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NUCLEAR ENERGY: AN OPTION FOR GREENHOUSE GASES MITIGATION IN PAKISTAN

Muhammad Saleem Ullah, Muhammad Imtiaz, Ijaz Ahmad

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By:

Muhammad Saleem Ullah[1], Muhammad Imtiaz[2], Ijaz Ahmad[3]

1. Introduction

Energy is an essential input for socio-economic development of a country. Nearly every aspect of the development – from reducing poverty, raising living standards, improving health care, industrial and agriculture productivity, and enhancement of exports – requires reliable access to modern energy sources.

The growing population mostly in developing countries and expanding world economy will drive a mounting demand for energy. At present, due to COVID–19 pandemic, the electricity demand is low in all sectors of the economy throughout the world as well as in Pakistan, however, in future a faster growth rate is expected due to the recovery of economic activities after the pandemic, growing urbanization and industrialization. To meet this demand, expansion of power system capacity is essential. However, growing public awareness of the deteriorating environment coupled with supply system cost, and security of energy supply will affect the energy choices made by countries.

Pakistan needs to utilize all the available resources for a sustainable supply of electricity to meet its growing energy demand and achieve the development targets while addressing the climate change issues. Nuclear energy provides a reliable, competitive, and environment friendly base-load electricity in Pakistan. The country's generation mix has skewed primarily towards oil/ gas during last few decades due to slow development of hydro potential and coal resources.

For achieving the goal of the Paris Agreement to limit the long-term temperature rise well below 2°C above pre-industrial levels, the developed country parties to UNFCCC are setting binding targets for absolute reduction of greenhouse gases (GHGs). Likewise, the developing country parties are emphasised in the agreement to enhance their GHGs mitigation efforts to reach global peaking of GHG emissions as soon as possible.

In the world, the production and use of energy currently account for around two–thirds of the total GHG emissions and the electricity generation in turn accounts for one–third of these energy related emissions. Energy production and electricity generation mixes are shifting towards the low carbon pathways. When analysed realistically, nuclear power is better in terms of reliability, base–load and carbon emission from other alternative energy options. Some developed countries are also considering to keep nuclear energy as a part of their energy supply system for achieving their GHGs mitigation targets.

1 Director, Applied Systems Analysis Division (ASAD), Pakistan Atomic Energy Commission

2 Deputy Chief Scientist, ASAD, PAEC

3 Deputy Chief Engineer, ASAD, PAEC

Pakistan, with 2,530 MW nuclear capacity, is pursuing its nuclear power programme which will contribute effectively in national GHG emissions reduction efforts as acknowledged in the national climate change policy and second national communication to UNFCCC.

This paper highlights the current status of power sector of Pakistan, climate change issue and GHGs mitigation efforts, and delineates the global prospects of nuclear energy and development of nuclear power programme of Pakistan as a low carbon electricity generation option.

2. Current Status of Pakistan Electricity Supply Sector

At present, the total installed electricity generation capacity of Pakistan is more than 40,000 MW (see Table 1). About 52% of this capacity is based on oil/ gas, 24.6% on hydro, 11.6% on coal, 6.3% on nuclear and about 5.3% on others (including wind, solar etc.). The growth of the capacity remained 7-8% per annum during 1970 – 2000. Notably, this growth had been exceptionally low (2%) during 2000 – 2014 (see Figure 1), which resulted in severe load–shedding in the country. Starting from 2007, this load–shedding adversely affected the economic development, besides causing frustration amongst the people.

During last five years, there has been a significant growth in installed electricity generation capacity in the country, mostly based on imported Liquefied Natural Gas (LNG), coal, hydro and nuclear that resulted in significant reduction of electricity supply shortage. Still, some key problems with the electricity supply system of the country still persist including; high import dependence, slow pace of indigenous energy resources development, and inefficient & inadequate transmission/ distribution networks, etc.

Table-1: Electricity Installed Capacity (As of March, 2021)

Sector	Capacity (MW)	Share (%)
Oil/ Gas	20,975	52.2
Hydro	9,874	24.6
Coal	4,670	11.6
Nuclear*	2,530	6.3
Wind	1,285	3.2
Solar	480	1.2
Bagasse	364	0.9
Total	**40,178**	**100**

* K-2 Nuclear Power Plant of 1,100 MW connected to grid on March 18, 2021.

Source: Based on [NTDC 2021].

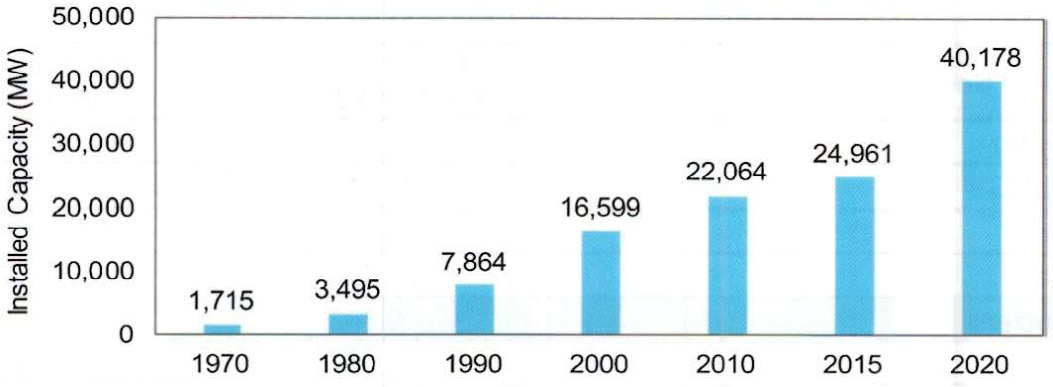


Figure-1: Evolution of Power Generation Capacity in Pakistan (HDIP 2019, NTDC 2021)

During 2019-2020, the grid supplied electricity was 135,259 million kilowatt-hours (see Table 2). The power generation is dominated by hydro, coal and gas sources. The share of nuclear power in the installed electricity generation capacity is only 3.7% however it is contributing more than 7% of the country's electricity. The evolution of electricity generation mix (Figure 2) indicates that unlike other countries, oil based electricity generation remained one of the major source in Pakistan during last three decades except during 2004 – 2006 and in recent years. Recently, the import of natural gas, induction of coal fired and nuclear power plants (NPPs) (C – 3/ C – 4) helped to drop the share of oil based generation to 6%. Unlike many large economies, coal based electricity generation in the country remained negligible till recent and with latest additions, coal share has increased to 19%. During 2019 – 2020, the country generated 35% electricity from gas. Imports of oil and gas are increasing at an alarming rate. The increasing dependence of the country on imported fuel is not only increasing import bill and badly hurting our economy but also increasing vulnerability of our security of energy supply. In electricity supply, share of variable renewables (wind & solar) is less than 3%. Some electricity generation is also based on bagasse while 100 MW is being imported from Iran.

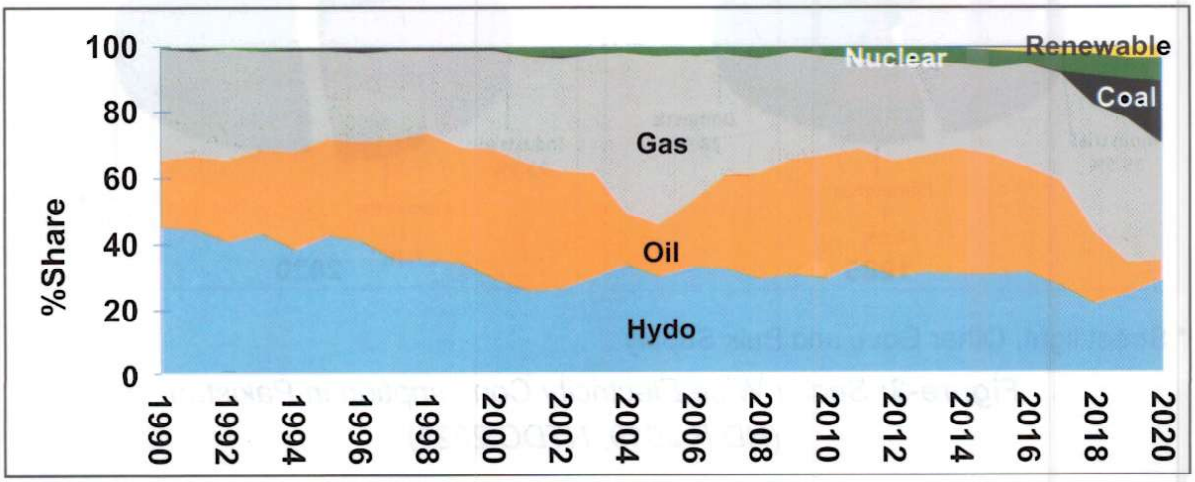


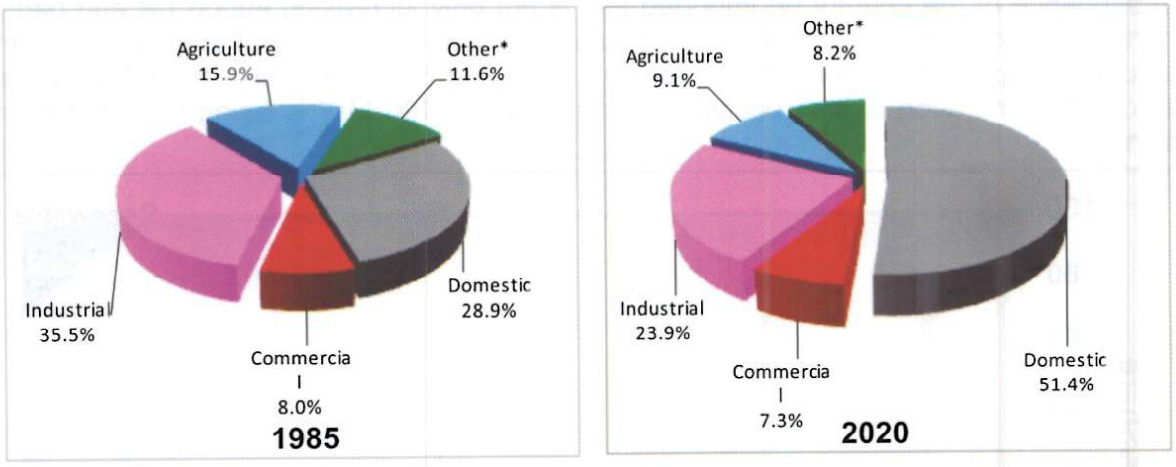
Figure-2: Evolution of Electricity Generation Mix in Pakistan (HDIP 2019, NTDC 2021)

Table-2: Pakistan's Electricity Generation Mix (2019 – 2020)

Sector	Generation (million kWh)	Share (%)
Hydro	38,988	28.8
RLNG	26,816	19.8
Coal	25,966	19.2
Gas	20,615	15.2
Nuclear	9,898	7.3
Oil	8,157	6.0
Wind, Solar, Bagasse, Import	4,819	3.6
Total	**135,259**	**100.0**

Source: [NEPRA 2020]

Along with the inappropriate electricity generation mix, the consumption pattern of electricity in Pakistan is also not sustainable. There has been a significant shift in the electricity consumption from industrial and agriculture sectors (productive sectors) to domestic sector (non-productive sector). The share of industry dropped from 36% to 24% in the last thirty-five years (See Figure 3). On the other hand, the share of residential sector has increased from 29% to 51%. While one cannot deny the significance of domestic energy consumers for social uplift and improved quality of life, there is an urgent need to provide uninterrupted power supply to industrial and agriculture sectors for sustainable socio–economic development on a priority basis.



* Street light, Other Govt. and Bulk Supply

Figure-3: *Sector Wise Electricity Consumption in Pakistan (HDIP 2019, NTDC 2021)*

3. Electricity Supply Options and Domestic Energy Resources

Electricity can be generated by various fuels and technologies. Each fuel and technology has its own pros and cons. No single fuel or technology can fulfil the electricity requirement of a big country like Pakistan. The country has various options to meet the growing demand of electricity i.e., indigenous coal, natural gas, hydro, nuclear and renewables. The future mix of electricity in Pakistan will be governed mainly by the supply potential of the available energy sources, along with their economics and environmental impacts. In future, the availability of indigenous fossil fuels for power generation will be very limited. The recoverable natural gas reserves as of June 30, 2019 were 22 trillion cubic feet (See Table 3). If used exclusively for electricity generation, these reserves can support 13,000 MW of capacity for thirty years. Whereas, natural gas is also required for residential, industrial, transport, and commercial sectors, and for fertilizer production as well. Additional commitments of gas supply for power generation can only be made if some new large gas fields are discovered. In view of the limitations of indigenous natural gas supply, it is also being imported.

Among the indigenous fossil fuel sources available for electricity generation, the only relatively abundant source is coal at present. Total coal resources of Pakistan are reported to be 186 billion tonnes, of which the measured reserves are 8 billion tonnes. These measured reserves alone can support 54,000 MW of power generation capacity for thirty years. Out of these total reserves, 95% are in the Thar coal field. In recent past, the mining of these lignite reserves is initiated through a public-private partnership and using that coal, the first unit of 330 MW capacity started commercial operation in 2018-2019. Recently, another 330 MW also started commercial operation. Likewise, a power generation capacity of 1,980 MW at the field is under construction.

Although, Pakistan is endowed with large hydropower potential (60,000 MW), only 15% of this potential has been exploited so far. Socio–political and environmental issues coupled with projects financing requirements are the main barriers to large–scale development of hydro power. Nevertheless, there is a need to expedite the development of hydro resources both for security of water as well as energy supply. Pakistan is blessed with huge potential of alternative and renewable energy. The country has wind corridors that can accommodate about 50,000 MW (NEPRA, 2020) of wind based capacity and potential for solar power is also high as sunlight is available abundantly almost throughout the country. The role of these renewable resources is expected to increase gradually.

Nuclear power is a proven base–load electricity generation option to enhance the security of supply and diversity of the power system. Pakistan has good nuclear power infrastructure and 49-year experience of safe operation of NPPs. The country is in position to develop its nuclear power programme to meet the growing need of electricity ensuring security of energy supply.

Table-3: Fossil Fuel Resource Potential of Pakistan (as of June 30, 2019)

	Oil (Million Barrels)	Natural Gas (Trillion Cubic Feet)	Coal (Million Tonnes)
Proven recoverable reserves	1499	63.2	7,776
Cumulative production, so far	930	41.2	~ 200
Remaining recoverable reserves	569	22.0	7,576
Annual production	32.5	1.4	5.5
Reserves to production ratio	17 years	16 years	1,377 years

Source: [HDIP 2019].

4. Global Picture of Nuclear Power

Currently, 33 countries / regions worldwide are operating 443 nuclear power reactors / units of about 400 Giga Watt (GW) capacity. The share of these NPPs in the world total electricity generation is about 10%. At present, 52 more NPPs of over 55 GW capacity are under construction in 19 countries/ regions. In addition, many more countries are planning the construction of their first NPPs, including oil rich Kingdom of Saudi Arabia. In future, significant economic growth is projected in Central and Eastern Asia, where nuclear power capacity is expected to increase substantially. According to the recent estimates of International Atomic Energy Agency (IAEA), around 323 GW of new nuclear power capacity would be installed by 2050; raising the total to 715 GW under high case scenario. The IAEA projections, estimate global nuclear installed capacity increase of 21% from 2019 to 2030, 59% by 2040 and 82% by 2050 in the high case scenario. In the low case scenario estimates, the capacity is projected to gradually decline until 2040 and then will start to rebound (IAEA, 2021).

In our region, China has 50 operational NPP units with 48 GW capacity while 14 units of around 14 GW are under construction. China plans to have around 200 GW installed nuclear capacity by 2030 and 400-500 GW by 2050 (WNA-China, 2021). India has 23 NPP units of 6.9 GW capacity. It is also constructing 6 more units of 4.6 GW and plans to increase its nuclear capacity to 63 GW by 2032 (WNA-India, 2021). Bangladesh is constructing two NPPs with Russian assistance, each having 1,200 MW capacity. In UAE, one 1,400 MW NPP is operational while three plants of 1,400 MW each are being constructed by South Korea (IAEA, 2021). Iran's first power NPP of 1,000 MW capacity is in operation while another plant is under-construction. Turkey has signed a deal with Russia for construction of 4 x 1,200 MW NPPs at Akkuyu and construction of three units is underway (IAEA, 2021).

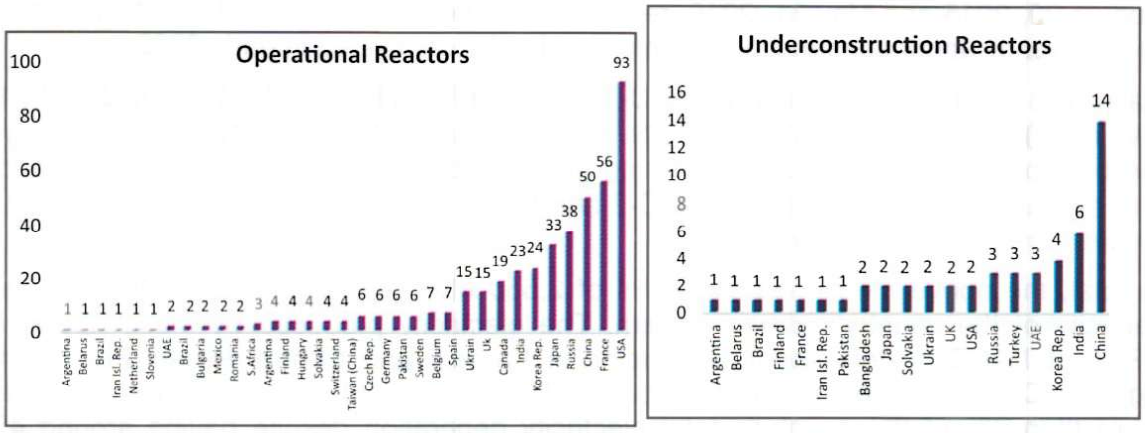


Figure-4: Operational and Under-Construction NPPs in the World (IAEA, 2021)

5. Nuclear Power Development in Pakistan

Pakistan Atomic Energy Commission (PAEC) is the only utility authorized in generation of electricity through nuclear power in Pakistan. In performing its functions, it undertakes planning, sitting, construction, operation, radioactive waste management and decommissioning of all its nuclear power plants.

Pakistan made an entry into the nuclear power club in 1972 when the first unit of electricity was sent to the Karachi grid from the 137 MW Karachi Nuclear Power Plant (KANUPP). When KANUPP was commissioned, Pakistan became the 15th country in the entire world to have set up an NPP. The global politics of embargoes restricted Pakistan's further growth in nuclear power capacity for many years. However, it turned out to be a blessing in disguise as PAEC started efforts to develop necessary infrastructure and soon became able to keep KANUPP operational with indigenous fuel, spares and other technical supports. Operation of KANUPP with indigenous capabilities led to self–reliance and self–confidence. After China had developed an indigenous capability for constructing NPPs in 1991, Pakistan decided to set up a 325 MW Pressurized Water Reactor (PWR) with the help of China National Nuclear Corporation (CNNC) - setting the first example of South-South cooperation in the development of nuclear power.

5.1 Operational and Under–Construction Nuclear Power Plants

The country's first NPP i.e., (KANUPP) of 137 MW nameplate capacity is located at Karachi site. In 2002-2003, after surpassing 30 year of design life, KANUPP was refurbished for life extension. The plant received operation license from the country's nuclear regulator (Pakistan Nuclear Regulatory Authority-PNRA) for the next 20 years, but with a reduced capacity to 90 MW. It has now completed 49 years of safe and successful operation. The KANUPP site's second NPP i.e., K – 2 of 1,100 MW gross capacity achieved the status of commercial operation on May 21, 2021. This NPP was constructed under a twin unit (i.e., K-2/K-3) project. The project contract was signed with China in early 2013 and the ground breaking ceremony was held in November, 2013. The first concrete pour of K-2 and K-3 plants took place on

August 20, 2015 and May 31, 2016, respectively. The project's other 1,100 MW unit (K-3) is currently under construction and expected to be completed in early 2022.

Pakistan's other four operating NPPs (C-1 and C-2 of 325 MW each; C-3 and C-4 of 340 MW each) are located at Chashma site, near Mianwali. These four NPPs are amongst the best performing electricity generating plants in the country, in terms of endurance and availability. Two of these NPPs, C-2 and C-4 made national records of continuous longest operation for over one year.

In total, the above mentioned six NPPs of 2,530 MW constitute 6.3% in the installed capacity of the country's power system. The electricity produced by these operating NPPs of PAEC is delivered to K-Electric in Karachi and Central Power Purchasing Agency (CPPA-G) in the rest of the country. During 2019-2020, these NPPs generated more than 7% of the country's total electricity generation despite having around 4% share in the installed capacity. In current fiscal year (2020-2021), the average share of electricity from these NPPs is more than 8% (see Figure 5).



Figure-5: Nuclear Share in Electricity Generation (NEPRA 2021).

5.2 Indigenous Capabilities of PAEC

By virtue of experience, PAEC has developed a base in operating, maintaining and upgrading NPPs. It has also developed an indigenous know-how in site selection, design, equipment manufacturing, in-service inspection and safety analysis of NPPs. With this background, PAEC can develop a large nuclear power programme towards meeting the energy requirements of the country.

5.3 Human Resource Development

Trained and experienced manpower is a key factor for nuclear power development in the country. Pakistan has ensured continued inputs for its programmes through a large infrastructure for human resource development with several dedicated institutions. Three main institutes that are providing education and training related to nuclear technology, plant operation and maintenance include; Pakistan Institute of Engineering and Applied Sciences (PIEAS), Karachi Institute of Power Engineering (KINPOE) and CHASNUPP Centre of Nuclear Training (CHASCENT). Among these institutes, PIEAS is a degree awarding university and was ranked number one engineering university in 2004, 2012 and 2013 by the Higher Education Commission (HEC) of the country and also ranked

number one in Pakistan by QS Asian University Ranking in 2015. For enhancing their skills and knowledge, PAEC professionals also participate in international trainings, workshops, conferences and seminars being organized by IAEA, and other nuclear energy related organizations.

5.4 Safety Oversight and Interaction with Global Nuclear Community

Pakistan is using atomic energy under the regulatory regime of the Pakistan Nuclear Regulatory Authority (PNRA). PNRA Ordinance 2001, empowers it to regulate all matters pertaining to nuclear power plants and radiation protection. PNRA Regulations specify the national requirements applicable in the domain of nuclear safety, radiation protection and the extent of civil liability for nuclear damage resulting from any nuclear incident.

PAEC professionals share their operational experience with experts of other countries through international meetings, conferences and seminars being organized by IAEA, and other nuclear energy related organizations. All operating and under construction NPPs of Pakistan are under IAEA safeguards. PAEC has been maintaining a good record of safety and, performance of these NPPs is audited and reviewed by international organizations like CANDU Owners Group (COG) and World Association of Nuclear Operators (WANO).

5.5 Nuclear Energy and Greenhouse Gases (GHG) Mitigation

5.5.1 Climate Change Impacts on Pakistan

Pakistan is highly vulnerable to climate change which is a challenging reality for professionals, planners and policymakers. Country's projected temperature increase is expected to be higher than the global average. Projected temperature increase in northern parts is expected to be higher than in the southern parts of the country. The climate change will impact all socio-economic sectors of the county, e.g., agriculture, water, energy, health, coastal areas, infrastructure, etc. It will impact the food security of the country mainly through reduced crop productivity and adverse impacts on livestock health, productivity and reproducibility as well as through increased production losses caused by extreme events (GOP, 2010).

During the year 2010, Pakistan faced several extreme weather events i.e., drought in the beginning, heat spell in March which reduced wheat production, tropical cyclone in June, temperature of 53.7°C at Mohenjo Daro (4th hottest ever recorded in the world history), followed by severe floods in August. The floods during the period 2010-2014 resulted in monetary losses of over US$ 18 billion with 38 million people affected, 3.45 million houses damaged and 10.6 million acres of crops destroyed. Likewise, over 1,200 people lost their lives due to the unprecedented heat wave in Karachi in 2015 (Pak-INDC, 2016; Pak-SNC, 2018).

Hunza River Basin in the Karakoram Range is facing the effects of climate change. Rapid melting of glacial ice mass is causing expansion of the existing lakes and creation of new lakes. There will be serious impacts of formation of these new lakes posing a greater threat to adjacent villages. Formation of Ataabad Lake since 2010 has already displaced thousands of people and damaged their properties.

For the period 2000-2019, the Climate Risk Index (CRI) of Germanwatch (2021) ranked Pakistan among the 8 most affected countries by the catastrophes originating from climate changes.

Energy is essential for socio-economic development. On Pakistan's energy sector, some likely impacts of climate change, identified in Second National Communication and National Climate Change Policy, included:

a) Reduction in reliability of hydro electricity supply due to changeable water resources. Variations in water supply will be further aggravated by increased sedimentation of major reservoirs;

b) Direct damage to energy and electricity infrastructure due to extreme weather events which will increase operational costs;

c) Peak electricity demand spike will become sharper with increased demand for space cooling and refrigeration requirements, and need of water pumping for irrigation would increase due to global warming;

d) Warmer air and increase in water temperature used for cooling will affect efficiency of nuclear and other thermal power plants.

5.5.2 National Objectives of GHG Mitigation

Direct GHGs, i.e., CO_2, CH_4 and N_2O, are emitted during fossil fuel combustion, raising of livestock, rice fields, industrial processes, and decomposition of waste/ biomass.

Total GHG emissions of the country are above 406 million tonnes (Pak–SNC, 2018). The GHG inventories of Pakistan for the years 1994, 2008 and 2015, showed that the energy sector was the largest source of GHG emissions in Pakistan. The share of energy related emissions was more than 45% in 2015 with average annual growth rate of 3.7% during 1994-2015 (Pak–SNC, 2018). The energy supply system of the country is much cleaner than the world average. However, with increasing share of coal in the energy mix, the system will become gradually carbon intensive in future.

An important goal of the Paris Agreement is limiting the long–term temperature well below 2°C above pre–industrial levels and pursuing efforts to limit this increase to 1.5°C above pre-industrial levels. In order to achieve this goal, parties are agreed to reach global peaking of GHG emissions as soon as possible, recognizing that peaking will take longer for developing country parties, and to undertake rapid reductions thereafter (UN, 2015).

In the Intended Nationally Determined Contribution (INDC), Pakistan has shown its commitment to reduce the GHG emissions subject to transfer of technology which has been recognized in the Paris Agreement.

5.5.3 Nuclear Power: A Low Carbon Option

5.5.3.1 Global GHG Mitigation Potential of Nuclear Energy

Global GHG emissions have been increasing almost continuously since the start of the industrial revolution and have nearly doubled since 1970. The production and use of energy currently account for around two thirds of the total GHG emissions and electricity

generation in turn accounts for one third of these energy related emissions. Annual emissions would have been around 2 giga–tonnes (Gt) of CO_2 higher over the past decade if electricity from NPPs had instead been supplied using the average global fossil fuel generation mix. The IAEA estimates that over the period 1971-2018, nuclear power avoided a total of 74 Gt CO_2 (IAEA, 2020).

According to the Intergovernmental Panel on Climate Change (IPCC), in order to limit the average global temperature increase to 1.5°C, global energy production and use need to be fully decarbonized by around 2050. Electricity production, like other energy sectors, faces the immense challenge of shifting almost entirely to low carbon energy sources in just 30 years from a system dominated today by fossil fuels. All four scenarios of IPCC's 2018 Special Report on Global Warming of 1.5°C call for a substantial increase in global nuclear power capacity. In the IPCC pathways compatible with the 1.5°C goal, average nuclear generation triples by 2050 from 2018 levels (IAEA, 2020).

For meeting the targets of GHG mitigation, several countries are recognizing the role of nuclear energy. The UK government has considered nuclear power (existing large size and future small modular reactors) as a way to help the country to achieve the four-fold increase in clean energy. Nuclear power is providing about 16% of the UK's electricity but the existing fleet of reactors is approaching the end of their lives. The government has a commitment to remove coal–fired electricity from the mix by the year 2025. Energy white paper of the UK government issued in December 2020, defines that decarbonising the energy system over the next thirty years means replacing – as far as it is possible to do so – fossil fuels with clean energy technologies such as renewables, nuclear and hydrogen. Analysis of the white paper suggests additional nuclear beyond Hinkley Point C will be needed in a low-cost 2050 electricity system of very low emissions. Hinkley Point C which is under construction will provide 7% of the country's current electricity needs (UK, 2020).

Since 2016, some nuclear power plants in Untied States which were near to permanently shutdown due to high operating costs, are receiving subsidies of $10/ MWh under Zero-Emission–Credit (ZEC) program for GHG mitigation. New Jersey has recently extended ZEC for two plants until 2025 (NW, Vol. 62-No.17/18).

After Fukushima accident, nuclear power faced worst scenario in Japan. The share of nuclear power which was 25% in 2010, remained zero percent for two years after the accident. This share has reached to 6% in recent years. Now, Japan's Agency for Natural Resources and Energy is leaning towards keeping the share of nuclear power between 20%-22% in the target of 2030 power mix. Japanese Prime Minister recently said that the government will try to reduce GHG emissions by 46% by 2030 compared to emissions in the year 2013. The role of nuclear power is being highlighted in Japan to realize this target (NW, Vol. 62-No.20).

5.5.3.2 GHG Mitigation by Nuclear Power in Pakistan

Nuclear power is a low carbon energy source because it does not emit harmful pollutants and GHGs responsible for climate change. Annually, a 1,000 MW NPP avoids around 6 million tonnes of CO_2-eq. GHG emissions compared to a coal fired power plant with same capacity (see Figure 6).

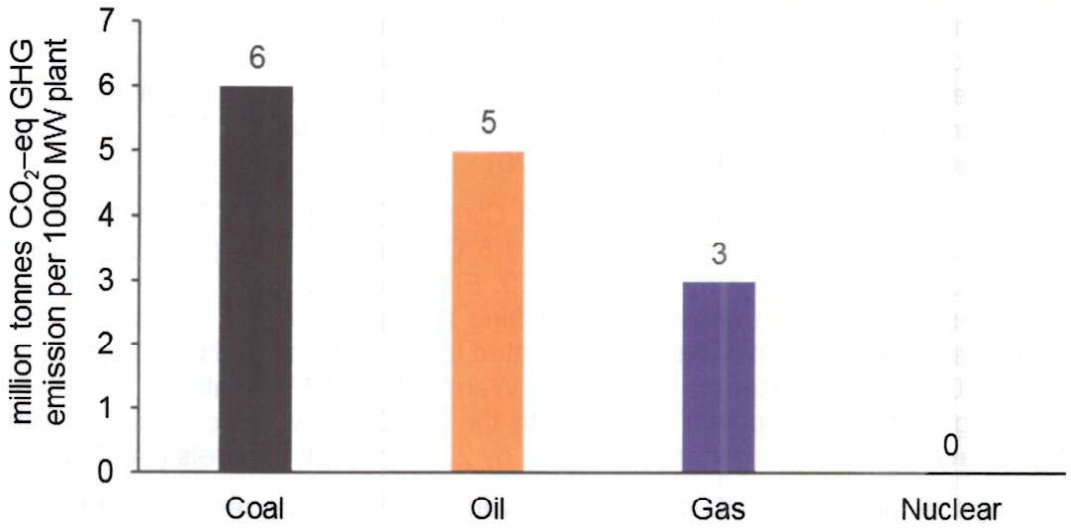


Figure 6: Annual Greenhouse Gas Emissions from Various Electricity Generation *Sources* [based on WNA, 2011]

The six operational NPPs of Pakistan are contributing to global efforts for mitigation of CO_2. By June 30, 2020, cumulative avoidance of CO_2 by operating NPPs was about 65 million tonnes.

Developing nuclear energy has also been recognized as a CO_2 mitigation measure in national low carbon goals/ policies. National Climate Change Policy 2012, emphasizes climate change mitigation by increasing share of nuclear power, hydroelectric power and renewable energy in Pakistan. The Second National Communication of Pakistan recognizes the change in energy mix, the development of renewable energy resources and the increase in nuclear and hydroelectric share as an opportunity to achieve the objectives of reduction in carbon emissions in the energy sector (Pak-SNC, 2018).

6. Role of Nuclear Power in Electricity Scenario of Pakistan

In Pakistan, 44% of the commercial primary energy needs are met through imports that consume more than 60% of the export earnings. Nuclear power helps to enhance energy security as it reduces dependence on imported fuels. In addition, nuclear power is a reliable source for baseload generation. Owing to round the clock availability of an NPP, unlike hydro plants (output of which varies with season and weather conditions) and natural gas plants (in cold months when natural gas is diverted to the residential sector for heating purposes), the nuclear power enhances power system reliability in Pakistan. Wind and solar PV systems are unreliable as output of these plants is subject to daily and seasonal variations, and weather conditions. Resultantly, the NPPs operate at very high capacity factors in the power system of Pakistan (see Figure 7).

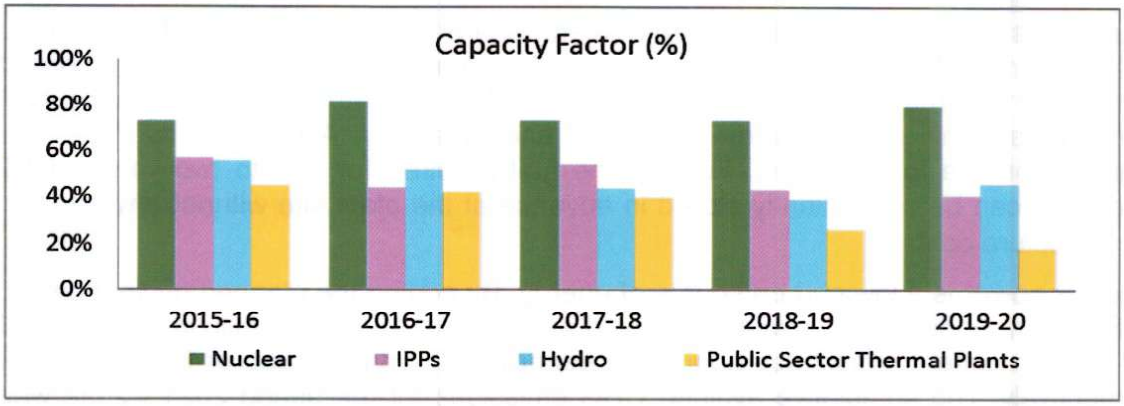


Figure-7: Performance Comparison of NPPs with Other Plants (NEPRA 2020)

It is fact that NPPs are more capital–intensive than fossil fuel powered plants. However, the fuel cost of an NPP is much lower therefore, the overall cost of electricity is comparable with other baseload power plants even during the loan payback period. The advantage of nuclear power is that once a nuclear power plant has been built, the cost of nuclear electricity generation is relatively independent of the fluctuation in the price of fuel since fuel cost is a very small part of the total cost of nuclear electricity. Favourable cost economics, coupled with freedom from the import dependence on fossil fuels, makes nuclear power attractive particularly for the energy deficient, oil–importing countries like Pakistan. Further, once built, nuclear power plant requires very low foreign exchange for import of fuel. In Pakistan nuclear energy is also an economical source of energy. Per unit cost data of NPPs along with power plants using other sources of electricity generation is presented in the Figure 8.

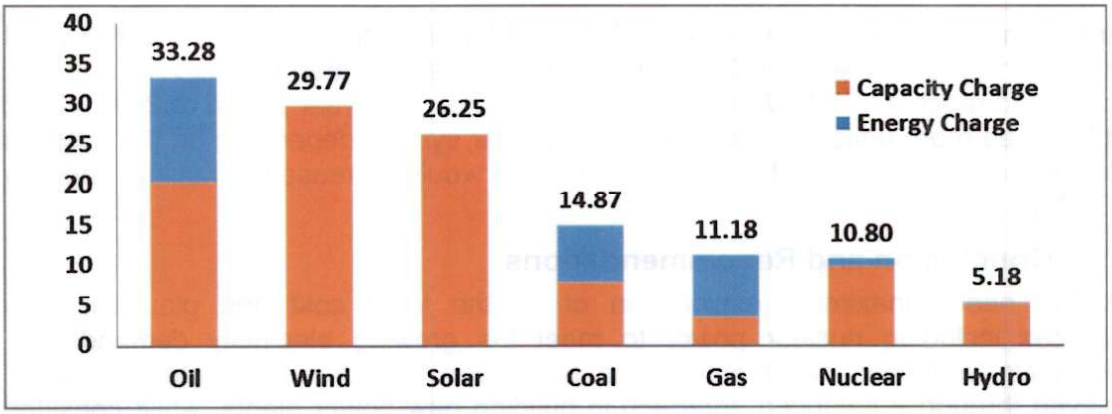


Figure-8: Average Electricity Generation Cost (Rs./ kWh) in 2019 – 2020 (NEPRA 2020).

As mentioned earlier, the operating costs of NPPs are very low due to low fuel cost as compared to other thermal power technologies. Therefore, after loan repayment, all NPPs produce electricity at less than Rs. 6 per unit, which is quite low in comparison to LNG, wind and solar.

Pakistan imports a large part of its energy that not only eat–up our foreign exchange earning but also our energy supplies are vulnerable to fuel price fluctuation, supply

disruptions, international political environment, and economic conditions. Nuclear power is less vulnerable to fuel supply disruptions due to international and national conflicts, transport infrastructure damages/ blockade, etc. With such unique characteristics, NPPs contributes significantly towards security of energy supply. A refuelled NPP can keep working for one to two years. Further, the fuel required for one to two years of NPP operation can be conveniently stored in advance at the plant site without any additional infrastructure cost.

Nuclear power is a low carbon source of energy. By adding the planned nuclear capacity of Pakistan, annual GHG avoidance would approach to 18 and 50 million tonnes of CO_2 by 2035 in case it substitutes equivalent generation by natural gas or indigenous coal, respectively. The cumulative avoided GHG emissions for the period 2021 - 2035 would be 160 to 445 million tonnes CO_2 by nuclear energy.

7. Nuclear Power Development Plans

Pakistan has planned to expand its nuclear power generation capacity. For this purpose, PAEC has developed soft expertise with the cooperation of international organizations for implementation of nuclear power project including Integrated Nuclear Power Planning, Site Evaluation Studies, Design & Engineering of nuclear plants and equipment, Safety & Regulatory Compliance, Environmental Impact Assessment, Public Acceptance, etc. In addition, PAEC has well established infrastructure for human resource development in nuclear science and technology in the country. The education and training institutions of PAEC, engaged in skill development and PhD studies in cutting edge science and technology disciplines, are equipped with laboratories, simulators, libraries. The institutes are therefore ranked among the top R&D centres and universities of the country.

The current installed nuclear capacity is 2,530 MW. With the completion of K-3 plant at Karachi and construction of C-5 plant at Chashma, nuclear capacity is most likely expected to reach 4,630 MW by 2030. During the next five-year period of 2031 - 2035, a slot for three more units can be found in the power system depending on the economics of technology and enhanced indigenization which would increase the nuclear capacity to 7,930 MW.

8. Conclusion and Recommendations

Pakistan needs maximum exploitation of all the least cost and plausible energy resources including nuclear power to meet the growing electricity demand due to prospective economic development and population growth. This exploitation can be achieved through a balanced approach in building new power plants, while considering economics, securing of energy supply, reducing environmental pollution, minimizing energy imports, etc.

To achieve these objectives, it is recommended that capabilities of research and development institutes be synergised for capacity building and local industrial infrastructure be upgraded. Research and development in areas like solar, wind, biogas, hydrogen production, fuel cell, energy efficiency, energy storage and end use technologies should be encouraged and promoted.

Though, Pakistan has come out of the dreadful electricity supply crisis, still, the larger electricity generation capacity based on imported LNG and coal has increased instability in the power system fuel prices and security of supply. Storage of fossil fuels is costly and the fossil fuel imports are vulnerable to supply disruptions because of its transportation disruption, prices and exchange rate fluctuations, foreign exchange requirements, international political situation, etc.

PAEC is developing and maintaining Pakistan's Nuclear Power Programme since its inception. For a safe, reliable, and efficient operation of the existing NPPs, PAEC is collaborating with international agencies such as IAEA, WANO, COG, etc. These plants are generating 11-12% electricity of the country and contributing to global efforts of CO_2 mitigation. By June 30, 2020, cumulative avoidance of CO_2 by operating nuclear power plants was about 65 million tonnes. With the construction of planned nuclear power capacity, the CO_2 annual avoidance by nuclear generation in Pakistan would approach to 18 and 50 million tonnes by 2035, assuming gas and coal generation replacement by the nuclear generation respectively.

To reduce import dependency, PAEC is gradually increasing indigenization of nuclear power technology by developing its engineering design and manufacturing capabilities. Furthermore, education programmes related to nuclear engineering and other related disciplines have also been introduced in different universities. This will expand the country nuclear power programme and will contribute in reducing the country's power system costs which is backbone of national power policy for affordability of people and growth of economy. Taking the challenges of enhancing indigenization in plant construction, fuel development, qualitative manpower development, and making the use of international experience and collaboration, PAEC looks forward to construct four more nuclear power plants and increase the nuclear capacity to 7,930 MW by 2035.

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