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NUCLEAR POWER
IN LONG-TERM ENERGY FUTURE

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ABSTRACT

Despite having a large potential for power generation through alternative and renewable energy in Pakistan, the power sector in the country is relying heavily on fossil fuel resources. Nuclear energy provides a reliable, competitive, and environmentally safe option for base-load electricity generation in the country and is better than other alternative resources in many terms. Pakistan started production of nuclear power in 1971 and has good experience of use of nuclear energy. Currently, five plants are operating with total installed capacity of 1,430 MW. Two nuclear plants of 1100 MW each are under construction at Karachi. By 2030, Pakistan plans to have 8,800 MW and by 2050, 40,000 MW installed nuclear capacity. A comprehensive energy policy needs to be devised to meet the long-term future energy requirements, taking into account all the indigenous energy resources especially Thar coal, with minimal dependence on imported fossil fuels, a reasonable share of hydro and renewable energy sources along with the nuclear power. Due importance may also be given to energy efficiency improvement, energy conservation and improvement of transmission & distribution network.

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INTRODUCTION

Pakistan started planning use of nuclear energy for socio-economic development soon after its independence because of low availability of conventional energy resources. With commercial operation of Karachi Nuclear Power Plant (KANUPP) in December 1972, the country started using nuclear power early in the history of commercialization of nuclear power technology. KANUPP plant was built by Canadian General Electric under a turnkey contract. However, very early in KANUPP's life, international embargoes were imposed not only on supply of fuel, spares and technical services for the plant but also on further import of nuclear power plants (NPP) and its technology. It was challenging for Pakistan Atomic Energy Commission (PAEC) to keep operating the plant without vendor support. The engineers and scientist rose to the challenge and KANUPP was kept operational with the indigenous efforts of fuel fabrication, establishment of technical support system and facilities for production of spares. The plant is still operating after completing the original design life of 30 years, after necessary refurbishments and upgrades as required by the regulator. No further NPP was installed for a long period due to non-availability of vendor.

Construction of Pakistan's second NPP at Chashma began in 1992 with the help of China that was completed in 2000. Chashma site now has four NPPs with the latest one competed in 2017. Two more NPPs of 1100 MW each are under construction adjacent to KANUPP site. The Chashma plants, with combined generation capacity of 1,330 MW, are among the best performing power plants in Pakistan.

Though many energy resources and technology options are available to fulfil energy and electricity needs of Pakistan, however, there are many challenges to develop an energy supply system for sustainable socio-economic development. Major challenges include some constraints inherent to the energy resources, low indigenous industrial infrastructure, rapidly changing energy technologies, affordability, financing, etc. This paper presents experience of use of nuclear power and prospects of its role in future electricity mix of Pakistan especially in the perspective of energy security, reliability and affordability.

To put the nuclear power program in perspective, first we present the status of Pakistan's power sector and domestic energy resources followed by status of nuclear power in Pakistan and worldwide. The next sections describe the need for nuclear energy development in the country and future nuclear power development plans.

2. Status of Pakistan's Power Sector

Pakistan is at very low level of socio-economic development. This is depicted by the low Gross Domestic Product (GDP) per capita of the country. Electricity consumption per capita and GDP per capita of a country have strong correlation. Unfortunately, Pakistan is well below the world average in respect of per capita electricity use and a large population of the country does not have access to electricity. With increasing population and low level of economic development, a sustained high GDP growth rate of energy and electricity supplies will be essential to meet the socio-economic development challenges.

The growth of installed electric capacity remained 7-8% per annum during 1970-2000. However, this growth had been exceptionally low (2%) during 2000-2014, which resulted in severe load-shedding starting from 2007. It adversely affected the economic development besides causing frustration amongst the people. During the last five years, there has been a significant growth in installed electric 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. However, some key problems with the electricity supply system of the country still persist including high import dependence, slow pace of development of indigenous energy resources, non-sustainable electricity supply mix, and inefficient & inadequate transmission/ distribution networks, etc.

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 electricity consumption from industrial and agriculture sectors (productive sectors) to domestic sector (nonproductive sector). The share of industry dropped from 36% to 25% during the last three decades. On the other hand, the share of domestic sector increased from 29% to 51%. While one cannot deny the significance of domestic energy consumers, for social uplift and quality of life, there is an urgent need to maintain uninterrupted power to industrial and agriculture sectors for sustainable socio-economic development.

At present, the total installed electricity capacity is more than 37,000 MW [See Figure 1]. About 56% of this capacity is based on oil and gas. Unlike other countries, oil based electricity generation remained significant during last two decades. Installed hydro-electric capacity is around 26. During 2016-17 the country generated more than 32% electricity using oil. The country imports more than 80% of its oil needs as it has meager oil reserves. Gas based generation also remained 32% that too is increasing reliance on imported LNG. Imports of oil and gas are increasing at alarming rate. Increasing dependence of country on imported fuels is not only increasing import bill and badly hurting country's

economy but also increasing vulnerability of its energy security. The share of nuclear power in the installed generation capacity is only 3.9%, however, it is contributing more than 5% of the country's electricity.

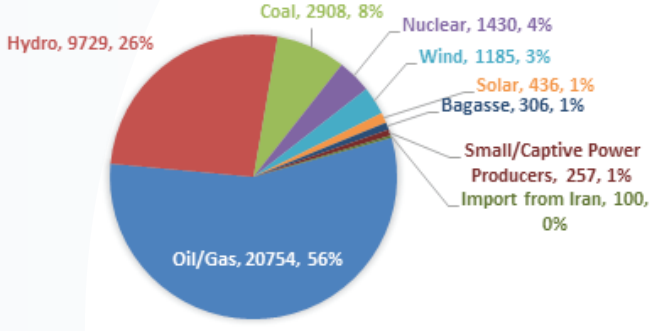

Figure 1: Installed Electricity Generation Capacity in MW (as of October 2018)[2]

Unlike many large economies, coal based electricity generation in the country remained negligible until recently. With recent additions, coal's share has increased to 7.8% while after completion of the under construction plants, share of coal is expected to reach in double digits.

Renewables, wind & solar combined, also have a share of 4.4% in installed capacity, however, their share in electricity supply is small owing to their low availability factors. Some electricity generation is also based on bagasse and 100 MW is being imported from Iran.

3. Domestic Energy Resources

Pakistan energy reserves have increased over time with the global developments in energy technologies, investments in mineral exploration and energy infrastructure development in the country. The resource base is small and pace of resources development is also low resulting in heavy dependence on imported fuels despite very low per capita demand of energy/ electricity. The energy imports have become unsustainable because of fundamental shift in country's energy consumption pattern and low economic growth due to various reasons, the most important being deployment of unsustainable energy mix despite having approved energy/ electricity supply plans. Some important energy resources of the country and their characteristics are given below.

Table 1: Conventional Energy Reserves and Their Worth[3]

Resource	Reserves (Resource Potential)	1000 MW plants that could be fueled for 30 years
Oil	332 million barrels	1
Gas	21 trillion cubic ft.	13
Thar Coal (Proven Reserves)	8 billion tons	54
Total Coal resources	(186 billion tons)	1,300
Hydro	(60,000 MW)	
Shale Oil	(9 billion barrel)	Potential resource[4]
Shale Gas	(105 trillion cubic ft.)	

The recoverable natural gas reserves as of June 30, 2017 were 21 trillion cubic feet. If used exclusively for electricity generation, these reserves can support 13,000 MW of capacity for thirty years. However, natural gas is also required for fertilizer production, industry, domestic, transport, and commercial sectors. Gas reserves are being depleted faster than the rate of additional resources being added as a result of new discoveries resulting in huge shortfall of natural gas in 2017, the country imported 5.11 million tons of LNG. Around 23% of electricity was generated based on imported LNG in 2018. The imports of natural gas depletes significant amount of foreign exchange reserves, the country is in dire need of, in the current economic conditions. The dependence on LNG imports impact our energy security significantly.

The balance of recoverable reserves of crude oil as of 30 June 2017 was 332 million barrels. Projections of conventional oil discoveries are also not encouraging. The indigenous oil reserves can support only one 1000 MW plant for its lifetime, if not used for other sectors like transport, industrial heat applications, etc.

The 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. However, 95 percent of the coal reserves of Pakistan lie in the Thar coal field in the Sindh province. Thar coal reserves were discovered in the early 1990s but never used. Thar coal is of lignite quality with high (30-56 percent) moisture content and of low heating value(average heating value of 8,645 British thermal units (Btu) per pound). Development of Thar coal mines is underway that may play a vital role in power generation during the coming years. Commissioning of the first Thar coal based power plant is scheduled in early 2019. There is need to accelerate the exploitation of the resource to fulfil the immense future energy

needs of the country. This would also facilitate development of mega mining industry in Pakistan.

The identified hydro power potential of Pakistan is about 60,000 MW, of which only 9,623 MW has been exploited so far. Socio-political and environmental issues coupled with project financing requirements remain the main barriers to large-scale development of hydro power. However, there is need to exploit the hydro resources not only for increasing the water security but also for energy security perspective.

The coastal area of Pakistan, mainly in the Sindh province, has a considerable potential for wind energy – the gross wind power potential being around 50,000 MW. There are however technical limits on development of the resource due mainly to intermittency of resource and unavailability of the low cost energy storage technologies. The country needs to exploit the resource to its optimal potential.

The country has also large potential of solar energy. Globally, sharp reduction in solar electricity prices have been reported in different parts of the world, however, such price reductions in Pakistan is not yet been achieved. Further, there are currently technical limits on development of the resource due to intermittency and unavailability of low cost energy storage technologies. However,the resource needs to be exploited to its optimal potential, especially for those areas where electricity grid is not available.

To summarize, the country has limited oil and gas resources; hydro resources are associated with socio-political, environmental and financing issues; coal though abundant is of low quality, and its development is hampered by the daunting requirement of large-scale mining infrastructure; and renewable resources are in their initial stages of development and are not expected to meet large scale base-load electricity requirements. Hence, nuclear power has a viable role to play along with domestic coal in meeting the based-load electricity generation requirements of the country.

4. Nuclear Power Development in Pakistan

In 1972, Pakistan was the 15th country of the world to commission its first nuclear power plant, KANUPP at Karachi. Construction of KANUPP started in 1966. Canadian companies constructed the plant on turn-key basis. After the Indian nuclear weapon test in 1974, Canada unilaterally withdrew support for KANUPP. International embargoes on transfer of nuclear technology and materials were also imposed on Pakistan. It became difficult for Pakistan to keep the plant operational for long term because industrial infrastructure for supply of spares,

services and nuclear fuel was not available. 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. The embargoes/ non-availability of vendor, however, halted further development of nuclear power plants in the country. It took three decades to set up the next NPP; Chashma Nuclear Power Plant unit-1 (C-1) and another decade to commission Chashma unit-2 (C-2). Two more units (C-3 & C-4) of the same type have recently started commercial operation at Chashma site. These plants are amongst the best performing power plants in the country. The plants are supplying over 1,330 MW of competitive electricity to the national grid at high capacity factors. Despite having low share of ~ 4% in installed capacity, NPPs generated around 6% of total electricity during 2017-18 (Figure 2). The average share of electricity from Chashma plants is estimated to be around 7% during 2018.

Construction of Karachi Nuclear Power Plant unit- 2 & unit-3 (K-2 & K-3) with cumulative capacity of 2,200 MW is underway since 2013. The K-2 & K-3 plants are scheduled to be commissioned by 2020 and 2021, respectively.

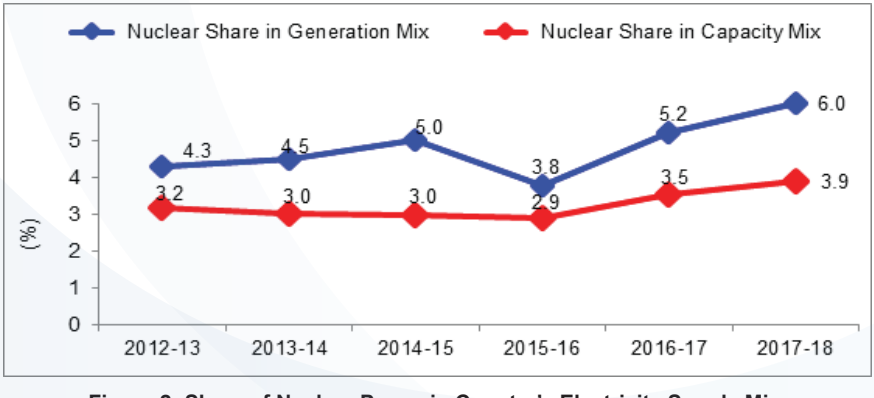

Figure 2: Share of Nuclear Power in Country's Electricity Supply Mix.

5. Global Picture of Nuclear power

Currently, 30 countries worldwide are operating 454 NPPs with over 400 Giga Watt (GW) capacity. These NPPs have over 11% share in global electricity generation. At present, 54 more NPPs of over 55 GW are under construction in 17 countries of which four countries are constructing their first NPP while other 13 countries are already generating nuclear power and consider it an important part of their electricity supply mix. Many more countries are planning construction of NPPs including oil rich Kingdom of Saudi Arabia. Significant growth is projected

in Central and Eastern Asia, where nuclear power capacity is expected to increase significantly. According to the recent estimates of International Atomic Energy Agency (IAEA), at least 312 GW of new nuclear power capacity will be installed by 2050; raising the total to 712 GW. The IAEA projections estimate global nuclear installed capacity increase of 42% from 2016 to 2030, 83% by 2040 and 124% by 2050 in the high case scenario. In the low case scenario, the capacity is projected to gradually decline until 2040 and then rebound to about 2016 level by 2050[5].

In our region, China has 46 operational NPPs with 43 GW capacity while 11 units of around 12 GW are under construction. China plans to have 120-150 GW installed nuclear capacity by 2030. India has 22 NPPs of 6.3 GW capacity. It is also constructing 7 more units of around 5 GW and has plans to increase its nuclear capacity to 22 GW by 2030. Bangladesh is constructing two units with Russian assistance, each having 1200 MW capacity. Four reactors of 1400 MW each are near completion in UAE by South Korea. Iran's first power reactor is in operation and is further planning to build two more reactors with the Russian assistance.

6. Role of Nuclear Power in Energy Security

Nuclear power helps to enhance energy security as it reduces dependence on imported fuels. Nuclear power is a reliable source for baseload generation. Owing to its round the clock availability unlike hydro plants (with seasonal variations) and natural gas plants (with higher demand for residential sector in winter), nuclear power enhances power system reliability in Pakistan. Wind and solar PV systems are unreliable as output of these plants is subject to daily & seasonal variations and weather conditions.

The nuclear power plants are built using state-of-the-art technologies and materials, follow high quality standards and pass through stringent quality assurance and controls processes. Resultantly, the nuclear power plants operate at very high capacity factors (Figure 3). According to the statistics published by National Electric Power Regulatory Authority (NEPRA),[6] if all power plants in Pakistan would have operated, or could operate, at the combined average capacity factors of NPPs, there would have been no load shedding in the country.

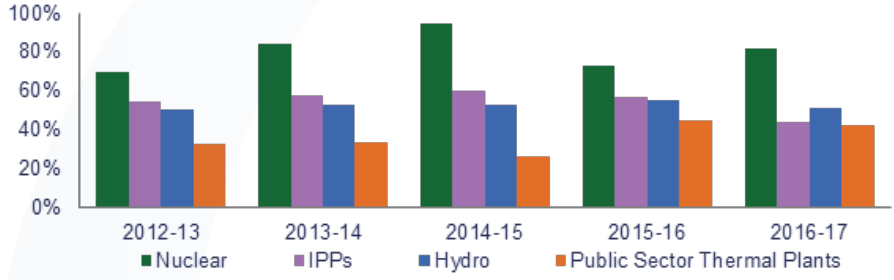

Figure 3: Capacity Factors of Base Load Power Plants in the country[7]

Although, NPPs are more capital-intensive, however, their total lifecycle cost is small compared to the fossil fuelled power plants as depicted from Table 2. Fuel cost of NPP is much lower than the cost of fossil fuel plants. Further, the modern NPPs like K-2/K-3 have 60 years design life compared to 30 years life for fossil fuel power plants. Therefore, total lifecycle costs and levelized generation cost of nuclear electricity is lower compared to fossil fuelled power plants.

Table 2: Life Cycle Costs of Fossil Fuel Plants and a 1100 MW NPP

Cost Factors	Nuclear	Oil*	Coal*	LNG*
Capital Cost (Rs Billion)	522	274	371	161
O & M cost (Rs Billion)	393	258	550	296
Fuel Cost (Rs Billion)	298	4,778	1,837	2,874
Total Cost for 60 years (Rs Billion)	1,213	5,311	2,758	3,331
Levelized Generation Cost (Rs/kWh)	8.11	16.82	8.86	9.08

** Cost of two plants of Coal/ Oil /LNG has been included to compare with 1100 MW NPP having 60 years life.*

The advantage of nuclear power is that once built, the cost of nuclear electricity generation is relatively independent of the fluctuation in the price of fuel since fuel costs is a very small part of the total cost of generation.

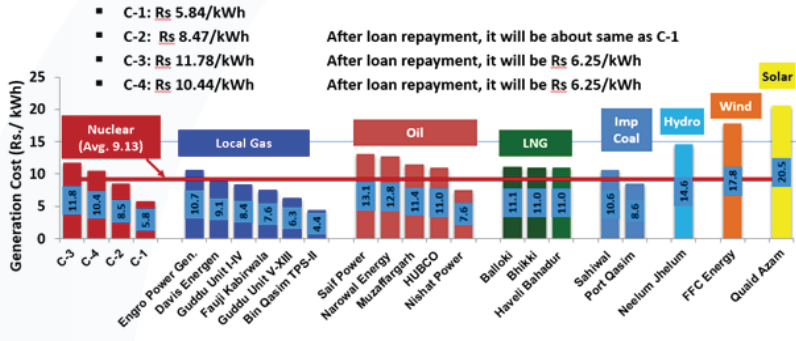

Figure 4: Generation Costs Comparison of Nuclear Plants with some other Power Plants in the Country[8]

Favourable cost economics, coupled with freedom from the import dependence on imported fossil fuels, makes nuclear power attractive particularly for the energy deficient, oil-importing countries like Pakistan. In Pakistan, nuclear is also an competitive source of energy. Per unit cost data of nuclear and other type of power plants is presented in the Figure 4. After loan repayment, all NPPs will produce electricity at less than Rs. 7 per kWh, which is low in comparison with other sources and even lower than the power plants using local natural gas.

Pakistan imports a large part of its energy that not syphens-off foreign exchange earnings but also makes our energy supplies vulnerable to fuel price fluctuations, 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 energy security. Once fueled, a NPP can keep working for one to two years without refueling. Further, the fuel required for one to two years of NPP operation amounts to few tons that can be conveniently stored in advance at the plant site.

Nuclear power is also a clean source of energy because it does not emit harmful pollutants and GHGs responsible for climate change. For instance, a 1000 MW power plants based on coal, oil and natural gas fuels annually emit, on average, 6, 5 and 3 million tons of CO_2, respectively.

7. Nuclear Power Development Plans

In 2005, the Government of Pakistan set the target of 8,800 MW of nuclear capacity by 2030. The current installed nuclear capacity is 1,430 MW and PAEC is endeavoring to meet the target of 8,800 MW by 2030.

Based on the experience gained and the outstanding performance of NPPs in the country as well as the cooperation extended by the Chinese government for supply of large sized 1000 MW NPPs, a self-sustaining Nuclear Power Vision 2050 was approved by the National Command Authority for 40,000 MW installed nuclear capacity by 2050.

PAEC is actively planning to develop additional sites to install future NPPs. Pakistan 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 plant and equipment, safety & regulatory compliance, environmental impact assessment, public acceptance, etc. PAEC is collaborating with international agencies such as International Atomic Energy Agency, World Association of Nuclear Operators, CANDU Owners Group and World Nuclear Association for safe, reliable and efficient operation of nuclear power plants.

PAEC has well established infrastructure for human resource development in nuclear science and technology. These institutions offer education and trainings for different levels of workforce ranging from skill development of technicians to PhD in cutting edge science and technology disciplines. The education and training institutions not only are equipped with laboratories, simulators, libraries but are also backed by other R&D institutes of PAEC.

Having significant nuclear power infrastructure in the country, good experience of use of nuclear power and availability of support of the reliable partner in nuclear technology development, Pakistan is poised to develop nuclear power as envisioned in nuclear power Vision-2050 (Figure 5).

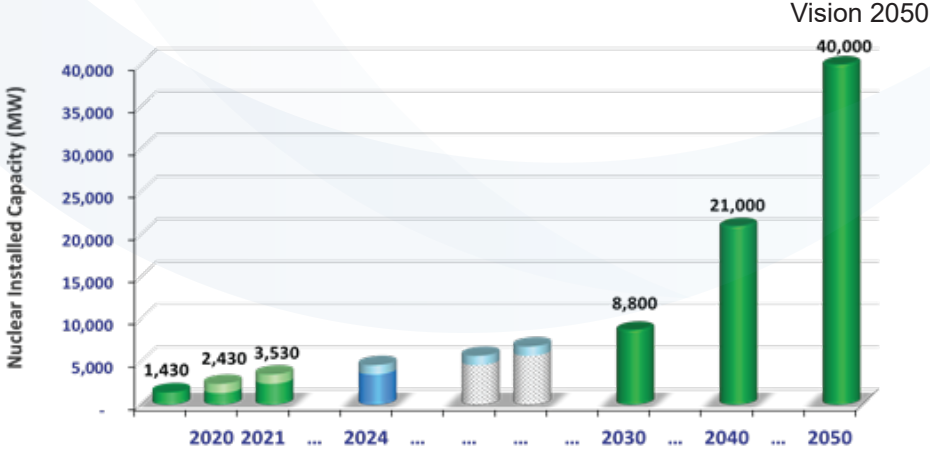

Figure 5. Nuclear Power Development Plans

8. Conclusion and Recommendations

Pakistan needs to have a balanced approach in building power plants using nuclear, hydro, coal, gas and other renewable sources. PAEC is working to achieve 40,000 MW installed nuclear capacity target set by NCA by 2050. PAEC has capacity to develop its human resource having the competency to run and maintain NPPs. PAEC isgradually increasing indigenization in nuclear power technology. In order to achieve the nuclear capacity addition target with significant indigenization, education programs related to nuclear engineering and other related disciplines need to be introduced in different universities of Pakistan.

While there is still a lot of work to do to eradicate the energy crisis, it is recommended that capabilities of research and development institutes be synergized for capacity building. Research in areas like solar, wind, biogas, hydrogen production, fuel cell, energy efficiency, energy storage and end use technologies may be appreciated and promoted.

Though Pakistan has developed sufficient electricity generation capacity through a short term fix based mainly on imported fossil fuels like LNG and Coal, however, this has increased vulnerability of our national security as it is highly dependent on energy imports. Storage of fossil fuels is costly and the fossil fuel imports are vulnerable to supply disruptions because of transportation issues, fluctuating fuel prices & exchange rate, foreign exchange requirements, international politics, etc. Pakistan needs preparation of an energy security plan with due weightage to factors like reliability, affordability, stability of electricity prices, jobs creation, use of indigenous resources and environmental impacts.

Notes

1. National Transmission and Dispatch Company, 42nd NTDC Power System Statistics, 2016-17; Personal Communication with NTDC.

2. Ibid

3. Source: Pakistan Energy Yearbook 2017

4. Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, US EIA, June 2013.

5. Energy, Electricity and Nuclear Power Estimates for the Period Up to 2050, Reference Data Series No-1, 2018 Edition, IAEA.

6. NEPRA *State of* Industry *Report 2017* (Published in 2018).

7. NEPRA State of Industry Report 2017 (published in 2018) and 42nd Power System Statistics 2016-17, NTDC.

8. Nuclear, LNG and Imported Coal tariffs based on determinations and fuel cost adjustments by NEPRA. Remaining generation costs based on NEPRA State of Industry Report 2017, published in 2018

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