

Mitigating Climate Change: Evaluating the Role of Nuclear Energy in Pakistan's Sustainable Energy Transition

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Abstract:

Pakistan sits between two rapidly growing economies, China and India, which are the major sources of carbon emissions. As a result, it faces severe environmental challenges, including climate change, extreme weather patterns, and rising temperatures. To address these challenges, Pakistan aims to reduce its dependence on fossil fuels; however, it also faces the enormous challenge of transitioning to green energy sources. At this critical juncture, nuclear energy can serve as a viable solution to Pakistan's energy woes. This study, using a qualitative methodology based on secondary sources of data, addresses the question of how and in what ways nuclear energy can help mitigate the adverse impacts of climate change in Pakistan, especially through its contribution to power generation. Additionally, this study examines the role of nuclear energy in the transportation sector. The research paper summarizes the significance of nuclear power in Pakistan as a reliable energy source that can support sustainable development, reduce the nation's energy crisis, and contribute to global endeavors to combat climate change. Moreover, the paper emphasizes that Pakistan should prefer nuclear energy as a cost-effective, sustainable, and climate-friendly solution to its climate crisis. To lay down theoretical foundations, this study employs energy transition theory.

Keywords: Pakistan, green energy, climate change, nuclear energy, sustainable energy transition, carbon emissions

INTRODUCTION

Pakistan's population exceeds 240 million people, and it is grappling with a complex energy crisis that affects social development, environmental sustainability, and economic growth. Its energy requirements are hampered by several factors, including dependency on imported fossil fuels, an immature renewable energy sector, and electricity shortages. The shortage of energy impacts daily life, obstructs industrial productivity and leads to countrywide poverty, particularly in areas with limited electricity (Asghar et. al., 2023).

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Climate change further exacerbates the energy crisis across Pakistan. Pakistan is extremely vulnerable to the impacts of global warming, due to which it is facing erratic rainfall patterns, increasing temperatures and dangerous events in the form of droughts, floods and heatwaves. These climate-based hurdles put stress on both the energy infrastructure and energy requirements by disrupting energy production sources. Additionally, Pakistan's reliance on fossil fuels in the form of coal, oil and gas results in the emission of greenhouse gases, which further add to climate change (Hussain et al., 2020). To deal with these hurdles, Pakistan is in dire need of an all-encompassing model to diversify its energy sector. The diversification must be focused on ensuring energy security by expanding energy production, i.e., increasing energy capacity and diversifying renewable resources, including wind, solar and hydropower. To limit reliance on fossil fuels and reduce environmental effects, Pakistan's renewable energy resources offer a valuable alternative. Simultaneously, there is a need to decrease transmission losses and improve energy infrastructure for both the rural and urban population (Shah & Solangi, 2019).

Dealing with climate change needs a joint effort towards adopting sustainable development and practices of low-carbon energy. This policy will ensure the well-being of Pakistan's citizens and long-term stability. Timely investment in initiatives like small grids, storage technologies and climate-resistant infrastructure will address Pakistan's climate woes (Hussain et. al., 2023). Pakistan's energy challenges and fighting climate change are not segregated efforts but the same phenomenon. Once Pakistan is able to secure a low-carbon and sustainable future, it will help both in combating climate change and also drive its economic engine. By diversifying its resources and adopting a vigorous energy system, Pakistan can achieve sustainable growth (Swain & Jägerskog, 2016).

As far as climate change is concerned, nuclear energy offers a potent solution to the dire need for low-carbon energy. With global temperatures rising due to greenhouse gases, there is an urgent need to transition towards cleaner energy to ensure sustainable development. Among the many options available to ensure large amounts of electricity with less amount of greenhouse gases, nuclear power stands at the top of the table (Mathew, 2022). This gives rise to a debate about how to reduce carbon emissions in the global energy system and limit the impacts of climate change.

Nuclear fission produces nuclear energy. It is a process in which the nucleus of a heavier atom, plutonium or uranium, is split to produce a great amount of energy in the form of heat. Electricity is generated by using the heat in nuclear power plants. The benefit of producing electricity through nuclear power is that it is done without releasing CO₂, which is a primary ingredient for global warming (Brook et al., 2014). Unlike oil, coal and natural gas plants, nuclear plants release less amount of CO₂, proving nuclear energy a better alternative. As the world gears up to realise the targets established in the Paris Agreement, which aims to reduce global temperature below 2 degrees, decreasing CO₂ emissions from energy production is vital, and in order to meet this objective, nuclear energy can play a significant role (Wagner, 2021).

Additionally, in terms of energy density, nuclear power provides a fair advantage. As compared to fossil fuels or renewable resources such as wind and solar, nuclear fuel, even in a small amount, can generate a great amount of energy. This high energy density means that nuclear power can provide reliable, consistent, and large-scale electricity generation. Unlike renewable energy sources, such as solar and wind, which are intermittent and dependent on weather conditions, nuclear power plants

can operate continuously, providing what is known as "base-load" power—essential for maintaining a stable electricity grid, particularly in countries with high energy demands. However, while nuclear energy presents clear benefits, it is not without its challenges. The most important concern surrounding nuclear energy is the issue related to nuclear waste and its disposal. Nuclear waste refers to a byproduct of nuclear fission are radioactive and remains hazardous for thousands of years (Kartal et. al., 2023). Throughout the world, safe, secure and long-term storage of nuclear waste poses a serious challenge for the countries where nuclear power plants are operational. In addition to waste management, a substantial upfront investment is required for the construction of nuclear power plants. These challenges have hindered the global salience of nuclear energy. However, the climate crisis has generated a global consensus that environmentally friendly sources of energy, including nuclear energy, are viable options to address the mounting challenge of climate change.

Pakistan has been at the forefront of an energy crisis for years, and its dependency on fossil fuels results in environmental ruin and high carbon emissions. In these circumstances, a nuclear energy mix can be of great importance to tackle the pressing energy crisis and the requirement of a sustainable future, which is a low-carbon energy system.

LITERATURE REVIEW

Previous studies generally support nuclear energy as a low-carbon source, with lifecycle emissions comparable to other low-carbon technologies such as hydropower and wind. However, environmental impacts and risks vary across technologies and methodological assumptions (Sovacool, 2008; Turconi & Boldrin, 2013).

The economic affordability of nuclear power is still a contested topic (Portugal-Pereira et al., 2018). Findings suggest that high costs for building a nuclear power plant and delays in the construction process lead to additional costs. On the other hand, Suna and Resch (2016) suggest that renewable energy sources, like solar or wind power, might be a more economical choice. However, a more recent study highlights that nuclear power can still be competitive, especially in systems where energy is mostly generated from low-carbon sources, and where storing and managing energy is a challenge. This means that nuclear power can play a role in helping to reduce carbon emissions, but its economic viability depends on various factors, including the overall energy system and technology (Sepulveda et al., 2018)

Pakistan confronts twin challenges of climate change and energy security. As an agricultural nation, the economy heavily relies on this sector, which contributes 24% to the GDP and employs half of the working population, either directly or indirectly (Bajwa & Amjad, 2024). Agriculture also generates the majority of the country's foreign exchange earnings. Climate change is the primary concern, as rising global temperatures have significantly disrupted Pakistan's climate, despite natural variability. This increasing temperature poses serious risks to the agriculture-dependent economy and the livelihoods of millions of people. These factors have led to a significant increase in CO₂ emissions, which in turn has worsened climate change and global warming in Pakistan. Climate change is expected to affect precipitation patterns and accelerate the melting of glaciers, with a particular impact on the timing and intensity of monsoon rains (Khatri et al., 2022). Water-dependent sectors like agriculture and energy generation will be severely affected. Several studies

have explored the nexus between nuclear energy and economic growth. While there is supporting evidence of positive long-term relationships between Nuclear Energy Consumption (NEC) and GDP for a set of countries over time, the extent of cross-country variation does not allow for broad generalization (ALMulali, 2014)

According to Ramana, radioactive waste management and the risk of accidents are concerns that need to be addressed (Ramana, 2018). Establishment of strong regulatory institutions, ensuring nuclear security, and adequate preparedness to handle accidents are also essential for the development of nuclear power. In terms of contribution to energy diversity, nuclear energy can be combined with renewable energy sources, as suggested by Kok and Benli and recently also applied for production of electricity and hydrogen for transport de-carbonization (Kok & Benli, 2017).

The second major issue is the country's energy shortage, caused by a lack of new projects and rapid population growth. As per the National Electric Power Regulatory Authority's (NEPRA) 2022 annual report, Pakistan's installed energy capacity stood at 43,775 MW, with energy sources including 3,620 MW from nuclear, 10,635 MW from hydropower, 1,838 MW from wind, 530 MW from solar, 369 MW from biogas, and 26,683 MW from thermal (coal and gas) energy (NEPRA, 2024). At peak demand, Pakistan faces a shortfall of 9,000 MW, leading to frequent multi-day power outages. The country's electricity distribution infrastructure is outdated and inadequate, further exacerbating the issue. Over half of Pakistan's electricity is generated by its 64 thermal power plants, which rely on carbon-intensive and inefficient processes, releasing large amounts of waste thermal energy (Khan, Yu, & Waseem, 2022).

Pakistan, home to over 2.56% of the world's population, is one of the most populous economies in South Asia. As the fifth-largest populous country, Pakistan has a strong agricultural foundation with a rapidly developing industrial base, and a per capita GDP of \$1,561 USD. As per World Bank reports, Pakistan has abundant resources and huge potential for industrial development. Its geo-strategic location positions the country to become an important global energy and trade hub. Pakistan's rapid industrialization and massive urban population demand an uninterrupted power supply. To fuel sustainable economic growth, Pakistan needs to invest in reliable energy options. However, the existing energy infrastructure is still highly dependent on non-renewable energy sources.

According to the International Energy Agency (IEA) report, Pakistan's primary energy comes from oil and gas. Interestingly, almost 40 million people remain without access to electricity (IEA, 2023). These statistics clearly indicate that despite being hard-hit by climate change, Pakistan continues to depend on heavy fossil fuels for its energy needs. As a result, Pakistan is ranked as the most polluted country in 2025, with concentrations of hazardous particles 13 times higher than WHO's recommended level (Latif, 2026). The 2025 report further reveals that Pakistan's overwhelming dependence on fossil fuels to provide energy to its industries was the primary reason behind the pollution. There are various studies that explain that Pakistan's dependency on coal and hydrocarbons to meet its energy demands has not only an adverse impact on climate change, but these energy options also slow down economic progress (Rehman et al., 2021).

Despite enormous political, economic, and social challenges, Pakistan needs to ensure that its energy outlook effectively meets both the nation's immediate as well as long-term needs for

sustainable economic development, while also assisting regional and global initiatives. In 2009–2010, the energy gap in demand and supply was 26.82% (Ilyas et. al., 2021). Yet, by the summer of 2012, this difference had swelled to 50%. However, with robust policy initiatives, Pakistan's power supply has improved greatly in recent years (Faheem, 2016). As per Pakistan Economic Survey 2019-2020, the total electricity production capacity in 2020 was around 37,402 MW. Yet, transmission and distribution capacity remained limited at approximately 22,000 MW, whereas ideal demand from residential and commercial sectors was around 25,000MW. This situation has somewhat improved but still remains unresolved (Usmani et. al., 2021).

RESEARCH METHODOLOGY

This study adopts a qualitative explanatory research design based on secondary sources of data. The secondary sources of data include books, journal articles, opinion articles, and policy memos. This study employs energy transition theory, which is deemed appropriate to assess the current study on Pakistan's energy transition from fossil fuels to environmentally friendly energy alternatives such as nuclear power. Furthermore, this study opts for qualitative thematic and document analysis, whereby relevant scholarly articles, documents and statistical data are examined and organized around the key themes of the study.

THEORETICAL FRAMEWORK

This research employs the Energy Transition theory (Smil, 2017); a framework that studies how societies and energy systems go through transition from one state to another, especially in the case of changing to more sustainable sources (Leach, 1992). Smil and Leach both make a case for the substitution of traditional energy sources with modern sources of energy, which are renewable and friendly to the environment. Transition theory posits that technological advancement in energy transition, a gradual shift from fossil fuels to more modern, climate-friendly energy sources, has limited global warming. The theory further illustrates that global economies have gradually shifted away from traditional sources, subsequently unfolding de-carbonization processes (Smil, 2017).

Some proponents of transition theory argue in favor of a gradual transition towards renewable energy sources as environmental friendly alternative. They propose multiple renewable options, including wind, solar and other renewable sources, to meet the energy demands (Kabeyi & Olanrewaju, 2022). Though transition theory focuses on the importance of renewable energy sources, it's also argued that, due to the high construction and maintenance costs of renewable energy alternatives, opting for nuclear power generation becomes more feasible (Lin et al., 2025). In Pakistan's case, the maintenance cost of renewable energy resources and also the lack of ideal conditions for wind turbines make these alternatives less viable in the long term. Therefore, nuclear energy stands out as a viable energy option. The basic premise of transition theory is that the global community can systematically move away from fossil fuels to low-carbon energy alternatives to minimise the adverse impacts of climate change (Leach, 1992). The theory argues that technology alone cannot bring transition; in fact, it must be a collective effort of societies, governments and policymakers to create an enabling environment for a smooth transition process. In this context, Pakistan's case is unique. Its economic progress has already been hindered by worsening climate conditions. The realization of climate emergency exists at both societal and

governmental levels. Under these circumstances, Pakistan Atomic Energy Agency's (PAEC) ambitions to deal with climate change with nuclear options appear viable and necessary.

There are various arguments in the favor that Fukushima nuclear incident raised global concerns about the safety and security of nuclear power plants, which eventually led France to a gradual phase-out of nuclear power plants (Smil 2017; 132). However, these arguments miss an important aspect: France, currently, is betting on nuclear energy as an alternative to phase out its fossil fuel dependency, which has massively contributed to environmental degradation in the country (Zimmermann & Keles, 2023). This clearly indicates that there's a growing tendency towards nuclear power generation. The theory further states that nuclear energy is reliable as a baseload, low-carbon technology which bridges the gap during the transition process—providing reliable and uninterrupted power, whereas intermittent renewables, including solar and wind, fall short when complementing them in a diversified mix.

Transition theory is quite relevant in Pakistan's context as it signifies the process of slow change and factors that impact this transition. Historically, Pakistan maintained a steadfast reliance on fossil fuels to fuel its economic growth. Although the energy transition was followed by more energy options in later stages, much of the energy came directly from the burning of fossil fuels, including coal etc. These options, though they appeared cheap initially, put Pakistan in a state of persistent crisis due to their role in climate change. As a result, the small scale of energy transition from traditional to modern energy options remained insufficient to tackle the climate crisis. Consequently, the slow process of transition hindered economic uplift at a large scale.

The theory is also a reflection of the interplay between social dynamics, policy frameworks, market forces and technological innovation, which could either hinder or support a new energy mix. The theory, in this regard, helps us in understanding how Pakistan can transition from its dependence on fossil fuels to a more reliable energy alternative, which is nuclear energy. Employing transition theory will further help us to comprehend the challenges and opportunities that Pakistan might confront when it moves away from traditional energy options to environmentally friendly energy options. In this regard, the theory posits that such a transition occurs in different phases where there is incremental change in technology as well as social behaviour towards it.

On the other hand, Climate change is threatening the safety of many nations, with the risks being particularly severe for less developed countries. In South Asia, this pressing issue has made the region increasingly vulnerable to natural disasters, amplifying the challenges it faces. Additionally, due to its heavy reliance on agriculture, the region is particularly susceptible to the effects of climate change. In particular, Pakistan is ranked amongst the top ten nations that are susceptible to these environmental variations. Climate change, in turn, has significant impacts on the society, environment and economy of Pakistan. The 2010 floods are a case in point where around 20 million people either lost their lives, were displaced or got injured.

On the same pattern, in 2012, Pakistan yet again suffered due to massive flooding, which further worsened the situation. In view of the grim situation, Pakistan must take steps on an urgent basis to work against the impacts of climate change. The government has also realized the depth of the situation and prioritized the issue by terming it a sensitive and critical issue. In order to achieve the target, Pakistan has employed many measures, which include a national climate policy and the

establishment of development plans. Pakistan, in 2012, reached a vital milestone and initiated the preliminary climate change policy. The policy mentioned approximately 120 policy guidelines across diverse sectors to adapt to current trends and lessen the impacts of climate change (Talal, 2020). Given the rapidly changing global climate, there is a high likelihood that Pakistan will face increasingly severe impacts, including extreme weather events such as floods, droughts, hurricanes, coastal erosion, and a decline in agricultural productivity. Pakistan is ranked eighth globally in the 2017 Global Climate Risk Index, having incurred damages of approximately US\$3.8 billion (PPP) from 1996 to 2015 due to climate change (Shahid & Adnan, 2021). This stark reality underlines the need for urgent and robust policy measures to mitigate and adapt to an unending climate crisis. Therefore, a transition to a more reliable yet environmentally friendly energy alternative such as nuclear appears imminent. The theoretical foundation of energy transition offers a systematic and logical understanding of the countries that aim to develop and invest in climate-resilient energy infrastructure.

POTENTIAL OF NUCLEAR ENERGY FOR SUSTAINABLE ENERGY TRANSITION IN PAKISTAN

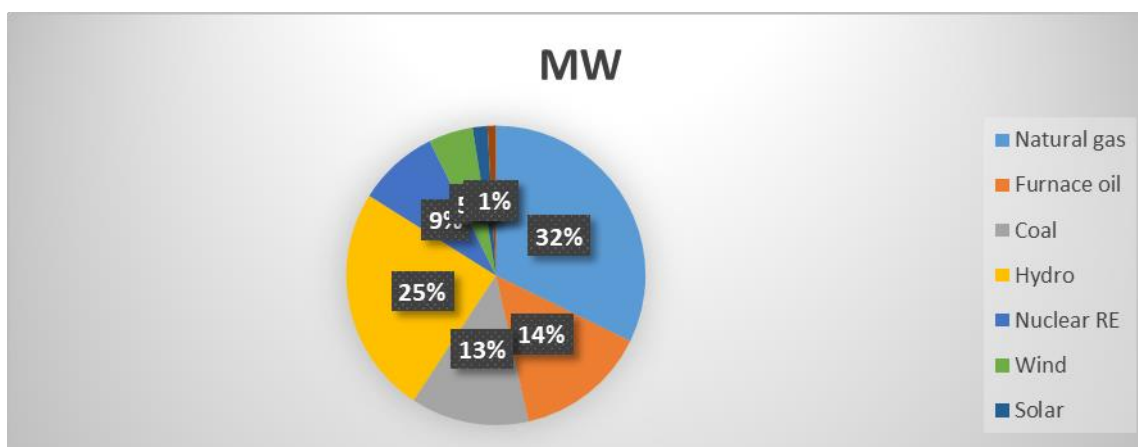
One of the important prerequisites for a country's development is energy production, coupled with a balanced demand and supply ratio. Unfortunately, due to the drastic impacts of climate change and also the rising energy consumption driven by industrial growth, Pakistan is in dire need of clean, affordable and reliable energy sources. There is a lack of adequate power supply, which not only hinders economic growth but also contributes to social and developmental setbacks. The 2023 power breakdown has resulted in losses of billions of dollars, highlighting the urgent need for improvements in energy infrastructure and sustainable energy solutions to secure the country's future. In addition to that, the massive hikes in the prices of hydrocarbons leave Pakistan with no other option but to strategically invest in the nuclear energy sector, which has the potential to become the second most reliable energy source at the global level. Nuclear energy offers greater dependency, environmental benefits, which also has lower CO₂ emissions. In the face of an unending climate crisis, Pakistan may face a host of challenges if it fails to swiftly adopt a reliable and low-carbon energy infrastructure (Ullah & Lin, 2024). It is equally crucial for Pakistan to transition from conventional energy options to more reliable and efficient nuclear energy to address these challenges and further secure a sustainable energy future.

In retrospect, the climate crisis represents the gravest threat to traditional energy alternatives, exposing countries to significant risks. The lack of investment in reliable and affordable energy alternatives may further exacerbate countries' energy crisis. Pakistan, which is an agrarian nation, is particularly vulnerable to the environmental impacts. While Pakistan fulfils its energy requirements from multiple sources, including renewable and non-renewable options, a clear breakdown of each resources clearly indicate that the country's energy production is heavily dependent on hydrocarbons.

Pakistan has a variety of alternatives and options to mitigate the threats posed by climate change. These options include investment in renewable sources such as solar, wind, and hydropower. However, these options alone may not be sufficient to fully meet the growing energy demands. Conventional energy methods, which include relying on fossil fuels, are increasingly becoming unsustainable due to their environmental impact. Most importantly, global disruptions in the supply of hydrocarbons due to violent conflicts targeting supply chains further deepen a country's

energy woes. The volatility of global energy prices is yet another important aspect that merits a careful assessment (Murshed, Khan, Khan, & Parvin, 2023).

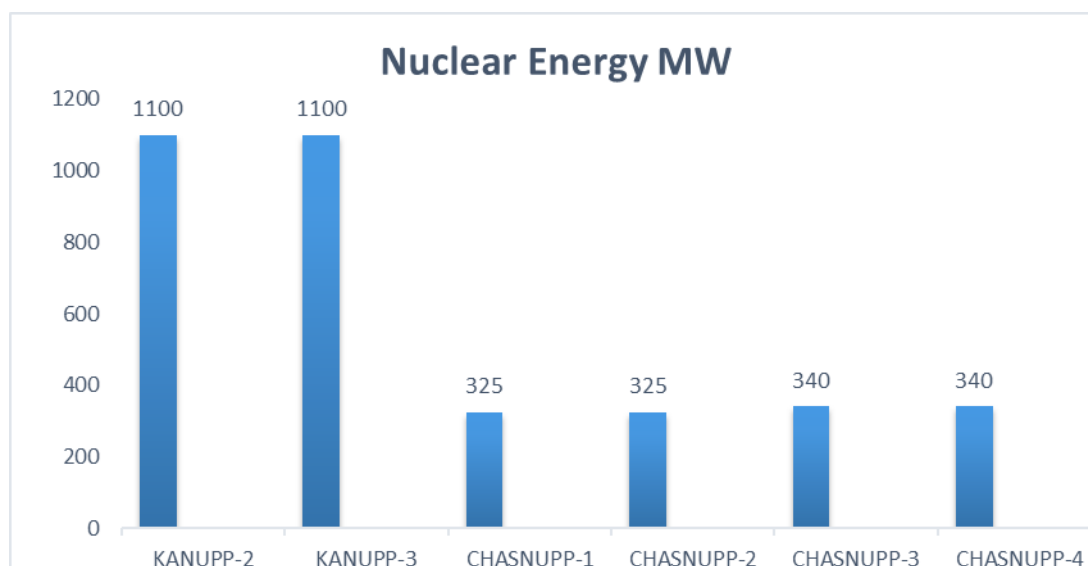
Chart 1: Breakdown of electricity generation by different resources.



(Source: Authors' own interpretation of data extracted from World Nuclear Association)

Pakistan's peaceful use of nuclear energy program, with six operational nuclear power plants (NPPs), remains insufficient to tackle climate issues. As shown in the graph below, these nuclear power plants play a crucial role in supplying clean energy to the national grid, helping to meet Pakistan's energy needs while reducing its reliance on conventional and other energy sources, which are massively adding CO₂ to the country's atmosphere.

Chart 2: The overall contribution of the nuclear energy mix generated by six NPPs of PAEC.



(Source: Official website of PAEC)

In December 2022, nuclear power reactors met 27% of Pakistan's total energy needs, with the cost of the energy generated being as low as half a US penny per unit (Khan & Malik, 2023). Nuclear power plants were among the top energy producers, generating 2,284.8 GWh of electricity in that

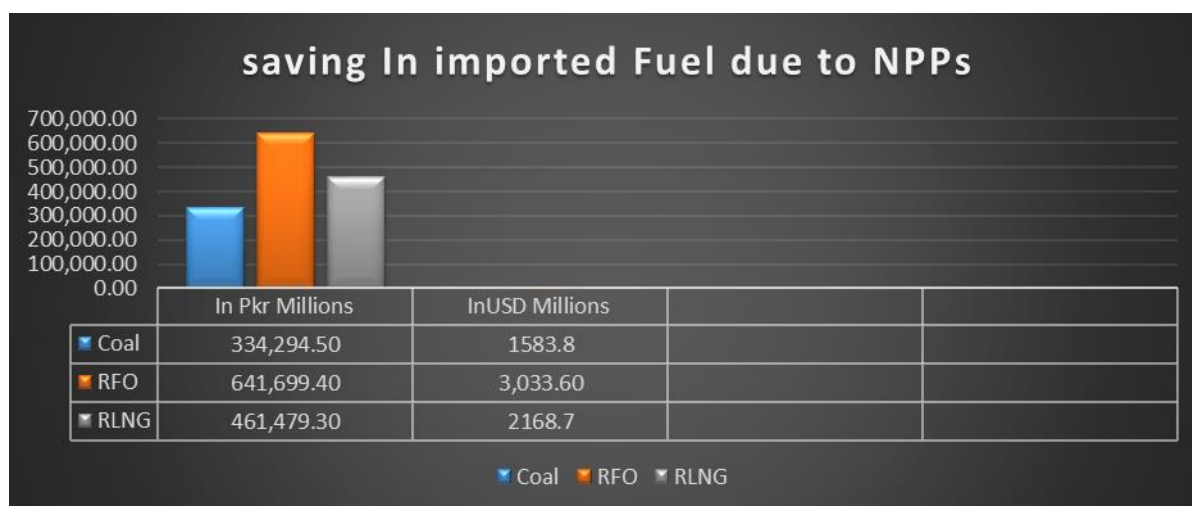
month. Following nuclear energy, hydroelectric, coal-based electricity, natural gas, and regasified liquefied natural gas (RLNG) were the next major sources of energy in the country.

Economical Energy Generation in Pakistan

Since inception, Pakistan has been using hydroelectric power and fossil fuel energy to meet its demand. This has, over the years, proved inadequate to fulfil the ever-increasing needs of its population. The traditional energy sources come with vital benefits; however, they also have significant loopholes and are potentially susceptible to the implications of climate change. In stark contrast to this, nuclear power plants offer a safe and trusted alternative when operated under safety regulations and standards. Nuclear energy offers a secure and efficient solution to produce electricity while fulfilling energy requirements. It is also clean and contributes less to climate disaster. Moreover, the United States Department of Energy has established that nuclear energy is the most secure technique of generating electricity. Nuclear energy, also known as a zero-emission form of energy, make sure loftier air standard for society. In 2022, the US was able to avoid 471 tons of carbon emissions by using nuclear energy (Fowler et al., 2021). This shows that nuclear energy is both environmentally friendly and reliable.

In 2012, since the launch of the Nuclear Threat Initiative (NTI) Index, Pakistan scored the second-greatest gains, with its score showing a twenty-five-plus increase in its cumulative score of safety and security of power plants. This shows efforts on the part of Pakistan to increase the durability of its nuclear energy infrastructure. Resultantly, Pakistan has been able to save an estimation of 6785.7 million dollars in fuel imports due to the use of nuclear energy. This further highlights the strategic and economic advantages of nuclear energy for Pakistan (Neakrase & Nalabandian, 2020). The chart below clearly explains how NPPs have benefited Pakistan's economy by decreasing the country's reliance on imported fuel.

Chart 3: Economic contribution of NPPs in saving imported fuel costs



Source: Pakistan Institute of Development Economics (PIDE)

Pakistan's energy needs are better served by nuclear energy production, as it provides the most economical, clean, and environmentally friendly electricity. Like many other countries, Pakistan is not immune to the devastating impacts of natural disasters, which threaten both natural

ecosystems and precious lives. Therefore, it is crucial for the country to address its energy demands practically and sustainably. To further mitigate the effects of climate change and meet the growing energy needs of its population, Pakistan must place a greater focus on expanding its nuclear energy generation capabilities (Azam, 2023).

Reduction in Carbon Emissions

One of the most important steps in reducing global greenhouse gas (GHG) emissions is through the lowering of the reliance on thermal energy sources for power generation. At the moment, thermal power generation accounts for more than 65% of global electricity production, contributing significantly to GHG emissions. A timely shift toward nuclear power generation can help mitigate these emissions. Scientific estimates suggest that nuclear power reactors produce CO₂ at a rate nearly 1/3rd lower than solar power generation, lower than hydropower generation, and at par with wind power generators (World Nuclear Association, 2025). These evidences make nuclear energy a reliable option to reduce the environmental impact of electricity generation while also maintaining reliable energy production (Stirling, 2020et. al.,). Recognizing the urgency created by climate change, Pakistan has started to increase its nuclear energy output. In this context, Pakistan's Nuclear Energy Mission 2050 appears promising and aims to reduce the adverse impact of the climate crisis.

In order to restrict the rise in global temperature and lessen the impacts of climate change, Pakistan signed the Paris Agreement in 2015. The target needs restricting emission of greenhouse gases from power plants to zero towards the middle of the century. This radical decrease is significant to combat global warming and stabilise the climate. Pakistan, as a vulnerable nation, must ensure cleaner energy in the form of nuclear energy to participate in the global efforts of curbing greenhouse gases. Nuclear power is an important element in Pakistan's efforts to achieve the goal. Pakistan also generates its electricity from water and other renewable and green energy resources; still, there are issues, as the water resources are vulnerable to climate change and Indian hegemonic designs, particularly in the context of the Indus Water Treaty in abeyance. Contrastingly, nuclear energy for Pakistan is a reliable resource as it is not vulnerable to outside factors of weather patterns and water availability (Liu et al., 2023).

The case of nuclear energy production is important to understand. Uranium is found in rocks across the world, but the specific isotope required for nuclear reactors, uranium-235, is relatively scarce. Despite this, nuclear power emits very little greenhouse gas, making it an environmentally friendly energy source. In fact, its CO₂ equivalent emissions are often lower than those of some renewable energy sources, such as solar and wind, during the entire lifecycle of power generation, including mining, construction, and decommissioning. All this makes nuclear energy an important part of the global energy mix, which reduces carbon emissions and combats climate change. Although issues related to radioactive waste material, including spent reactor fuel and uranium mill tailings etc. are important environmental concerns associated with nuclear power, the latest safety measures and mechanisms introduced by the IAEA have further diminished the issues related to nuclear waste management. Radioactive waste with a short half-life is often stored temporarily before disposal to allow its radioactivity to diminish (Michaelides & Michaelides, 2020). This temporary storage helps reduce radiation exposure to workers handling and processing the waste, as well as lowering radiation concentrations at disposal sites. It is essential to properly manage the radioactive waste

material to reduce the impact on the environment and enable security throughout the whole disposal process.

Moreover, nuclear facilities generate a smaller amount of radioactive waste as compared to other sources of energy. For example, the amount of waste produced by nuclear plants in seventy (70) years is equal to the waste generated by coal plants in a time period of one hour. This happens due to the density of nuclear energy, which means that even a small quantity of nuclear fuel can produce a great amount of energy. Resultantly, nuclear fuel is more efficient and productive, as it produces less waste. Also, nuclear plants need relatively less space as compared to wind and solar power farms. According to an estimate, solar power needs 75 times more land space as compared to a nuclear power plant for producing an equal amount of energy. Similarly, land-based farms are more land-intensive as they need 360 times more physical space than nuclear power plants to generate the same quantity of electricity. Owing to this, nuclear plants are more space-friendly and are beneficial in areas with a high density of population in a limited space.

Nuclear energy is the future as it specifies a way out for Pakistan to expand its energy requirements and reduce carbon emissions. With time when urbanization will grow in Pakistan and limited space becomes available, energy needs will multiply, and pressure will be exerted on existing energy infrastructure. As long as Pakistan doesn't shift to nuclear energy, Pakistan will grapple with carbon emissions, which will ultimately worsen its climate change ratio. Nuclear energy, with a low carbon footprint, provides a sustainable solution to Pakistan's growing energy requirements with the least environmental damage.

Base-Load Power

The minimum level of demand that is required on the electrical grid 24/7 to maintain a solid and reliable electric supply is called base-load. In a country like Pakistan, this is an important element of any energy system where ensuring a solid power supply is significant for quality of life and economic development. In this regard, nuclear energy is an ideal source of base-load electricity, since it has the potential to produce great amounts of power uninterrupted. Nuclear energy plants, unlike solar and wind power plants, work seamlessly without support from an external source. This ensures a stable and smooth flow of electricity. This feature lends credence to nuclear energy over other sources of energy, especially in developing countries like Pakistan, which have serious energy issues. (Ali, Alkaabi, Alameri, & Addad, 2021).

The significance of base-load power cannot be overlooked in Pakistan. The country is heavily dependent on hydroelectric power, which is vulnerable to seasonal water capacity and political factors. Factors like floods, droughts and varying water patterns can significantly impact the availability of water for electricity generation. This factor makes water, as a source of power generation, less reliable and less predictable. On the other hand, nuclear energy offers a better alternative as it is less dependent on weather conditions and seasonal water flow. Since nuclear power plants provide a continuous supply of energy, they are more reliable and ready to be tested as compared to other sources of energy. This continuation of uninterrupted supply to maintain the country's base-load makes nuclear energy more efficient.

Additionally, other sources of energy like wind, water and coal pose some challenges, which lends significance to nuclear energy. Coal, which is a vital source of electricity across Pakistan, suffers

from economic and environmental setbacks. Coal supply can be disrupted by geopolitical factors, and its prices also fluctuate, which makes it less reliable. In the same pattern, natural gas is also affected by price increases, supply-chain disruptions, and import dependency. These weaknesses make natural gas and coal less reliable sources of energy. Nuclear energy, on the other hand, is less vulnerable to disruption. Once the nuclear power plant becomes functional, it is easy to continue producing electricity due to a rich supply of uranium. Furthermore, nuclear energy gives an efficient, readily available and stable source of energy to a developing state like Pakistan.

Nuclear energy, in addition to ensuring base-load power, plays a role in the incorporation of renewable energy sources into Pakistan's energy requirements. Nuclear energy, as opposed to other sources of energy, ensures base-load with continuity and less fear of disruption. Solar, water and wind sources of energy cannot be relied on for producing continuous energy as they are subject to disruption and changing weather patterns. This is where nuclear energy comes into play and ensures a smooth, stable and continuous supply of energy. By incorporating nuclear energy, a developing state like Pakistan can achieve resilience in the energy grid and reduce dependency on fossil fuels.

Pakistan is striving to match climate goals and limit its carbon emissions, and it is important for Pakistan to support the incorporation of renewables. Pakistan is already marred by climate change, irregular weather and rain pattern and water deficiency. If Pakistan shifts to nuclear energy, it can meet its growing energy demands without any significant impacts on the environment. Nuclear energy is low in carbon and offers a better alternative to other sources of energy, which inter alia include coal, wind and natural gas. These steps can help Pakistan meet its energy requirements.

Role of Nuclear Energy in Transportation

The transportation industry is a major contributor to air pollution and urban smog, with transportation-related CO₂ emissions reaching around eight billion tons globally in 2022, according to the International Energy Agency (IEA) (Chen et al., 2023). Conventional fossil fuel vehicles account for a quarter of all energy-related greenhouse gas emissions, as reported by the United Nations Environment Programme (UNEP). In response to growing environmental awareness, electric and hybrid vehicles (EVs) are becoming more popular, with around 45 million EVs in use worldwide by 2023 (Hassan, Khan, Zhu, & Batool, 2022). EVs now represent 15% of all new car sales, up from 14% in 2022, and it's predicted that global EV sales will reach 16.7 million units by the end of the year. The Global EV Outlook 2024 projects that there will be 100 million passenger EVs by 2026, with their total sales value expected to reach USD 8.8 trillion by 2030 (BloombergNEF, 2026). Despite having one of the lowest greenhouse gas (GHG) emissions globally, Pakistan is one of the nations most affected by climate change. The transportation sector contributes around 30% of Pakistan's total carbon emissions, while accounting for only 10% of the nation's GDP. This sector also consumes 30% of Pakistan's hydrocarbon imports, costing over USD 15.6 billion annually (Asim et al., 2022). In fiscal year 2022, the transportation sector was the largest consumer of energy products, using about 17.4 million tons out of the country's total 23.09 million tons of energy products (Rehman et. al., 2022).

Despite the environmental and economic benefits of electric vehicles (EVs), they remain rare on Pakistani roadways. By 2024, only 15,000 of the 30 million registered cars in Pakistan were

electric, making up just 0.05% of the total. Additionally, the proportion of hybrid electric vehicles (HEVs) among light-duty passenger vehicles is less than 1% (Arshad, 2020). The growth of Pakistan's EV industry faces several challenges, including the high cost of EVs, which makes them unaffordable for most Pakistanis. Another major hurdle is the lack of charging infrastructure, with only eight EV charging stations available nationwide. The practicality of EVs is under scrutiny from many potential customers. They doubt their charging and raise questions on its price tag. E-mobility functions through Electric Vehicles and promotes greener transportation with zero tailpipe emissions. The success of EVs depends on the source of energy used to charge EVs. Additionally, their reliability is determined by the type of electricity used to charge EVs. If Pakistan wants to reduce climate vulnerability, clean energy must be used for most of the activities.

As EV adoption grows in Pakistan, significant challenges also arise for the energy grid, particularly concerning the charging stations across the country. It is expected that with increasing reliance on EVs, energy requirements will further increase to charge a large number of vehicles. In this regard, the nuclear-renewable hybrid energy system (N-RHES) is increasingly being considered as a promising solution to meet increasing energy demands (Esteves & Gabbar, 2023). N-RHES will provide surplus energy that can be further used to produce hydrogen as a storage system and charge fuel cell cars. Hydrogen is an energy carrier which can be utilized to power electric vehicles. Many of the developed countries, including US, Japan and Germany, are investing in N-RHE systems to power their vehicles, which in turn reduces CO₂ emissions up to 90% (Esteves & Gabbar, 2023).

In the presence of power outages and other problems, nuclear energy is essential to the transition to EVs. Nuclear energy offers a practical solution as compared to other sources. It is reliable, cheap and works without disruption of geopolitical signalling. Moreover, nuclear energy generates electricity without producing waste that may harm the climate. So, it is climate-friendly, and by integrating nuclear energy into EV charging infrastructure, Pakistan can run stable and flexible methods to ensure a smooth flow of electricity. With a potential of 300 MWe, SMRs are smart and stable to ensure the operation of traditional nuclear power plants. It decreases construction time and extra costs for the plants. The built-in structure and hardware ensure an efficient and stable source of energy with fewer accidents and power outages. This has increased the demand for EVs.

CONCLUSION

Pakistan is facing an increasing demand for energy amidst rising climate change vulnerabilities; transitioning to a reliable and low-carbon energy source is crucial for the country. This study finds that current energy consumption based on fossil fuels such as coal, oil and gas leads to energy insecurity and environmental challenges. Nuclear energy, as a low-carbon option, can be reliable for electricity generation to support a sustainable energy transition in Pakistan. However, the extent to which nuclear energy contributes to climate change mitigation would depend on sustained investment, adequate institutional capacity, safety, infrastructure and a long-term policy framework.

Unfortunately, throughout its history, Pakistan maintained a steady reliance on hydrocarbons and other traditional sources for its energy demands. Despite being one of the few countries to benefit from President Eisenhower's Atoms for peace program, Pakistan couldn't harness the potential benefits of peaceful nuclear technology. Pakistan's dependency on fossil fuels and other sources

directly contributed to the worsening climate conditions. Traditionally, coal remained the dominant energy source that powered industries in the country. As energy resources evolved, the focus also shifted to oil and gas, which further became central to power generation. However, this scenario led to a significant environmental consequence, contributing to the climate crisis. Today, Pakistan, as a result of these policy choices, has become a hard-hit victim of climate-induced threats. However, with greater realisation of climate risks associated with fossil fuels, Pakistan has been rapidly expanding its reliance on renewable energy resources, including nuclear energy. Pakistan, which is located at the heart of the climate crisis, is also directly impacted by the carbon emissions from its neighboring countries, China and India. Both nations are heavily reliant on the industrialization, are major contributors to CO₂ emissions, which have further worsened climate change. These emissions directly affect Pakistan's socio-economic outlook, leading to increasingly severe climate challenges, including extreme weather patterns, rising temperatures, and environmental degradation.

In order to address these pressing challenges, Pakistan can enhance its dependence on nuclear energy option which is a viable alternative. Although there are challenges associated with NPPs, such as the safety and security of the plants, Pakistan has over 40 years of experience in the safe operation of NPPs. Currently, Pakistan is facing a dual challenge: first, a persistent energy crisis and second, a climate emergency exacerbated by the use of fossil fuels. In this regard, given Pakistan's climate vulnerability, the need for a reliable, sustainable, low-carbon energy solution has never been more urgent. Nuclear energy offers an important alternative that can help Pakistan meet its increasing energy needs while reducing the drastic impact of fossil fuel consumption.

Given the relatively modest contribution of nuclear power to Pakistan's national energy mix, the study proposes that nuclear energy should be considered as one of the alternatives for meeting Pakistan's energy requirements through a low-carbon energy strategy, besides renewable energy, energy efficiency and modernized grid. Pakistan should strengthen a long-term nuclear energy plan and requisite institutional structure while maintaining the highest safety standards, especially under IAEA safety and regulatory frameworks. Thus, nuclear energy presents great opportunities to address Pakistan's energy and climate-related challenges. These opportunities must, however, be tapped through a balanced, economically competitive, and sustainable energy plan. This research further suggests that Pakistan must explore international cooperation in the peaceful application of nuclear energy to meet its growing energy demands.

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