Addition of Nuclear Energy as a Clean and Sustainable Energy Source

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OVERVIEW

Climate change is an extremely important issue in the politics of today. In order to reach net-zero emissions and prevent global warming from exceeding an increase of 1.5 degrees Celsius, we must phase out the usage of fossil fuels in energy production. Although a complete switch to renewable sources would be ideal, our research suggests that a much more realistic approach would involve reliance on both nuclear and renewable energy sources to replace fossil fuels.

EMPIRICAL COMPARISON OF NUCLEAR VS RENEWABLES

The two main approaches to reducing emissions in the energy sector are replacing the usage of fossil fuels with either renewable or nuclear sources. Given the complexity of the issue, many point to the real-life example of Germany versus France's energy portfolios, with the former comprised of primarily renewables and the latter of primarily nuclear.

Germany and France are geographically close, similar in size, and exist within the same sphere (EU). For these reasons, the two are often brought up in discussions on the topic of zero carbon emissions, as they boast drastically different energy systems, representative of the two main paths towards eliminating carbon emissions from energy production. This article provides a more in depth overview of the two countries, including their political climates, economy, etc.

Both countries consume roughly equivalent amounts of oil

- 276 million tons Germany vs 224 million tons France

Germany, 2021: 45.7% of electricity generated by renewables (wind, solar, biomass, hydroelectric)

- German energy portfolio much more diverse compared to France
- Almost no reliance on nuclear power in recent years, with the last NPP having been decommissioned in Apr. 2023.
- HOWEVER: Still reliant on fossil fuels such as lignite coal, hard coal, and natural gas.

France, 2021: 68% of annual electricity generated by nuclear power plants

- 56 operable nuclear reactors
- HOWEVER: Aging reactors. 26/56 nuclear reactors were "offline heading into the winter of 2022, some for routine maintenance and others for inspection and repairs after corrosion issues were discovered in reactor pipes. Widespread reactor outages in 2022 resulted in a 24% decline in annual nuclear output—its smallest output in 30 years."
    - In 2020, every French NPP was shut down on average for 115.5 days.

Germany has approx. double France's CO_2 emissions

- 2021: 665.88 megatons (8 tons/capita) vs 302.33 megatons (4.5 tons/capita)

However, Germany has had a higher percentage reduction in emissions from 1990-2021

- -41% vs -24%

Germany has a more stable system

- "System Average Interruption Duration Index" (SAIDI) measures average power outage duration
- Germany 0.25 hours in 2020
- France 0.35 hours in 2020
- US 1.28 hours in 2020

It is worth noting that Germany's energy costs were almost double that of France

- Germany: 49.5 euro cents/kWh (approx 55 cents/kWh)
- France: 26.7 euro cents/kWh (approx 30 cents/kWh)
- MD: between 7.19-18 cents/kWh

PUBLIC OPINION

The following will provide an analysis of the public opinion regarding nuclear energy in the United States. Nuclear energy has been a topic of considerable debate due to its potential benefits and associated risks. Understanding public sentiment is crucial for policymakers and industry stakeholders to effectively address concerns, develop policies, and promote informed decision-making. The following will examine the historical context, factors influencing public opinion, the current state of public attitudes, and the future outlook of nuclear energy in the United States.

I. Historical Context

- Public opinion on nuclear energy in the US has been mixed over the years. In the early days of nuclear power, public opinion was generally positive, with many people seeing it as a safe and efficient way to generate electricity.
- However, the accidents at Three Mile Island and Chernobyl in the 1970s and 1980s, covered extensively by media sources, led to a decline in public support for nuclear power.

- In recent years, public opinion on nuclear energy has begun to recover, as people have become more aware of the risks of climate change and the need for alternative sources of energy.

II. Current State of Public Opinion

- A 2021 poll by the Pew Research Center found that 62% of Americans support building new nuclear power plants. This is up from 50% in 2016. The poll also found that 70% of Americans believe that nuclear power is a safe way to generate electricity.[1]
- In 2022, Pew Research also found that most Americans (69%) favor the US taking steps to become carbon neutral and a majority of Americans believe the government should encourage the production of carbon-free energy sources.[2]
- There are a number of reasons for the recent increase in public support for nuclear energy. One reason is that people are becoming more aware of the risks of climate change, especially in the past month, with a multitude of global climate records being broken. Nuclear power is a low-carbon source of energy, and it does not produce greenhouse gasses like coal and natural gas. Another reason is that the technology for building and operating nuclear power plants has improved significantly in recent years. Modern nuclear power plants are much safer than the plants that were operating in the 1970s and 1980s.
- Men are twice as likely to support nuclear energy than women according to the Pew Research Center, with Maryland having a slight majority (51.55%) of women.[3]
- Republicans are slightly more likely (10%) to support nuclear energy, with Maryland having a 31% republican/lean republican.[4]

III. Factors Influencing Public Opinion (reference our other research papers to see a more in depth assessment and analysis of the risks and concerns mentioned below)

- Nuclear incidents, such as the accidents at Three Mile Island (1979) and Chernobyl (1986), as well as the Fukushima disaster (2011), have raised concerns about the safety and long-term effects of nuclear energy.
- The management and disposal of radioactive waste generated by nuclear power plants remains a significant concern, with apprehensions about potential environmental and health risks.

[1] Americans' views about nuclear power continue to be mixedPew Research Centerhttps://www.pewresearch.org › short-reads › 2022/03/23

[2] https://www.pewresearch.org/short-reads/2022/03/23/americans-continue-to-express-mixed-views-about- nuclear-power/

[3] https://www.states101.com/gender-ratios/maryland#:~:text=There%20are%20more%20women%20than,94 %3A100)%20or%200.94.

[4] https://www.pewresearch.org/religion/religious-landscape-study/compare/party-affiliation/by/state/

- The high capital costs associated with building and maintaining nuclear power plants, as well as the need for government subsidies, can be viewed as a financial burden on taxpayers.
- The media's framing, sensationalism, and choice of expert sources in media coverage can shape risk perception and affect public understanding of the technology's benefits and risks.

IV. Communication Strategies and Public Engagement

- Effective communication plays a crucial role in shaping public opinion. Accurate and accessible information about the benefits, risks, and safety measures associated with nuclear energy can influence public perceptions.
- Public education initiatives, engaging with communities, and fostering open dialogues can contribute to a more informed understanding of nuclear energy.
- Accurate, balanced, and transparent reporting from the media is crucial for fostering informed public debates and decision-making.

V. Future Outlook

- The future of public opinion on nuclear energy is subject to ongoing developments, including advancements in reactor technology, waste management solutions, and renewable energy alternatives.
- Public sentiment may be influenced by policy decisions, scientific research, and the outcomes of international climate change discussions.
- Economic and regulatory factors will continue to improve the competitiveness of nuclear plants as an energy source and make them more attractive to the public.[5]
- Nuclear energy has the potential to play a significant role in the future of energy in the US. Nuclear power is a safe, low-carbon source of energy, and it can help to reduce our reliance on fossil fuels. With continued investment in research and development, nuclear energy can become even more affordable and efficient in the future.

VI. Conclusion

- Public opinion on nuclear energy in the US has been mixed over the years. However, recent polls have shown that public support for nuclear energy is increasing. This is likely due to the growing awareness of the risks of climate change and the need for alternative sources of energy. Nuclear energy has the potential to play a significant role in the future of energy in the US, and with proper communication and engagement, it has the possibility of garnering more widespread public support. Research reveals a complex landscape of opinions, highlighting both support and skepticism, and emphasizing the importance of

[5] https://dspace.mit.edu/handle/1721.1/45065

effective communication strategies to foster public understanding and engagement.

CONCERNS

Understandably, there are many concerns surrounding nuclear energy. We will use the following sections providing thorough examinations and rebuttals of the most common concerns.

Construction Costs:

***Specific costs and their magnitudes can vary depending on factors such as the size and design of the nuclear power plant, regional regulations, labor costs, site-specific considerations, and advancements in technology and safety practices. Stats are estimates for the average sized nuclear power plant from data around 6-7 years ago to present day.

Cons of Construction and Maintenance Costs of Nuclear Power Plants: (Nuclear Power Economics | Nuclear Energy CostsWorld Nuclear Associationhttps://world-nuclear.org › economic-aspects › econo...) and (Nuclear Power Plant Construction Costs - Synapse Energyhttps://www.synapse-energy.com › default › files) and (The Costs and Benefits of Nuclear Regulation - AAFThe American Action Forumhttps://www.americanactionforum.org › Research) and (Backgrounder On Decommissioning Nuclear Power PlantsNuclear Regulatory Commission (.gov)https://www.nrc.gov › doc-collections › fact-sheets › dec...)

High Initial Capital Costs: (Initial costs of nuclear energy is comparable to other renewables)

- Building a nuclear power plant requires a significant upfront investment, 1 gigawatt reactor costing around 5 billion.
- Barrier to entry for some companies considering nuclear energy as an option, only choice is to look outside of Maryland for companies willing to build.

Long Construction Time:

- Nuclear power plant construction involves a lengthy process that takes a decade or more to complete.
- Delays in construction due to regulatory laws, environmental concerns, or changes in safety requirements can significantly impact the project's cost upward. Additionally, during the extended construction period, inflation (+ other changes in market conditions) can escalate expenses.

Safety and Regulatory Compliance:

- Nuclear power plants are subject to strict safety regulations and require many safety measures to prevent accidents, protect workers and ensure the safety of the surrounding environment. Meeting these standards entails additional costs during both construction and operation.
- Regular inspections, maintenance, and necessary upgrades to keep up with evolving safety regulations add greatly to the overall expenses of nuclear power plants.

Nuclear Waste Management:

- One of the significant challenges of nuclear power is the management of radioactive waste. Disposing of nuclear waste safely requires storage facilities, transportation

systems, and long-term management strategies. Substantial costs and ongoing expenses to ensure the proper handling and containment of radioactive materials.

Decommissioning Costs:

- When a nuclear power plant reaches the end of its operational life, it must be decommissioned, and the site must be restored to its original condition or repurposed (approx. 0.5 billion). Decommissioning involves dismantling the plant, managing waste, and addressing environmental concerns. Process can extend over many years, requiring ongoing financial resources even after the plant's closure.

Counter Arg for Construction and Maintenance Costs: (Advantages and Challenges of Nuclear EnergyDepartment of Energy (.gov)https://www.energy.gov › articles › advantages-and-ch...) and (Nuclear Power Economics | Nuclear Energy Costsworld-nuclear.orghttps://world-nuclear.org › economic-aspects › economic...)

Baseload Power Generation:

- Nuclear power plants provide a stable and continuous supply of electricity, operating consistently at high capacity (this is baseload power generation capability), making them valuable for meeting the base demand for electricity, which is important for grid stability. The cost-effectiveness of nuclear power plants can be enhanced by their ability to provide reliable and dispatchable electricity, especially when compared to other renewable energy sources.

Long-Term Cost Stability:

- Nuclear power plants have relatively stable operational and maintenance costs over their lifespan (around 1.25/ Kw per year, average plant has around 1 million Kw). While the initial construction costs can be high, the day-to-day operational expenses, including fuel costs, are relatively predictable. This stability allows for better long-term financial planning and reduces the vulnerability to fluctuations in fuel prices and the market.

High Energy Density:

- High energy density means nuclear power plants can produce a significant amount of electricity from a small amount of fuel. One kg of enriched uranium can generate a substantially larger amount of energy compared to the same mass of fossil fuels reducing the need for large quantities of fuel. Cost savings in transportation, storage, and handling.

Low Fuel Costs:

- The cost of nuclear fuel itself is relatively low compared to fossil fuels over the long term. Uranium, the primary fuel used in nuclear reactors, is widely available and has a high energy content. While the mining and processing of uranium incur costs, the overall fuel expenses constitute a smaller portion of the total operational costs of a nuclear power plant.

Long Operational Lifespan:

- Nuclear power plants are designed to operate for several decades, typically between 40 and 60 years. This extended operational lifespan allows for spreading out the construction and maintenance costs over many years, resulting in a more favorable return on investment. Longer lifespan can also provide stable and reliable electricity generation to meet long-term energy demands.

Conclusion: High initial costs and compliance to safety regulations cost significant amounts, but are offset by consistency and stability in the post-construction stage in power generation

and maintenance cost predictability. Additionally, costs are further offset by nuclear power's high efficiency and cost effectiveness.

Uranium Supply:

Cons of Using the Limited Uranium Supply in Nuclear Power Plants: (Pros And Cons of Nuclear Energy - EnergySageEnergySagehttps://www.energysage.com › about-clean-energy › pro...) and (Uranium mining and health - PMCNational Institutes of Health (.gov)https://www.ncbi.nlm.nih.gov › articles › PMC3653646) and (The Future of Nuclear Energy: Are We Running Out of Uranium?enCore Energyhttps://encoreuranium.com › uranium › the-future-of-nu...)

Finite Resource Concerns:

- Uranium availability is limited. As the demand for nuclear power grows, the consumption of uranium increases, which can deplete known reserves over time. While new uranium deposits may be discovered, the overall global supply remains stagnant, which poses a challenge for the long-term sustainability of nuclear power. Uranium prices are steadily rising, some estimates predict a doubling of prices by the next decade.

Mining and Environmental Impacts:

- Uranium mining can have environmental and social impacts. It involves the extraction of radioactive materials and requires significant energy and water resources. Improper mining practices can lead to habitat destruction, water pollution, and disruption of local communities. Additionally, the processing and disposal of uranium mining waste raise concerns about radiation exposure and environmental contamination and increase costs.

Counter Arg for Limited Uranium Supply: (3 Reasons Why Nuclear is Clean and SustainableDepartment of Energy (.gov)https://www.energy.gov › articles › 3-reasons-why-nucle...) and (What is Uranium? How Does it WorkWorld Nuclear Associationhttps://world-nuclear.org › introduction › what-is-uran...)

High Energy Density:

- A small amount of uranium can produce a large amount of energy. This makes uranium an efficient fuel source for nuclear power plants, allowing for the production of significant amounts of electricity from a relatively small quantity of fuel easing concerns about sustainability.

Long-Term Supply:

- While uranium is a finite resource, the current known reserves of uranium are substantial and estimated to last for several decades or even centuries (subject to future demand and exploration efforts). With proper management and the development of advanced reactor technologies, the available uranium supply can be utilized for a considerable period, providing a reliable energy source in the interim.

Energy Independence and Green Energy Benefits:

- Using uranium as a fuel in nuclear power plants can help reduce dependence on fossil fuels, particularly imported oil and natural gas. This energy independence can enhance energy security by diversifying the energy mix and reducing vulnerability to fluctuations in global fuel markets. Additionally, nuclear energy produces little to no carbon emissions.

Tech Improvements:

- Advancements in nuclear technology, such as the development of advanced reactor designs, fuel recycling, and alternative fuel sources like thorium, could potentially mitigate some of the challenges associated with the limited uranium supply in the future.

Conclusion: The limited supply of uranium is not an issue, rising demand will result in rising exploration for uranium and more scientific research to create more efficient uses for uranium. Benefits of uranium offset costs of mining and transporting due to environmental concerns or hazards.

Aging Plants:

(Aging Nuclear Power Plants - Princeton UniversityPrinceton Universityhttps://www.princeton.edu › ~ota › disk1) and (The Perils of Aging Nuclear ReactorsStanford Universityhttp://large.stanford.edu › courses › may1) and (Nuclear power plant ageing and life extensionInternational Atomic Energy Agencyhttps://www.iaea.org › sites › default › files)

Safety risks:

- Materials and systems degrade over time, leads to safety issues, including the potential for equipment failures, leaks, and malfunctions, risk of accidents or incidents increases with aging infrastructure, up costs of maintenance

Obsolete technology:

- Upgrading aging plants to meet modern standards can be costly and challenging.

Risk concerns:

- Aging nuclear power plants have a higher risk of radioactive leaks or emissions. Decommissioning old plants requires handling of radioactive materials and waste disposal increasing risk.

Public perception:

- The age of a nuclear power plant can impact public perception and confidence in its safety. Concerns about potential accidents, radioactive leaks, and long-term waste storage can arise, leading to increased scrutiny, opposition, and calls for plant closure.

Conclusion: While there are risks and costs coupled with nuclear power plants as they age, not all aging plants are automatically problematic. Most operators implement rigorous maintenance and inspection programs to ensure safe operation, offsetting concerns on the increased safety risks.

Allocation of Resources:

Central argument: Investment into nuclear power prevents resources from being invested into ‘true’ renewables, such as solar or wind. The cost of nuclear power, on average, is approximately 5 times that of solar or wind. Furthermore, solar and wind are becoming increasingly more reliable, and diversification of energy portfolio is important for overall stability in an energy grid. Given the ever-present dangers and disadvantages of NPPs, removing the intermediary step of investing into nuclear power whatsoever and focusing entirely on renewables would be a better usage of resources.

Counterargument: While achieving decarbonization of our energy grid is technically achievable without nuclear, it is not necessarily always feasible. As such, we deem the incorporation of nuclear energy as a likely necessary intermediary.

Some sort of simultaneous investment into both nuclear and solar/wind could be a viable proposal. As mentioned before, a diverse energy portfolio is a much better way to ensure energy reliability than a single, consistent base load source, and the supplementation of nuclear alongside solar/wind would make up for times when the weather does not permit for solar or wind to supply enough.

Profitability of Nuclear Energy:

A big barrier to the implementation of nuclear energy is the relatively low profitability of the market, which is cited by companies such as Exelon.

As mentioned earlier, NPPs are expensive to build, with most of the expenses frontloaded in the capital cost. It is estimated that the capital costs account for at least 60% of the levelized cost of electricity (LCOE) of an NPP (LCOE is the cost of building, operating, and maintaining a power plant over its lifetime divided by the total energy output during this time). This article (cited twice before in this paragraph) provides an extensive breakdown of the various costs associated with NPPs.

In a 2018 Union of Concerned Scientists article, it was noted that approximately ⅓ of US NPPs were unprofitable or scheduled to close, and would likely be replaced by cheaper fossil fuel plants if no new beneficial policies were passed.

Thus, we recommend that substantial incentive be provided to companies to build and maintain NPPs, given their importance in reaching net-zero emissions by 2050 and preventing the more catastrophic consequences of global warming.

Risk-Benefit of Nuclear Energy:

LOW PROBABILITY, HIGH CONSEQUENCE:

Accidents at NPPs are low probability, high consequence: that is, the chance of them occurring is extremely low, but the repercussions of an accident are often widespread, severe, and long lasting (just look at the legacies of Three Mile, Chernobyl, and Fukushima).

- Uncontrolled nuclear reaction → widespread contamination of air and water (1)
- Produces radioactive waste: uranium mill tailings, used reactor fuel, etc (1)
- Radioactive leaks (1)

- “When nuclear power companies do well they reap the profits, and when they struggle we foot the bill. It’s a win-win for them, and a lose-lose for us.” (1)
- “A study in 2019 by the economic think tank DIW Berlin, found that nuclear power has not been profitable anywhere in the world. (2)”
- Most plants built while heavily subsidized by governments, often motivated by military purposes, not a good approach to climate change (2)
- Trends in nuclear power plant construction since 1951, avg 1000MW nuclear power plant incur avg economic loss of 4.8 euros [https://www.kernd.de/kernd-wAssets/docs/fachzeitschrift-atw/artikel/atw_2019-10_wendland_peters.pdf] (2)
- Large upfront costs and long project cycles, many factors such as fluctuations in global economy, energy prices, or regulations make other alternatives cheaper
- Nuclear power plants cost twice as much as coal plants to build and five times what a natural gas plant costs (5)
- "One of the big problems with nuclear power is the enormous upfront cost. These reactors are extremely expensive to build. While the returns may be very great, they're also very slow. It can sometimes take decades to recoup initial costs. Since many investors have a short attention span, they don't like to wait that long for their investment to pay off.” [Indiviglio, Daniel (1 February 2011). "Why Are New U.S. Nuclear Reactor Projects Fizzling?". *The Atlantic*.] (2)
- Recent liberation of the electricity market in many countries made economics of nuclear power less enticing (2)
- Construction delays can add a significant amount to the costs (2)
- Easy targets for terrorist threats, vulnerable in times of military conflict (3)
    - War in South Ukraine, puts nuclear plants in high risk (3)
- Waste, not only harmful but also costly for nuclear waste cleanup (3)
- The government hasn’t devised a good plan on how to get rid of nuclear waste, and it’s costly to store them (5)
- Cleaning up the plant after operating license expires will cost $290-370 million, excluding costs of radioactive waste (5)
- Radiation can break DNA bonds, causing cells to die or function erroneously, potentially leading to cancer. When radiation affects a reproductive organ, it may lead to hereditary or genetic defects passed along to offspring. (5)
- National Academy of Sciences: no safe dose of radiation, direct exposure to high-level radiation from fuel in the core of a nuclear reactor delivers lethal dose of radiation within seconds (5)
- CALVERT CLIFFS (5)
    - As long as nuclear plant operates, it generates spent fuel
    - Byproducts of nuclear fission accumulate and interfere with efficient release of energy, 1/3 of spent nuclear fuel removed from reacher each year
    - Waste was stored at Calvert Cliffs
    - Spent fuel is placed in reactor cooling ponds not designed for the long-term
    - Full pool is dangerous
    - Tritium may be released into the air

COUNTER ARG:

Although generally quite alarming to the public, there have been only a handful of major incidents involving NPPs, with no major incidents occurring in the past 10-20 years. The Union of Concerned Scientists has also conducted an independent review of safety in NPPs, concluding that since 2000 “today’s nuclear reactors achieved the Nuclear Regulatory Commission’s top safety rating 80 percent of the time”, and when a reactor did not meet this safety rating due to performance issues, it took “an average of one year to remedy the shortcomings.”

With appropriate operator training and newer technology, the many dangers of NPPs can be mostly mitigated.

SUMMARY OF RECOMMENDATIONS

In order to transition our energy portfolio to one that produces little or net-zero emissions, we propose a simultaneous investment into both nuclear and renewable energy sources, with solar and wind comprising the majority of the renewables. Given the current and projected climate, a diverse energy portfolio is a much better way to ensure energy reliability as opposed to a single, consistent base load source. Battery technology has advanced to the point where solar and wind energy’s dependency on optimal weather conditions has been lessened substantially, and the supplementation of nuclear alongside solar/wind would make up for when the weather does not permit solar or wind energy to supply the grid for extended periods of time. Furthermore, the implementation of nuclear alongside renewables would require less space than renewables alone, and the usage of renewables, besides the aforementioned reliability and diversification, would come at less cost than nuclear.

Of course, none of this comes easily. One cannot entirely separate nuclear energy from the dangers that accompany it, only mitigate them somewhat with the implementation of better regulations, training, safety, etc. The monetary costs and time needed for the construction of nuclear power plants and sources of renewable energy are necessary investments if we want to fully decarbonize by the 2050 deadline. In that vein, policies incentivizing or aiding companies to invest in renewables and nuclear energy are necessary.

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