A Study on Nuclear Energy and Comparing It to Other Energy Sources Yields a Promising Energy Source but Future Advancements Are Required to Mitigate Drawbacks

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Nuclear energy was first discovered in 1951 on the 20th of December by Enrico Fermi. About 8 years later, the first nuclear power plant was built in the United States. Since then, nuclear power plants have only gotten better as technology advanced through the decades. They are more reliable and produce more energy with minimal drawbacks and operate on near-maximum capacity annually. For the past 6 decades, nuclear energy has been a main energy source for the United States, producing an average of 1 gigawatt of energy per plant. Not only do they produce more energy than fossil fuels and other energy sources, but there is also no carbon emission.

However, nuclear energy isn't the only energy source available. There are other energy sources like coal, oil, biomass, and natural gas. We also have access to energy sources like wind, water, and solar. However, these energy sources can not make as much energy as nuclear power sources. As we continue to use these different energy sources, the benefits and drawbacks engender themselves. By using energy sources like coal and geothermal, massive amounts of greenhouse gas emissions are released into the atmosphere. A ton of coal will produce 5,720 pounds of carbon dioxide (Hong and Slatick) which accounts for 81% (United States Environmental Protection Agency) of the entirety of greenhouse gases in 2018 and has an atmospheric lifetime of 300 to 1,000 years (Buis). Although natural gas emits much less carbon dioxide than coal, it is still a great contributor to these heat-trapping gases. Natural gas primarily emits methane into the atmosphere which is 34 times stronger than carbon dioxide at trapping heat over 100 years and 86 times stronger over 20 years (Union of Concerned Scientists). Even with 'clean' sources like solar and wind, there is still carbon emissions being produced. Wind produces about 1/20th the amount or about 50g compared to 950g which is generated from fossil

fuels. It seems no matter which energy source is used, whether it is renewable or nonrenewable, there are still benefits and drawbacks to each of them can impact or mitigate climate change.

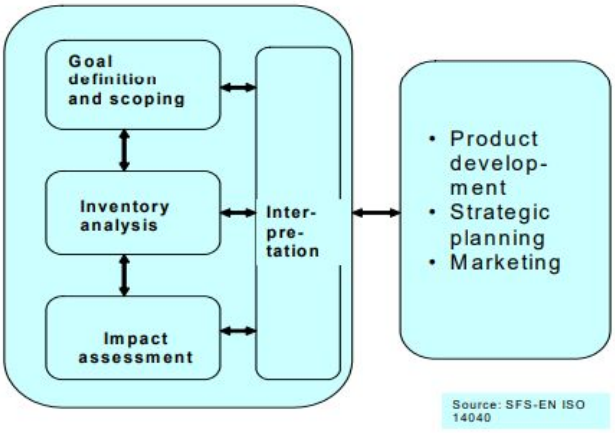
Nuclear energy appears to be the one energy source that produces a large amount of energy while also not emitting any carbon and being exceptionally reliable. Simply replacing existing energy sources for nuclear energy will not eliminate climate change either as other factors such as soil cultivation practices would release a powerful greenhouse gas called nitrous oxide. In addition, greenhouse gases do not all present negatively upon the earth. The most abundant greenhouse gas is water vapor, it serves as an aid in the formation of clouds and precipitation as the atmospheric temperature increases (Global Climate Change NASA). Overall climate change will not be eradicated by the simple replacement of energy sources as other factors would always play a role in the temperature fluctuations of the Earth. Changing the energy sources must be a carefully thought out procedure that considers all possible alternatives and compares them across several attributes like cost, reliability, energy production, and safety. In this paper, we attempt to identify where nuclear energy ranks among alternative energy sources in such attributes and whether or not it continues to be a plausible source of energy. Nuclear energy is already known to be reliable and efficient compared to other alternatives and is expected to only improve further as technology advances.

Methods:

In order to properly come to the conclusion that nuclear energy is an acceptable alternative to other energy sources, one needs to see how this energy source performs against others. For this case the tool used is called Life Cycle Assessment (LCA) in which the entirety of a product's life cycle is considered. The publication by World Energy Council, uses this tool by considering electrical power or energy output and environmental emissions as its products (World Energy Council).

Life-Cycle Assessment is a set of procedures in which the inputs and outputs of a certain subject as well as its corresponding environmental impacts are recorded. Such inputs and outputs could be raw materials, manufacturing, maintenance of recycling or products, atmospheric emissions, waterborne wastes, etc. respectively (World Energy Council).

Life Cycle Assessment consists of four components: Goal definition and scoping, Life-cycle inventory, Impact analysis and Improvement analysis. These four components would be what is considered each step of the product's creation to consumption.



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Goal definition and scoping is the identification of what purpose the LCA might have and what products are to be expected as well as assessing the study's boundaries and assumptions. Life-cycle inventory would quantify the inputs and what is being released into the atmosphere as each stage of production progresses. Impact analysis would analyze the possible impacts of the

inputs on the health of the population and environment. Lastly, improvement analysis would evaluate the ways in which material and energy inputs as well as the impact on the environment could be reduced throughout the product life cycle.

The use of LCA would provide evidence in regards to the atmospheric emission by nuclear power compared to other energy sources. LCA would allow for clear understanding of which of these energy sources is the most favorable in terms of environmental health and if the use of nuclear power could in reality be a promising alternative.

In addition to the use of Life Cycle Assessment in order to measure the atmospheric emissions by nuclear power it is of importance to understand how effective this source is at supplying energy. Nuclear power has the advantage of requiring minimal maintenance and being able to perform for long periods of time compared to other types of energy sources. In order to acquire this information the capacity factor by energy source has been presented.

A capacity factor indicates what percentage of the year are these energy sources producing at maximum power. Due to its high capacity factor nuclear power accounted for 20% of the United States' electricity in 2019 (World Nuclear Association).

Results:

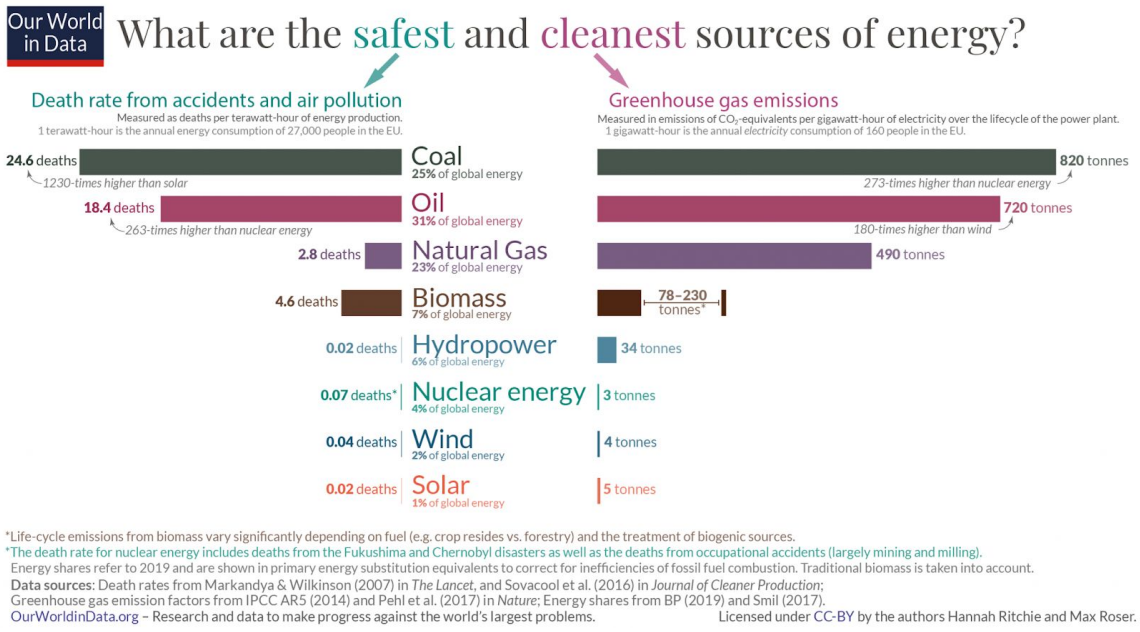

Figure 1: A bar graph of deaths, greenhouse gas emissions, and the breakdown of global energy use (Ritchie).

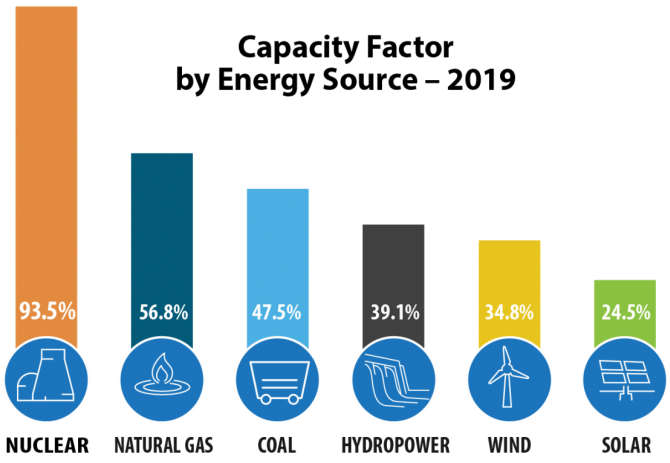

Figure 2: A bar graph highlighting the capacity of different energy sources (Mueller).

In Figure 1, three different types of results are recorded in the bar graph for 8 different energy sources, coal, oil, natural gas, biomass, hydropower, nuclear energy, wind and solar. On the left side, is the death rate resulting from these 8 different energy sources in death per terawatt-hour and each terawatt-hour is 27,000 people. From the lowest to highest, the ranking is solar and hydropower tied, wind, nuclear energy, natural gas, biomass, oil and then coal. We see that nuclear energy is the fourth lowest contributor of deaths from accidents and air pollution. On the right side is the measurement of greenhouse gas emissions in ton CO2 emission per gigawatt-hour and each gigawatt-hour is 160 people. The ranking of greenhouse gas emission from lowest to highest is nuclear energy, wind, solar, hydropower, biomass, natural gas, oil and coal. Unlike the death rate, the rankings are different for the greenhouse gas emissions. Nuclear energy contributes the least amount of greenhouse gas. In the middle, the percentage of global energy is labeled underneath the energy source. From the least contributor to highest contributor of global energy, it is solar, wind, nuclear energy, hydropower, biomass, natural gas, oil and coal. Nuclear energy again falls under a different rank and is the third least contributor of global energy. In Figure 2, the capacity factor of energy sources in percentages of nuclear energy, geothermal, coal, hydropower, wind and solar energy are graphed using bars. Under the same order, the capacity is shown to have a negative trend line. Thus, nuclear has the greatest capacity at 93.5%, almost double that of geothermal's capacity of 56.8%, which is the second highest capacity.

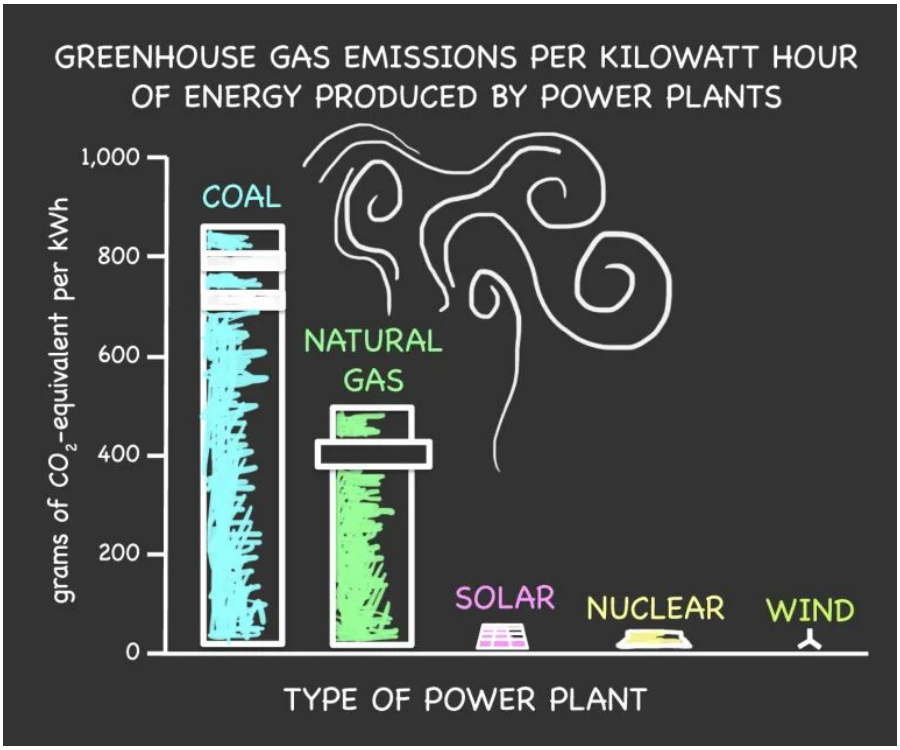

Figure 3: A bar graph of greenhouse gas emissions by power plants of various energy sources (Wilkerson and McArdel).

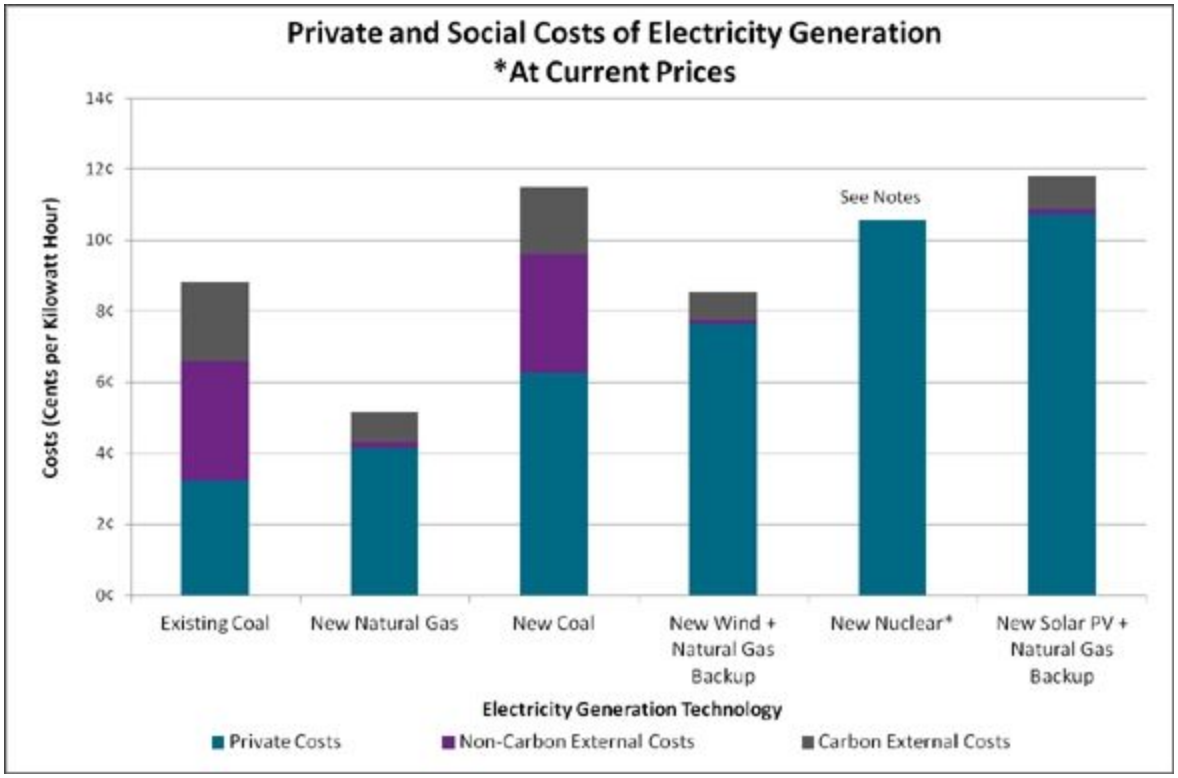

Figure 4: A bar graph of existing prices for various energy sources (Greenstone).

In Figure 3 grams of greenhouse gas emissions(CO_2) per kilowatt hour of energy produced by 5 different energy sources were graphed. From the highest grams of CO_2 to the lowest, it is coal, natural gas, solar, nuclear and wind. While there is a negative trend line, solar, nuclear and wind all have less than 100 grams of CO_2 emitted per KWh, whereas coal and natural gas have at least 500 grams. In Figure 4, the private costs, non-carbon external costs, and carbon external costs are all graphed in cents per kilowatt hour. From the most expensive to the least expensive isNew Solar PV + Natural Gas Backup, New Coal, New Nuclear, Existing Coal, New Wind + Natural Gas Backup, and New Natural Gas. This time, nuclear energy is the third

most expensive total cost of generating electricity and is within 2 cents of the top 2 most expensive electricity generating energy sources.

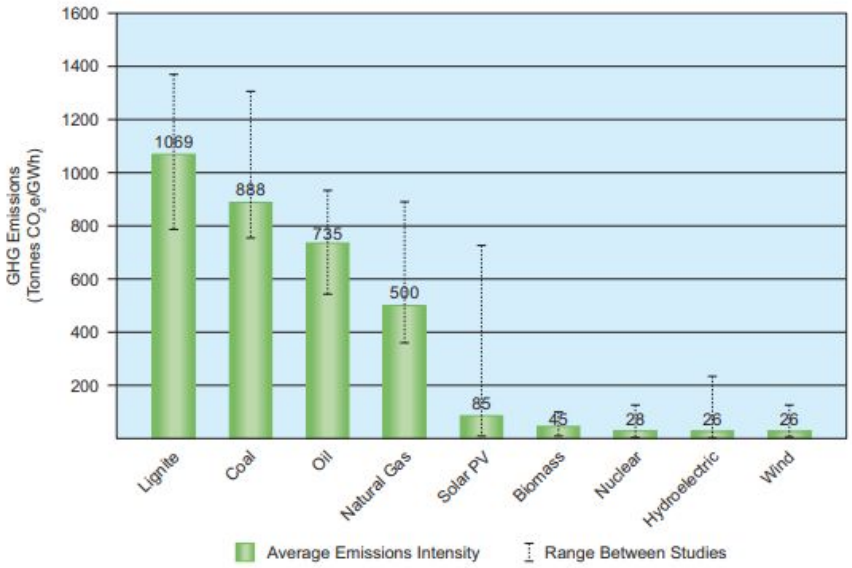

Figure 5: Results of LCA for Greenhouse Gasses Released ("Comparison" 7)

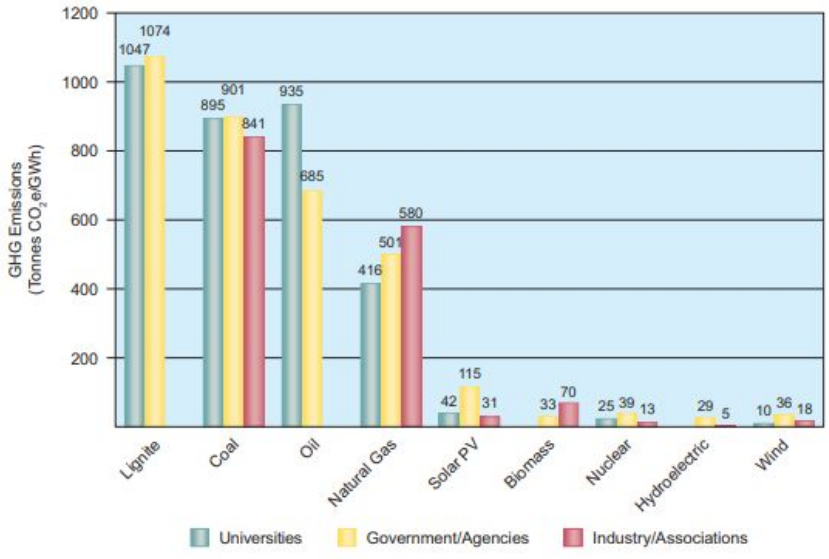

Figure 6: Results of LCA of the use of energy sources in different areas. ("Comparison" 8)

In Figure 5, the average emission intensity of greenhouse gases were measured and recorded in tonnes of CO2 per gigawatt-hour. In the order of, lignite, coal, oil, natural gas, solar PV, biomass, nuclear, hydroelectric, and wind, there is a negative trend line. This means in that order, the average greenhouse gas emission decreases. Thus, nuclear energy emits the third lowest amount of greenhouse gasses. Another thing is along with nuclear energy, solar PV, biomass, hydroelectric and wind, all release greenhouse gasses under 100 tonnes of CO2 per gigawatt-hour, whereas, lignite, coal, oil and natural gas release greenhouse gasses of at least 500 tonnes of CO2 per gigawatt hour. In Figure 6, a similar data is shown as in Figure 5, however each energy source is broken down into the greenhouse gas emitted by universities, government agencies, and industries. In this figure, nuclear energy is the fourth lowest contributor of greenhouse gases in universities and government agencies, but the second lowest in industries.

Discussion:

After consolidating the results from various sources, nuclear energy continues to remain one of the better sources of energy compared to other sources like coal, oil, natural gas, wind, solar and hydroelectric despite being scarce and costly. Yet it remains a viable solution to climate change in the future. Nuclear energy continues to be a more reliable and clean energy source. According to Figure 1, nuclear energy had only 0.07 deaths per terawatt-hour, which is the fifth largest contributor of death between coal, oil, natural gas, biomass, hydropower, wind and solar energy. It precedes natural gas, which had only 2.8 deaths per terawatt hour, which is 40 times more than deaths caused by nuclear. Because nuclear energy, hydropower, wind and solar, remain 0.05 deaths/terawatt-hour within each other, nuclear energy continues to remain one of the safest energy sources, along with the renewable sources of energy. The graph even takes into account deaths caused by accidents and air pollution. Even with the Fukushima and Cherenobyl disasters, it continues to remain one the safest methods of obtaining energy.

Nuclear energy also continues to have one of the lowest gas emissions compared to other sources of energy and the amount of gas emission resembles that of solar and wind. Solar and wind are considered renewable energy sources, and yet nuclear energy is shown to release the lowest ton of carbon dioxide at 3 tonnes/gigawatt-hour, compared to 4 tonnes/gigawatt-hour by wind energy and 5 tonnes/gigawatt-hour by solar power (Ritchie). In Figure 3, nuclear is again shown to release one of the lowest amounts of CO2 grams equivalent per KHW, along with solar and wind, at under 200 grams. Sources like natural gas and coal release over 400 grams (Wilkerson and McArdel). Since nuclear energy has produced relatively low gas emissions, it continues to be one of the better sources for energy during climate change. Even if it continues producing some amounts of carbon dioxide or other greenhouse gasses, that amount being

produced is significantly less than alternative sources and is better for the near future. In Figure 6, nuclear energy falls between biomass and hydroelectric, making it the third safest energy source based on the tonnes of greenhouse gases released (“Comparison” 7). In a world where the environment is impacted by the amount of greenhouse gases, nuclear energy provides a viable solution, on par with some of the other renewable sources. When choosing an energy source to mitigate gas emissions, nuclear stands out since it can not only produce enough energy to satiate our growing demands but doesn't produce much carbon. It is also more reliable since it is operational annually and does not depend on windy or sunny areas like solar or wind.

The capacity factor indicates how often a certain energy source produces at its maximum during a period of time. Taking into account the capacity factor of nuclear power and other energy sources, in Figure 2, it is clear that nuclear power is one of the most reliable energy sources working at maximum power for 93.5% of the time. This allows for more energy to be produced annually than any other source. Geothermal comes second at 56.8% and coal third, at 47.5% capacity, which are both over 30% less in capacity than nuclear (Mueller). Nuclear ranks first in being able to retain the energy it produces. This allows it to be more efficient in the future where energy consumption will only go up.

Even though nuclear power is an exceptional alternative energy source with its high performance and low environmental harm it is still one of the most expensive. Figure 4 presents the costs by type of various energy sources. Nuclear energy is the third most expensive in private costs after New Solar PV + Natural Gas Backup. The vast cost of nuclear power plants will continue to be one of the greatest deterrents to the future use of this energy source. Because other energy sources are less expensive, it might cause poorer nations to adopt those energy sources as

means to save energy rather than using nuclear energy. As a result, those countries won't be able to use the benefits of nuclear energy, but rather another energy source.

Despite high cost and low gas emission, nuclear energy is also not as popular. Due to its size and misconception of explosive failures, nuclear still remains a scarce energy source. Nuclear energy only consists of 4% of the global energy, making it more popular than wind at 2% and solar at 1%, but less popular than hydropower at 6% (Ritchie). Even with all its benefits and drawbacks, having nuclear as a potential energy source means nothing if nations and governments are not invested in this technology. In Figure 7, based on the amount of greenhouse gas produced, industries utilize the lowest amounts of nuclear energy while governments use it the most, and universities fall somewhere in between ("Comparison" 8). If more institutions are able to implement nuclear energy, it might become more appealing as a source in the future and this might allow nuclear energy to contribute more towards global energy in the future.

Regardless of its potential positive environmental impact,the use of nuclear power still has its limitations. Nuclear power is not a renewable source of energy, it requires the mining of Uranium which accounts for the indirect emissions of carbon dioxide, there is always the possibility of runoff from the plant to the ocean resulting in the harm of marine life. Lastly nuclear plants produce toxic radioactive waste which could result in the harm of organisms and the environment. Although nuclear power presents these limitations they are avoided by independent continuous reviews of the operating power plants throughout the world (Power World Analysis).

Although nuclear energy is not as widely used, it is a grand part of the energy sources of multiple countries. Thirty years ago France and Japan adopted the use of nuclear energy due to

the exhaustion of native resources. Nowadays this specific type of energy source accounts for 78 percent and 30 percent of total energy in France and Japan, respectively (Goldemberg). The use of nuclear plants by these two countries serve as a way to demonstrate how carbon emissions could be greatly reduced by implementing nuclear energy. Taking France for example, thirty years from the date of publication of the Goldemberg article the trend of carbon emissions by this country fell from 9.64 metric tons in 1979 to 9.16 metric tons in 1980. The trend only continued to fall from that date until the last year recorded with 4.57 metric tons in 2014 (The World Bank). To finalize, the use of nuclear power has been proven to be capable of greatly reducing the negative impact humans have on the environment and future studies can explore if nuclear energy impacts different environments or cities. Nuclear energy can provide many benefits during a time when climate change is impacting the biosphere. While it has its limitations, by continuously investing and researching into nuclear energy, it continues to remain a viable solution to providing energy in the future.

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