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Nuclear Power Programme of Pakistan

1. Introduction

Total installed electricity generation capacity of Pakistan is 19,342 MW. During the year 2004-05[1], the power system of Pakistan generated 85,629 million kWh of electricity (*Table 1*) of which almost half (50.8%) was by natural gas. The rest was from hydro (30.0%), oil (15.8%), nuclear (3.3%) and coal (0.2%). Though nuclear power has a small share in the electricity mix of Pakistan, the country took a major step in this field 35 years ago, in 1971, by commissioning a 137 MWe Pressurized Heavy Water Reactor (PHWR) type power plant, Karachi Nuclear Power Plant (KANUPP), through a turn-key agreement with Canadian General Electric. Despite the keen interest of Pakistan in building additional nuclear power plants, it took some two decades to start construction of the second nuclear power plant owing to an unfavorable international environment coupled with the lack of indigenous technological and industrial capability for independent design and construction of nuclear power plants. The second nuclear power plant of the country, a 325 MW Pressurized Water Reactor (PWR) type, Chashma Nuclear Power Plant unit-1 (CHASNUPP-1), constructed by China National Nuclear Corporation, also through a turn-key agreement, started commercial operation on 15th September 2000.

KANUPP has been functioning safely during its designed life of 30 years. After various inspections and reviews carried out by international experts, KANUPP approached the Pakistan Nuclear Regulatory Authority (PNRA) for a life extension of another 15 years. After fulfilling the regulatory requirements, KANUPP got a license from PNRA to operate at a reduced power. Additional safety upgrades are being implemented for its operation at a higher power to be allowed by PNRA. CHASNUPP-1 is operating very well. Its life-time capacity and availability factors are 68.4% and 73.4%, respectively. *Figure 1* shows that the performance of CHASNUPP-1 is improving. In recent two years, the capacity factor of CHASNUPP-1 has been well above 80%.

The successful functioning of KANUPP and CHASNUPP-1 has given the country great confidence and a sense of direction to plan more nuclear power plants in a manner that would progressively lead to a high degree of self-reliance. A contract between Pakistan and China was signed in May 2004 to construct the second unit at Chashma (CHASNUPP-2). The construction is in progress. The first concrete pour for the nuclear island was carried out on 28 December 2005. CHASNUPP-2 is scheduled to be commissioned in the year 2011.

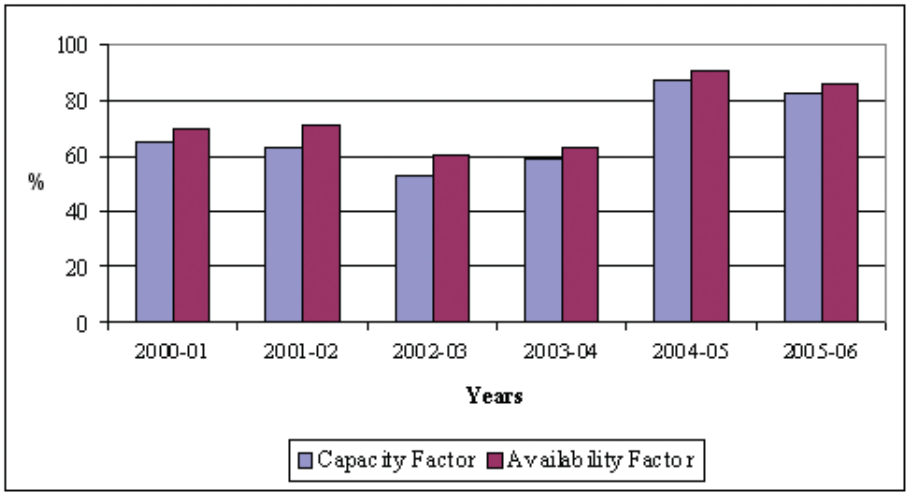

Figure 1: Operational Performance of CHASNUPP-1

Keeping in view (i) the increasing demand of electricity, (ii) limited energy resources, and (iii) 35-year experience in nuclear power industry, the Pakistan Atomic Energy Commission (PAEC) has formulated a 25-year nuclear power programme. The government of Pakistan (GOP) has approved the plan. The programme envisages a nuclear capacity of 8,800 MW by the year 2030 corresponding to a

Table 1: Power sector in Pakistan

Fuel/Technology	Installed capacity on 30-6-2005	Electricity generation during year 2004-05
	MW	Million kWh
Hydro	6,494	25,671
Oil/Gas	12,273	56,988*
Coal	150	175
Nuclear	425	2,795
Total	19,342	85,629

Source: HDIP (2005)

[1] Unless specified otherwise, years are financial years i.e 2004-05 is from 1 July 2004 to 30 June 2005.

Table 2: Grid electricity demand projections

Year	Baseline scenario		LEG scenario	
	Electricity demand	Peak demand	Electricity demand	Peak demand
	TWh	MW	TWh	MW
2005*	61	14,502	61	14,502
2015	151	31,888	121	24,923
2020	230	48,173	160	32,937
2025	361	75,636	211	43,693
Average annual growth rate (2005-25)	9.3%	8.6%	6.4%	5.7%

* Actual data from HDIP (2005) and NTDC (2005)

share of 5% in the total installed electricity generating capacity of the country. In pursuit of this programme, PAEC will enhance indigenization capability to gradually increase local content to reduce the capital cost of nuclear power plants. For the future, efforts will be made to increase unit capacity from 300 MW to 600 MW and then standardise at 1,000 MW. This paper will briefly discuss the nuclear power programme of Pakistan.

2. Electricity demand projections

Electricity consumption in Pakistan has been growing at a higher pace compared to economic growth due to increasing urbanisation, industrialisation and rural electrification. From 1970 to the early 1990s, the supply of electricity was unable to keep pace with demand that was growing consistently at 9-10% per annum. In the early 1990s, the peak demand exceeded supply capability by about 15-25%, necessitating load shedding of about 1,500 - 2,000 MW. On the demand side, there was a weak link between the electricity price and demand, which failed to manage the demand. On the supply side, the main reason behind this capacity shortage was the inability of the public budget to meet the high investment requirement of the power sector, despite the allocation of a high share to this sector. During the 1990s, the economic growth rate of Pakistan declined to a level of 4-5% per annum from a level of 6% per annum in the 1980s.

Along with this decline, there have been real increases in the price of electricity, although substantial cross subsidies are continuing. Furthermore, there have been changes in legislation resulting in a large increase in the self-generating capacity installed in the industrial sector. All these factors contributed to a slowing down of electricity demand on the national grid, i.e. electricity demand in 1998-99 was 2.9% lower than that of 1997-98.

The level of economic activity (Gross Domestic Product - GDP) and its structure are the most important factors which drive energy and electricity demand. Due to the economic reforms of the GOP, the economic growth of the country has been increasing again, resulting in an increase in electricity demand on the national grid. After many years, distribution companies are unable to meet the electricity demand and have announced schedules for load shedding. GOP is envisaging 6%-8% economic growth during the next two decades. Considering the economic growth targets of GOP, the Applied Systems Analysis Group (ASAG) of PAEC has projected the energy and electricity demand of Pakistan, using MAED methodology, in a country study (ASAG, 2004) carried out under the Regional Co-operation Agreement (RCA) of International Atomic Energy Agency (IAEA).

The study considered two scenarios of energy and electricity demand for Pakistan representing two levels of economic growth. The Low Economic Growth (LEG) scenario is based on the GDP growth targets set by the GOP in October 2003, i.e. envisaging an average GDP growth rate of 6.1% per annum in the period 2002-25 (NTDC, 2003). In the year 2004, GOP increased the GDP growth targets to 8.3% per annum during 2002-25 (GOP, 2004 & NTDC, 2004). The Baseline scenario is based on the increased GDP growth targets. Both the scenarios have common demographic assumptions based on demographic targets of the Population Policy of Pakistan (GOP, 2002). With the above-mentioned targets of economic growth and assumptions for demographic parameters, GDP per capita of Pakistan rises from US$ 466 in year 2002 to US$ 2,0602 and US$ 1,276[2] in the year 2025 in Baseline and LEG scenarios, respectively.

Corresponding to the above-mentioned assumptions, electricity demand reaches a level of 361 TWh and 211 TWh in 2025 in Baseline and LEG scenarios, respectively. Projected electricity demand has been translated into

[2] In US dollars of year 2002.

demand for grid electricity and peak demand on the basis of assumptions made by Planning and Development Division of GOP for T&D losses, auxiliary consumption and load factor in the country and assuming declining trend in self-generation. The peak demand rises to 75,636 MW and 43,693 MW in Baseline and LEG scenarios, respectively in year 2025 from 14,502 MW in year 2005 (*Table 2*).

GOP is envisaging high economic growth as considered in Baseline scenario of ASAG (2004). Though ASAG (2004) has formulated energy/electricity supply strategies for the both Baseline and LEG scenarios, in the following sections, this Paper discusses only electricity supply mix corresponding to the Baseline scenario.

3. Future electricity supply mix

Two optimal electricity supply mixes have been obtained, with the help of the MESSAGE model, corresponding to two scenarios of nuclear power development.

- The first scenario (Baseline) assumes maximum exploitation of the hydro resources, optimistic development of coal resources, limited import of gas (3.0 billion cubic feet per day by 2025) and an indigenous moderate nuclear power programme with the help of the People's Republic of China.
- The second scenario (Favourable International Environment - FIE) assumes availability of indigenous energy supplies as in the Baseline scenario, but with high import of gas (6 billion cubic feet per day by 2025) and an expanded nuclear power programme. Currently, there are international embargos on the transfer of nuclear power technology to Pakistan, and the People's Republic of China is the only supplier of nuclear power plants and their components. The expanded nuclear power programme assumes that Pakistan will be able to acquire advanced nuclear power plants from Western countries. These plants will have a shorter construction period, lower investment costs and higher plant factors compared to plants imported form China, with increasing local participation, as assumed in the Baseline scenario.

The MESSAGE model optimises an objective function under a set of constraints. *Table 3* reports upper limits imposed on capacity additions on alternative sources of electricity generation. The capacity additions based on gas are dictated by the availability of indigenous and imported gas. In order to fill the gap between demand and supply there is no limit on the addition of oil-fired generation and oil imports.

The following fuel prices (delivered), in constant US dollars of year 2002, have been assumed for the power sector: domestic natural gas: US$3 million BTU: imported natural gas: US$3.50 million BTU: furnace oil: US$4.70 million BTU; diesel: US$7.10 million BTU; and domestic coal: US$ 3.59 million BTU.

The total installed capacity of the power sector, obtained with the help of the MESSAGE model, is given in *Table 4*. Against each period, the total capacity indicates net existing after retirement and the additions up to that period. For both the scenarios, the model builds the whole capacity allowed on nuclear according to a given schedule showing the competitiveness of nuclear power in the future expansion of the power system of Pakistan.

The electricity generation mix for both scenarios has been compared in *Table 5*. In the FIE scenario, nuclear power and natural gas based electricity generation replaces the coal and oil based electricity generation. The share of nuclear power increases in the FIE scenario compared to the Baseline scenario due to the higher installed capacity and higher plant factor of nuclear power plants. In both scenarios nuclear power has a modest share in electricity generation i.e 5.1% in the Baseline

Table 3: Upper bounds on additional capacities for electricity generation

MW

Fuel/Technology	**Scenario**	**2006-2010**	**2011-2015**	**2016-2020**	**2021-2025**	**Total**
Hydro	Both	1,588	3,798	8,175	4,048	17,609
Nuclear	Baseline	-	900	1,200	1,800	3,900
	FIE	-	900	1,200	3,000	5,100
Indigenous coal	Both	1,800	2,700	4,200	5,400	14,100
Renewable (Wind)	Both	450	600	800	900	2,750
Renewable (Solar)	Both	50	50	50	100	250
Gas-fired Combined Cycle	No Limit. But depends upon supply of gas.					
Combustion Turbine	5% (fixed) of the new installed capacities of all other technologies.					
Oil-steam	No limit. It will meet the gap between demand and supply.					

Note: - = nil

Table 4: Installed capacity of electricity generation for Baseline and FIE scenarios

MW

	2005*	2010	2015	2020	2025	Share in 2025 (%)
Baseline	**19,342**	**27,500**	**36,932**	**54,159**	**81,879**	**100.0**
Hydro	6,494	7,881	11,883	20,058	24,106	29.4
Combined Cycle	6,950	13,175	17,346	20,259	18,646	22.8
Combustion Turbine	308	457	942	1,839	3,276	4.0
Coal steam	150	150	150	2,343	14,250	17.4
Oil/Gas steam	5,015	5,411	5,411	5,411	14,652	17.9
Nuclear	425	425	1,200	2,400	4,200	5.1
Renewable	0	0	0	1,850	2,750	3.4
FIE	**19,342**	**27,500**	**36,870**	**54,117**	**81,526**	**100.0**
Hydro	6,494	7,881	11,883	20,058	24,106	29.6
Combined Cycle	6,527	13,175	17,287	24,261	39,289	48.2
Combustion Turbine	338	457	940	1,837	3,259	4.0
Coal steam	150	150	150	150	2,161	2.7
Oil/Gas steam	5,445	5,411	5,411	5,411	4,561	5.6
Nuclear	425	425	1,200	2,400	5,400	6.6
Renewable	0	0	0	0	2,750	3.4

* Actual data from HDIP (2005)

Table 5: Electricity generation

TWh

Generation Source	Scenario	2005*	2010	2015	2020	2025
Hydro	Baseline	25.7	34.8	53.8	91.9	113.4
	FIE	25.7	34.8	53.8	91.9	113.4
Gas	Baseline	43.5	70.2	95.3	130.8	119.7
	FIE	43.5	70.2	94.9	151.3	255.3
Oil	Baseline	13.5	14.8	27.6	21.8	78.8
	FIE	13.5	14.8	27.6	19.3	12.5
Coal	Baseline	0.2	0.7	0.7	15.1	92.6
	FIE	0.2	0.7	0.7	0.7	13.2
Nuclear	Baseline	2.8	1.9	7.8	15.6	27.5
	FIE	2.8	1.9	8.2	16.6	37.6
Renewable	Baseline	0.0	0.0	0.0	4.5	6.8
	FIE	0.0	0.0	0.0	0.0	6.8
Total		**85.6**	**122.4**	**185.1**	**279.7**	**438.6**

* Actual data from HDIP (2005)

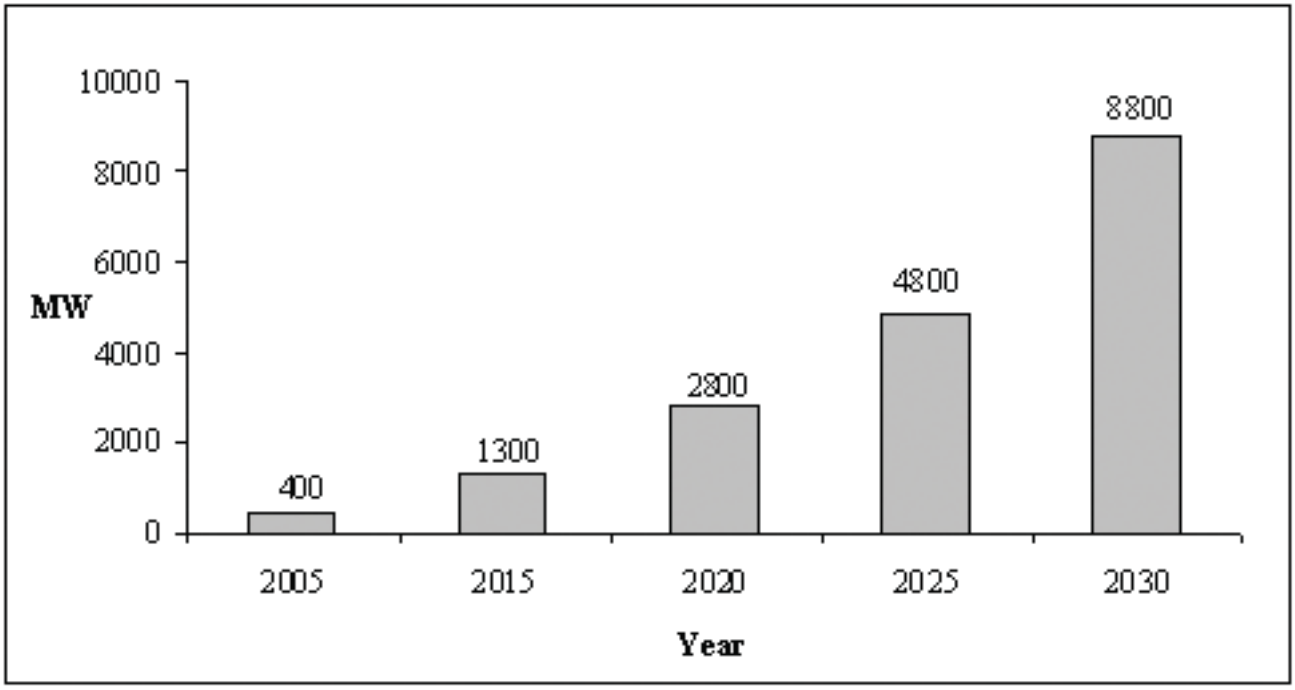

Figure 2: Nuclear power programme of Pakistan (GOP, 2005)

scenario and 6.6% in the FIE scenario by 2025, mainly due to constraints on the building of nuclear power plants.

4. Nuclear power programme of Pakistan

The Government of Pakistan's plans and targets for economic growth and higher standard of living of people will require a large increase in energy and electricity supply. Pakistan's heavy reliance upon reserves of natural gas for meeting its energy needs for electricity generation, industry, household and commercial sectors, will start declining by 2010 (GOP, 2006). Pakistan has insignificant proven reserves of oil. The proven reserves of coal are large and can make significant contribution to electricity generation, if these can be mined economically. The economically exploitable hydro resource is around 40,000 MW, of which one-sixth has already been exploited. The Alternative Energy Board has been created to exploit renewable energy resources. Though efforts are being made to exploit maximum indigenous energy resources, Pakistan has to import natural gas, oil and/or electricity to meet its future electricity demand. GOP has prepared an Energy Security Plan (GOP, 2005) to decrease reliance on energy imports through maximizing new electricity generation capacity from indigenous energy resources and creating a link between sustainable development and energy.

According to the Energy Security Plan, the present installed nuclear capacity of 400 MW is to be enhanced to 8,800 MW by 2030, comprising 2 units of 300 MW, 2 units of 600 MW and 7 units of 1000 MW capacity. *Figure* 2 shows the nuclear power programme envisaged in the Energy Security Plan (GOP, 2005). This target will correspond to a share of about 5.4% in capacity and 8% in generation in 2030. This plan is close to FIE scenario of ASAG (2004).

5. Implications of the developing nuclear power programme

5.1 INVESTMENT PLAN

Total investments required for the construction of nuclear power plants of the envisaged nuclear power programme (beyond CHASNUPP-2) are about US$18-20 billion (2004 prices). CHASNUPP-1 was fully financed by GOP from its Public Sector Development Plans (PSDP). CHASNUPP-2 is being financed through a mix of allocation in the PSDP of GOP and supplier's credit from the People's Republic of China. The next 2-4 units of nuclear power plants will also be financed from PSDP of GOP, together with supplier credit and plough-back of income from CHASNUPP Units 1&2. The subsequent units would be financed from the net revenues of the operating nuclear power plants and supplier's credit.

5.2 FUEL REQUIREMENTS AND LOCAL CAPABILITIES

The natural uranium requirements (as yellow cake, U_3O_8) for nuclear fuel will increase from less than 100 tonnes per year for CHASNUPP-1 and KANUPP at present to about 1,000 tonnes and 1,880 tonnes per annum in year 2025 and 2030 respectively.

The supply of nuclear fuel will be a part of the contracts for the purchase of nuclear power plants. However, it is planned that indigenous fuel fabrication facilities will be developed to reduce dependence on foreign sources as far as possible.

As regards the local potential of meeting the fuel requirement, uranium exploration in Pakistan was started in late 'sixties. Geological and exploratory work carried out since then has resulted in the delineation of favourable areas for uranium deposits in Pakistan. The geological data

compiled with detailed prospection and exploration on such sites indicate a resource potential in excess of 30,000 Metric tons of U3O8. In addition, the mineral sector of PAEC has initiated the "Pakistan Uranium Resource Evaluation (PURE)" programme to enhance the reserves by the identification of new favourable rock sequences in more areas. In view of the existing capability and the above scenario, we are confident that requirements of yellow cake for projected needs can be catered to a significant extent from indigenous resources.

Regarding the potential of local manufacturing of nuclear fuel, it may be mentioned that a CANDU fuel fabrication facility was established in Pakistan in the late 'seventies. Extensive R&D work, process development and optimization and stringent quality control led to the successful performance of the test bundles. Successful in-core performance led to the local production of fuel for KANUPP. Besides fuel manufacturing, the subsidiary production lines for uranium refining and Zr-4 products have also been set up. In parallel, over the years the engineering manufacturing base has been established as required for fuel fabrication. Pakistan has the essential capability for enrichment which can be expanded to meet a part of the fuel requirements for the nuclear power programme. So it is hoped that Pakistan may be able to meet its needs in fuel fabrication in the long term future.

5.3 WASTE POLICY

The capability and infrastructure for the safe management of radioactive waste is an essential pre-requisite for the nuclear power programme. IAEA has rendered valuable help in providing the assistance in the development of the Radioactive Waste Management infrastructure and trained manpower in PAEC. A Waste Management Advisory Programme (WAMAP) mission also visited Pakistan in October 1990. The recommendations by the mission were instrumental in the improvement and strengthening of the overall waste management system in Pakistan.

Currently, the spent fuel generated by KANUPP and CHASNUPP-1 is being stored at the plant sites. Work is in progress to build an interim fuel storage facility for KANUPP. For the final disposal of spent fuel, PAEC is accumulating a waste disposal fund from the revenues of CHASNUPP-1 and plans to continue this policy for future nuclear power plants to meet the future liability of waste disposal. Low level and intermediate level wastes are disposed of according to the environmental guidelines of PNRA. It is hoped that Pakistan will be able to manage its nuclear waste safely in the long term.

5.4 ENVIRONMENTAL ADVANTAGE

Nuclear power plants are environmentally less polluting compared to fossil fuel fired power plants. In fact, nuclear power is the only technology used for electricity generation, which from the very beginning of its development has taken into account the possible environmental impacts. The radioactivity released to the environment by a nuclear power plant is continuously monitored. Unlike the fossil fuel-fired power plants, a nuclear power plant does not produce any carbon dioxide or oxides of sulphur and nitrogen, which lead to adverse environmental degradation through the well known phenomena of greenhouse effect and acid rain.

The envisaged nuclear power programme of Pakistan (beyond CHASNUPP-2) would avoid 22-52 million tonnes of CO_2 per annum in 2030. The cumulative CO_2 avoidance by nuclear power programme, during 2013 (when the first unit will be operational after CHASNUPP-2) and 2030 would be 190-460 million tonnes. The lower value in the range corresponds to equivalent generation by natural gas and higher values correspond to equivalent generation by indigenous coal.

5.5 IMPACT OF INCREASING FUEL PRICES

One important feature of nuclear power is that its fuel cost hardly amounts to 20% of the electricity generation cost as compared to some 50-70% for fossil fuel-fired power plants. This makes the cost of nuclear electricity generation relatively stable and insensitive to possible future escalation in the fuel prices.

At current furnace oil prices oil-fired steam plants are the most expensive electricity generation option in Pakistan. Their levelised generation costs are almost two times those of nuclear power plants, mainly due to high furnace oil prices in international market.

The present (July 2006) natural gas price of US$4.4 million BTU for the power sector in Pakistan is inherently subsidized. The producer price of gas in Pakistan is 67.5% - 75.0% of the international price of crude oil, with increasing discount for oil prices up to US$36/barrel. The producer price of gas is capped if the international oil price is higher than US$36/barrel, as has been the case in recent years. Domestic gas prices are expected to increase to about US$6 million BTU in next few years, if capping of gas producer prices is discontinued to promote local exploration activity; the international crude oil prices stabilize at US$50/barrel (as against US$70/barrel in recent months); and gas prices per unit of energy are about 70% of the crude oil price. The delivered price of imported gas for the power sector is expected to be even higher than US$6 per million BTU. The levelised electricity generation cost of gas-fired combined cycle plants with fuel cost of US$6 per million BTU, corresponds to US5-6 cents/kWh.

Although uranium prices are also increasing, the uranium costs in 2005 constituted only about 20-25% of the nuclear fuel cost of PWRs. The remaining nuclear fuel costs are due to enrichment, fuel fabrication and conversion processes. The PWR fuel costs are typically about 0.6 cents/kWh. Even

if the uranium price increases by 100%, over the 2005 price level, the nuclear fuel cost will still be about 0.8 cents/kWh. Hence, the comparative economic advantage of nuclear power programme is enhanced, if fossil fuel prices increase.

6. Need for international cooperation

Nuclear technology was developed and largely remains in a few industrialised countries. Some developing countries have developed their nuclear power programme either by importing technology or the nuclear power plants. Several developing countries are aspiring to use nuclear power technology for their economic growth. However, the use of nuclear power is suppressed in developing countries mainly due to non-proliferation issues. It is to be pointed out that IAEA has a comprehensive system of safeguards in place for civilian nuclear power plants. The entire nuclear power programme of Pakistan is under IAEA safeguards. To address the issue of proliferation, Pakistan is also working on the concept of "Nuclear Parks" where foreign firms can build and operate the nuclear power plants. Though efforts are being made to develop indigenous capability for nuclear power technology, Pakistan needs international cooperation for its envisaged civilian nuclear power programme.

7. Concluding remarks

In order to achieve the Government of Pakistan's targets and plans for economic growth, increased industrialization and higher standards of living, reliable and sufficient quantities of electricity are required at minimum costs. Nuclear power presents a technologically proven option for the supply of reliable base-load electricity in a cost effective way. In-house analysis shows that nuclear power is part of the optimal electricity supply mix for Pakistan. As fuel costs have a small share in total electricity generation cost, nuclear power is relatively immune to future fluctuations in fuel prices. These advantages, together with increased energy independence, make a nuclear power programme attractive for the sustainable economic development of Pakistan. As the nuclear power programme of Pakistan is working under IAEA safeguards and will contribute to global efforts to reduce carbon emissions, countries of the Nuclear Suppliers Group and nuclear power related international organisations should assist Pakistan in the implementation of its envisaged nuclear power programme. We must act and seek help now to secure our energy needs. 2030 is closer than we think.

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