dakota, South Dakota, Nebraska, Iowa, Kansas, Oklahoma, and Texas, and their power production. National statistics will be used to generate averages for comparison criteria, then regional differences between the Great Plains and other regions in the USA will be compared.

Currently the main source of power production is coal power plants which makes up one third of the power production in the USA (Stevens, 2017). Such power plants have been heavily regulated in order to minimize environmental impact, but with the rise of wind, solar, and even nuclear power, which one best serves the needs of the Great Plains communities while also minimizing the impact on the environment? This study is focused on answering that question. Presently, concise reporting about what power production method provides the most power for the least amount of environmental impact is difficult to find. This study will, at its conclusion, provides an educated answer to these questions so that people will have the information to make educated statements and speak up in their own cities, towns, or power districts and take steps as a society to minimize the amount of environmental damage that power production causes.

In order to come to a conclusion on the most environmentally sound power production method for the Midwest, there are two questions that need to be answered. First, which method

of power production will provide the most power? The location of the study needs to be taken into account, as well as the method of power delivery and the resources of the communities that the power producer will be serving. In the Midwest there is not shortage of land that can be used to house the power plants, however the weather conditions can be problematic for some power producers. The second question is how much impact do the power production methods have on the environment? Most of the study will be comprised of this analysis, as there is not a clear measurement that can be used for each power producer. The aspects of environmental impact that will be used to compare the different methods will be amount of land used, waste emissions during its lifetime,. The result of these two questions will be compared side by side, and the power production option that provides the most power and the least amount of environmental impact will be proposed at the conclusion of this study. This paper will first go through the method of obtaining the information required to analyze each power production method, then, using that information, the study will develop a comparative analysis matrix that will answer the questions of amount of power produced and environmental impact. Finally, using the results of the comparative analysis matrix, the study will determine which power production method is most suitable for the Great Plains region in the United States of America.

Methods

The method of this study is a qualitative literature review. The objective of this study is to determine the power generation method with the most power output for the least environmental impact. The process that this study took was to first develop the questions related to the topic of environmentally sound power production. This stage resulted in the following questions:

1. Which method of power production will provide the most power?
2. How much impact do the power production methods have on the environment?

These were the focus of the study during the literature review process, and drove the development of a matrix that compared four criteria for power production in which coal, solar, wind, and nuclear power production methods would be compared. After developing this matrix the method that delivered the most power and the least amount of environmental impacts pronounced. Finally, the possibility of using the different methods in the Great Plains region was discussed to ensure that any geographical or technological impediments were considered. The process for the literature review was done using the 5-Step Systematic Literature Review Process (Khan, n.d.). The five steps are as follows:

Step one, framing the question. At the beginning of the fall semester of 2018 the need to develop a thesis question and plan a thesis arose. The desire was to put together a document that demonstrated the learning of the students up to this point in the environmental studies program. The topic of this study was power production and the influence that different power producers had on the environment. The problem with this idea for a thesis, however, was that the scope was very broad. Where would the study draw the line for too in depth on the environmental impact? How many power production processes would be considered for the study? What purpose would this study serve?

These questions were integral for the development of the final research question and narrowing the topic. After a brief amount of research the study began to take shape as a geographically-local focused study on four mainstream power production processes: coal, wind, solar, and nuclear. The final result of the first step was the research question:

Of the four mainstream power production processes: coal, wind, solar, and nuclear, which process provides the most power produced with the least amount of environmental impact within the region of the Great Plains of North America?

Step two of the literature review was to identify the relevant work surrounding the topic of study, and step three was to assess the quality of the studies included in the literature review. This was the most time consuming process of the study, as a literature review requires a large amount of outside information in order to be considered a proper review of current material on the topic. It was also the most straight forward part of the study, just reading the articles and determining the key elements that needed to be included in the study. This went right into step four, summarizing the evidence in a concise manner and prepare for the analysis and the results.

Step five was interpreting the findings, which was arguably the hardest part of the study. Now that the information had been gathered, it needed to be translated to a concise format. The final product ended up being a matrix of characteristics by which each power production process was graded: Acres of land used per megawatt, average power produced per power plant, average waste produced per power plant, and renewability of fuel resources for the power plants. After putting all the information gathered into the matrix, the power process with the best score was determined to be the best choice for the Great Plains region to use as a source of power.

Literature Review and Results

Power production of any type requires the use of a material or resource in a process that results in the output of energy in the form of electricity, and some form of waste. An everyday example is the personal automobile engine. A car uses gasoline, a fossil fuel, as a raw resource in a combustion reaction that results in explosive energy that spins the motor, but also results in carbon monoxide, water vapor, and soot, which has a negative impact on the environment (Niranjan, 2017). In the same way, wind, solar, nuclear, and coal power production all use resources and impact the environment as a result of the power they produce. This literature review goes through a process of looking at each power production option, determining what

their environmental impact is, and inserting the information gathered into a matrix that scores each power production option on: waste produced, power produced, land usage, and whether or not it is a renewable resource.

The first method of power production that will be looked at is coal power. Coal power production is a method of turning water to steam by burning coal, sending the steam through turbines to spin a generator, and capturing the steam on the other side of the turbines and condensing it back into water (How a Coal Plant Works, n.d.). This simple system means that it is relatively easy to build and operate a coal power plant, so it is an easy choice for cities nationwide, especially in the Great Plains area of the USA. The popularity of coal power plants is substantial as, "Coal combustion residues account for 90% of all fossil fuel combustion wastes produced in the USA (Carlson, 1993)." However, this simplicity of a system comes at a cost of waste produced. The waste comes in the form of heavy metal emissions, carbon monoxide, and volatile organic compounds, which means there is a physical waste that can be seen as well as a gas component that impacts the atmosphere (Coal and Air Pollution, 2014). "Presently, only about 20% of these wastes are utilized, with the remainder deposited in landfills or surface impoundments (Carlson, 1993)." A study from 2014 determined that in one year US coal power plants generated forty six tons of toxic heavy metal waste, 576,185 tons of carbon monoxide, and 22,124 tons of volatile organic compounds (Coal and Air Pollution, 2014). This is a large amount of potentially harmful waste the impacts daily lives as well as the environmental health of the planet. With 427 coal power plants in the USA presently, this means that each individual power plant is creating, on average, 215 pounds of toxic heavy metal waste, 1349 tons of carbon monoxide, and 52 tons of volatile organic compounds each year (U.S. Energy Information Administration. Count, 2016). This is only one aspect of environmental impact. Coal power

plants require massive amounts of coal each year to run, and coal is not a renewable resource (Nonrenewable Energy Explained, n.d.). Coal power plants also require 12.21 acres per megawatt produced to operate, so land usage is a measurable impact on the environment (Stevens, 2017). The use of land referenced calculates the land required for the power plant, the land required to gather the resources, the land required to transmit and transport the resources and the electricity, and the land required to store the waste. Finally, in one year 427 power stations generated 282,236 megawatts of electricity, which means that on average, a single power station generated 661 megawatts of electricity (U.S. ENergy Information Administration. Electric, 2016). Expanding on the referenced footprint, the average coal power plant uses 8070 acres of land to operate. In reality, here are some power plants that are larger and some that are smaller, but for the sake of this study averages will be used to standardize the information to drive relevant conclusions. Coal power clearly creates a massive amount of waste each year, but in comparison to the other power production options, it does not use as much land, as will be shown in the following sections. It is also important to note that for the sake of the study the results will be applied to the Great Plains location of the United States, but factors related to the geography of the study will be discussed later.

The second method of power production considered is wind power. Wind power is very popular in the Great Plains because of the wide expanses of open flat land which allows for easier installation as well as more area for turbines in free flowing air; however, the east and west coast would also be good options for wind power due to the consistent ocean winds. One of the biggest positives of wind power is the fact that it is completely renewable energy and can be remotely controlled with minimal man power because it does not require constant attention. Wind power production has been on the rise over the last decade and is continuing to grow at a

substantial rate. In an article by John Hall, Assistant Professor of Mechanical and Aerospace Engineering at the University of Buffalo in New York, he states that “the total amount of electricity generated by wind turbines nearly doubled between 2011 and 2017” (Hall, 2018). In the year 2000 the total wind power capacity of the USA was 2539 MW, and in eighteen years that number has risen to 96,487 in 2018 (U.S. Installed, 2018). Ultimately, not all of this generated energy ends up being used in the USA. Wind power, much like solar power, is not consistent enough to be used on a daily basis or even as a sole power source for a community or city. Some days there is just not enough air moving to spin the turbine, and some days there is so much air moving that there is more energy being produced than can be used (Lofthouse, n.d.). On days that there is more energy being produced than used, there is no where for the extra energy to go because technology has not developed enough to be able to store the massive amounts of energy. The only other options are to either have some turbines not running, or to export the extra energy to other countries or other parts of the USA (Orrell, 2017). Regardless, the amount of energy produced by wind farms is substantial and increasing.

While wind power production is an ever growing source of energy, and only getting bigger, it faces a challenge of land usage. At 70.64 acres per megawatt produced, wind power uses the most land per megawatt compared to the other four power sources (Stevens, 2017). This is a deceptive number, because while it does require a lot of land to build a wind farm, the land under the turbines can still be used for farming, so the actual footprint for a turbine is about the size of a football field, or one acre per turbine. However, it is also worth noting that the land around them can only be used for farming, there is no other use for the land, no buildings can be built around them.

For energy output, it was already stated that in 2018 wind power had the capacity to produce 96,487 megawatts of energy (U.S. Installed, 2018), and, since there were 57,636 wind turbines in 2018 (Ingraham, 2018) that means that on average each wind turbine had the capacity to produce 1.67 megawatts. Compared to amount the amount of land required to produce that energy, it is difficult to justify that usage of land, except for the waste produced. While operating, wind turbines generate virtually zero waste, their only waste comes from their production and installation. For this study, the waste created during installation and production will not be considered. However, it is important note that there are other environmental impacts from wind power production. In his book Renewable and Sustainable Energy Reviews, Dennis Y.C. Leung notes that, "Wind energy, commonly recognized to be a clean and environmentally friendly renewable energy resource that can reduce our dependency on fossil fuels, has developed rapidly in recent years… However, there are potential environmental impacts due to the installation and operation of the wind turbines that cannot be ignored." He later goes on to talk about three main environmental impacts that he determined to be important: noise and visual impact, effect on animals and birds, and climate change. Unfortunately none of those are relevant to the four criteria that are being used to judge the power production methods, but this source is included because it is important to remember the there are sacrifices that a community must make to generate power, and while it will not be considered in this study, the comfort of the community that the power production method serves does matter.

The third power production method that this study looked at was solar power. Solar power has also been on the rise as renewable energy has made its way onto the world stage. In 2000 solar power production had the capacity to generate 85 megawatts, and in 2009 that number was up to 1.68 gigawatts (Devabhaktuni, 2013). In 2018 the total power production of solar

power was up to 10.6 gigawatts (U.S. Solar Market Insight, 2019). As with wind power production, the benefit of not having to procure fuel for the turbines or solar fields. This results in cheaper operation since there is only the setup process and then maintenance for the remainder of its operational period. However, solar energy also faces the issue of energy storage because when there is cloud cover, they do not produce as much power, but on days that have intense sunlight, they can produce more power than needed. The difference between solar and wind power, however, is that solar panels cannot be shut off, so the panel will continue to generate power, but the power will never go anywhere. This form of power production is still much less damaging to the environment than conventional power production methods, so the US government has added a significant amount of monetary backing through subsidies which has also helped it gain popularity in the world market (Energysage, 2019).

As mentioned above, last year solar power in the USA was able to produce 64 gigawatts of power. Based on a study done by the Solar Energy Industries Association, SEIA, there were approximately 1.9 million solar installations in the USA in 2018 (Will Solar Power, 2017). This is a huge number of installations and the SEIA predicts that by the year 2023 there will be almost 4 million installations, which means that the USA will have the ability to generate over 100 gigawatts of power through solar power alone, enough to power well over 20 million homes. One thing that makes solar power different than the other three methods of power production is that solar is used in both the corporate market and the consumer market. There are companies with massive solar fields, but there are also people who install their own solar panels to power their own homes. This is great for people who want to make a change to their situation and help decrease the dependency on fossil fuel. At the same time however, it makes an exact count of the number of solar panels in use nationwide, difficult to determine. Based on the 1.9 million

installations and 64 gigawatt capacity, the average energy output per installation is 33 kilowatts. This is not a huge number, but if each household had 5 solar installations of their own, and the power output was consistent year-round, the USA would be completely self sufficient on solar power.

Solar power does have its setbacks as it does require a lot of land to setup. At 43.5 acres per megawatt (Stevens, 2017), it requires the second most land per megawatt. Often times the larger solar fields are build in tight acreages, since the panels only need to be far enough apart from each other so that they do not cast shadows on each other, and for the smaller private solar installations, panels are sometimes put directly on buildings, reducing the amount of space required. Despite the ability to place panels close together or even on buildings, the land usage just to install them, not taking into account land from resources, production, transmitting, or storage, is over 30 acres per megawatt (Stevens, 2017).

Solar power is much like wind power in its environmental impact as well. There are a variety of impacts that solar power has on the environment, but very little, if any, waste is produced during the operational time of a solar panel or solar field. The majority of the waste comes from the production and disposal of the solar panel. Since this study is comparing the operational waste of each power production method, solar power, like wind power, will have a negligible amount of waste produced. However, there are other environmental impacts to be aware of with solar power. Their construction releases a gas called “nitrogen trifluoride (NF3), which is 17,200 times more potent than carbon dioxide as a greenhouse gas” (Will Solar Power, 2017). When compared to the disposal waste of nuclear reactors, “solar panels create about 300 times more toxic waste per unit of electricity generated than nuclear power plants” (Will Solar Power, 2017). Solar panels provide a clean source of energy because they do not rely on fossil

fuels, but without a proper means of disposal, they are extremely toxic to the environment. They also require the local community to sacrifice the surround land to the solar fields due to their visual impact. They are reflective enough that they can shine through windows and be blinding to the buildings around them, or to cars if they are close enough to roads (Aman, 2014). That is why most solar panels are either in large open fields, or on the roofs of buildings.

The fourth and final power production method that will be looked at for this study is nuclear power. Nuclear power has been a controversial topic since its inception, since there is a volatile reaction occuring in a small space that can result in massive repercussions in the event of catastrophic failure. With the events of Chernobyl in 1986 and the most recent accident at Fukushima in 2011, people have first hand accounts of what catastrophic failure can look like, and understandably do not want to be near a nuclear power plant. The exact numbers of the public's opinion range from two thirds in support of nuclear power in the future (N., 2016), to an almost fifty fifty split (World Nuclear News, 2019). This is far more controversial than the argument for wind or solar power as both renewable energy methods have over 80% public support (Pew Research Center, 2019). People understand that renewable energy is important to the future, but people also realize that the technology required for the USA to be dependant on renewable energy is not yet available, and in the meantime communities must choose between power production methods that rely on non-renewable resources. In the case of this study, the choices are nuclear power or coal power.

There are currently 60 operational nuclear power plants in the USA with a combined 98 reactors (U.S. Energy Information Administration -EIA, 2018) that produce a combined 91 gigawatts of electricity per year. This is an extremely high energy output per power plant with each power plant averaging 1.517 gigawatts per year. This puts nuclear power production at the

top of the four power production methods for average power produced. Nuclear power is also relatively clean energy when compared to the waste produced by coal power plants. Nuclear power plants consistently produce minimal greenhouse gases that are released into the atmosphere (Efremenkov, n.d.), and based on a study by Mara Hvistendahl, the nuclear waste produced by nuclear fission, the process by which nuclear power plants make energy, is actually less harmful to the environment than coal ash (Hvistendahl, 2007). On average, the amount of waste produced by nuclear power plants amounts to 20 tons of radioactive waste per year (NEI).

Nuclear power also uses land in a conservative way, requiring only 12.71 acres per megawatt, coming in second after coal power production (Stevens, 2017). Nuclear power plants save on land required to operate because the size of the reactors, themselves are relatively small and do not require much surrounding land except to house the cooling towers. However, nuclear power plants require twice as much land for fuel resource collection, which is where coal power surpasses nuclear power due to the abundance of coal worldwide (Stevens, 2017). In 2017 the USA required almost 19 thousand tons of uranium to operate its reactors, and most of those 19 thousand tons were collected elsewhere in the planet due to the lack of abundant uranium in the USA (World Nuclear Association, 2019).

In closing for the literature review, a few key points are important to remember. First, the figures for waste produced are only for waste produced during operation of the power plants. Second, the environmental impacts are important factors that communities must take into account when deciding on the power production method that best suits their region. Third, and finally, the land required by each power production method is a sum of the land of the actual power plant, the land required for resources, the land required for transmitting the power, and the

land for the storage of waste for each method. All of these numbers together make up the acres per megawatt number presented with each power production method.

Results

In the tables below, the following criteria are compared and ranked against each other, with first being the best and fourth being the worst. These tables are filled with the information provided in the literature review above. The fifth and final table is a summary of the points each power production earned through the four criteria presented. The power production method with the lowest score is the one deemed to have the least amount of environmental impact for the amount of power produced:

Table 1. Acres required per megawatt of energy produced.

Production Method	Coal	Nuclear	Solar	Wind
Acres per Megawatt	12.21	12.71	43.50	70.64
Score	1	2	3	4

Table 2. Average power produced per power plant annually.

Production Method	Coal	Nuclear	Solar	Wind
Average Power (Megawatts)	661	1517	0.33	1.67
Score	2	1	4	3

Table 3. Average waste produced annually during operation, in tons.

Production Method	Coal	Nuclear	Solar	Wind
Average Waste (tons)	1616	20	Negligible	Negligible
Score	4	3	1	1

Table 4. Renewability of resources required to operate power plants.

Production Method	Coal	Nuclear	Solar	Wind
Renewability	No	No	Yes	Yes
Score	3	3	1	1

Table 5. Final scoring for the four methods of power production.

Production Method	Coal	Nuclear	Solar	Wind
Final Score	10	9	9	9
Final Ranking	4	1	1	1

Discussion

At the end of the literature review and the summary of data collected, nuclear power plants, solar farms, and wind farms all tie for the best choice of power production when comparing environmental impact. This is unsurprising as renewable energy will be the way of the future (Hall, 2018) , but currently nuclear power is the most reliable of the three because of

its ability to operate consistently. However, which one is really the best choice for cities in the Great Plains? The answer is all of them, and the only reason that it is not just one of them is because of the progression of technology allows for multiple sources of power to minimize the impact on the environment in a specific sector. After the events of Chernobyl and Fukushima, people are hesitant around nuclear power (N., 2016). Wind and solar power are not friendly to communities for noise and visual reasons (Amam, 2014) (Devahbaktuni, 2013). All three have issues with waste, but wind power is the better choice in this criteria, as the waste produced by building and decommissioning wind farms is relatively minimal and it largely recyclable, while nuclear and solar waste are not very recyclable, and tend to be toxic to the environments in which the waste is stored (Amam, 2014).

Realistically, at their current states, wind and solar power will not be the primary sources of power production due to their in ability to provide consistent power are the rate required to power a city. This is especially true for the Great Plains area of the because inconsistent weather, like elsewhere in the USA, can inhibit renewable energy methods from consistent energy production (Lofthouse, n.d.). Renewable energy is the power supply of the future, and every day there are jumps in technology that bring the modern world ever closer to the inevitable transition to power generated by the environment, and less man made methods of power production. In the next twenty to thirty years this study will be completely out of date, and based on the trends of technological advance and the desire of humanity to transition to a more responsible treatment of the environment. Right now the technology and demand for electricity leaves us in the position of needing to use fossil fuel and nuclear power, and while their impacts on the environment have been minimized as much as possible, they cannot be a permanent option in the long term, as they

will burn out the Earth's natural resources, and that goes against the desire for sustainability that is driving power production innovation for a better, cleaner future.

This study is a limited study investigating the environmental impacts of coal, wind, solar, and nuclear power in the Great Plains region of the USA. The information gathered is from nationwide data bases and has been adapted to apply to this region. This study also limited the environmental impacts of the four power production methods to waste produced during the operational period of the power plants. It would be worth studying the impacts due to the installation and decommissioning to determine if that places one of the three methods that tied in a different rank. Another topic of study that would be of interest is the development of technology for power production, specifically the development of energy storage to improve the consistency from renewable energy sources.

Conclusion

In a world that is growing increasingly aware of the impact that humanity has on the environment, it is important that the method that cities and communities choose to power their homes are the most effective choices possible. This study focused on four methods of power production: coal, nuclear, wind, and solar. The goal was to determine which of the four would be most effective in the Great Plains region of the USA and to answer the question of which method provides the most amount of power while having the least amount of impact on the environment. After developing a matrix of criteria to judge each of the methods by, it was determined that nuclear, wind, and solar power all provide a similar amounts of power for the amount of environmental impact they produce. However, when looking at the viability of the three power in the Great Plains region, it is important to note that renewable energy is still developing into a reliable and consistent source of power, and that the waste produced by nuclear power is difficult

and expensive to dispose of, and if mishandled, could result in great harm. The perceived instability of nuclear power from the examples of Chernobyl and Fukushima have left the general public wary of the ability of nuclear power to become their main source of power production. While all three have the same rank in the matrix developed by this study, coal power plants will be the main source of power production for the Great Plains region due to the public support for a stable method of power production.

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