The Feasibility of Nuclear Power to Sustain Growing Energy Demand

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This paper evaluates the feasibility of nuclear power as a sustainable solution to global warming and increasing energy demands. It reviews technological advancements in nuclear reactors, specifically their enhanced fuel efficiency and safety management. The study also highlights the strengths and constraints facing nuclear energy expansion, from a technological, economic, environmental, and social perspective. Additionally, this study incorporates original analytical models and data visualisations. Specifically, a linear regression fit was created to present the projection of nuclear energy production and the efficiency analysis of uranium extraction. These models offer a novel perspective by quantitatively projecting future trends and efficiency improvements in nuclear power, grounded in historical data. Through a comprehensive analysis, this paper argues for a realistic assessment of nuclear power's role in a sustainable energy future, providing actionable insights for policymakers and stakeholders.

Keywords: Nuclear power, Energy demand, Nuclear energy, Feasibility of nuclear power, Uranium, Sustainable energy, Nuclear reactors, Nuclear Energy

Introduction

The Paris Climate Agreement set a goal to limit the mean average global temperature rise to below 2°C, with additional efforts to keep it below 1.5°C. All countries have set pledges for reducing carbon emissions in the form of nationally determined contributions (NDCs). Currently, the NDCs do not align with achieving the 2°C target, thus significant reductions CO2 are required to meet this goal[1]. However, the increase in energy demand due to advanced technological developments is exacerbating the difficulty in achieving low-carbon emissions. As energy demand grows, there is greater reliance on energy production from fossil fuels which increases greenhouse gas emissions and aggregates climate change. The growing energy demand also puts pressure on the unsustainable use of resources. Thus, this paper investigates "To what extent is nuclear energy feasible in sustaining the growing energy demand?". Nuclear energy is a form of power generation that utilises the energy released by nuclear fissions, and it could be helpful in providing a reliable, large-scale source of low-carbon energy. However, the role that nuclear energy plays in limiting CO2 emissions is a topic of debate. Some question the potential of nuclear energy in contributing to a low carbon future, highlighting various limiting factors; while others believe that nuclear energy will be a significant portion of electricity production in the future[2].

This paper hypothesised that nuclear power can play a significant role in meeting the rising energy demand sustainably, provided that advancements in reducing operational cost, reactor efficiency, waste management are implemented. To approach the research question, this paper will primarily review the existing literature that highlights significant advancements and persistent challenges in the field of nuclear energy. This literature review aims to address these gaps by providing a comprehensive analysis of recent studies, identifying key trends, and proposing future research directions. In addition to the reviews of relevant literature, this paper will incorporate original analytical models in an attempt to seek quantitative evidence to expand on the literature.

Background Information

Nuclear Fission

Nuclear energy is sourced from nuclear fission reactions. During this reaction, a neutron collides with a large uranium atom making them unstable and split into two smaller neutrons. These resultant neutrons from the reaction go on to collide with another large uranium atom to create a chain reaction of nuclear fission. During this fission reaction, a significant amount of heat energy is released and absorbed by a coolant, usually water. Thus, the heat energy absorbed by the water creates a heating effect, which changes the state of the liquid into high-pressure steam. This steam then drives turbines that are connected to generators, hence converting mechanical energy to electrical energy through electromagnetic induction[3].

Historical Context of Nuclear Power Development

The birth of nuclear energy occurred in 1942 when Enrico Fermi successfully controlled a nuclear chain reaction. In 1954, the first nuclear power plant generated electricity for a power grid, this marked the beginning of generation I of nuclear reactors. This generation of reactors had low efficiency between 30-33%. Following the advancement of Generation, I, nuclear power became technically proven to be a viable energy source to generate electricity. Thus, generation II of Pressurised Water Reactors (PWR) and Boiling Water Reactors (BWR) became proliferated globally. A decade later, there were 253 nuclear power plants in operation across 22 countries, combining a total capacity of 135000MWe. In 1979, a meltdown of a power plant in Pennsylvania, United States was the first major incident regarding nuclear power plants. This incident negatively impacted the reputation of the whole nuclear industry. Specifically, the public started rejecting the use of nuclear power due to their concerns about public safety. Scientists learned from the issues associated with this incident and put in efforts to improve the safety of nuclear reactors. Thus, the 1980s was a period followed by a rapid expansion of reactors with up to 3500 in operation, reaching the peak growth phase of nuclear power which accounted for 17% of global electricity[4]. These were all Generation III reactors, which are characterised by improvements in safety, efficiency and minimise nuclear waste[5]. However, in 1986, the largest nuclear incident in history occurred in Chernobyl, which exacerbated the already inherent negative public perception of the nuclear power industry. This led to a gradual decrease in the rate of expansion for nuclear power, slowing down many nuclear projects from European countries due to public opposition from the Chernobyl incident. Although countries are focused on international cooperation to recover from nuclear power incidents, emphasising on collaboration between the Eastern and Western nuclear engineers, the global share of nuclear power has dropped to 9% in 2024. The nuclear industry is aiming to increase this figure by making further improvements in the safety design of nuclear reactors and fuel efficiency of reactors[5].

Current Status of Nuclear Power

To date, the implementation of Generation IV reactors have contributed to the efficiency rate of power plants increasing from 30% to 45% from Generation I. Although, on the surface level, the efficiency of nuclear power plants may still seem low due to the value of efficiency being less than half. However, the improvement from 30% to 45% corresponds to major advancements in the industry which are gradually making nuclear energy more significant in the energy sector[6].

The recent advancement are Small Modular Reactors (SMRs) has further enhanced efficiency of nuclear power reactors. SMRs are currently under design, the paper written by Michaelson and Jiang in 2021, reviews the benefits and costs implementation of SMRs in the renewable energy sector. SMRs operate at a higher thermal efficiency, as advancements in the cooling systems allow for more efficient heat extraction and conversion to electricity. Furthermore, SMRs are smaller than traditional reactors, which makes them more financially accessible for more countries to build and implement. However, most designs of SMR are still in the regulatory approval phase and it can take years to be approved. As of 2024, there are only 80 SMRs which are underdevelopment and not yet operational. Once more SMRs are developed, they could be key to increasing nuclear power's contribution to global energy, but currently the contribution of SMRs to nuclear energy is insignificant[6].

Current statistics show that there are over 400 nuclear reactors across 31 countries, these largely consist of generation III reactors rather than SMRs. PWR accounts for 67% of the total number of reactors, whilst BWR accounts for 16% and pressurised heavy water reactors (PHWR) is 11%. These are characterised as the generation III reactors, which is a simple standard design used to reduce costs, and time of construction and minimise risk of malfunction. The figure below shows a configuration of the components that make up Generation III nuclear reactors. This generation of reactors can last up to 60 years if no major accidents occur[7].

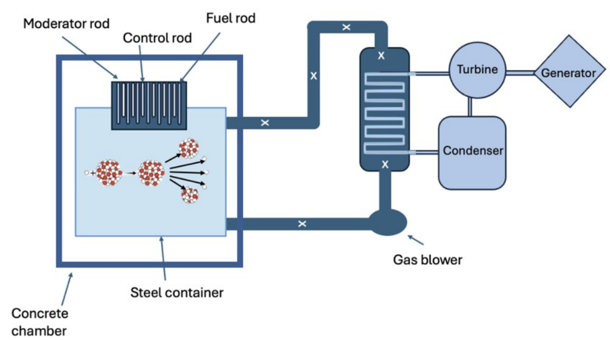

Fig. 1 Diagram of a Nuclear Power Station. This diagram illustrates the key components and process flow of a nuclear power station. The reactor core contains fuel rods, control rods, and moderator rods within a steel container and concrete chamber. The nuclear fission reactions in the fuel rods release energy, which heats a coolant gas. This gas is circulated by the gas blower through the reactor core, and then to a heat exchanger. The heat exchanger transfers the energy to water, producing steam that drives a turbine connected to a generator, ultimately producing electricity. The steam is then condensed back into water in the condenser and recirculated in the system.

As discussed previously the total energy generated by nuclear power reactors worldwide contributes to around 9% of the total energy demand worldwide, and with around 80 SMRs under construction, this number is expected to increase. The six countries that have the largest production of nuclear power are the United States, China, Russia, France, Japan, and South Korea, making up 70% of the total nuclear power produced globally. Whilst these countries act as exports of nuclear power, many countries in Europe import nuclear power, such as Italy, Germany, and Belgium[7].

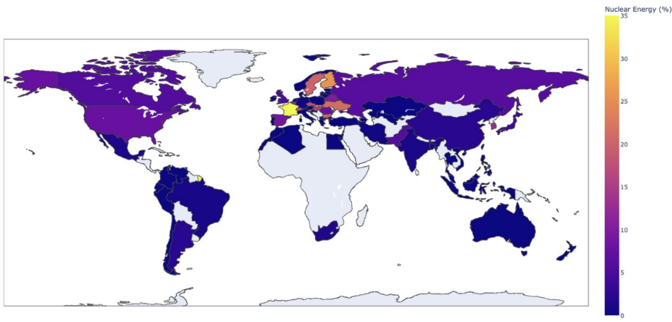

Fig. 2 Country's Nuclear Energy Production. The data for the percentages was obtained from the Energy Institute - Statistical Review of World Energy for 2024[8]. This map provides a comprehensive overview of the distribution of nuclear energy usage across different countries. The legend explains the percentage of energy used in a country which is sourced from nuclear power. The percentage of nuclear energy usage in countries can range from 0% to 35% out of the total energy usage. The darker purple colours represent countries which utilise very little nuclear energy, and predominantly utilise energy which are generated from fossil fuels and other renewable energy sources. The lighter colours represent countries which utilise a higher percentage of nuclear energy, and less from other energy sources.

Methodology

The data for our data analysis of the historical trend of nuclear power are collected from official governmental sources, specifically the Statistical Review of World Energy 2024, which is an official statistical review of world energy usage[8]. This source is the most comprehensive and the timeline of the data extends over the longest period compared to other sources, thus it allows comparisons to be made over a longer period of time.

The data analysis is modelled by a linear regression fit using python, which effectively captures the overall growth in nuclear power usage. Linear regression is a statistical method that models the relationship between a dependent variable and an independent variable by fitting a linear equation to observed data. In this case, the dependent variable is the year, or time since nuclear energy was firstly introduced, and the independent variable is the energy generated from nuclear fission. The linear regression assumes the normality of residuals and homoscedasticity. This means that residuals should follow a normal distribution and have constant variance. The method of using a linear regression to conduct the data analysis is because it is one of the most fundamental statistical methods to estimate future outcomes based on observed data and allows qualitative value of the strength of between the dependent and independent variable.

To make a more comprehensive analysis of the feasibility of nuclear power, we conducted a literature review which looks into real-world factors that cannot be captured by the quantitative data. The literature review was conducted using a systematic approach to ensure comprehensive coverage of relevant studies. Google Scholar was the primary database used, along with PubMed, ScienceDirect, and Web of Science. The search terms included a combination of keywords and phrases relevant to the topic, such as "nuclear-renewable hybrid energy systems," "feasibility of nuclear energy," "constraints of nuclear power," "future of nuclear power," and "constraints of nuclear power." Grey literature includes government reports, and publications from international organisations such as the International Atomic Energy Agency (IAEA) and the World Nuclear Association. The most significant limitation search was the constraint to studies published in English, reducing the comprehensiveness of studies from different cultural perspectives.

Results

Data Analysis

The data analysis reveals a clear upward trend in the increase of nuclear energy production up until recent years (figure 3). By examining the fitted curve, we can observe that nuclear power production experienced significant growth starting in the mid-20th century, and continuing to rise through the early 21st century. This rise aligns with the historical data points and the linear regression model. Projecting future energy demand based on this model, we see a continued increase in nuclear power usage. This suggests that assuming current trends continue, nuclear power may remain a significant component of the energy mix in the coming decades.

Current data on uranium reserves and extraction rates indicate that while there are substantial reserves, the rate of extraction and the efficiency of energy conversion play critical roles. The model shows a positive trend in nuclear power output, which depends on the continued availability and efficient extraction of uranium. To estimate the potential energy output from existing uranium reserves, we consider current extraction rates and advancements in nuclear reactor technology that could enhance efficiency. However, even with optimistic scenarios of improved efficiency, the finite nature of uranium reserves presents a significant challenge.

The R-Squared value for this regression model was R^2=0.89. The R^2 value is an indication of how good the linear regression model is fitted to the data, by measuring how much variation of the dependent variable is caused by changes in the independent variable. The R^2 of 0.89 is considered statistically significant, showing that the regression model captures most of the variation in the data. Thus, it is acceptable to use this model to predict the future growth trend of nuclear energy[9].

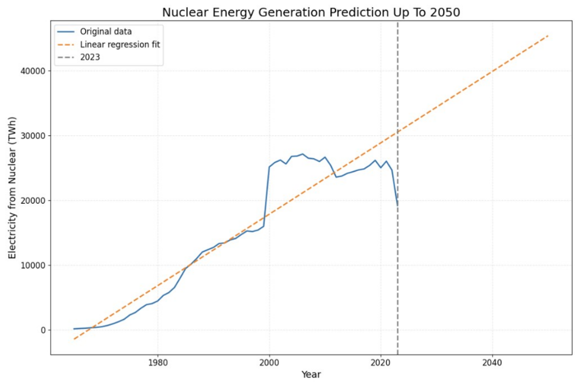

Fig. 3 Total Nuclear Energy Production and Linear Regression Fit Prediction. The blue line shows the historical data figures of nuclear energy production from the 1950 to 2023. Using these data figures from 1950 to 2023, predictions for the future nuclear energy production are shown by the orange line. These predictions up to 2050 are made from a linear regression model, which observes the current trends to predict future outcomes. The grey dashed line indicates the year 2023, distinguishing the observed data from the predictions. The linear regression fit effectively captures the overall upward trend in nuclear energy production, despite fluctuations in the data.

Model Limitations

The constructed model, which uses a linear regression fit to predict nuclear power usage has several limitations. Firstly, the model does not adhere to the normal distribution fit of the residuals. As mentioned in the methodology, a major assumption of a linear regression is that the residuals are normally distributed.

Although the residuals are not demonstrating a normal distribution trend, figure 4a shows that the model is not systematically over or under-estimating values, which is evidence supporting the accuracy of the model. Moreover, the outlier of around -10000 doe not directly invalidate the model, especially in real-world context, where data collection is subjective to many external factors. Since the model is being used for long-term predictions, slight devotions from normality in residuals may be acceptable. This is because the key factor is how well the model can capture the trend, rather than the distribution. So with an R^2 of 0.89, it can be said that the model captures a significant portion of the variance.

While the linear regression provides a straightforward and optimistic projection of nuclear power trends, it does not account for other complex influences that can affect this trajectory in real world scenarios. Factors such as technical advancements, economic viability, environmental factors, and social acceptance can significantly impact nuclear power development, and needs to be accounted for to obtain comprehensive analysis of the nuclear energy. These external factors are accounted for in the discussion, which details if these factors are supportive or unsupportive of the feasibility of nuclear energy. Despite the model not accounting for these influential factors, the linear regression model provides a straightforward and interpretable method to understand the general pattern of nuclear power growth, serving as a useful tool for initial predictions and highlighting the need for more sophisticated models for detailed, long-term forecasting.

Discussion

The studies discussed below acknowledge the projected rapid increase in electricity consumption due to the proliferation of artificial intelligence and the gradual rise in living standards. Specifically, the researchers note that electricity consumption is expected to rise by 45% by 2040[10]. However, the difficulty in expanding access to energy whilst decreasing carbon emissions has been one of the biggest challenges in the 21st century. The discussion below highlights the uncertainty of nuclear energy in the future aim of decarbonizing the electric power sector. It emphasises the technical, economic, environmental, and social concerns in regard to widely implementing nuclear energy in the future.

Technical Feasibility

Technological and operational constraints in nuclear power reactors are the major limitations in the viability of implementing nuclear power to meet future energy demands. Dittmar's study in 2012 emphasises how these technological constraints are impeding advancements in nuclear power[11].

One advantage of the technicality of nuclear power is that uranium is much denser compared to fossil fuels. This means that uranium can produce more energy per unit mass compared to fossil fuels. Specifically, the energy produced from one kilogram of uranium makes up for the energy produced from thousands of tonnes of coal. Although there are significantly more fossil fuels remaining in known reserves compared to uranium, the higher energy density of uranium makes nuclear energy more feasible in the long run. The uranium left in current known uranium reserves is expected to last around 150 years, whilst the large amount of fossil fuels can only last up to 100 years. This long-run implementation of nuclear energy is beginning to be carried out in more countries. According to Sadekin et al.'s paper in 2019, around 30 countries are considering implementing nuclear power in their energy mix, with 20 expressing strong interest[12]. This expansion is driven by the need for reliable, low-carbon energy sources to meet growing global demands. Countries such as Turkey have already signed contracts to construct new nuclear reactors, highlighting a broader international trend towards nuclear energy adoption. This indicates a robust potential for nuclear power plant construction in the near future, driven by both technological advancements and international energy policies.

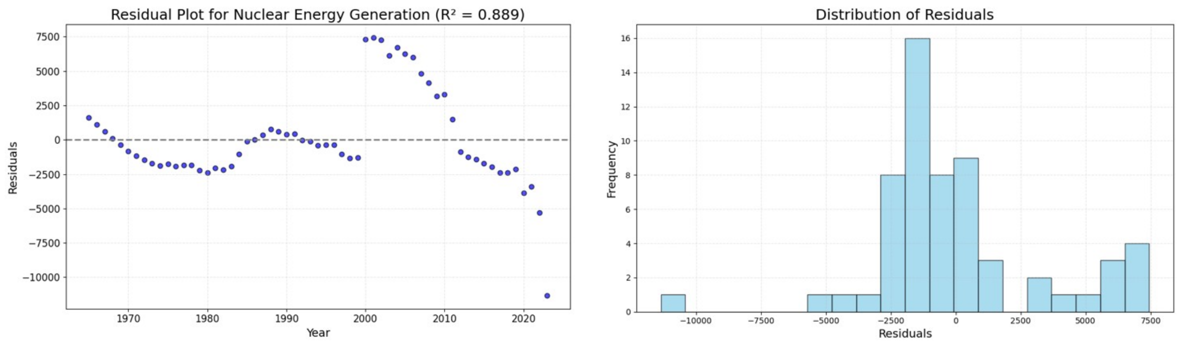

Fig. 4 Distribution of residuals. Residuals are taken from the difference between the observed data value to the predicted value from the regression model. A positive residual value indicates the model overestimated the data, whilst a negative residual value indicates the model underestimated the data. The residuals values are assumed to be evenly spread across positive and negative and normally distributed, in a bell shaped curve. Figure 4a depicts the residuals values being mostly even spread between positive and negative values. Figure 4b shows most residual points are distributed between -2500 and 0, which suggests that the model has a minor skew rather than being a perfect normal distribution.

Moreover, the uranium extraction process has been highly efficient, which further supports the potential for large implementation of nuclear power[11]. Dimmartar's study highlights that the uranium mining has an efficiency of 85% to 95%, whilst efficiency for coal mining has a lower efficiency level of 60-80%, depending on the technique used.

Thus, from the energy output per kilogram and extraction efficiency aspect, fossil fuels are less efficient over the long term when compared to uranium for nuclear energy.

The limitation of technical feasibility, highlighted by Dimmttar, lies in its constrained capacity to expand. As mentioned above, nuclear power plants only contribute to 9% of the total consumption of energy. The capability of expanding nuclear power reactors to make it a dominant producer of energy is arguable. While advanced reactor designs are promised to be safer and more efficient, they also require significant new technical knowledge and expertise to allow for such dramatic improvement. Dimmttar claims that successful wide integration of nuclear energy into existing energy systems is not guaranteed, as it requires significant research and development efforts to make a breakthrough in the efficiency of reactors. However, our analysis of the nuclear power extraction efficiency offers promising evidence to contradict Dimmatar's claim.

The contradiction lies in Dimmtar's skepticism about the feasibility of expansion due to technical and developmental challenges, while the efficiency data provides a more optimistic view, showing that advancements in reactor design have led to significant improvements in efficiently using uranium.

Whilst Dimmtar's study offers a relatively comprehensive view of the technical feasibility of nuclear power, there are still certain aspects that are essential to address. One advantage of the technicality of nuclear power plants that was addressed in the literature is that nuclear power can continuously supply electricity, while other renewable energy sources such as solar and wind are inconsistent in supplying power. These energy sources are entirely dependent on weather conditions, but nuclear power plants are more reliable, as they can operate continuously to provide electricity at any given time. Conversely, a limiting factor that was not discussed in Dittarmar's study is the scarce uranium resources. Currently, generating electricity from uranium resources requires approximately 68,000 tons of uranium annually. Uranium mining only supplies 65-75% of this demand, with the remainder coming from secondary sources. These secondary sources come from a process that involves enriching uranium tails, more known as depleted uranium from previous processes. Researchers expect the uranium mining capacity to increase, however, this is largely uncertain as past predictions have overestimated the true extraction of uranium. Using the "Red Book" projections for nuclear capacity as an example, their projections have constantly overestimated actual developments[13].

Economic Viability

The MIT study emphasised that the magnitude of the reduction in carbon emissions will be significant as the cost of nuclear power production is reduced[14]. However, the costs of constructing and operating nuclear reactors still require significant financing to become a largely implemented energy source. However, without nuclear energy, the difficulty and cost of meeting the low carbon target will be significantly larger than the costs of investing in nuclear energy. The IEA estimated that there will be an additional $1.6 trillion required to address carbon concerns without widely using nuclear energy[15].

Despite that the investment in nuclear energy is relatively lower, the costs still remain high. For instance, the construction of fast breeder reactor technologies is currently delayed due to its inability to meet its costs. Several viable recommendations

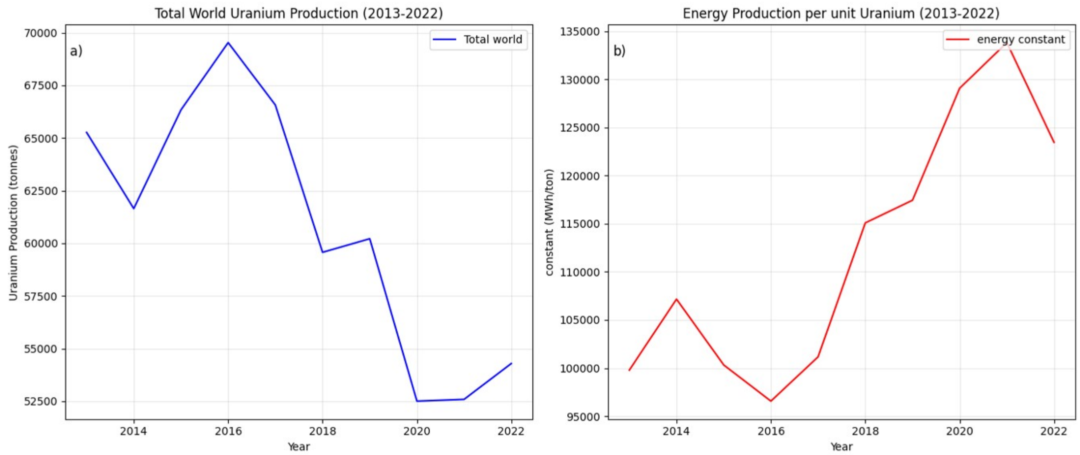

Fig. 5 Comparison of total world uranium extracted for production to energy produced per unit uranium[8]. The two figure 5 graphs show historical nuclear energy production from 2013 to 2022. Figure 5a displays the total world uranium production from 2013 to 2022, indicating the amount extracted from mining each year. Figure 5b illustrates the energy production per unit of uranium from the same period, which represents the global efficiency of nuclear reactors in extracting nuclear power. By making comparisons of the figure 5a and figure 5b over time, it is quantitative evidence disputing Dimmatar's claim, by supporting the capacity for nuclear power expansion. Figure 5b shows that despite the decrease in the amount of uranium extracted each year in figure 5a, the nuclear energy generated per unit of uranium follows an increasing trend. This value is calculated by dividing the annual nuclear energy production by the annual uranium production, which represents the global efficiency of nuclear reactors in extracting nuclear power. It is evident that reactor designs which have been introduced in recent years have higher fuel efficiency, as recent years' data in figure 5b shows that it requires less uranium to generate more energy. This data strongly supports the capacity for expanding nuclear power.

for reducing the cost of nuclear power are presented in the MIT study[14]. Firstly, it is suggested to ensure the design of the nuclear power reactor is well-detailed before construction. By ensuring this, it will enhance the execution and efficiency of constructing the reactors. Secondly, utilise skilled workers who are reliable and experienced in this project to reduce the time of construction. These two recommendations can be applied to all different modifications of reactors to reduce the cost of construction.

However, a limiting factor that most literature does not account for, when assessing the feasibility of nuclear energy, is the costs of decommissioning nuclear power plants when they reach the end of their operational life. The cost of dismantling reactors, managing radioactive materials, and restoring the site to safe conditions can be substantial. A typical nuclear power plant is expected to last around 20-40 years, and the cost of decommission can cost billions per plant. For instance, the expected cost to decommission Entergy's Indian Point plant is around $2.3 billion. This cost is largely dependent on the type of reactor and the generation, more modern reactors designed to ease the cost of decommission. Data from the World Nuclear Association suggests that there will be about 200-400 reactors in need of decommissioning before 2040[16]. This represents a significant cost that needs to be considered when addressing the feasibility of nuclear power on a financial level[17].

Environmental Impact

It is clear that widely utilising nuclear power can make major improvements to the environment by largely reducing carbon emissions. Nuclear power plants can generate electricity with little to zero carbon emissions. Currently, the small fractional use of nuclear energy is already contributing to reducing 471 million metric tons of carbon dioxide annually[18].

Although, nuclear power offers an effective solution to reduce CO2 emissions. It imposes negative environmental impacts elsewhere. The largest environmental concern regarding nuclear power is the radioactive waste produced in the process. The radioactive materials in this waste remain hazardous for thousands of years, making long-term containment essential. Up until now, there is no widely accepted solution to dispose of nuclear waste. The currently most viable solution is the use of deep geological repositories to store nuclear waste; however, there are many constraints regarding this approach to managing waste. The geographical locations where these nuclear waste can be stored is limited. This is because the repositories must be in areas unlikely to experience seismic activity and volcanic events that could compromise the waste storage. Thus, the limited areas that meet these requirements will eventually run out if we continue managing nuclear waste this way[19]. Recently, Japan has released treated water into the Pacific Ocean and has faced significant backlash from the public, emphasising that the water is still unsafe to release.

There have been some advancements in the nuclear waste management strategies highlighted by Alwaeli and Mannheims' paper in 202220. The paper outlines nuclear waste management strategies like spent nuclear fuel recycling and high-level waste conditioning. Recycling recovers usable uranium from spent nuclear fuel, reducing the total waste volume and enabling their reuse in reactors. Conditioning of high-level waste involves stabilising it for safe long-term disposal, often through vitrification which turns the waste into glass. These strategies aim to minimise nuclear waste by improving resource efficiency, and promote sustainability in nuclear waste management. Even though these strategies are in place in various countries, nuclear waste management is still a constraint to the feasibility of nuclear energy in the long term. This is because not all radioactive elements can be effectively recycled or stabilised, thus they need to be stored until there's an appreciated strategy to address the high radioactivity. Thus, without a proper solution or a significant breakthrough to safely dispose of nuclear waste, significantly expanding the use of nuclear power would become unfeasible[20].

Social Acceptance

Due to the Fukushi major nuclear energy accident that occurred in Japan in 2011, the public has been concerned regarding the safety of nuclear power plants. However, according to the study conducted by Sadekin et al, nuclear energy is in fact safer than fossil fuels[12]. The study highlights that fossil fuels were the main contributor to air pollution, causing 6.5 million deaths in 2012. Out of the over 100 nuclear energy incidents that have occurred since the invention, only Chernobyl was considered a major accident by the International Atomic Energy Agency, when there are over 400 reactors globally[21]. Thus, that one large incident is relatively insignificant compared to the other 400 reactors that are working safely.

The general concern with the safety of nuclear power is surrounding the radiation emission into the atmosphere which can cause damage to human DNA and cells. However, this rarely occurs because nuclear reactors are highly controlled and shielded. Factors such as safely transporting used fuel, safely cooling the reactor core, and managing radioactivity are all in place to ensure a high extent of safety. The MIT study supports this matter, as they note that nuclear reactors utilise stable core materials and the design and construction process strictly adhere to safety guidelines to reduce risks of accidents[14]. Moreover, the MIT study suggests making modifications to upgrade existing nuclear power plant designs can increase the efficiency and therefore the power output of reactors. Specifically, making modifications in the cooling systems, reactor core, and steam generators. These modifications can allow the nuclear power plant to operate at a high power level while keeping it safe.

Despite these safety factors suggested by the two studies, they do not take into consideration that the possibility of incidents cannot be completely reduced to zero. Realistically, it is impossible to construct a power plant that is 100% safe and it is also impossible to guarantee that it won't cause an accident. This factor is causing the majority of countries in Europe to still be reluctant to construct nuclear power plants as they are still worried about potential incidents[22]. However, if such incidents do occur in neighbouring countries of Europe, they would likely suffer from the consequences as well. For instance, the Chernobyl incident caused more than eight million people in Belarus, Russia, and Ukraine to be exposed to the radiation from the incident[23].

Another factor that studies did not account for when addressing the social acceptance of nuclear power is that nuclear power proliferators could cause the spread of nuclear weapons. The expansion of nuclear power through uranium enrichment and spent fuel reprocessing are direct pathways for nuclear weapon development. This proliferation poses significant global security risks due to the potential for increased nuclear weapons use, terrorism, and regional instability[24].

Conclusion

In summary, nuclear power holds substantial promise as a sustainable energy source capable of meeting growing global demands. The historical and current data on nuclear energy production, supported by technological advancements and international interest in new reactor construction, paints an optimistic picture of nuclear power's future.

Our data analysis and projections further support the critical role of nuclear power in the global energy mix, particularly in the context of decarbonization efforts. The efficiency of nuclear power reactors has improved, as evidenced by Figure 5. This trend highlights the potential for nuclear power to meet future energy demands sustainably.

The challenges associated with nuclear energy, such as safety concerns, and limited uranium resources, are significant but not insurmountable. Addressing these issues requires concerted efforts in innovation, regulatory reforms, and public engagement. However, the major two problems which this paper identifies as difficult to address and will majorly limit the expansion of nuclear energy is due to the waste management and financial cost. A major breakthrough is needed for the nuclear industry to be a large contribution of global energy source.

Thus, to answer the research question "Can nuclear power sustain the growing energy demand?", it cannot be the sole solution to the energy crisis, unless there are advancements in the solutions to address the two significant limitations. But combined with other renewable energy sources and with improvements in fuel efficiency, it can contribute to a sustainable and low-carbon energy future. .

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