Editorial

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Nuclear power option for a low-carbon climate resilient future India

Currently, India is one of the fastest growing economies of the world and the country is also one of the top energy consumers as well as producers in the world. India's total primary energy supply (TPES) is around 900 million tons of oil equivalent (Mtoe). Coal is the largest primary energy source in present scenario. Of the total 900 Mtoe TPES, 600 Mtoe (nearly two-thirds) is being provided by domestic production and remaining is imported[1].

Amongst the different fuels, the share of electricity consumption in India is only 17 % of the total final consumption, which is around 370 GW installed capacity. Even though, the country is the 3rd largest electricity producer in the world, however, our per capita electricity consumption is much below than the world average (India - 1182 kWh; Singapore - 9220 kWh; Malaysia - 4810 kWh; Thailand - 2870 kWh, China – 4600kWh,world average - 3150 kWh, OECD countries - 7990 kWh)2. If we have to provide a comfortable living standard to our growing population, we have to increase significantly the share of electricity in the total energy consumption.

India's population is continuously growing and it is expected to touch 1.7 billion by 2047[3]. The Population Reference Bureau (PRB)4 has also estimated Indian population to reach 1.67 billion by 2050 surpassing that of China. Similar estimates have been made by UN5 for India to have around 1.64 billion population by 2050. In future, India will see substantial increase in power demand on account of population rise, increased urbanization, GDP growth, increase in manufacturing, etc.

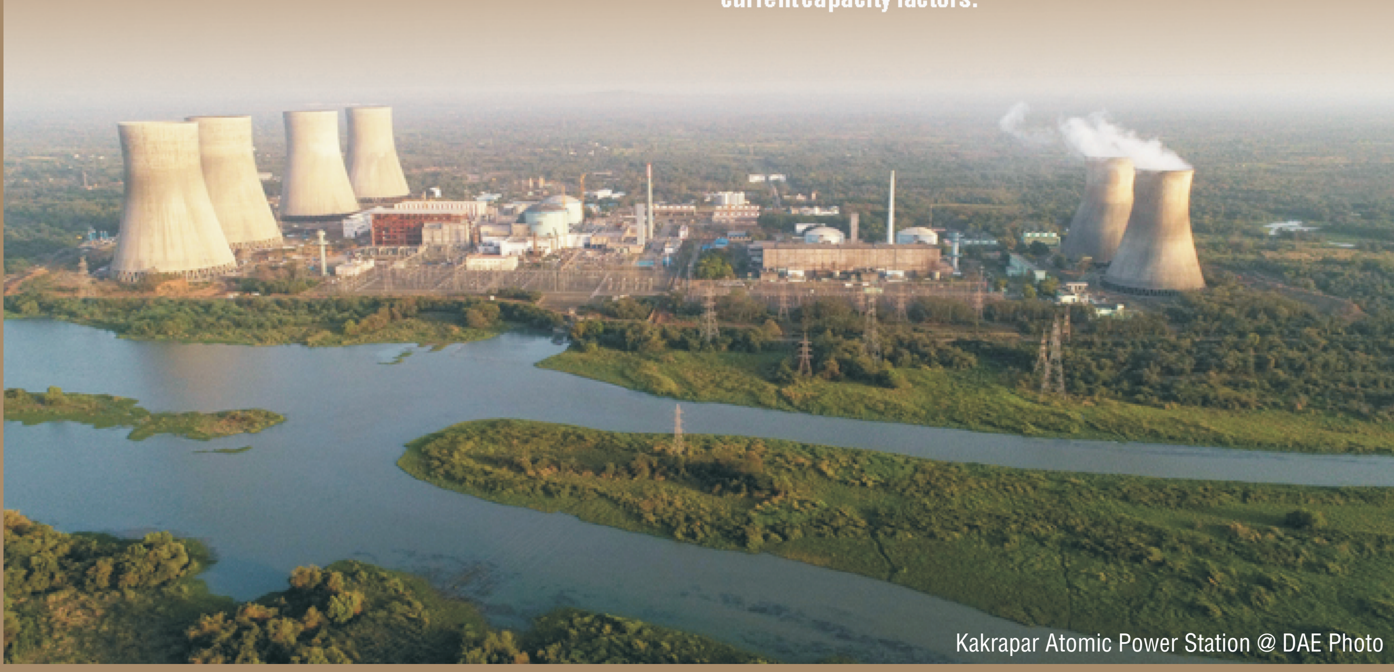
So how much electricity we require by 2050?

Based on a conservative estimate of 1.7 billion population by 2050, the electricity demand can be postulated by the following scenarios:

1) World Average Level (WAL) - meeting world average of ~ 3000 kWh/annum per capita consumption

2) Ambitious -achieving HDI close to 0.9 in developed countries where saturation effect is seen at around per capita consumption of 5000 kWh/annum[6]

These translate to raise the current capacity to 5100 TWh/annum (excluding transmission losses) for WAL target, and if we go for ambitious target, we need to grow to around 8500 TWh/annum (excluding transmission losses) in less than 3 decades. Or, in other words, the country needs to have at least 1200 GW (WAL target) or 2000 GW for an ambitious target by 2050 from the current installed capacity of 370 GW assuming current capacity factors.



Kakrapar Atomic Power Station @ DAE Photo

So what are our options? Electricity Option from Coal

Currently, coal is main driver of electricity production in India, and if it continues to be the main stay, there are other adverse effects in terms of Green House Gases emission (GHG). The potential of CO_2 emission from coal-based plants is ~500 folds more than nuclear, hydro and wind power generation[7]. A few decades ago, the energy policies were more focused for alternate energy sources because of concerns of fossil based fuels getting exhausted by the end of this century. Now the situation demands early induction of clean and green sources of energy much before fossil based resources are exhausted. To reduce the GHG emissions, Clean Coal Technologies are also being developed. The clean coal technology is primarily based on carbon capture and storage (CCS) with additional energy penalty. Moreover, if CCS is used, the costs for electricity production are likely to increase by 45-50%, due to an increase in fuel costs and capital expenditures[8].

To save the environment from the GHG, deep de-carbonization (reduction by one order of magnitude or more in GHG emission) of the electrical energy sector has been felt globally. Towards this, United Nations Framework Convention on Climate Change (UNFCC) was adopted in March 1993 in Rio Convention. Thereafter, Kyoto protocol (2005) and Copenhagen Accord (2009) targeted to limit the future increase in the global mean temperature to below 2°C[9-14]. The next major international commitment took place in 2015 in Paris, which replaced the Kyoto protocol. According to the Paris agreement with 197 countries' participation, the developing countries must be financially supported by the developed nations to meet emission goals[15,17]. In 2019, the British parliament became the first nation to officially declare climate emergency[18]. As of 5th Jan 2020, 25 countries including the UK, France and Argentina have made national declarations of climate emergencies. To achieve the 2050 target for climate stabilization set by the Paris Agreement, the United States would need to reduce CO_2 emissions by more than 97%; in other words, reduce the carbon intensity of its electricity mix from 500g CO_2/kWh to less than 15g CO_2/kWh. In a separate study, researchers at MIT estimated that emissions need to be further reduced to levels approaching 1g CO_2/kWh[19].

In the Indian front, the country submitted its Nationally Determined Contributions (NDCs) to reduce the emissions intensity of Gross Domestic Product (GDP) by 33–35% of 2005 levels by 2030. In addition, the NDCs also targeted 40% fossil-free power generation capacity by 2030 and the creation of an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent (CO_2eq)[20]. However, in 2016, India's CO_2 emissions increased by about 4.7% to 2.5 Gt CO_2. To achieve the Paris agreement target, India needs a substantial reduction in carbon emissions. *It is now predicted that if India abandons further plans to build new coal-fired power plants, it could become a global climate leader and Climate Action Tracker (CAT) would rate it "1.5°C-compatible"*[21]. To achieve the target, IINDC has recommended utilizing the potential for all green energy sources to achieve the above targets, which include renewable energy sources like solar, wind, hydro power, and nuclear.

Energy Option from Renewable sources

Different agencies have assessed maximum potential of solar energy in India. MNRE[22] has estimated that solar potential of the country is around ~ 1640 TWh/annum assuming 3% of the waste land (~ 3% of 500000 Sq km = 15000 Sq km) area to be covered by Solar PV modules. NITI Aayog has estimated the potential to be around 2040 TWh/annum with storage technology available and smart grids in place[23]. Sukhatme[24] has made different postulates for utilization of 5%, 10% or 15 % of barren and uncultivated land in India (200000 Sq km), which can give 1095 TWh/annum - for 5% of land (10000 Sq km); 2190 TWh/ annum -- for 10% of land (20000 Sq km) and 3285 TWh/annum - for 15% of land (30000 Sq km) with 25 % annual plant load factor considering availability of solar energy for average 8 hrs per day and 9 months per year in Indian context. Assuming that, by 2050, storage technology is fully deployed, and there are no plant outages and other losses and around 10 % barren land has been utilized; the potential of solar energy may optimistically be considered to be around 2000 TWh/annum.

Potential for Wind energy

MNRE[22] has predicted maximum wind energy potential for the country as 978 TWh/annum with 100 meter MAST height above ground level.

Hydro power

As per assessment made by CEA[25], India is endowed with economically exploitable hydropower potential of the order of 150 GWe. However, at 60% load factor, it can contribute 788 TWh/annum.

Bio Energy

The bio energy potential has been estimated by MNRE to be 60 TWh/annum.

Total Energy potential by renewable alone is given in following table

Energy	Potential TWh/annum
Solar	2000
Wind	978
Hydro	788
Bio	60
Total	**3826**

It can be seen that, with only renewables alone with the assumptions that 10% barren land area is available for solar (as per Sukhatme[24]) with full deployment of storage technology and smart grids, and with 100 m Mast height for wind, there will be a deficit of 1274 TWh/annum to meet the WAL target of world average of 3000 kWh/annum. However, if we want to achieve HDI of 0.9, there is very large deficit of 4674 TWh/annum to meet the target of 8500 TWh/annum. This roughly translates into deficit of minimum 180 GWe for WAL target and more than 660 GWe for ambitious target assuming 0.8 plant load factor.

So the biggest question is what can meet this large energy deficit of India by 2050?

Obviously, this cannot be met without large scale deployment of nuclear energy.

Nuclear energy is well established as a compact green energy source recognized by IPCC (energy which does not contribute to direct GHG emissions)[26]. One kilogram uranium-235 contains two to three million times the energy equivalent of oil or coal. This implies that for high grade (G4 grade) coal with 6100 kCal/kg calorific value, around 2900 tons of coal per annum is required per megawatt of electricity produced for a plant load factor of 85 %. On the other hand, only 0.2 tons per MW per year natural uranium is required for the same energy production. If we use enriched uranium, the requirement comes down to mere 0.025 Tons per MW per year.

Currently, India operates with 19 PHWRs with an installed capacity of 5160 MW. In addition, new plants under construction are a 700 MW PHWR at Kakrapar, Gujarat and 2x700 MW PHWRs at Rawatbhata, Rajasthan. Financial sanction has been obtained for 2x700 MW PHWRs at Gorakhpur, Haryana. Administrative approval and financial sanction have been obtained for ten 700 MW PHWRs in fleet mode. To increase the capacity building, NPPs with LWR technologies are being built with foreign co-operation. These include 2x1000 MW PWRs at Kundankulam, Tamil Nadu; another 2x1000 MW PWRs are under construction at the same site and financial approval has been obtained for another 2x1000 MW PWR plants. This process has facilitated the import of fuel and fuel security for Indian NPPs from foreign sources through the international civil nuclear cooperation agreement. In addition, negotiations are being held with other vendors for import of light water reactors to increase the capacity building. Apart from this, the country is in the advanced stage of development of a mid-sized Indian PWR which can further enhance the capacity building. For second stage of the three stage nuclear power programme, the Prototype Fast Breeder Reactor is in advanced stage of commissioning. Once this technology matures, it is expected to provide 42000 GWe-year electricity in future. Technology development of molten salt reactors for third stage is also ongoing.

Since nuclear power growth using technologies from 2nd stage and 3rd stage will take some time, we need to explore other technologies including Modular Factory Assembled Nuclear Reactors (MFARs) which can help significant nuclear power growth in next 2 to 3 decades. MFARs are targeted to be built in factories and shipped to sites for installation. They are small, integral type reactors housing all the major components like SG, Pressurizer, pumps inside RPV. The RPV is placed inside a steel containment which is submerged under a water pool.

These reactors have advantage of small core size which requires less amount of decay heat to be removed as compared to large reactors. This enables use of several passive safety systems in its design to remove the small decay heat during any transients or accidents without leading to core melt during design extension conditions thus qualifying for “no impact in public domain”.

Being small size, modularity in design and manufacturing can be established. Modularity will help in fabrication of the major components including the reactor pressure vessel, steam supply systems, and cooling systems in centralized manufacturing facilities and integrating them as a single unit; that means the nuclear steam supply system involving the reactor core, steam generator, pumps and pressurizer, are housed inside the pressure vessel making it a single product. In addition, modularized construction of steel containment saves a lot of civil construction at site. Reduction in civil construction and factory fabrication at site makes possible to connect the MFAR to grid in a small time period. The integrated reactor can be shipped directly to the site for installation and connection to the grid. If several such reactors are to be built, the economy of numbers will compete with the economy of scale. These technologies can be implemented for liquid metal cooled reactors in second stage and molten salt reactors for third stage.

Closure

Nuclear energy has to play significant role in the energy mix to meet the large energy deficit by 2050. Apart from current nuclear reactors, new technologies should be explored which have the ability for rapid multiplication and are extremely safe. Modular Factory Assembled Reactors (MFAR) is a promising option to meet the growing electricity demand of India.

References

1. IEA, India 2020: Energy Policy review, 2020.
2. IEA, World energy balances 2018 Report, 2018..
3. International Energy Agency, 2018 World Energy Outlook: Executive Summary. Oecd/Iea, 2018.
4. Population research bureau, international research data, accessed March 2021.
5. World Population Prospects, UN data booklet, 2019 revision.
6. R. B. Grover, Science Diplomacy Case Studies, Science Resumption of International Civil Nuclear Cooperation, 2019.
7. World Nuclear Association, Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources. WNNA Rep., 2011.
8. Viebahn, P., Vallentin, D., and Höller, S., Prospects of carbon capture and storage (CCS) in China's power sector - An integrated assessment. Appl. Energy, 2015.

9. Jones, T., The economics of climate change. OECD Obs., 1992.

10. Bigg, G., After Rio: The United Nations Framework Convention on Climate Change. Weather, 1993.

11. Oliver, J. E., Kyoto protocol. In Encyclopedia of Earth Sciences Series 2005.

12. UNFCCC, Copenhagen Accord. Nature, 2009.

13. Bodansky, D., The Copenhagen Conference - A Post-Mortem. SSRN eLibrary, 2010.

14. Dubash, N. K., Copenhagen: Climate of mistrust. Econ. Polit. Wkly., 2009.

15. Daniel Bodansky, The Copenhagen Climate Change Conference: A Postmortem. Am. J. Int. Law, 2010.

16. Convention-Cadre des Nations Unies sur les Changements Climatiques, Accord de Paris. 21ème Conférence des Parties, 2015.

17. United Nations, Status - The Paris Agreement. United Nations Treaty Collect., 2019.

18. BBC News, UK Parliament declares climate change emergency. BBC News, 2019. climate emergency declaration.

19. J. Buongiorno, J. Parsons, M.I Corradini, D. P., The Future of Nuclear Energy in a Carbon-Constrained World. MIT Futur. Ser., 2018.

20. India, India's Intended Nationally Determined Contribution 2015.

21. Climate Action Tracker, India - Climate Action Tracker. http://climateactiontracker.org, 2017.

22. Ministry of New and Renewable Energy, Programme/Scheme wise Physical Progress in 2019-20 & Cumulative upto Jan, 2020 Government of India, 2020.

23. India Energy security scenarios, iess2047.gov.in, NITI AAYOG.

24. Sukhatme, S.P. (2012). Can India's future needs of electricity be met by renewable energy sources? A revised assessment. Current Science. 103. 1153-1161.

25. National Electricity Plan, Volume–I, CEA, January 2018.

26. IPCC AR5 WGIII chapter 7 section 7.5.4 2014