Nuclear energy in the global and Pakistan contexts: Trends and perspectives

La energía nuclear en el contexto mundial y de Pakistán: tendencias y perspectivas

Mohid Iftikhar[1]* and Iraj Abid[1]

1 Center for International Strategic Studies Sindh, Pakistán.

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*E-mail de correspondencia:
mohidcisss@gmail.com

ABSTRACT

This policy brief argues that nuclear energy is a promising option for developing countries such as Pakistan. At the global level, alongside geopolitical crises and climatic threats have led to a renewed interest in nuclear energy. Currently, both advanced and developing countries are exploring options for energy self-sufficiency, primarily in order to mitigate adverse effects on power infrastructure, the disruption of supply chains, market distortions and inflation. It is suggested that Pakistan should consider investing in new nuclear power plants (NPPs) as a means of reducing the country's energy import costs, shifting to clean energy, tapping into electric vehicle markets, and becoming more resilient in the face of climatic shifts and geopolitical crises.

Keywords: *nuclear energy, Pakistan, geopolitical crises, climate change*

RESUMEN

Este *policy brief* argumenta que la energía nuclear es una opción prometedora para los países en desarrollo como Pakistán. A nivel mundial, junto con las crisis geopolíticas, las amenazas climáticas han llevado a un renovado interés por la energía nuclear. Actualmente, tanto los países avanzados como los países en desarrollo están explorando opciones para la autosuficiencia energética, principalmente para mitigar los efectos adversos en la infraestructura eléctrica, la interrupción de las cadenas de suministro, las distorsiones del mercado y la inflación. Se sugiere que Pakistán debería considerar invertir en nuevas plantas de energía nuclear como un medio para reducir los costos de importación de energía del país, cambiar a energía limpia, aprovechar los mercados de vehículos eléctricos y volverse más resistente frente a los cambios climáticos y crisis geopolíticas.

Palabras clave: *energía nuclear, Pakistán, crisis geopolíticas, cambio climático*

Introduction

Alongside global climate change, big power contestation has negatively impacted the supply of energy worldwide. The Ukraine crisis has resulted in global market distortions, including price instability and supply chain disruptions of both essential and energy commodities. In turn, global growth has been severely hampered. The International Monetary Fund (IMF, 2023) estimates that global growth is expected to decline from an estimated 3.4% in 2022 to 2.9% in 2023. Guan *et al.* (2023) state that «Energy costs for households around the globe are estimated to have risen by between 62.6% and 112.9% since the beginning of the Russia-Ukraine conflict.»

Currently, fossil fuels account for over 75% of global greenhouse gas (GHG) emissions (United Nations, 2022). Shifting to clean energy is imperative, in order to minimize GHG emissions and achieve the target of net zero by 2050. This is crucial, given that power consumption is expected to increase threefold by 2050 (McKinsey, 2022). The share of energy produced by fossil fuels in the global energy mix is approximately 80% (Environmental and Energy Study Institute, 2021). However, according to a Met Group (2021), fossil fuel reserves are likely to be exhausted over the next 50-115 years: oil in 51 years, natural gas in 53 years, and coal in 114 years. Such estimates are a cause for alarm.

Geopolitical crises and climate change

The Ukraine crisis has severely disrupted energy markets and supply chains. Russian energy has found new consumers in Asia to replace European buyers, and US and Middle Eastern oil and gas have replaced Russian supplies in Europe. The Organization for Economic Cooperation and Development (OECD) estimates that by the end of 2023 the global economy will face losses totaling USD 2.8 trillion as a result of the Ukraine crisis. The International Energy Agency (IEA, 2022) has stated that «Energy markets and policies have changed as a result of the Ukraine crisis, not just for the time being, but for decades to come.»

The effects of global climate change have exacerbated the impact on the energy supply chain and infrastructure. The World Meteorological Organization (WMO, 2020) states that «climate change directly affects fuel supply, energy production as well as the physical resilience of current and future energy infrastructure». Globally, the increasing frequency of heatwaves, floods, wildfires, rains and snowfall has adversely affected power generation and supply.

Global trends

It is important to note that the share of nuclear energy in the national energy mix of many advanced and emerging economies is significant. For example, it is 70% in France, 52% in Slovakia, 50% in Belgium, 47% in Hungary, 40% in Slovenia, 37% in the Czech Republic, 35% in Bulgaria, 34% in Finland, 31% in Sweden, 29% in Switzerland, 28% in South Korea, 21% in Spain, 20% in the US, and approximately 20% in Russia (estimates vary) (IAEA, 2022).

One important aspect of nuclear power generation is the cost of waste management. The World Nuclear Association (WNA, 2022) notes that waste disposal and decommissioning costs are factored into operating costs. Typically, the waste management and disposal costs of nuclear power constitute approximately 5% of the total electricity generation cost. At the same time, history has shown that «in over 50 years of civil nuclear power experience, the management and disposal of civil nuclear waste has not caused any serious health or environmental problems, nor posed any real risk to the general public» (WNA, 2022).

The risks associated with nuclear power plants have become of global concern due to three past accidents. In 1979, the Three Mile Island nuclear power plant accident was caused by a meltdown in part of the core of reactor which resulted in a cooling malfunction. No injuries or harmful health effects were reported as a result of the accident (WNA, 2022). In 1986, the Chernobyl accident was the result of a combination of faulty reactor design and poorly trained staff. In March 2011, the Fukushima Daiichi accident occurred as a result of a major earthquake followed by a 15-meter tsunami that disabled the power supply and cooling system for three reactors. However, no deaths or cases of radiation sickness were reported in the wake of the Fukushima Daiichi accident (WNA, 2022).

Globally, these nuclear accidents served as important lessons, resulting in significant advances in nuclear technology, training of personnel, design and safety protocols. A study by Ayoub and Sornette (2022) published in the Swiss Finance Institute concludes that new concepts introduced into the design of nuclear power plants means that accidents on the «Fukushima scale can be brought down to about one per 300 years of operation of the worldwide fleet.»

Pakistan's NPPs, namely K2 and K3 (ACP-1000), are third-generation reactors. Former Pakistan Atomic Energy Commission (PAEC) chairman Ansar Pervaiz (2014) has stated that «the ACP 1000 is a generation three reactor with diverse safety systems including passive safety features that could handle extreme situations like a complete station black-out [...] the additional safety systems based on the lessons learnt from the Fukushima accident make the plant more robust against power failures, earthquakes, flooding and tsunamis.»

There is concern regarding the supply of uranium, which is the most widely used fuel source for nuclear power plants. However, Science Daily (2016) notes that «the oceans hold more than four billion tons of uranium —enough to meet global energy needs for the next 10,000 years if only we could capture the element from seawater to fuel nuclear power plants. Major advances in this

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area have now been made». A 2014 article in Forbes also emphasizes that «common wisdom, that limited uranium supplies will prevent a substantial increase in nuclear energy, is incorrect. We have plenty of uranium, enough for the next 10,000 years». Such figures make it clear that nuclear energy is a promising option for the future.

Today, there is renewed interest at the global level in nuclear power generation, as it offers an attractive alternative for dealing with the repercussions of geopolitical crises and the devastation caused by climate change. At present, there are 410 operational NPPs, while a total of 57 nuclear power reactors are under construction worldwide (IAEA, 2023). The share of total power generation produced through nuclear energy may increase to 14% by 2050 (IAEA, 2023). Some experts, including Mignault (2022), estimate that the share of nuclear energy may double (to 20%) by 2050. Such projections are made based on factors such as climate conditions, regulatory frameworks, and the drive for clean energy.

Given the many benefits of nuclear energy, which is clean, affordable and reliable, it seems clear that developing countries such as Pakistan need to take a closer look at their energy mix and consider enhancing their share of nuclear power.

Pakistan perspective

Pakistan's energy market has long faced structural problems such as low investment, reliance on imported energy commodities, depreciation of the rupee, aging power infrastructure, and controversy surrounding the development of dams. The high cost of imported energy commodities is a major contributor to Pakistan's balance of payments crisis, which poses a grave challenge to the overall economic stability of the country.

The United Nations Framework Convention on Climate Change (UNFCCC, 1992) advocates clean sources of energy in order to minimize global GHG emissions, and to «limit the temperature increase to 1.5°C above pre-industrial levels». In the case of Pakistan, the United Nations Development Program (UNDP, 2023) suggests that in order to achieve a 50% reduction in its overall GHG emissions by 2030, Pakistan must achieve a 15% reduction from its own resources and a 35% reduction subject to the provision of international grant finance. Renewable energy sources such as solar, wind and hydro are clean and affordable sources of energy. However, renewable energy sources are also dependent upon several factors, such as climatic conditions, geopolitics and pandemics that may adversely affect the supply of their essential components and parts (Solaun and Cerdá, 2019). Nuclear energy merits attention as a baseload source of power for assured economic development, given that the fuel supply for NPPs is not dependent upon market conditions (OECD-NEA, 2011).

Pakistan has more than 50 years' experience in nuclear power generation. The IAEA has commended Pakistan's safety record and the quality of the human resources in its nuclear power sector (IAEA, 2021). Pakistan currently operates six nuclear power plants (NPPs), which collectively produce approximately 3,500 MW of electricity. Four NPPs are located in Chashma (C-1, C-2, C-3 and C-4). The two largest NPPs (K-2 and K-3), located in Karachi, produce 2,200 MW. K-2 and K-3 are third-generation NPPs, fitted with highly sophisticated multilayered safety mechanisms (IAEA, 2023).

Pakistan's energy policies, namely the «National Power Policy 2013», the «Power Generation Policy 2015», the «Alternative and Renewable Energy Policy 2019», and the «National Electricity Policy 2021», are aimed at promoting affordability, a consumer-centric approach, reducing reliance on imported fuels, and encouraging economic growth and public-private partnership (PPP) in the energy sector. Pakistan's wealth of experience in nuclear power generation, coupled with energy-friendly policies, constitutes an ideal environment for new investments in NPPs.

Numerous studies, such as Kirikkaleli *et al*. (2020), have identified a positive association between nuclear energy consumption and economic growth. In this regard, the Planning Commission of Pakistan (2022) estimates that electricity generation in Pakistan would increase from its 2021 level of 143,589 GW to 230,176 GW by 2030. However, in the context of power generation the primary concerns are cleanness, affordability and reliability, and nuclear energy performs well according to all these metrics.

According to the Nuclear Energy Institute (NEI, 2000) «Uranium is an abundant metal and is full of energy: One uranium fuel pellet creates as much energy as one ton of coal, 149 gallons of oil or 17,000 cubic feet of natural gas». A joint report by the OECD Nuclear Energy Agency and the International Energy Agency (2020) estimates that the levelized cost of energy (LCOE) of «nuclear in 2025 will range from about USD 55-95 per MWh as compared to almost USD 100 per MWh for coal and about USD 80 per MWh for gas». Nuclear energy, therefore, is an attractive non-fossil fuel option for Pakistan, given its reliability, affordability and environmental friendliness.

With regard to nuclear waste management, the PAEC has adequate measures in place for its six NPPs. The United Nations notes that the «IAEA's Safety Standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation». According to Bill Gates (2023): «The waste problems should not be a reason to not do nuclear [...] Say the US was completely nuclear-powered — it's a few rooms worth of total waste. So no, it's not a gigantic thing [...] the cost of storing and sequestering nuclear waste underground is not a huge problem [...] it can be put into deep boreholes

underground [...] where it stays geologically for hundreds of millions of years [...] I'm involved in that —where the countries that are committed to nuclear prove it out and show that economic safety, waste management is handled». The Pakistan Nuclear Regulatory Authority (PNRA) states that «Currently, Pakistan has one spent fuel dry storage facility in operation whereas another facility is under construction phase».

Jalil (2022) highlights that the share of nuclear power in total electricity generation in Pakistan has increased from 1% in 1990 to 12% (estimates vary) in 2022. In December 2022, the share of nuclear energy in total power generation was 27.1%, as a result of a decline in power generation from other sources (Business Recorder, 2023). This situation has led to significant savings for the country. According to the National Electric Power Regulatory Authority (2023), the total nuclear fuel cost for the 22,227 GWh generated by six NPPs in 2022 was USD 112 million. It would have cost (after adjustments for nuclear fuel costs) USD 3.0 billion if generated by using furnace oil, USD 2.2 billion by RLNG, and USD 1.6 billion using imported coal (these figures represent net savings). Nuclear energy is, therefore, a promising option. Investment in new NPPs could help to substantially reduce Pakistan's energy import bill of USD 27 billion.

The installation of NPPs through public-private partnership (PPP) is also an option. The PPP model for NPPs has been implemented successfully in Canada and the US. In May 2021, India's Department of Atomic Energy (DAE) announced that it will be constructing the country's first research reactor on the PPP model (Hindustan Times, 2021). Pakistan is also in a position to explore the option of investing in NPPs through the PPP model.

The option of small modular reactors (SMRs) in remote areas can also be explored through the PPP model. SMRs are advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit (estimates vary). Due to their smaller size, they are easier to install at locations unsuitable for larger NPPs. SMRs are cost effective and can be built relatively quickly (IAEA, 2021).

At the global level, nuclear energy is being considered in the context of the electric vehicle (EV) market. According to Durham (NEI, 2022):

> Carbon-free energy like nuclear is needed to power these stations to deliver on clean energy targets [...] Nuclear energy is the most viable option for a steady stream of reliable, affordable, carbon-free electricity that can power EV charging stations 24/7/365. Nuclear reactors are responsible for over half of all carbon-free energy produced in the US, and nuclear energy pairs well with renewables, like wind and solar, to create a cleaner grid [...] Nuclear energy is essential to ensuring EVs succeed in helping reach decarbonization goals, meet increasing electricity demand, and keep electricity costs low [...] EV manufacturers, battery manufacturers and recharging stations can all harness nuclear technology to power clean transportation. That way when you plug in your next EV, you know that your choice is truly making a difference.

Pakistan's EV Policy aims to boost the market share of EVs to 30% by 2030 (International Council on Clean Transportation, 2020). Based on global trends within the EV industry, nuclear power generation has the potential to help facilitate Pakistan's EV Policy.

Conclusion

In order to achieve economic growth, Pakistan must have an affordable and reliable supply of electricity, while at the same time minimizing the country's dependence on imported fossil fuels. It is therefore important that the government of Pakistan focuses upon implementation of its Nuclear Energy Vision for 2030 and 2050, with the aim of generating 8,800 MW and 42,000 MW, respectively.

It is encouraging to note that, at the inaugural ceremony for K-3 NPP in Karachi on February 2nd 2023, Prime Minister Shehbaz Sharif spoke in favor of enhancing cooperation with China in the field of nuclear energy (Business Recorder, 2023). During his visit to Pakistan in February 2023, Rafael Mariano Grossi, the Director General of the International Atomic Energy Agency (IAEA), stated that «Pakistan has technical and engineering capacity for new nuclear power plants including small modular reactors (SMRs), which indicates a promising future for nuclear energy and achieving Sustainable Development Goals (SDGs)» (Radio Pakistan, 2023). According to PAEC (2019), the viability of SMRs in Pakistan's context in «far-flung areas [that] require small power plants [and the] modular design of SMRs will allow customized NPPs for different regions [...] Northern areas face severe winter hence, district heating could be provided through the deployment of SMRs [...] Desalination using nuclear energy through the deployment of SMRs is viable [...] Hybrid energy systems based on SMRs could be deployed in wind corridors and sun-rich areas [...] Ship-based SMRs are also a feasible option for coastal areas». These statements and various scientific assessments point to a promising future for nuclear energy in Pakistan, where nuclear energy has the potential to help the country to absorb exogenous shocks resulting from climatic threats and geopolitical crises, as well as to achieve an affordable and reliable supply of clean energy for Pakistan's future electricity needs and economic development.

Conflicts of interest

The authors have no conflicts of interest to declare.

Authors' contributions

M.I.: conceived the idea for the article, developed the argument, gathered data and arrived at important conclusions (70%). M.I. presented this research previously on the occasion of Pakistan Defence Day, in September 2022, at an event jointly organized by Sindh Rangers, DHA

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