

Pakistan's Nuclear Energy Outlook*

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INTRODUCTION

Due to concerns over carbon emissions and volatility in fossil fuel prices, there has been a renewed interest in nuclear energy worldwide as a solution to growing energy demands (Veigel and Quinn, 2017). Currently, fossil fuels comprise 63% of Pakistan's commercial energy supplies, while the remaining 37 percent is derived from renewables (including hydro)(28 percent) and nuclear power(9 percent) (GOP, 2023).

GLOBAL NUCLEAR ENERGY EXPANSION

For centuries, fossil fuels remained the dominant source of energy globally. It was in the 1950s that commercial nuclear power stations started operations. With this, an avenue for nuclear energy opens, reducing oil and gas import dependency in many countries. Several countries embarked on nuclear power programs after the 1970s energy crisis (dramatic surge in global oil prices). Most Nuclear Power Reactors (NPRs) were constructed from 1970 to 1985.

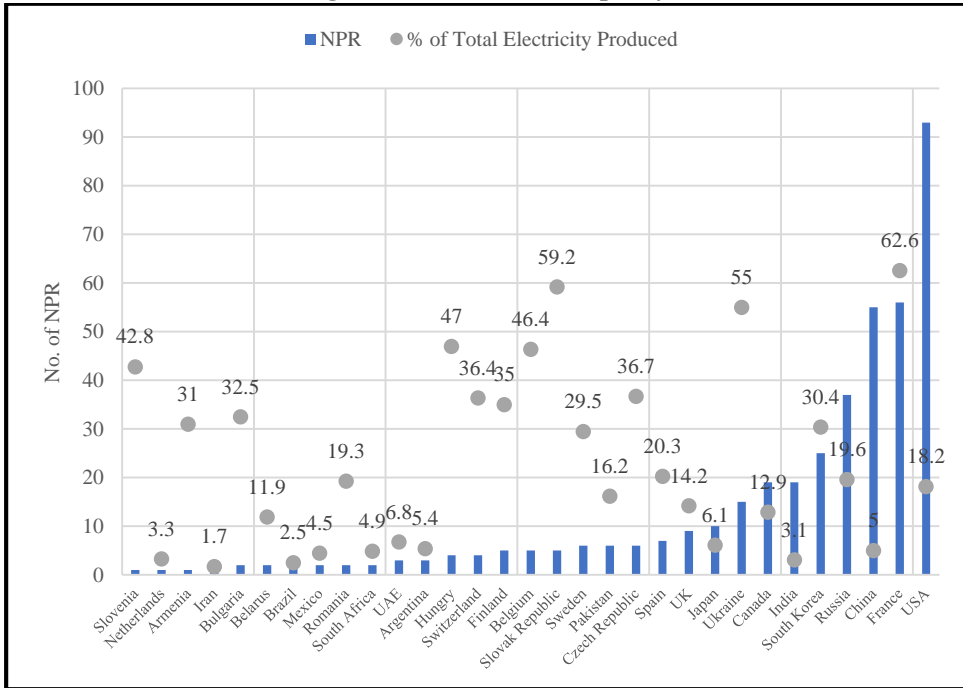
As of August 16, 2023, nuclear energy meets around 10 percent of global energy demand, with 408 currently operational NPRs with a capacity of 366736 MW in 31 countries (Figure 1). In addition, 57 new NPRs are under construction (IAEA, 2023).

France stands out among 31 countries, generating 63 percent of its electricity through nuclear power. It began expanding its nuclear power industry in the 1970s to reduce dependence on foreign oil and lower emissions¹⁷⁰. Ukraine and the Slovak Republic follow France for depending on NPRs for more than 50 percent of electricity generation (Figure 1).

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¹⁷⁰ By increasing its reliance on nuclear power, France reduced its fossil-based CO₂ from the power industry from 112 MtCO₂/year in 1980 to 34.7 Mt CO₂/ year in 2021 (Crippa et al., 2022).

Fig. 1. Global Nuclear Capacity



Source: IAEA Power Reactor Information System.

SALIENT FEATURES OF NUCLEAR POWER REACTORS

Dependability

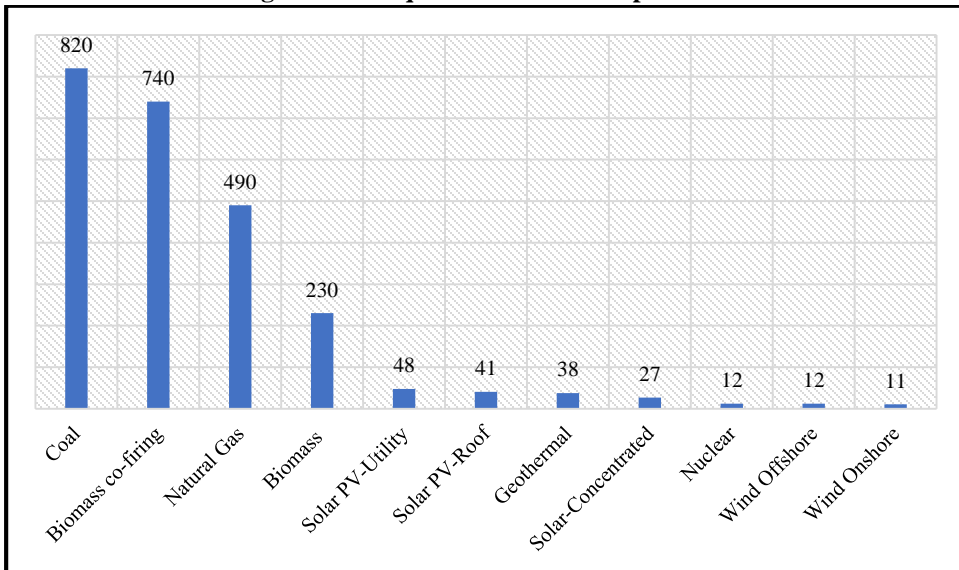
Nuclear power plants can operate for up to 18 months without refueling. Additionally, they can store fuel on-site for an additional 18 months without incurring extra costs (GOP, 2023). Due to this, nuclear power plants are less susceptible to price fluctuations and supply chain disruptions. Furthermore, they minimise the risks of grid disruptions caused by weather events. Nuclear power also has the highest reliability or capacity factor. For example, in 2021, nuclear power in the US had a capacity factor of over 92 percent, compared to coal (49.3 percent), natural gas (54.4 percent), wind (34.6 percent), and solar (24.6 percent)¹⁷¹.

Eco-Friendly

It is not a renewable energy source because of its dependence on a chemical - uranium. While uranium can be found in rocks worldwide, power plants need a specific type, uranium-235, which has limited supplies (Patapati, 2022). However, it is a clean energy source with negligible greenhouse gas emissions. Its CO₂ equivalent emissions are even less than some renewable energy sources (Figure 2).

¹⁷¹ <https://www.energy.gov/ne/articles/what-generation-capacity#:~:text=The%20Capacity%20Factor&text=It%20basically%20measures%20how%20often,of%20the%20time%20in%202021.>

Fig. 2. CO2 Equivalent Emissions per kWh



Source: <https://world-nuclear.org/nuclear-essentials/how-can-nuclear-combat-climate-change.aspx#:~:text=Nuclear%20power%20plants%20produce%20no,electricity%20when%20compared%20with%20solar.>

A primary environmental concern regarding nuclear power is creating radioactive waste, including uranium mill tailings, used reactor fuel, and other radioactive materials. However, the radioactivity of nuclear waste decreases over time through a process called radioactive decay. Radioactive waste with a short half-life¹⁷² is often temporarily stored before disposal to decrease potential radiation doses to personnel handling and transporting the waste while reducing radiation levels at disposal sites¹⁷³.

Additionally, although nuclear plants produce toxic nuclear waste, the amount produced is negligible. The amount of nuclear waste produced in 70 years equals what coal plants produce in an hour. Nuclear fuel is highly dense and contains enormous energy in a small amount (Perch Energy, 2022).

Compared to solar and wind, nuclear power plants require significantly less land. One estimate suggests that a wind farm needs 360 times more land to generate the same energy as a nuclear power plant, while solar requires 75 times more land area (cited from Perch Energy, 2022).

Economics of Nuclear Power Plant

Nuclear power plants are expensive to build (CAPEX) but cheap to run. Safety costs, including waste disposal and decommissioning costs, are included in their operating costs¹⁷⁴. Nuclear energy is even more economical than fossil fuels when considering social,

¹⁷² The time duration for the radioactivity of radioactive material to reduce to half its original level is referred to as the radioactive half-life.

¹⁷³ <https://www.eia.gov/energyexplained/nuclear/nuclear-power-and-the-environment.php>

¹⁷⁴ Nuclear power expenses consist of capital and operating costs. Capital expenses comprise site preparation, engineering, manufacturing, construction, commissioning, and financing while operating expenses include fuel costs (from uranium mining to fuel fabrication), maintenance, decommissioning, and waste disposal.

health, and environmental costs. System costs for nuclear power are much lower than for intermittent renewables¹⁷⁵.

Repaying the initial investment each year is more expensive due to the technical complexity of these plants and the strict licensing and design requirements they must meet. Building a new nuclear power plant involves hiring highly qualified specialists, which can take many years and add to financing costs. Delays caused by design changes or lawsuits can further increase financing charges, which may even exceed the actual construction costs in some cases.

Over the past few decades, the costs of nuclear plants have increased. Many of these costs result from the indirect expenses of constructing plants, such as engineering, management, and supervision. In addition, these costs have risen due to increased safety regulations. However, the cost constraints have been reduced through the small modular nuclear reactors (SMRs) ((Box 1).

Box 1. Small Modular Reactors (SMRs)

- SMRs can produce up to 300 MW of electric power.
- Cost-effective for smaller electricity grids.
- Easy to transport and install to meet demand in the market at any remote or distant location; specific SMR designs can replace diesel generators in small islands or remote regions.
- It can be deployed as a single or multi-module plant with advanced safety measures.
- Provides flexible power generation for a broader range of users and applications (even for non-electrical use, providing heat for industrial processes, hydrogen production, or seawater desalination).
- Can be replaced with aging fossil-fired units.
- Has improved safety performance.
- Moderate financial commitment compared to large nuclear power reactors.
- Can achieve improved thermal efficiencies through cogeneration, resulting in better returns on investment.
- SMRs have lower fuel requirements. Unlike traditional plants that require refueling every 1 to 2 years, SMRs may only need to be refueled every 3 to 7 years. Some SMRs are designed to operate for up to 30 years without refueling.

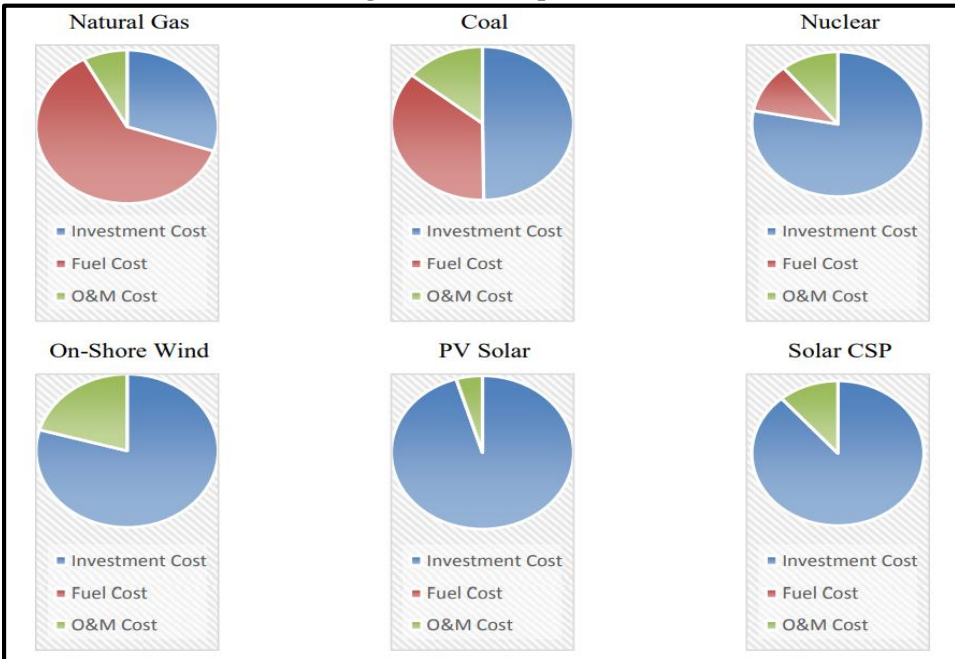
While SMRs have lower upfront capital cost per unit, their economic competitiveness is yet to be proven.

Source: IAEA, 2020.

<https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs>

¹⁷⁵ Source: World Nuclear Association

Fig. 3. Cost Comparison



Source: Cited from <https://progress.institute/nuclear-power-plant-construction-costs/>

Despite having large capital investment, the levelised cost of electricity generated through nuclear power plants is less than coal or gas power plants.

Table 4

Normalised Levelised Cost of Energy

	Nuclear LCOE	Coal		Natural Gas	
		LCOE	LCOE with carbon cost	LCOE	LCOE with carbon cost
US	1	0.88	1.21	0.67	0.85
South Korea	1	1.40	1.99	1.54-2.69	1.78-2.93
Japan	1	0.94	1.23	0.92-1.46	1.05-1.58
China	1	1.03	1.63	0.74-1.72	0.97-1.95
France	1	–	–	0.58-1.05	0.71-1.18
Pakistan	1	1.09	–	–	–

Source: Faizi (2020) and MIT (2018)

Note: Cost values are normalised to a value of 1 for nuclear power reactors; if the normalised value is less than 1, that energy option is more competitive than nuclear, and if it is greater than 1, nuclear is more competitive.

PAKISTAN NUCLEAR POWER CAPACITY

Pakistan has six nuclear power reactors (NRPs) with a capacity of 3,530 MW, contributing about 27 percent of the total electricity generation in the national grid in December 2022. All these plants are pressurised water reactors (PWR), the technology mainly used worldwide. China has assisted Pakistan’s civil nuclear energy program since the late 1970s by helping construct nuclear power plants (Khalid, 2020).

Box 2. History of Pakistan's Nuclear Power Industry

- 1955: The Pakistan Atomic Energy Committee was established.
- 1956: To develop nuclear technology and regulate the use of radioactive substances, the Atomic Energy Council was established. It was tasked with procuring, supplying, manufacturing, and disposing of radioactive materials. The Council also conducted surveys for radioactive minerals. They created comprehensive plans to explore and mine uranium, construct nuclear research, and power reactors, and utilise other applications of nuclear technology.
- Pakistan started its nuclear program in 1965 with a 5 MW research reactor at the Pakistan Institute of Nuclear Sciences and Technology (PINSTECH). The construction of this research complex was initiated in 1961. The project was designed by Edward D. Stone and won the 1966 American Society of Landscape Architects (ASLA) Professional Award for design excellence.
- In 1961, the Pakistan Atomic Energy Commission (PAEC) created a nuclear minerals division to aid in Pakistan's geological surveys. During that same year, the search for uranium began. This search was for nuclear minerals and to establish milling processing facilities. The survey concluded that the Siwaliks of Suleiman Range (Dera Ghazi Khan)_ *uranium favourable*.
- 1964, aerodynamic surveys were conducted.
- 1965, the Pakistan Atomic Energy Commission (PAEC) was given a legal cover by promulgating the PAEC Ordinance.
- Pakistan established a nuclear safety division within PAEC, which became the Directorate of Nuclear Safety and Radiation Protection after the Pakistan Nuclear Safety and Radiation Protection Ordinance 1984. The Pakistan Nuclear Regulatory Authority was created to oversee regulatory affairs and separate promotion and regulatory functions by promulgating the Pakistan Nuclear Regulatory Authority Ordinance in 2001.

Source: Sultan et al. (2015); https://inis.iaea.org/collection/NCLCollectionStore/_Public/21/020/21020770.pdf#page=11; and <https://www.pnra.org/history.html>

Pakistan constructed its first nuclear power plant, KANUPP, in Karachi in 1972¹⁷⁶. After its shutdown in August 2021, KANUPP's infrastructure and knowledge supported the development of reliable nuclear power reactors in Pakistan. KANUPP, a Pressurised Heavy Water Reactor (PHWR), was built with Canada's assistance. However, all six new generations of nuclear plants in Pakistan are Pressurised Water Reactors (PWR) designed and constructed with the help of China (Government of Pakistan, 2023).

¹⁷⁶ In 1959, Canada and Pakistan signed an agreement for nuclear cooperation that included the installation of a 137 MW CANDU-style power reactor named KANUPP. Later, in 1969, a deal was struck between Canada, Pakistan, and the IAEA, with the IAEA being responsible for safeguarding the KANUPP reactor. The reactor commenced commercial operations in 1972 (Sultan et al., 2015).

Table 5a

Pakistan Nuclear Power Plants

Name	Capacity		Connected to Grid	Gross Electricity sent to grid up to	
	MW (Gross)	Capacity MW (Net)		March 31, 2023	Plant Factor % FY2022
Chashma Nuclear Power Plant – 1 (C-1)	325	300	Jun-2000	46225	89
Chashma Nuclear Power Plant – 2 (C-2)	325	300	Mar-2011	27294	86.3
Chashma Nuclear Power Plant – 3 (C-3)	340	315	Oct-2016	15311	78.3
Chashma Nuclear Power Plant – 4 (C-4)	340	315	Jun-2017	13013	73.5
Karachi Nuclear Power Plant-2 (K-2)	1100	1017	Mar-2021	14052	68.1
Karachi Nuclear Power Plant-3 (K-3)	1100	1017	Mar-2022	7853	19.6
Chashma Nuclear power Plant – 5 (C-5)	1200		Expected in 2029	–	–

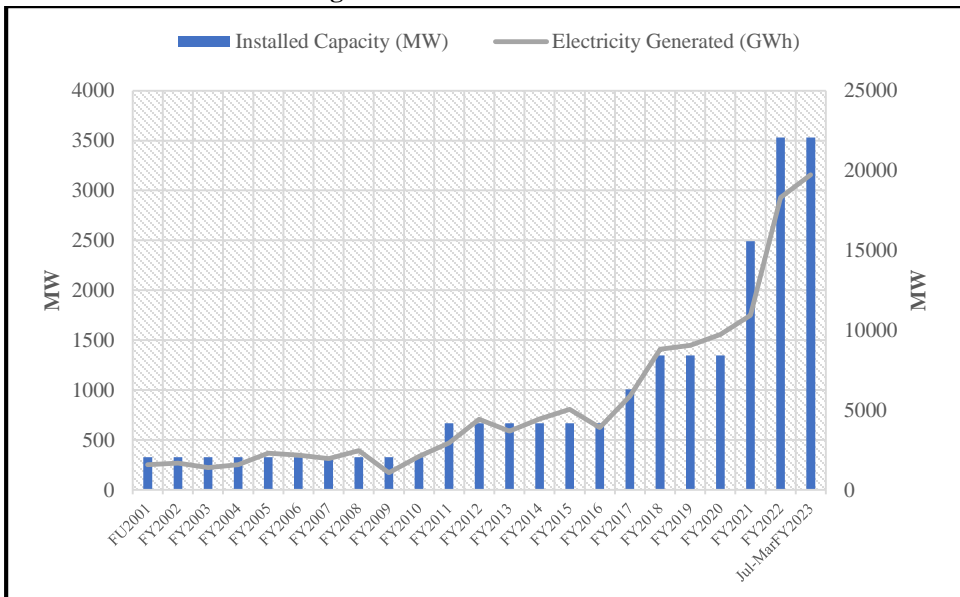
Source: Pakistan Atomic Energy Commission.

Table 2b.

Name	Fixed O&M	Var. O&M	Fuel Cost US\$/GJ	Heat Rate GJ/MWh	Cost US\$/MW	Cost Rs/kWh
C-1	135.48	0	0.50	10.91	5.47	0.97
C-2	124.60	0	0.58	10.91	6.33	1.13
C-3	99.91	0	0.49	10.91	5.35	0.95
C-4	99.08	0	0.61	10.91	6.65	1.18
K-2	52.28	0	0.47	10	4.77	0.85
K-3	52.20	0	0.47	10	4.70	0.84
C-5	73.89	0	0.47	9.57	4.50	0.80

Source: IGCEP 2022-31.

Fig. 4. Pakistan Nuclear Power



Source: NTDC Power System Statistics, 47th Edition, 2022 and GOP, 2023.

NPRs accounted for only 8.6 percent of Pakistan’s installed generation capacity from July to March FY2023. However, due to the high-capacity factor of NRPs, they generated 21 percent of the country’s electricity in the same period (Figure 4). In December 2022, nuclear was the leading source of electricity generation, with a share of 27 percent, followed by hydro (20.4 percent) and coal (18.1 percent) (Table 3). Nuclear has the highest capacity utilisation rate. In FY2021, the average capacity utilisation rate of nuclear energy was at 72 percent, followed by hydro (45 percent), thermal (38 percent), wind (27 percent), solar (19 percent), and Bagasse (15 percent) (PBS, 2022).

Nuclear energy is significant in Pakistan’s electricity generation mix due to its dependable nature and consistently low energy costs (Table 3a). Most of the cost of nuclear power comes from capital costs, which are fixed, so nuclear plants are usually operated continuously to supply baseload power, as was the case in Pakistan in December 2022. No doubt, the capacity costs of nuclear plants are higher than those of local coal and gas power plants (Table 3b), but they have much lower energy costs and a much larger operating life.

Over the decades, the nuclear power industry has significantly improved its performance and operational safety worldwide. In addition to developing reactor technology in Pakistan, the nuclear power industry is also focused on improving regulations and learning from past events. The Pakistan Nuclear Regulatory Authority (PNRA) is an independent national regulator responsible for implementing these regulations. The Pakistan Atomic Energy Commission (PAEC)¹⁷⁷ conducts Periodic Safety Reviews with the help of experts from the nuclear industry and international peers. Furthermore, the PAEC regularly organises courses to promote and ensure a safety culture at all levels¹⁷⁸.

Table 3a

Generation Mix with Energy Costs (Monthly Comparison)

	% Share in Total Generation		Energy Cost (Rs/kWh)	
	Dec. 2022	Jun. 2023	Dec. 2022	Jun. 2023
Hydro	20.44	30.14	–	–
Coal	18.07	17.75	11.5	14.05
HSD	–	0.07	–	30.45
RFO	0.46	5.43	25.8	26.1
Gas	15.13	8.54	10.5	11.74
RLNG	13.71	18.55	20.2	24.07
Nuclear	27.15	13.54	1.07	1.07
Import	0.47	0.18	21.5	23.63
Mix	0.03	0.20	3.3	6.29
Wind	2.51	4.36	–	–
Bagasse	1.20	0.48	5.97	5.98
Solar	0.83	0.77	2.8	–
Units Generated (GWh)	8417	13715		

Source: NEPRA.

¹⁷⁷ The Pakistan Atomic Energy Commission was established in March 1956 to develop nuclear technology, regulate, procure, supply, and manufacture all radioactive substances, and conduct surveys for radioactive minerals. It became a lawful entity following an act of parliament in 1965.

¹⁷⁸ <https://paec.gov.pk/Parameters/Safe/>

Table 3b

Generation Mix with Power Purchase Price

Generation Mix	FY2023			FY2024		
	Projected Generation (GWh)	Energy Price (Rs/KWh)	Capacity Price (Rs/KWh)	Projected Generation (GWh)	Energy Price (Rs/KWh)	Capacity Price (Rs/KWh)
Hydro	44859	0.12	5.19	41226	0.09	6.84
Imported Coal*	39202	19.25	9.22	16552	17.18	23.36
Local Coal				22696	10.55	13.42
Gas	12685	8.44	4.52	14312	8.57	4.45
RLNG	15036	22.36	8.16	6639	23.56	27.86
Bagasse	1012	7.14	8.69	1136	6.06	8.77
Wind	5611	-	20.69	5212	-	33.64
Solar	1163	-	21.22	2563	-	15.04
Nuclear	22281	0.95	13.65	25566	1.04	17.34

Source: NEPRA Tariff Determinations.

Pakistan Trade Potential in Nuclear Energy

Pakistan has developed its civil nuclear fuel cycle with the support of China, independent of its nuclear weapons. Due to its weapons program, Pakistan is not a member of the Nuclear Non-Proliferation Treaty¹⁷⁹, limiting its potential to trade or access nuclear materials (uranium) and hindering indigenous development of civil nuclear energy¹⁸⁰.

Over the past three decades, China has installed four nuclear power generation units in Chashma, with a net generation capacity of 1230MW, and began the construction of a fifth one with a capacity of 1200MW (Table 1). C-5 will be Pakistan's largest generation-III plus nuclear power project (Box 3).

Despite not being a significant player in the global uranium market, Pakistan has plans to increase the use of nuclear energy in power generation significantly; the availability of uranium will play a key role in Pakistan's nuclear future (Sultan et al., 2015).

Between 1993 and 2005, the production of weapons-grade uranium (enriched to 90 percent uranium-235 or greater) in Pakistan increased (Akhtar et al., 2015). However, despite this increase and ongoing efforts, the evidence suggests Pakistan is experiencing a uranium shortage. Based on assessments of only Khushab reactors in Pakistan, four reactors operating at about 70 percent efficiency may need 70 tU per year. Hanhum et al. (2018) cited that Pakistan only mines about 45 tU annually. It means Pakistan already uses more uranium than it produces to operate its four Khushab reactors. Adding Chashma nuclear reactors means Pakistan's demand for uranium is much more. Enriched fuel for the power reactors is currently imported from China¹⁸¹.

The shortage of uranium has prompted the Pakistan Atomic Energy Commission (PAEC) to initiate costly exploration drilling projects in the Kirthar mountain range, the Kohat plateau, and the Potwar plateau. To aid in this effort, the PAEC signed a technical cooperation contract with the China National Nuclear Corporation (CNNC) in July 2017 for uranium resource exploration and development (Hanhum et al., 2018).

¹⁷⁹ The Treaty aims to facilitate the use of nuclear technology for peaceful purposes by constraining the development and production of nuclear weaponry.

¹⁸⁰ <https://world-nuclear.org/information-library/country-profiles/countries-o-s/pakistan.aspx#ECSArticleLink1>

¹⁸¹ <https://world-nuclear.org/information-library/country-profiles/countries-o-s/pakistan.aspx>

Box 3. Evolution of C-5 and its Challenge

- In April 2015, the Strategic Plans Division signed a framework agreement for C-5.
- PAEC and their Chinese counterparts signed a commercial agreement in November 2017.
- Due to the strategic nature of the project, the C-5 was included in the committed projects in IGCEP 2019 and 2022.
- The IGCEP (2022-31) was primarily based on the least cost principle. Therefore, C-5 was labeled a candidate project because of its high upfront cost. The plan did not fully consider other factors, such as the lower operational costs and longer lifespan, to support the baseload.
- In June 2023, China began its construction with advanced safety and foolproof security features.
- It is estimated to cost a minimum of US\$ 3.7 billion, with roughly 85% Chinese credit. Cost has escalated by more than 50 percent since its planning. China's Import and Export Bank is expected to provide a major part of the financing.
- The location of C-5 is strategically important due to its proximity to load centers; its transmission costs are lower than other baseload options, such as Thar coal plants or large hydro projects (with similar CAPEX) (Dasu and Diamer Bhasha).
- Being eco-friendly, it is a better baseload option.
- However, the only challenge is that the system's existing capacity is surplus. If the existing capacity remains underutilised, it escalates the capacity cost component in the consumer-end tariff. For FY2024, these costs will be around Rs 2 trillion. C-5 addition may offset plans to include renewable power plants in the system to keep the capacity burden under control. By the time C-5 is completed and added, with all other factors constant, this will further increase the capacity challenge.

Source: IGCEP 2022, Ghumman (2023), and NEA (2023).

Note: Tariff details are not publicly available.

KEY TAKEAWAYS

- Pakistan desires to join the Nuclear Supplies Group (Khalid, 2020). After completing this task, harnessing the potential for nuclear energy trade will be easier. Pakistan has developed significant expertise in building, operating, and designing nuclear reactors, resulting in a safe and reliable nuclear power industry that meets global standards. However, diplomatic efforts are needed to join the Nuclear Supplies Group.
- In Pakistan, 25 percent of the population still has no access to electricity, and more than 90 percent of the rural population relies on non-commercial energy sources. Per capita energy consumption is one of the lowest in the world, at only 17.1 gigajoules per capita, higher than only Bangladesh and some African countries. The biggest challenge in improving access to energy is the need for more infrastructure, particularly in rural areas where grid coverage is limited and

connecting to the grid can be expensive. In locations where transmission lines and grid capacity are inadequate or without access to the grid, SMRs can be a good option for providing reliable baseload support to renewable energy resources.

Microreactors are more efficient, cost-effective, safer, and offer greater process control than traditional reactors. They also produce reactions more quickly and with better yields. In addition, SMRs can be produced on-site and on-demand, making them an ideal solution for delivering clean electricity to industry or other economic activities and the population in remote areas.

- Constructing large nuclear plants can be costly despite their dependability, safety, and low energy costs. Even if energy prices remain low, the capacity purchase price will rise with any new addition, such as C-5. However, notwithstanding the high capacity costs, nuclear plants have an operation life of almost 60 years, longer than fossil fuel and other renewable power plants, except for hydro plants. At the same time, it is crucial to be transparent when finalising any new power purchase agreement by clearly defining the tariffs or incentives provided. This will allow for an independent assessment to be conducted beforehand.
- Pakistan currently has sufficient electricity generation capacity, but the costs of generating electricity have increased due to a reliance on imported fuels, dollar-denominated payments, rising interest rates, and financial difficulties. This has led to higher consumer tariffs, frequent power outages, and mounting circular debt. Boosting energy use in productive activities is crucial to alleviate the burden of capacity payment challenges in the coming years.
- In the future, Pakistan can augment its nuclear energy production while concurrently integrating renewable sources to promote a greener future.

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