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ASSESSING THE ROLE OF NUCLEAR POWER IN DECARBONIZING PAKISTAN'S ELECTRICITY SUPPLY SYSTEM BY 2060

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By:

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Abstract

Pakistan is consistently among the top ten countries that are most vulnerable to the climate change induced adversities. During last one and half decade, the economy of the country suffered losses of more than US$ 40 Billion due to extreme events of flooding. Hence, the country is putting all available options to adapt and contribute to the global efforts of reducing the pace of the climate change. At present, the energy sector of Pakistan emits around 45% of the country's total GHG emissions. Hence, the sector decarbonization is of prime importance and significance by developing clean energy supply options. In view of these options, Pakistan electricity supply system is evaluated considering four different cases of GHG avoidance by 2060. For the evaluation, the IAEA's models MAED and MESSAGE are used. The analysis showed that nuclear and hydropower are vital energy supply options to reduce the country's power system GHG emissions. In all the cases, hydropower capacity reached to its maximum limit owing to their cost effectiveness. However, addition of nuclear capacity is found only when GHG avoidance is desired. In the case of 100% avoidance, the required installed capacity of nuclear power capacity is around 43 to 87 GW by 2060. This addition of nuclear power increases the system cost up to US$ 15.2 billion in terms of 2022 and mainly offset coal-based capacity of the BAU case.

Introduction

Pakistan is a developing country having a population of around 230 million that currently grows at a rate of about 2.0% per annum. Of the population, 68% formed the country labour force. This substantial labour force and the country geographical location make an ideal scenario for the expansion and growth of the economy [1]. However, Pakistan is facing the adversaries of the climate change that are severely affecting both social life and the economy. During summer of 2022, besides more than 1,000 lives, Pakistan suffered losses and damages of over US$ 30 billion, mainly by agriculture and household sectors [2]. In 2010, the fatalities due to flood were 1,980 with around US$ 10 billion economic losses [3]. Among other factors, these economic losses reduced economic activities within the country that resulted in missing of the growth and poverty reduction targets.

In the recent past, the worldwide efforts of reducing the greenhouse gases (GHG) emissions signified with the rapid growth of global mean surface temperature (GMST). According to IPCC, the GMST is currently about 0.9^{o}C higher than its pre-industrial level with current growth rate of about 0.2^{o}C per decade. This means that world should act promptly for achieving Net-Zero GHG emissions and thus keep the GMST below 1.5^{o}C i.e., the threshold value [4].

Pakistan ratified the Paris Agreement in 2016 to play its role in reduction of the GHG emissions. The country total GHG emissions assessment by 2018 were around 490 Mt CO_2eq with approximately 45% share of the energy sector. Of the energy sector

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share, around 20% GHG emissions comes from power sector. The sector de-carbonization is therefore of importance, particularly keeping in view the potential growth of the country energy and electricity demand. In this study, efforts are made to evaluate Pakistan's electricity generation system across time horizon 2022 to 2060, considering three cases (60%, 80%, and 100%) of GHG avoidance. In relation to BAU case, the avoidance limit was introduced in the period 2045 that continue till the end of the study horizon. The purpose of the analysis is to assess optimal supply mix of the generation system in all the cases and approximate incremental system cost.

Pakistan's Electricity supply System

Pakistan's power generation system is relatively less GHG intensive due to high share of hydropower. However, the share is gradually declining, from 60% annual contribution in early 1980s to 23% in the year 2022 (Fig-1). The decrease can be mainly attributed to the sustainable growth of electricity demand and to the sector policies, particularly private investment policy introduced in 1994 [5]. This policy permitted private investors to choose generation technology for development with a guarantee of fuel supply and assurance of power purchase by the Govt of Pakistan (GOP). Consequently, low investment cost generation technologies (i.e., oil and gas) prevailed to meet the growing electricity demand while the capacity of hydropower remained the same for more than a decade (Fig-1).

Since Pakistan import a significant share of fossil fuel. Therefore, in the recent past, rise of the oil prices in the international market resulted in severe crises of electricity supply in the country, particularly in mid 2000s. These crises continued for almost a decade that dented the country economic growth and social life. Pakistan therefore aggressively opted to the development of coal-based generation capacity and exploitation of local lignite resources. Consequently, the share of coal in the country generation mix raised from almost nothing to 17% in just five years. In near-term, the share of coal is expected to grow further due to cost effectiveness. However, this expansion of coal also built up pressure on the GOP to support the expansion of clean energy supply options, including nuclear power. The existing installed capacity of nuclear power is 3.43 GW (i.e., 8% of the total installed capacity), hydropower 10.6 GW and of variable renewable sources is 1.3 GW in 2022 [6].

In long-term future, the country electricity demand is expected to grow. Therefore, a firm expansion of the power supply system is certain. Being a developing country, Pakistan has little obligations to reduce its GHG emissions. However, this prospective expansion is an opportunity for the country to develop a clean power supply system and avoid later financial drains due to transition of the system.

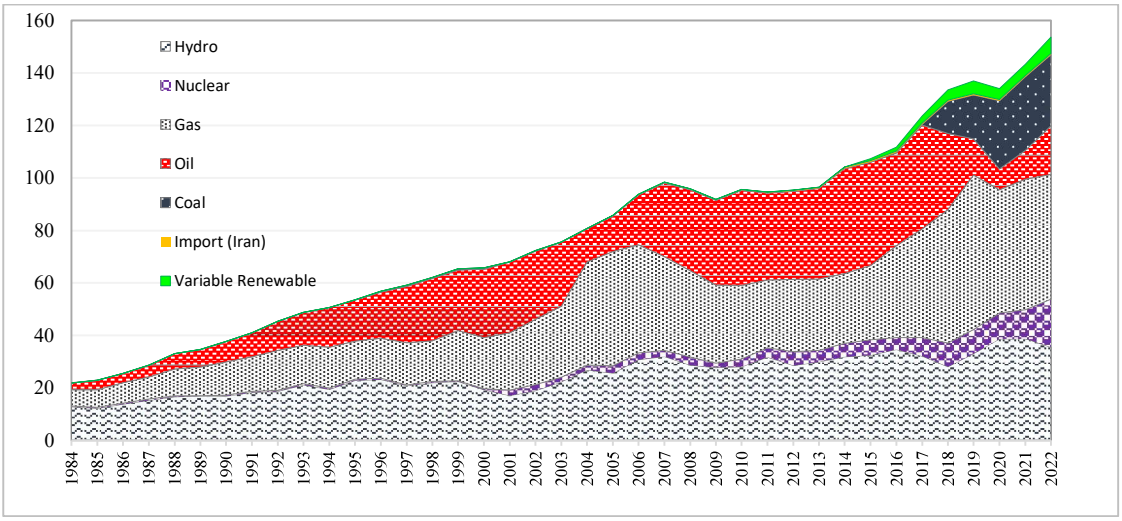


FIG-1. Evolution of Pakistan Electricity Generation System Mix

Methodology

For the analysis, the IAEA's modelling tools MAED and MESSAGE are used. MAED is an accounting model that takes into account existing as well as future projection/assessment of demography, social development, and economic activities to project future energy demand. Using MAED, Pakistan electricity demand is projected to be around 823 Billion kWh by 2060 that was around 143 Billion kWh in 2022. Using MESSAGE, the country's electricity supply system is modelled, taking 2022 as base year. For modelling, a temporal resolution of 288 time slots (i.e., 12*24 or one day per month) is used to incorporate seasonal and daily variations of hydropower and variable renewable sources. MESSAGE has a feature to apply limit or constraints on different variables. The same feature is used to evaluate the supply system in three different cases of GHG avoidance. These cases are limiting GHG emissions by 60%, 80% and 100% relative to BAU case by 2060.

Assumptions and Data

In Pakistan, a discount rate of 12% is used for medium term expansion planning of the power supply system [7]. keeping this in mind and by considering the country's financial and economic conditions, a discount rate of 10% is taken for this study. The Techno-economic data used for modelling of the generation system are given in TABLE-1 [7].

Table-1. Techno-economic Data Used For Modelling

Supply Options	CAPEX	Fixed O&M	Variable O&M	Life	Fuel Cost
	($/kW)	($/kW/Year)	($/MWh)	(year)	($/kwyr)
Nuclear	4,000	73.89	-	60	14.82
Imp. Coal *	NA	26.64	3.02	30	151.37
Local Coal	1,419	96.98	5.93 - 6.21	30	46.36
OCGT	476	13.29	3.14	30	392.12

Supply Options	CAPEX	Fixed O&M	Variable O&M	Life	Fuel Cost
	($/kW)	($/kW/Year)	($/MWh)	(year)	($/kwyr)
CCGT*	NA	13.29	3.14	30	392.12
Solar (PV)	638	7.19	-	30	-
Wind	1177	17.53		30	
Hydro**	1800-3600	9-28	-	50	-
***Imported coal, combine cycle gas turbine, and oil-based generation capacity are excluded by the GOP from future expansion planning of the country's power system.** ****Hydropower project capex is project specific.**					

Findings

Installed Capacity

In the following, Fig-2 shows the installed generation capacity requirements in different cases. From the figure, it is clear that;

nuclear power capacity off-set coal-based capacity with increasing restrictions on GHG emissions. In the case of 100% avoidance, nuclear power capacity reached to 58% (137 GW) of total installed capacity by 2060.

in all the cases, capacity of hydropower increases and reached to maximum level of 39.5 GW by 2040. In this capacity, around 8 GW is committed and the rest is taken in the supply mix due to cost effectiveness.

solar and gas power generation capacity increases by limiting the GHG emissions. However, in the case of 100% avoidance, the share of gas reduced to zero and of the solar to insignificant level.

wind reached to its maximum potential of 12 GW in 2045 in all the cases, mainly due to high discount rate that favours the development of low investment technology earlier.

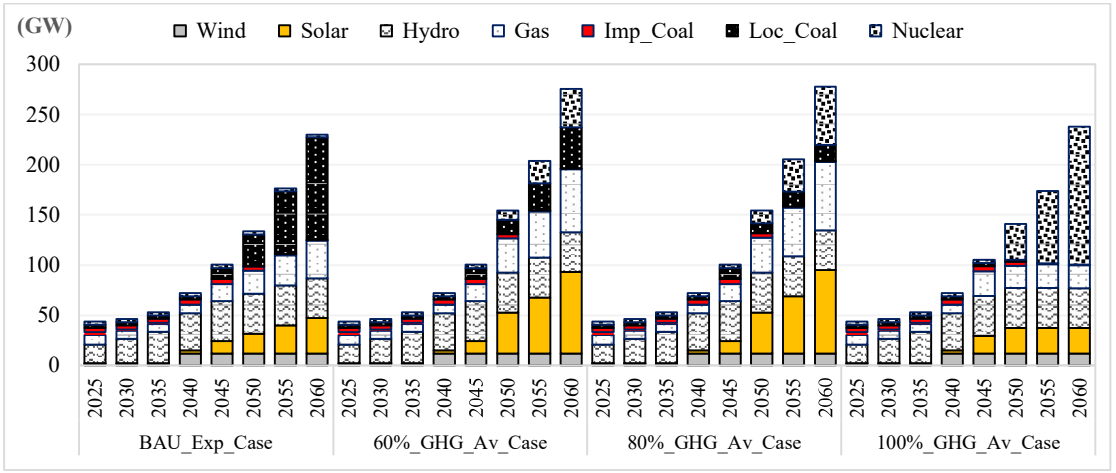


FIG-2. Installed Capacity in (a) BAU Scenario, (b) 60%_GHG_Av_Scenario, (c) 80%_GHG_Av_Scenario, (d) 100%_GHG_Av_Scenario

Generation Mix

The share of the local coal substantially increased in the generation mix of the BAU case of expansion. This means that the power system of Pakistan will become more GHG intensive, particularly after 2040, if the system expansion continues as usual. To offset the coal share, nuclear power is found the most cost-effective alternative option that increases proportionally with the increase of GHG avoidance in different cases, as shown in Fig-3. The analysis also showed that hydropower resources maintains same share in all the cases irrespective of GHG emission constraint. Their share increases and reached to it maximum value by 2040.

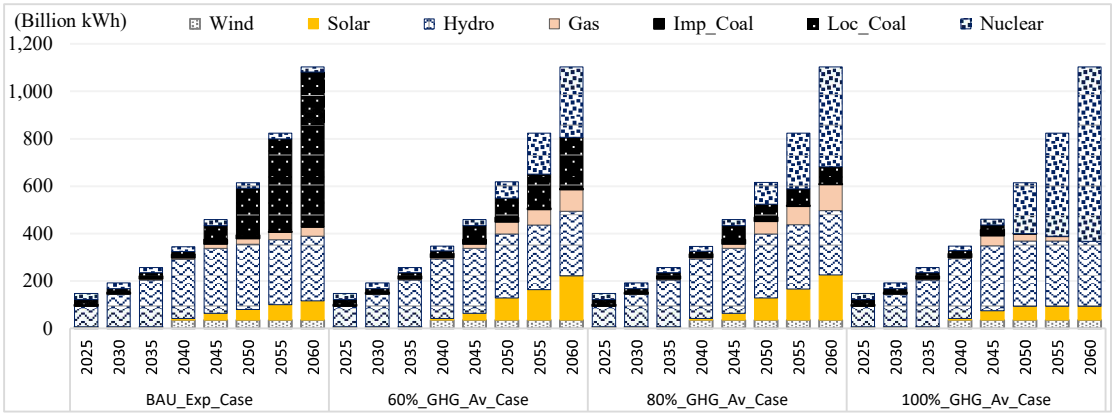


FIG-3. Generation mix (a) BAU Scenario (b) 60%_GHG_Av_Scenario (c) 80%_GHG_Av_Scenario (d) 100%_GHG_Av_sScenario

System Cost

The analysis showed that the system cost increase with increase of GHG avoidance. However, the increase in the cost is relatively low at a lower level of GHG avoidance. For instance, the initial 60% avoidance increases the system cost only by US$ 3.71 Billion (in term of 2022). But later, enhancing the avoidance from 80% to 100% increased the cost by US$ 9.61 Billion, as shown in Fig-4.

It is important to mention that the overall increase in the system cost (i.e., US$ 15.2 Billion) is relatively low. The reason is the presence of huge hydropower share in all

the cases. This means that the cost of GHG avoidance is mainly driven by the addition of nuclear capacity to offset coal as well as gas-based generation capacity.

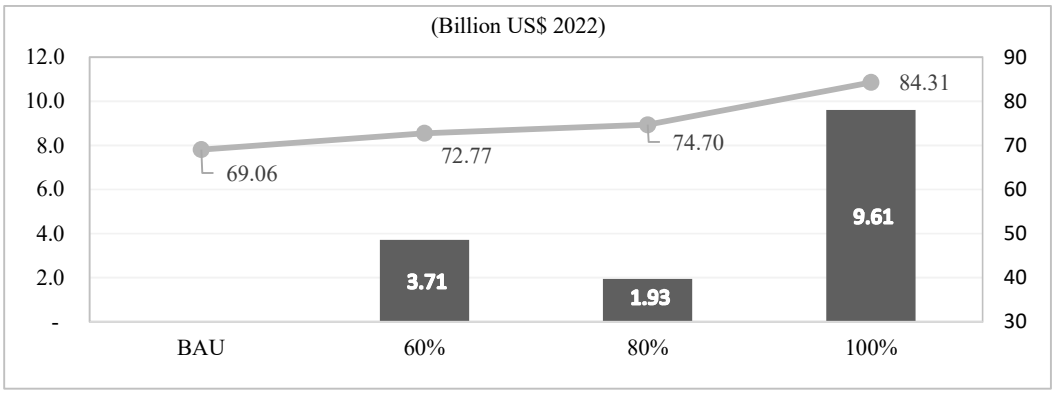


FIG-4. System Total Cost And Step Cost From One Level To The Next

Conclusion

Nuclear power is relatively expensive option of power generation but essential for Pakistan to achieve Net-Zero GHG emissions. Since the electricity demand of Pakistan is growing, therefore, the country can take advantage of the opportunity to add maximum viable share of nuclear during this phase of expansion and avoid the cost of transition. Since the required installed nuclear capacity (137 GW) by 2060 is too high and its development is challenging. Therefore, nuclear power must be part of the country current expansion plans. In addition, the development of hydropower is also important as it can help to follow and serve peaking of the load. Thus, a mix of nuclear and hydropower is the most cost-effective and viable solution to reduce GHG emissions of the Pakistan's power supply system.

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