Nuclear Power: A Comprehensive Analysis Of Its Benefits And Drawbacks

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Abstract: This review paper discusses the benefits and drawbacks of nuclear energy, focusing on its environmental friendliness, safety, and lower carbon footprint compared to wind and solar energy. However, it also includes persistent radioactive waste, which will take thousands of centuries to decay.Nuclear energy is a safer and sustainable alternative to solar and wind power, with a smaller carbon footprint. However, it has a long-lasting radioactive waste that takes thousands of years to degrade. The surge in nuclear power facilities is driven by the idea of "green energy" as a stopgap measure until renewable energy sources are prepared. High prices and financial instability have led to concerns about commercial feasibility. Emerging nations like China, Brazil, and India are focusing on sustainable energy sources like nuclear and hydroelectric power.

I. INTRODUCTION

Nuclear energy is the power stored within an atom's nucleus. This energy can be harnessed to generate electricity through nuclear reactions, primarily nuclear fusion and nuclear fission. In nuclear fission, uranium is used as fuel, causing atoms to split into two or more nuclei. The energy released during this process generates heat, which heats a cooling agent, typically water. The resulting steam or pressurized water is then directed to turn turbines, producing electricity. Nuclear reactors rely on uranium as the primary fuel to initiate nuclear fission.Compared to solar and wind energy, nuclear energy is far safer and has a smaller carbon footprint over its whole life. Long-lasting radioactive waste is one of the drawbacks of nuclear power. Numerous thousands of years are needed for legacy spent nuclear fuel to degrade to a nominal surroundings level. The considerably lesser amount of radioactive waste (approximately 1% of heritage) from sophisticated nuclear power will degrade to previous experience levels in roughly 400 years, which is why this paper supports it (Dungan et al. 2017).Not just because fossil fuels are scarce, but also because their usage is becoming intolerable for both current as well as future energy use and production, this is a clear and urgent requirement. Additionally, they contribute to the greenhouse effect by spewing copious amounts of atmospheric carbon dioxide towards the sky. Because of its immense capacity and minimal carbon emissions, nuclear energy is once again a topic of discussion when it comes to sustainability. This is because renewable energy sources like solar and wind power are still sometimes regarded as having insufficient supply (Brook et al., 2014).Consequently, there is currently much talk of a nuclear power plant resurrection following decades of slow development and even a reduction in the overall number of nuclear-power plants in several nations (Ramana, 2009). Since rising carbon dioxide emissions in light of changing climates pose a threat to natural diversity, human wellbeing, and global security, nuclear energy has once again attracted the attention of scientists and the general public. However, a contentious discussion is being fuelled by the possibility of nuclear breakdowns, their effects on the environment and human health, and the unsolved problem of radioactive waste (Ramana, 2018).Three incidents in particular show how susceptible nuclear power facilities are to unanticipated events like climate change or violent conflicts and the catastrophic effects that they can have: the devastating MCA (maximum reliable accident) at Chernobyl in 2013; the Fukushima nuclear generator accident in 2011, which was brought on by an earthquake and a tsunami in the country of Japan (UCSUSA, 2013). The risk is further demonstrated by the recent rise in the amount of radiation at the nuclear accident, which was as much as 20 times above normal after fierce combat broke out within Russian and Ukrainian forces in this region throughout Russian President Putin's aggressive war (Turner, 2022).The thought that nuclear energy will be branded as "green energy" and utilized more frequently as a stopgap measure until sources of renewable energy are prepared to meet the world's demand for energy is what is causing the current surge in nuclear power facilities. Furthermore, even in nations that long ago reduced their reliance on nuclear energy, growing costs for fossil fuels are sparking renewed interest in the technology. However, because of the high prices and unpredictability of the financial system, many people view the commercial feasibility of nuclear power as a barrier (Ramana, 2009).Grace Hilliard, H. G. (2014) explored the benefits and drawbacks of nuclear power in relation to national and international energy. Researchers from the fields of science, expertise, journalism, and strategic intelligence

are represented in it. In order to help make educated decisions on the most important resource in the world, the article also compares suggested nuclear energy advancement technologies to conventional energy.

II. BENEFICIAL ASPECTS OF NUCLEAR ENERGY RESOURCES OVER OTHER ENERGY RESOURCES

Nuclear energy should play a crucial role in mitigating the effects of a warming and increasingly volatile world, as it offers a low-carbon alternative for baseload electricity. Nuclear power generates baseload electricity without emitting carbon dioxide, a major contributor to global warming. Decarbonization can be achieved by transitioning from coal to petroleum and natural gas, as the latter emits about half the carbon dioxide of coal. The case for nuclear power is further reinforced by the urgency of addressing global climate change (GadigeppaGurikar, Shivaraj (2019).

CLEAN ENERGY SOURCE

Nuclear energy is the leading source of clean power in the United States, producing nearly 775 billion kilowatt-hours of electricity annually. It accounts for almost half of the nation's emissions-free electricity, preventing the release of over 471 million metric tons of carbon dioxide each year—equivalent to taking 100 million cars off the road. According to Office of Nuclear Energy (2024)reports Nuclear energy produces enormous amounts of carbon-free electricity, which enhances air quality. Apart from supplying energy to communities spanning 28 US states, it also facilitates an extensive array of non-electric applications, that ranged from missions to outer space to the medical sector. The Office of Renewable Energy at the United States Department of Energy (DOE) focusses mainly research on upholding the current fleet of reactors, developing new, cutting-edge reactor innovations, and improving the nuclear fuel cycle in order to improve the future viability of our energy source and support the American economy. These are some of the main advantages of nuclear energy, along with some current challenges the industry is facing. Study of Jônatas da Mata, F. C. (2017) highlights the focus of emerging nations such as China, Brazil, and India on sustainable energy sources like nuclear and hydroelectric power to meet increasing electricity demand. The growing use of renewable sources, including solar, wind, and hydro, is linked to pollution from non-renewable sources. Nuclear energy is described as a clean energy source, producing no harmful emissions and featuring controlled waste storage with minimal volume. The comparison of nuclear power with renewable sources centers on financial, environmental, and safety considerations

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3.1 NUCLEAR ENERGY: A LONG-LASTING POWER SOURCE

Nuclear energy is considered a long-lasting power source because it provides a highly efficient and reliable means of generating electricity. Unlike fossil fuels, which are finite and release large amounts of greenhouse gases, nuclear power plants can produce vast amounts of energy from small amounts of fuel, typically uranium or thorium. One of the key advantages is the ability of nuclear reactors to operate continuously for long periods, often for over 18 months without interruption, providing a stable and consistent supply of electricity.

According to Thomas E. Rehm et al. (2023), the safety of traditional nuclear energy, once regarded as the safest electricity generation method since the 1960s, has been increasingly questioned. A transition to

advanced nuclear energy is long overdue, as it offers significant renewable potential, enhanced security, waste reduction, and the ability to provide processing heat for industries. Chemical engineers in the nuclear sector have various opportunities, including designing high-temperature facilities, recycling radioactive waste, integrating the hydrogen economy, advancing moving pebble-bed reactor technologies, mining uranium and thorium, developing molten salt storage systems, addressing corrosion challenges, and transforming existing refineries into nuclear biorefineries. Rasel Hossain in (2022) explained that the nucleus of an atom contains nuclear energy, which is an increasingly popular source of electricity with potential for sustainability on the environment. Nowadays, power is produced through the fission of nuclear or heavy materials. Notwithstanding early expansion in nations like the US, Norway, and France, worries about radioactive contamination in the 1970s inhibited further growth. On the other hand, considerable growth has resulted from recent awareness of appropriate nuclear energy usage.

3.2 NUCLEAR ENERGY: FOR COMBATING CLIMATE CHANGE

The necessity of clean energy to combat climate change is discussed by Sadekin S. (2019).The inadequacy of traditional energy sources such as natural gas, oil, and coal. The study positions nuclear power as a strategic option due to its low carbon monoxide emissions compared to fossil fuels. Despite uncertainties surrounding the construction of new nuclear power plants, the study emphasizes nuclear energy as a sustainable solution while addressing public safety concerns and climate change issues.

GiambattistaGuidi et al. (2010)underscore in their research the significance of nuclear energy in the global clean energy revolution, citing its low environmental impact and minimal greenhouse gas emissions. It emphasizes the importance of considering the entire energy chain to reduce emissions. The study uses life cycle assessment (LCA) and external cost analysis to compare different energy generation methods, aiding decision-making in energy and environmental policies. The global transition from fossil fuels to cleaner energy sources is the central theme of the study done by Ayush Kumar A. (2020). It presents nuclear energy as an environmentally benign alternative due to its low greenhouse gas emissions. The research compares various nuclear reactor types by examining factors such as radiation emissions, safety, sustainability, and environmental contamination .Doris Klingelhöfer et al. (2023) study focuses on the debate over the sustainability of nuclear energy in light of climate change concerns, despite its low atmospheric carbon dioxide emissions. It raises critical questions regarding nuclear waste management and the potential risks to public health and the environment. The research also highlights the strong correlation between nuclear power plant numbers and global publication output, emphasizing the role of financial interests in nuclear energy research and the importance of international collaboration in the debate.

3.3 NUCLEAR ENERGY AS A GREEN ENERGY FOR SUSTAINABLE DEVELOPMENT

Nuclear energy plays a vital role in achieving sustainable development by providing a reliable, low-carbon source of electricity. As the world faces the twin challenges of growing energy demand and the urgent need to reduce greenhouse gas emissions, nuclear power offers a clean alternative to fossil fuels. Unlike coal, oil, and gas, nuclear energy generates electricity without releasing carbon dioxide into the atmosphere, making it a key contributor to the fight against climate change.

A major advantage of nuclear energy is its ability to provide consistent and stable power (known as baseload electricity), unlike renewable energy sources like wind and solar, which are dependent on weather conditions. Nuclear power plants can operate continuously for long periods, ensuring a steady energy supply. This makes nuclear energy an essential component of a sustainable energy mix, complementing renewable sources.

Moreover, nuclear energy uses uranium, a highly energy-dense fuel, meaning small amounts can generate large amounts of electricity. Advanced technologies are also being developed, such as nuclear fusion and next-generation reactors, which aim to further enhance the safety, efficiency, and sustainability of nuclear energy in the future.

By integrating nuclear energy into the global energy strategy, countries can ensure long-term economic growth, energy security, and environmental protection, thereby contributing to the broader goals of sustainable development.Florian Ion T. Petrescu (2017)addressing the challenge of inconsistent green energy production, this study proposes using nuclear power plants as "energy buffers." These buffers would increase production when green energy generation falls and decrease output when green energy is available. The study discusses the broader environmental concerns related to energy production and the role of nuclear energy in maintaining stability in energy systems.

Evgeny O. Adamov (2021) explores the contribution of nuclear and hydropower, which together account for a quarter of global renewable energy production. Over the past six decades, nuclear energy has been responsible for reducing over 60 gigatonnes of CO2 emissions. The study also points out the decline in nuclear energy use in developed countries and the limited funding for new projects. Despite challenges, some nations are focusing on advanced nuclear technology, including reactor and waste management innovations, to expand nuclear power in the context of global decarbonization.The article byAakash Kumar (2015) examined the

potential of nuclear power as a green energy solution, particularly in light of advancements in reactor design. Nuclear power is positioned as a low-emission alternative to fossil fuels, capable of producing large quantities of hydrogen, thereby reducing reliance on traditional energy sources. The study argues that for nuclear power to gain public and political support, it must meet certain safety and operational criteria.

Liam Darby et al. (2020) discussed the importance of securing power supply in a low-carbon economy, with nuclear energy emerging as a potential clean energy solution. The research emphasizes small-scale nuclear technologies, such as light water small modular reactors (LW-SMRs), which offer benefits like reduced capital costs, lower operating expenses, and a smaller environmental footprint. These reactors have been successfully used to power U.S. naval vessels for nearly 60 years, suggesting their potential for broader application in the energy sector.

IV. NUCLEAR ENERGY AND NATIONAL SECURITY

Nuclear energy plays a crucial role in supporting national security by providing a stable and reliable energy source that is essential for military operations and critical infrastructure. A strong civilian nuclear sector enhances energy independence, reducing reliance on foreign energy sources and increasing resilience against geopolitical tensions and energy supply disruptions.

Additionally, maintaining leadership in nuclear technology allows the United States to influence international norms surrounding the peaceful use of nuclear energy. This influence is vital for promoting non-proliferation efforts and ensuring that nuclear technologies are used responsibly and safely around the world.

JOB CREATION

The nuclear industry provides nearly half a million jobs across the United States. A single domestic nuclear power plant can employ up to 800 workers, with salaries averaging 50% higher than those in other energy generation sectors. Additionally, the industry contributes billions of dollars to local economies each year through federal and state tax revenues.

V DISADVANTAGES OF NUCLEAR ENERGY

- Radioactive Waste: One of the most significant challenges of nuclear energy is the management of radioactive waste. The disposal of spent nuclear fuel and other radioactive materials poses long-term environmental and safety risks, as they remain hazardous for thousands of years.
- Risk of Accidents: Nuclear power plants, while designed with multiple safety measures, carry the inherent risk of catastrophic accidents, as seen in incidents like Chernobyl and Fukushima. Such accidents can lead to widespread environmental contamination and serious health impacts.
- High Initial Costs: The construction of nuclear power plants requires substantial investment, often billions of dollars. Additionally, the time required to build these plants can lead to increased costs and potential delays, making nuclear energy less competitive compared to other energy sources.
- Nuclear Proliferation: The technology used for nuclear energy can also be applied to develop nuclear weapons. This poses a significant risk of proliferation, as countries with nuclear energy programs may have the capability to produce nuclear weapons materials.
- Public Opposition: Nuclear energy often faces strong public opposition due to safety concerns, environmental impact, and historical accidents. This can hinder the development and expansion of nuclear power projects, leading to regulatory and political challenges.
- Water Usage: Nuclear power plants require large amounts of water for cooling, which can strain local water resources, particularly in arid regions. This dependence on water can also affect aquatic ecosystems and biodiversity.

CONCLUSION

In conclusion, because nuclear energy will have an impact on both the environment and people, its long-term repercussions are too harmful. The primary defense offered by those opposed to the use of energy from nuclear reactors is the risk it poses. Currently, one of the world's most damaging and harmful forms of energy is nuclear energy. Nobody can promise that it will only be applied for nonviolent purposes. This is demonstrated by tragic historical events like the bombings of Hiroshima and Nagasaki and the Chernobyl accident. Nuclear energy proponents point out that when compared to nuclear energy, renewable energy sources like solar, wind, and other forms of energy are more efficient and pose less of a risk.

When all of the data has been analyzed and all study has been done, the potential benefits of nuclear energy are not greater than its drawbacks. There is no denying that as the globe grows and develops, additional studies and research are needed to demonstrate the potential advantages of nuclear energy. Energy will be needed for new technology, and the present supply of electricity cannot keep up with the rising demand. There have been experiments and tests with other energy sources. Certain energy sources, like renewables, cannot keep up with the increasing demand, while others, like fossil fuels, contaminate the air and water and increase the risk of global warming.A clean, sustainable energy source that can power the entire planet is required. Numerous domestic and worldwide issues can be resolved using nuclear energy.

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