High level analysis of costs and benefits of nuclear power plants in India

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1. Preface

India has embarked on plans for a massive addition to its nuclear power capacity. The Parliament was informed by the concerned minister on 3rd January 2019 that 21 nuclear power reactors, with an installed capacity of 15,700 MW was under implementation, envisaged for progressive completion by the year 2031. Whereas it looks very ambitious to plan to add 15,700 MW of nuclear power in the next 12 years as against about 6,780 MW which was actually added in the last 60 odd years, what is even more astounding is the plan to take India's total nuclear power capacity to 250,000 MW by 2075, as per an official plan by the department of atomic energy (DAE).

Such a plan to add enormously large capacity in the next few decades at humongous financial, economic, social and ecological costs to the country should make anyone worried about the overall impacts on our communities. Whereas, the global experience since the Fukushima nuclear disaster has been one of the decision to decommission many operational reactors on the basis of safety aspects alone, and vastly reduced capacity addition plans because of the overall economics of the technology, it is only India and China which have continued with the their plans to increase their total nuclear power capacity by vast margins.

When we also consider the credible concerns on other related issues such as the safety of nuclear reactors, demand for diversion of large chunks of land and water, nuclear fuel availability and nuclear waste management, and disaster preparedness etc. the critical need for a diligent examination of the very policy to continue to invest in nuclear power in the country should become evident. In this context, the absence of a legal mandate for the govt. to undertake the "options analysis" and "costs and benefits analysis" of adding more nuclear reactors in India has become a very serious impediment for the common man to appreciate the true relevance of the ongoing nuclear power policy of the government.

It is also a matter of grave concern to the civil society groups, who have been working for decades on various related issues, including the interaction with the project affected communities, that the concerned authorities have been persistently ignoring the request to provide effective clarification on very many associated policy issues. The complete absence of any diligent analysis of the true costs and benefits of the nuclear power in effective comparison with other techno-economically viable options available to our country by the concerned authorities is the primary concern in this regard.

While advocating a diligent and transparent economic decision making process before adding to the nuclear power capacity, this paper looks at high level issues of costs and benefits of nuclear power reactors in Indian scenario; compares them with other available options; and hopes that the same will enable the civil society groups to effectively persuade the government to arrive at a suitable decision making apparatus based on a diligent analysis of all the associated factors from the overall welfare perspective of the society.

2. High level issues of concern to the civil society

Probably, the most important issue from the perspective of a common man in the case of a enormously costly power project like a nuclear power project is the financial cost of the project and the estimated price of electricity from such a project. It is well known that the capital cost of a nuclear power project is the highest among all the known technologies. One commentator even has remarked that nuclear power technology is the costliest and riskiest technology to boil water. The Environmental Impact Assessment (EIA) report of the recent proposal to expand the capacity of Kaiga nuclear power project in Karnataka has mentioned that it will cost Rs. 20,000 crores for two additional units of 700 MW each at the existing site. This comes to about Rs. 14 crore per MW. But this cost estimation is exclusive of the cost of land required and fresh water supply from the nearby river, which were already given to the existing project in 1992 by the state of Karnataka. The cost estimation also excludes the cost of additional transmission lines required, which has been conveniently left out of the EIA report. If all these costs are taken into account the total cost per MW of this nuclear power project may not be less than Rs. 20 Crores.

Whereas, it is highly deplorable that there is no official estimate of the cost of the proposed Jaitapur nuclear power project (Jaitapur NPP with 6 reactors of 1,650 MWe each) in Maharastra, various estimates on the basis of the experience of similar technology reactors indicate that per MW cost can be anywhere between Rs. 30 crore to 60 crore. This project was originally mooted in 2009 at an estimated cost of Rs. 200,000 Crores. It is also reported by the news agency IANS on 15th Nov. 2017 that the project developer, EDF of France, is reportedly insisting on a hike in per MW cost of around 25 percent from the original quotation of Rs 30 crore per MW. When we also take into account the fact that there have been many safety modifications to the nuclear reactors around the world subsequent to the Fukushima disaster, it will be not be an exaggeration to state that per MW cost of the Jaitapur NPP may not be less than Rs. 40 crore.

As compared to such a huge capital cost, the per MW cost of other power producing technologies in India is estimated to be much lower. Coal power (@ Rs. 6 - 8 Crore/MW), Dam based hydro (@ Rs. 7- 10 crore/MW), Solar and Wind (@ Rs. 5 -8 crore/MW) all can come at much lower capital cost. Even if we make provision for the battery backed energy storage facility for the renewable energy sources (REs), their capital cost cannot be much more than Rs. 10-12 crore per MW, as per the global experience. The true relevance of REs is in the average life time cost of energy or the levellised cost of energy, which is less than or competitive to the per unit energy cost from nuclear power.

The recent international developments also confirm such stark capital cost difference. Credible estimates from various agencies such as (i) Lazard, the investment bank headquartered in New York, (ii) California Energy Commission, US, (iii) DOE and the National Renewable Energy Laboratory (NREL), US, (iv) Energy Information Administration (EIA), US, (v) Department for Business, Energy and Industrial Strategy (BEIS) of UK, (vi) Fraunhofer Institute for Solar Energy Systems ISE, Germany, (vii) Bloomberg New Energy Finance, (viii) International Renewable Energy Agency (IRENA), (ix) European Bank for Reconstruction and Development (EBRD), (x) International Energy Agency (IEA), all indicate that both the capital cost and the levelized cost of energy (LCOE) for nuclear power is generally the highest among various energy sources, even without taking into account the long term waste management costs and the unacceptably high societal costs of any nuclear disaster as happened at Chernobyl and Fukushima.

Such levelized cost of energy in India for any new nuclear power plant is estimated to be not less than Rs. 15 per kWH as has been estimated in the case of Jaitapur NPP, whereas the tenders for solar and wind power parks in 2017-18 have attracted energy prices of less than Rs. 3.00 per kWH. On the basis of the experience from various parts of the world even if the energy storage costs (through batteries) are added to stabilize the steady availability of the new and renewable energy, the levelized cost of renewable energy sources in India may not be much more than Rs. 5 per kWH. The cost of RE technologies and the energy storage systems are credibly being projected to drop further, whereas the nuclear energy price can only increase.

Whereas such high level cost comparison alone should be enough to view the nuclear power with much skepticism because of very many societal level concerns, an effective comparison of various direct and indirect costs and benefits of this technology to the entire nation w.r.t other established technologies can make it even starker.

Other issues of concerns to the larger civil society in the case of nuclear power technology are: (i) the availability of affordable and abundant amounts of nuclear fuel; (ii) true cost to the society of the large tracts of land and water needed, (iii) safety issues in various logistical and operational stages, (iv) safe disposal of various nuclear wastes including the spent fuel, (v) long term safe storage and the associated costs of spent nuclear fuel; (vi) decommissioning costs, (vii) disaster preparedness and the costs associated with any unfortunate nuclear accident of the type in Chernobyl and Fukushima.

3. The critical need to consider various options available to our country

The official stance of the Indian authorities all along has been that the nuclear power plants are required for meeting the growing electricity demand of the people of this country, and it is also implied that that producing electricity is the only objective of a nuclear power project. If it is really so, there should be no reason as to why all the options available to our country to bridge the gap between supply and demand for electricity should not be considered objectively.

But when we consider the long lasting and obstinate silence of the concerned authorities to satisfactorily clarify various concerns of the civil society for decades on nuclear power, it can be said that the defense analysts may not be wrong in assuming that the nuclear material required for the nuclear weapons may be the main objective behind or nuclear power policy. Even if it is so, the question that gets thrown up is: how many more nuclear reactors (in addition to 20 odd reactors we already have) will be required to meet such a demand for spent nuclear fuel for the nuclear deterrence purpose. The defense analysts are of the opinion that India may already have more than enough of such nuclear weapons to destroy the entire humanity many times. So why do we need additional nuclear reactors?

Going by the official line of thinking that nuclear reactors are required to meet our energy needs, let us consider the relative merits/costs of various technologies available to our country. A diligent analysis of all such options/technologies w.r.t their comparative costs and benefits should be the primary economic decision making tool in choosing the nuclear power technology; or for that matter, any relevant technology.

The true relevance of nuclear energy will become evidently clear only when its cost is realistically compared with other sources of electricity; such as from coal and other fossil fuels, hydro, and from renewable energy sources (REs). Its marginal cost should also be compared with other options available to our society, such as the efficiency improvement and demand side management (DSM) options in the existing power demand/supply system.

It should not be acceptable for the people of this country that the nuclear power policy is being pursued at enormous societal costs without establishing the real need for the same through such diligent analysis of costs and benefits, and in realistic comparison with other sources of electrical energy.

4. Costs and benefits analysis

In undertaking a diligent analysis of costs and benefits, fairly accurate data on different components of various direct and indirect costs and benefits are necessary. Sadly, since the government has no mandate to publish such data, many assumptions have to be made, and hence, only a high level analysis is feasible. But even in such a scenario the real costs and benefits of nuclear power to Indian society should be become crystal clear, whereas the definitive numbers of such costs and benefits can only consolidate such results.

In case of some of the costs and benefits, which are intangible, brief mention of the same in words can be listed.

4.1 Financial costs: While some of these costs can be quantified, many of them can only be listed until the official figures are made available. Whereas the scenario of Jaitapur Nuclear Power Project, in coastal Maharastra is kept in focus for such a discussion, the issues are generally applicable to any nuclear power plant site in India.

4.1.1 Capital cost: In the case of Jaitapur NPP (proposal for 6 X 1,650 MWe Reactors), whereas the total cost was reported in the media as estimated to be about Rs. 200,000 crores in 2009, the same has been estimated to be Rs. 360,000 crores by MV Ramana and Suvrat Raju in an article "Cost of Electricity from the Jaitapur Nuclear Power Plant" in EPW of June 2013. It is not known whether the costs associated with the land acquisition, transmission lines, disaster management preparedness, decommissioning, safe disposal of spent fuel etc. are all included. Keeping in objective consideration various developments w.r.t the capital cost of very few additional reactors reported from around the world since then, it seems to be safe to assume that the per MW capital cost in the Indian scenario can be in the range of Rs. 30 to 60 Crore.

4.1.2 Operational cost: Fuel cost, much of which may not be recurring in the case of nuclear power, is the primary component. Other costs such as salaries, water withdrawal from the nearby river or the ocean and purification, spares, transportation costs etc during the operation will have to be included.

4.1.3 The costs of short term and medium term safe keep of nuclear waste, both the ones with low radiation level and ones with the high radiation level, have to be included.

4.1.4 **Reactor decommissioning costs**: Whereas the nuclear reactors were initially thought to be fit for safe operation for about 40 years, there are many cases where the operational life of a reactor are being extended to 60 years, and also intended to be planned for 80 years. Since there is no example of complete dismantling operation of any nuclear reactor as of now, only a rough cost estimate for dismantling an Indian reactor can be assumed. One recent estimate from Japan indicates that the cost for decommissioning 53 commercial nuclear reactors in Japan (excluding the failed reactors at Fukushima) is estimated to total about ¥3.58 trillion, for an average at ¥57.7 billion per reactor. This comes to about 37.5 Billion Rupees per reactor or about Rs. 3,750 Crores per reactor. Another research paper by the title "Cost Estimating for

Decommissioning Nuclear Reactor in Sweden", 2014, has provided a list of US reactor decommissioning projects, according to which the cost of decommissioning for Pressurised Water Reactors vary between $ 0.38 – 3.64 million per MW. At the exchange rate of Rs. 71 per US$, this works out to between Rs. 3 – 26 crores per MW. For the Jaitapur NPP reactors (which are planned to be of 1,650 MWe capacity each) the decommissioning cost per reactor may range between Rs. 4,950 – 42,900 crores.

4.1.5 The costs associated with the **long term storage of spent nuclear fuel** at a site away from the reactor site, such as a deep geological repository for hundreds of years, cannot be ignored, because of the enormous financial/economic costs and risks associated. The fact that there is no proven technology for safe storage of the spent nuclear fuel until its radiation level reduces to a safe level fit for release into atmosphere, should throw up very serious challenges for our country. Only Finland is reported to have been working on such a definitive plan of constructing a deep geological depository, whereas the major nuclear power countries such as US and France have failed to come up with a suitable technology. Even though a deep geological depository is theoretically considered to be the best option, the issues such as the stability of rock or the hard soil surrounding it over thousands of years, the uncertainties associated with the earth quakes in the nearby earth crust, the possibility of subterranean water sources getting contaminated, the suitable language to be used in a warning to the future generations about the burial of nuclear waste at the given location, the willingness of the local communities to accept such a burial site in their community etc. have proved to be intractable. The fact that such spent nuclear fuel has to be kept safe from the atmosphere for hundreds of years (may be even thousands of years) and that the heat due to such radiation should be safely dissipated for such long periods can pose intractable problems for any society. While the total financial cost for such a facility can be horrendous, what is even more worrisome is the total amount of energy required to safely dissipate the heat from the spent fuel for hundreds of years. Undoubtedly, such an eventuality shall mean burdening the future generations with horrendous costs, as well as unacceptable risks, but without an iota of benefit to them. We must not ignore the immorality of such an eventuality. The fact that the half-life of uranium-235/238 (which is used as a common nuclear fuel) is estimated to be few million years, should settle all the issues in this discussion, because the spent nuclear fuel is supposed to be kept away from the atmosphere at least for this period.

The case of The Yucca Mountain Nuclear Waste Repository, as designated by the Nuclear Waste Policy Act amendments of 1987 in US, which was originally scheduled to be developed as a deep geological repository storage facility within Yucca Mountain, Nevada state can be an appropriate example to judge the kind of issues to be faced. The Department of Energy (DOE), US, had estimated in 2008 that the project as a whole would require up to $96 billion for completing. It is reported that already it has cost taxpayers $15 billion. It is also reported that the state of Nevada has already filed more than 200 objections to the DOE's application to build this repository, all of which would have to be resolved — at a cost of up to $2 billion — before the project could go forward.

4.2 Economic Costs: Whereas many of the direct financial costs can be quantified, the economic costs are not easy to quantify, and can only be judged by the kind of impacts they may pose to the local population.

4.2.1 Agricultural production loss: The loss of agricultural and horticultural produces due to the loss of agricultural lands (about 970 hectares in the case of Jaitapur NPP) can only be perpetual.

4.2.2 Loss of livelihood: Not all the people who are forcibly displaced for this project can get suitable compensation because they may not have legal land hold rights; but they will become dispossessed and destitute. Denial of access for the fertile fishing grounds near the plant (in the name of security) for the local fishermen, and the reduced loss of fish population or radiation contaminated fish population (due to the release of vast quantity of hot/warm water from the cooling system to the nearby sea) will not be inconsiderable.

4.2.3 Loss due to loss of export market: the export value of the famous Alphonso mangoes and other horticultural/agricultural products of the region around Jaitapur will face serious threat due to radiation contamination issues.

4.2.4 Loss due to bio-diversity destruction is another major issue on this bio-diversity rich region of Western Ghats wherein Jaitapur is situated. It is hard to estimate the financial value of such a loss but the various reports of the Union govt. on the importance of Western Ghats should raise serious concerns on the overall ecological impacts.

4.2.5 **Costs associated with nuclear accidents**: Such costs alone, when objectively considered from the perspective of the overall welfare of our communities, should make any rational person to become completely antagonistic about the nuclear power plants. Whereas such costs will vary w.r.t different nuclear power plant sites, many credible reports having done research into such costs to the larger society, especially to the project affected communities have indicated unimaginably high costs of any such nuclear accidents. The sites/countries where the two major accidents took place (at Chernobyl and Fukushima) are reported be incurring such associated costs even after many years (more than 30 years since Chernobyl accident). It may never be known as to what is the total cost in each of these cases, but even after many years of the accident the counting of costs is not completed, as more and more of additional costs are being incurred.

While there will be no international concurrence on such costs, the cost of Chernobyl nuclear disaster has been estimated at 1.5 billion euros, with the total cost of the New Safe Confinement Project exceeding 3 billion euros. It took nine years after the fall of the USSR to close the Chernobyl Nuclear Power Station and more than a quarter century to build a new shelter over the damaged reactor.

The cost of Fukushima nuclear accident: Japan's government estimates the cost of cleaning up radioactive contamination and compensating victims of the 2011 Fukushima nuclear disaster has more than doubled, reports say. The latest estimate from the Japanese trade ministry put the expected cost at some 20 trillion yen ($180bn, £142bn, as in Nov. 28, 2016). As per Japan Center for Economic Research, this cost can go upto $626 billion.

In order to realistically include the projected cost of any unfortunate nuclear accident to a given project, it may be acceptable to adopt the probability analysis to determine the credible risk of a nuclear accident and spread the cost of such a factor over a number of reactors.

4.2.6 **Environmental, Health and other social costs:** It is seems almost impossible to put a figure for such costs, because the respective governments either refuse to reveal the actual costs or provide vastly diminished costs. However, there can be no doubt that these costs to the project affected communities and the nation as a whole will be horrendous. The environmental health alone whether during normal operation or due to a nuclear accident of the type happened at Chernobyl and Fukushima can be horrendous. The area around the failed nuclear reactors at Chernobyl and Fukushima are declared as unfit for human habitation for hundreds of years; the agricultural crops grown in the region are known to be contaminated with radioactive substances.

As per Inter Governmental Panel on Climate Change - IV Assessment Report “Emissions from deforestation are very significant – they are estimated to represent more than 18% of global emissions”; “Curbing deforestation is a highly cost-effective way of reducing greenhouse gas emissions.” Large conventional

power projects are all major contributors for deforestation either through dams, buildings, transmission lines and pollutants like coal dust, coal ash and acid rains.
What our society is doing at present is to supply inefficiently derived electrical energy from limited conventional sources at subsidized rates for highly inefficient and /wasteful end uses, for which the real subsidy cost will be debited to the account of future generations.

In this context Mikhail Gorbachev's caution of wisdom cannot be ignored by a resource constrained country like India: "First of all, it is vitally important to prevent any possibility of a repetition of the Chernobyl accident. This was a horrendous disaster because of the direct human cost, the large tracts of land poisoned, the scale of population displacement, the great loss of livelihoods, and the long-term trauma suffered by individuals yanked from their homeland and heritage. Victims of the tragedy were confronted by a crisis which they could scarcely understand and against which they had no defense. The material damage inflicted by Chernobyl, although enormous, pales in significance when compared to the ongoing human costs. The true scope of the tragedy still remains beyond comprehension and is a shocking reminder of the reality of the nuclear threat. It is also a striking symbol of modern technological risk."

4.3 Benefits: It is quite common that the project proponents put a high value to the society from such benefits. Major benefits, which get highlighted, are as follows.

4.3.1 Benefits due to additional power to be generated, and its impact on the local and national economy. Although the installed capacity of Jaitapur NPP is scheduled to be 9,900 MW, the net power available to the end consumers of the grid can be only about 5,700 MW after allowing for the 80% capacity utilization factor (PLF), the station auxiliary consumption (10%), and the T&D losses (20%). Out if this net power of 5,700 MW, Maharastra may get only 2,850 MW as its share from a central sector power station. The issue for the people of Maharstra will be whether this additional net power availability of 2,850 MW is worth various costs and risks associated with a nuclear power plant.
4.3.2 Employment opportunities during the construction and during normal operation. Whereas the employment opportunities during operation can run to few thousands, the actual number of people required during the normal operational regime will be quite less, because of the specialised nature of training required and due to the automation/robotics employed in many activities.

5.0 Options Analysis
In order to achieve the same objective, which is to close the gap between electricity demand and supply, there are very many options available to India. Each of these options should be objectively compared with other options w.r.t to the total costs and benefits. Whereas such costs and benefits in the case of each such options will vary from location to location, a diligently arrived at comparison of all the credible options can provide a very good indicator of the most suitable option for a given location.

5.1 Efficiency improvement measures
The overall efficiency of the power sector as a whole in the country can be said to be one of the lowest as compared to the global best practices. The National Electricity Policy (2005) had stated: "It would have to be clearly recognized that Power Sector will remain unviable until T&D losses are brought down significantly and rapidly. A large number of States have been reporting losses of over 40% in the recent years. By any standards, these are unsustainable and imply a steady decline of power sector operations. Continuation of

the present level of losses would not only pose a threat to the power sector operations but also jeopardize the growth prospects of the economy as a whole. No reforms can succeed in the midst of such large pilferages on a continuing basis". It can be said that this scenario even in 2019 has not improved considerably. It is also a known fact that the cost associated with efficiency improvement measures can be as low as 25% of the costs of a new power plant, while such measures can provide the virtual additional power capacity. A high level estimate indicates that taking the efficiency of the Indian power sector at all levels of the sector (generation, transmission, distribution and utilization) to the global best practice levels can provide virtual power to the extent of 10-20 % of the total installed power capacity in the country. When we also consider the fact that the total installed capacity in the country as of January 2019 is about 350,000 MW, efficiency improvement measures alone can provide the equivalent of 35,000 to 70,000 MW without any of concerns on social, environmental and economic aspects. Whereas such efficiency improvement measures have one time cost but will provide perpetual benefits, any of the conventional technology power plants have long time recurring costs, and some of the environmental and social impacts, such as land degradation and pollution/contamination, can be perpetual.

The erstwhile Chairman of Infrastructure Development Finance Corporation had said in September 2004: "India's power sector is a leaking bucket; the holes deliberately crafted and the leaks carefully collected as economic rents by various stake holders that control the system. The logical thing to do would be to fix the bucket rather than to persistently emphasise shortages of power and forever make exaggerated estimates of future demand for power. Most initiatives in the power sector (IPPs and mega power projects) are nothing but ways of pouring more water into the bucket so that consistency and quantity of leaks are assured." Hence, it goes without saying that efficiency improvement measures alone can prevent enormous costs to our country in the form of avoided losses to set up new power plants such as Jaitapur NPP.

5.2 Demand Side Management (DSM) and energy conservation measures

As per Bureau of Energy Efficiency, a unit of energy saved is considered equal to four units generated as it saves losses on production, transport, transmission and utilisation.

It is pertinent to note that the expenditure for such energy efficiency and DSM measures is estimated to be about 25 to 40% of the cost of new power stations. These measures also require no additional land or natural resources; they also do not contribute to environmental pollution. Instead, by directly/indirectly reducing the electricity demand on the integrated electricity network they eliminate the need for additional conventional power projects, which in turn will reduce the total GHG emissions, and the need for additional transmission lines.

Keeping all these technical, social, economic, and environmental issues in proper perspective we have to diligently address the question: how desirable it is to invest in the construction of more of conventional power projects, including the nuclear power plants, without optimizing the usage of the existing electricity assets.

As per IREDA, under the Ministry of Non-Conventional Energy (NCE) Sources: "Promotion of energy conservation and increased use of renewable energy sources should be the twin planks of sustainable energy policy."

5.3 Other conventional technology sources of electricity

The true relevance of nuclear power to India will become clear when the overall costs and benefits of the same is diligently compared with that of other options such as thermal power (coal, natural gas and diesel power plants), hydro power plants, and renewable energy sources. Whereas each of the conventional type of electricity sources have many serious concerns associated with the demand for diversion of large tracts of agricultural and/or forest lands; huge quantities of fresh water; production of major GHG emissions such as CO_2, Methane and water vapor; reduction in forest and tree cover leading to the loss of bio-diversity; pollutants such as mountains of ash; health issue due to pollution/contamination of air, water and soil etc. the overall costs/benefits due to each of such technologies, when diligently compared with that of a similar capacity nuclear power plant in a given region, can provide a vivid picture of the relative costs/benefits to the society, which in most cases will indicate the highest cost in the case of a nuclear power plant.

Although the other conventional technology power plants (coal, natural gas, diesel power plants, and hydro power plants) have many of the major concerns to the society, similar to that of nuclear power plants, they are without the enormous radiation leakage / contamination risks.

5.4 Renewable energy sources

As compared to any of the conventional type of electricity sources, including the nuclear power, renewable energy sources such as wind, solar, bio-energy, tidal/wave energy, geothermal, have no major concerns listed in section 5.3 above, and are established as least damaging to the environment and sustainable. Initially they were viewed as uneconomical and not reliable; but in recent years they have been found to be much less costly because of their benign nature to the environment.

With the technological improvements in energy storage technologies such as batteries, it has been demonstrated that the overall cost of renewable energy source along with suitable energy storage devises/systems, is much less costly than any of conventional type of electricity sources, including the nuclear power. Not just in capital costs but also in life cycle cost consideration.

Renewable energy sources also have many other advantages such as not needing diversion of agricultural and forest lands/large quantities of water; being suitable to distributed communities; democratic in nature since sun and wind are available everywhere; not requiring complicated grid networks; giving control over their need to the local communities, renewable in nature etc.

The renewable energy sources also have enormous potential, as compared to the potential of the conventional energy sources, and are projected to be able to comfortably meet the entire global energy needs on a sustainable basis.

Whereas the cost of renewable energy sources and energy storage devices are plunging every year, the cost of nuclear power is escalating due to the concerns associated with the safety/waste management.

An assessment of two large nuclear power parks proposed in India by the Institute for Energy Economics and Financial Analysis (IEEFA) finds that: "Given that both projects are first-of-a-kind designs, the government's plan to invest in 12 units of untested GE and Westinghouse nuclear plants will entail significant and unnecessary economic, financial and technological risks. Even the conservative "best-case" scenarios we have considered reveal that the capital costs of building the new power plants and, consequently, the costs of power from them would be far higher than solar sources of electricity. Given that the reactor designs are untested and that there are other risks associated with land acquisition and nuclear accident liability, cost- and schedule-overruns are a near certainty. Even if no significant problems are experienced during construction, IEEFA estimates that the levelized tariffs for the two projects will range from INR 9.05 to INR 26.04 per KWH. This range reflects the substantial uncertainty in the actual cost of building the plants. These tariffs would mean significantly higher electricity prices for consumers unless the Indian government provides long-term and probably unsustainable subsidies."

In an article titled "A path to Sustainable energy by 2030" in Scientific American in November 2009, the authors have illustrated a plan as to how wind, water and solar technologies can provide 100 percent of the world's energy, eliminating all fossil fuels and nuclear power. It has quoted a 2009 Stanford University study which ranked energy systems according to their impacts on global warming, pollution, water supply, land use, wildlife and other concerns. The very best options were wind, solar, geothermal, tidal and hydroelectric power— all of which are driven by wind, water or sunlight. It was found in this analysis that the nuclear power, coal with carbon capture, and ethanol were all poorer options, as were oil and natural gas.

Another article under the title "Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9% of the time", as reported in *Journal of Power Sources* in March 2013, has referred to modelling of many combinations of renewable electricity sources. A major finding of the study was that at 2030 technology costs and with excess electricity from REs displacing natural gas, the electric system can be powered 90%– 99.9% of hours entirely on renewable electricity, at costs comparable to today.

Of huge importance in this overall context is a written testimony to the United States House of Representatives Committee on Energy and Commerce Democratic Forum on Climate Change (November 19, 2015, Washington D.C.) by Mark Z. Jacobson, a Professor of Stanford University under the title "Road maps for 139 Countries and the 50 United States to Transition to 100% Clean, Renewable Wind, Water, and Solar (WWS) Power for all Purposes by 2050 and 80% by 2030", which provides a highly relevant study for India. This paper indicates that the researchers at Stanford University and the University of California have developed road maps to transition the energy infrastructures of 139 countries (including India) and the 50 United States to 100% clean, renewable infrastructures running on existing-technology wind, water, and solar (WWS) power for all purposes by 2050, with 80% conversion by 2030. In this study all-purpose energy includes electricity, transportation, heating/cooling, industry, and agriculture/forestry/fishing. It says that converting the 50 states, 139 countries, and remaining countries of the world will reduce the social cost (business + health + climate costs) of energy by 60%. It is interesting to note that this study has mentioned that t*he* main barriers to such a conversion are neither technical nor economic; rather, they are social and political.

6.0 Other technological and logistics issues

Whereas the thermal and nuclear power plants are more suited as base load power plants, with a requirement to run at optimal load all the time, nuclear power plants are even more so, and they are known to be highly sensitive to variations in the grid parameters. They are, hence, most suitable for societies with much higher per capita energy consumption and for wealthy societies. Hence, it is hard to understand how a nuclear power policy is considered suitable to Indian conditions, where the per capita energy consumption is one of the lowest in the world, per capita income is very low, and grid parameters vary widely.

Since the modern nuclear power plants are all of large size because of the associated economics, they invariably need large size and complicated power network to function. Such large size power grids have failed to meet the electricity needs of the people in poorer sections and remote places, and hence, are not ideally suited to Indian scenario where, small and dispersed loads are common.

Nuclear power plants also need vast quantities of fresh water for cooling purpose, which are in severely short supply in India. Whereas the coastal power plants may draw such water supply through desalination plants, the ecological impacts of the massive wastes from such desalination plants on marine ecology cannot be ignored.

The availability of nuclear fuel in India is not adequate because of which the country has to depend on import of not only the fuels but also of the associated reactor technology. The erstwhile Planning Commission's Integrated Energy Policy (2011) document has stated that the Uranium reserve in the country can support only 10,000 MW nuclear power capacity, whereas the Union govt. has plans to take the total capacity to 63,000 MW by 2032 and to 250,000 MW by 2075. The import dependence will not only lead to concerns on the energy security, but also will lead to enormous foreign exchange outgo.

In view of the fast changing electricity demand pattern even within a day, the modern power grids are required to be much more flexible than the nuclear power plants can manage.

Whereas the risks associated with nuclear accident are considered as unacceptable, the risks due to terror attacks on the nuclear installations and the theft of nuclear fuels to be used for nuclear weapons by the non-state actors cannot be ignored either. A new dimension to the public safety is the 'nuclear terrorism'. In this regard Mikhail Gorbachev had expressed his concern in his article "Chernobyl 25 years later: Many lessons learned". He says: "…. I also remain concerned over the dangers of terrorist attacks on power reactors and terrorist groups' acquisition of fissile material. After the heavy damage wrought by terrorist groups in New York, Moscow, Madrid, Tokyo, Bali, and elsewhere over the past 15 years, we must very carefully consider the vulnerability of reactor fuel, spent fuel pools, dry storage casks, and related fissile materials and facilities to sabotage, attack, and theft. While the Chernobyl disaster was accidental, caused by faulty technology and human error, today's disaster could very well be intentional."

The debate as to whether nuclear power is a safe, suitable and essential option for India has been going on for many decades. While the proponents of the nuclear power have been offering many arguments in favour of the option, there have been any numbers of issues raised by those who consider it to be not the best solution to meet the legitimate energy requirements of our society on a sustainable basis. The fact that despite massive funding of nuclear establishment in the country for over last 6 decades, the installed nuclear capacity as on January 2019 was only 1.9% of the total installed power capacity, may indicate the true relevance of nuclear power to India.

When we objectively consider the oft-repeated nuclear power advocacy from the context of Climate Change, the associated fallacy becomes crystal clear. In the Indian context the prospect of a much higher percentage of nuclear power to effectively combat the phenomenon of Climate Change looks highly improbable. A Department of Atomic Energy (DAE) document of 2008 has projected a nuclear power capacity of 275,000 MW by 2050. Assuming an average power capacity of 1,000 MW each this means a total of about 275 reactors. In view of the need for a large quantity of water to run these plants, it is natural to expect that they are located close to the coast. With the main land coast line of about 6,000 kM this works out to approximately 22 kM between two reactors. Even assuming that 2 or 4 reactors are placed in a straight line perpendicular to the coast, the distance between two nuclear power projects can only between 44 to 88 kM. Assuming a circular safe zone with a radius of 2 kM around each reactor, 275 reactors would require a total of approximately 3,500 Sq. kM of un-inhabitable land. Can such a situation be feasible in a densely populated country? The very projection of nuclear power capacity of 275,000 MW for India is unrealistic, given the fact that the import of nuclear fuel and technology to support 275,000 MW of projected capacity is fraught with unacceptable levels of economic cost and energy security risks.

7.0 Sensitivity Analysis

In order to minimize the uncertainties associated with the variation in values of many parameters of the costs and benefits, a method called sensitivity analysis can also be deployed, if considered essential.

In this method the costs and benefits are increased and decreased by 10% in separate calculations, and the costs increased by 10% and benefits decreased by 10% simultaneously in another calculation. In each of these steps, the IRR, NPV and payback period should be calculated. Such a rigorous approach will most probably reveal the true economics of the project, on the basis of which the feasibility of the project can be arrived.

8.0 Conclusions

When we objectively take into objective account various technical, economic, social, and environmental, logistics, and inter-generational issues, the true relevance of nuclear power to India should emerge unequivocally.

Hence, a diligent analysis of costs and benefits associated with each nuclear power project proposal in comparison with all other techno-economically viable options available to our country has become critical. Such a diligent analysis at a policy level is a must before the country can continue with the nuclear power policy. A specific case of high level costs and benefits analysis, as may be applicable to Jaitapur NPP, is included to highlight the numbers associated as annexure to this discussion.

Since many of the numbers used in this high level CBA are assumed on the basis of the available information in the public domain, the focus should be to get an idea of the magnitudes associated instead of focusing on the accuracy of the numbers themselves.

References:

An overview of nuclear power in the context of additional capacity to Kaiga NPP
http://www.countercurrents.org/2017/07/01/an-overview-of-nuclear-power-in-the-context-of-additional-capacity-to-kaiga-npp/

Nuclear Power in the Context of Global Warming; Vol. 49, Issue No. 17, 26 Apr, 2014
http://www.epw.in/search/site/shankar%20sharma

Electricity Governance in India", 2014
http://ksm.sagepub.com/content/3/2/109.abstract

The total cost for scrapping the nation's nuclear power facilities - excluding Fukushima No. 1 nuclear power plants and other facilities under construction - is estimated to be about ¥6.72 trillion (S$84.2 billion), according to a tally by The Yomiuri Shimbun. The cost for decommissioning 53 commercial nuclear reactors is estimated to total about ¥3.58 trillion, for an average at ¥57.7 billion per reactor.

http://www.asiaone.com/asia/costs-scrapping-japans-nuclear-facilities-estimated-842-billion

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Cost Estimating for Decommissioning Nuclear Reactor in Sweden
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After the Shutdown: Oyster Creek Nuclear Generating Station
https://njmonthly.com/articles/politics-public-affairs/after-the-shutdown-oyster-creek-nuclear-generating-station-forked-river/

Former top regulator now says nuclear power 'hazardous'
https://www.wtae.com/article/former-top-regulator-now-says-nuclear-power-hazardous/25888972

"I now believe that nuclear power is more hazardous than it is worth," Greg Jaczko writes in his debut book, "Confessions of a Rogue Nuclear Regulator," which is based on his three years as chairman of the Nuclear Regulatory Commission under President Barack Obama. "Because the industry relies too much on controlling its own regulation, the continued use of nuclear power will lead to catastrophe in this country or somewhere else in the world. This is a truth we all must confront," Jaczko wrote.

Nuclear Power Stations Are Not Appropriate for Australia – and probably never will be
https://www.climatecouncil.org.au/nuclear-power-stations-are-not-appropriate-for-australia-and-probably-never-will-be/

Storage of nuclear waste a 'global crisis': report
https://www.france24.com/en/20190130-storage-nuclear-waste-global-crisis-report

The 100-page report, compiled by a panel of experts, dissected shortcomings in the management of voluminous waste in France, which has the second largest nuclear reactor fleet (58) after the United States (about 100). "There is no credible solution for long-term safe disposal of nuclear waste in France," the report said.

The True Cost of the Chernobyl Disaster Has Been Greater Than It Seems

http://time.com/5255663/chernobyl-disaster-book-anniversary/

" … the ultimate Chernobyl mortality toll, though difficult to estimate, may yet turn out to be significantly higher. Current estimates place it between the 4,000 deaths estimated by United Nations agencies in 2005 and the 90,000 suggested by Greenpeace International. The cost of the steel arch planned over the old sarcophagus has been estimated at 1.5 billion euros, with the total cost of the New Safe Confinement Project exceeding 3 billion euros. The new shelter over the damaged reactor No. 4 notwithstanding, the area around the nuclear plant will not be safe for human habitation for at least another 20,000 years.

CHERNOBYL disaster

http://chernobyl.undp.org/russian/docs/belarus_23_anniversary.pdf

"Economic damage of the Chernobyl accident is estimated at $235 billion for 30 years on after the explosion, making up 32 national budgets as of 1985. Chernobyl disaster vastly damaged the agricultural sector of the Belarusian economy, which is worth over $700 million annually. Due to radioactive fallout, Belarus lost one fifth of all agricultural lands. It also led to contamination of around a quarter of the Belarusian forests, 132 deposits of mineral resources and nearly 350 industrial enterprises."

Is Yucca Mountain back from the dead?

https://www.hcn.org/articles/is-yucca-mountain-back-from-the-dead

Yucca Mountain, the project to permanently store high-level nuclear waste underground in southern Nevada, has been considered dead since then-President Obama defunded it in 2012. But now, President Trump has moved to revive it. The Department of Energy estimated in 2008 that the project as a whole would require up to **$96 billion** to complete; it's already cost taxpayers **$15 billion**. The state has already filed more than 200 objections to the DOE's application, all of which would have to be resolved — at a cost of up to $2 billion — before the project could go forward.

The True Cost of the Chernobyl Disaster Has Been Greater Than It Seems

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But the ultimate Chernobyl mortality toll, though difficult to estimate, may yet turn out to be significantly higher. Current estimates place it between the 4,000 deaths estimated by United Nations agencies in 2005 and the 90,000 suggested by Greenpeace International.

Japan Fukushima nuclear plant 'clean-up costs double' - BBC News

https://www.bbc.com/news/world-asia-38131248

In September, 2017, Tepco and the national government were reported as reaffirming their previous timeline for the cleanup, estimating the decommissioning process would take 30 to 40 years to complete.

Near site of Fukushima nuclear disaster, a shattered town and scattered lives

https://www.washingtonpost.com/world/asia_pacific/near-site-of-fukushima-nuclear-disaster-a-shattered-town-and-scattered-lives/2019/02/02/0dea7886-1e8c-11e9-a759-2b8541bbbe20_story.html?utm_term=.1dab3e85d3b0

Annexure

High level indication of Costs and Benefits of Jaitapur Nuclear Power Project (JNPP) Proposal

(Proposal: 6 X 1,650 MWe Reactors @ 250,000 Crores project cost estimation)

	Societal Costs	**Benefits**	**Comments**
Option I (NPCL option for a Nuclear power Project)	About Rs. 250,000 Crores for the main project, without transmission line costs ?	Max. power (net) to the Western Region grid = 5,700 MW	10% of power goes to auxiliary consumption; about 20% T&D loss in Western Region (WR); assumed PLF = 80%
	Additional land for and cost of transmission lines: 6 * 765 kV lines ??	About 50,000 MU annual energy	@ 80% PLF
	Impact on Agricultural /horticultural production & due to radiation fears	Employment for about 500 people during operation?	Export demand for Alfonso mangoes and othe export product may come down because of radiation contamination fears
	Fisheries production loss		Anecdotal evidence of loss of fishes near Tarapur NPP
	Diversion of agricultural lands for the project		
	Denial of access to thousands of acres of land for grazing; wood and fodder collection		
	Impact on fresh water Sources		
	Impact loss on areas of ecologically very high value (bio-diversity hotspot)		
Option II			
Efficiency improvement In the existing system (T& D loss reduction)	@ 25% of cost of a new Coal power plant: about Rs, 12,000 Crores	About 5,500 MW can be saved; OR a virtual additional generation	T&D loss reduction from 20% to about 9% in Western Region; demand met in WR was 50,500 MW in 2017-18 (as per CEA)
		And about 40,500 MU per year of saved energy	Available energy in Western Region during 2017-18 was 368,000 MU (As per CEA)
		None of the other costs JNPP	
Option III			
(i) LEDs in place of incandescent lamps	Not estimated; but will be much less than Rs. 200,000 crores	Estimated to be about 3,000 MW and 5,500 MU per year of energy Saved	Replacement of incandescent lamps by LEDs in Western region
(ii) Loss reduction in IP sets	Not estimated; but will be much less than Rs. 200,000 crores	Estimated to be about 3,500 MW and 42,000 MU per year energy Saved	IP set loss savings can yield about 18 % of the energy consumption in WR (and at national le 18% of 233,000 MU
		None of the other costs of JNPP	

Option IV			
(i) PLF improvement in thermal power plants	Not estimated; but will be much less than Rs. 200,000 crores	About 5,000 MW	Thermal power capacity in WR = 81,415 MW in 2018-19; increase in PLF from 61% to 70%
(iii) Loss reduction in domestic and commercial uses	Not estimated; but will be much less than Rs. 200,000 crores	About 1,000 MW	Replacement of inefficient domestic appliance as fans, TV, refrigerators, water pumps etc.
		None of the other costs JNPP	
Option V			
Renewable Energy (RE): About 15,000 MW of wind PLUS about 5,000 MW of solar power PLUS Energy efficiency Measures	About Rs. 160,000 crores @ Rs. 8 crores per MW for RE sources PLUS Rs. 15,000 Crores for efficiency	About 50,000 MU of annual energy AND None of the other costs (environmental, social and intergenerational costs) of nuclear power	In view of the lower utilization factor for RE Sources, much higher installed capacity will be required. Combined with the efficiency measures this RE option can provide much more benefits than the nuclear power and at much lower overall costs.
