Nuclear riddles: TINA and NIMBY*

Atul H. Chokshi

There is no alternative (TINA) to nuclear power, claim proponents. Not in my backyard (NIMBY) respond those who may have to give up their homes, health, safety and livelihoods near proposed nuclear power plants.

For at least a decade, if not more, there has been a view that the large-scale use of nuclear power is inevitable when one considers the energy requirements to fuel India's growth[1–7]. This note examines critically the need for, and implications of, large-scale nuclear energy, and it considers a potential alternate approach for avoiding the NIMBY syndrome.

Energy is an important aspect of human development, and there is certainly a need for more energy in India. There have been two different approaches to predicting future needs. The first one considers the current energy production, and then obtains future energy requirements assuming a relationship between the growth in GDP and corresponding growth in energy. The second assumes a certain desirable level of average per-capita energy consumption, based on a saturation of the human development index, and uses this to determine the total energy needs of a country in future based on population growth. The differing assumptions regarding the GDP growth rate and its association with growth in energy requirements lead to substantial variations in long-term projections, indicating the potentially tenuous connection of projections with reality. Population estimates also vary, leading to uncertainty in projections. Grover and Chandra[4] assumed a stable Indian population of 1.5 billion in 2050, whereas Sukhatme[6] assumed a stable population of 1.7 billion in 2071. The use of an average per-capita energy consumption is a simpler approach, and the present analysis will follow the simple and transparent procedure used recently by Sukhatme.

Nuclear visions?

Homi Bhabha had visions of using nuclear energy for India's development, with a three-stage nuclear programme; India is currently in the first stage of the programme. After about 60 years of the nuclear programme, an experimental fast-breeder reactor is being built currently in Kalpakkam, and the Department of Atomic Energy (DAE) seems confident of its success, although it has generally failed in several other countries. Even if all proposed approaches are successful, it is likely that the significant full deployment of the three-stage nuclear programme will take at least another four decades.

The recent analysis by Sukhatme[6] considers the total energy requirements for India, the potential energy from renewable sources, and then concludes that the balance has to come solely from nuclear sources, once fossil fuels are exhausted in another 100 years. It is important to examine such analyses critically, as they may be used for policy decisions that have long-term important implications for future generations. Sukhatme's approach is briefly outlined below.

Assuming a stable population of 1.7 billion in India for the year 2071, and a per-capita energy consumption of 2000 kWh, the total energy required is

$$(1.7 \times 10^9 \times 2000 \text{ kWh}) = 3400 \text{ TWh} \quad (1)$$

From a total of 1 million sq. km of open land in India, assuming 1% is used for solar energy, the land available for solar energy is 10,000 sq. km. Further, taking a thumb rule of 4 ha (4×10^4 m^2) to provide 1 MW solar energy, and a load factor of 0.2 (fraction of time energy is produced), the total solar energy potential per year

$$(1 \text{ MW}/4 \times 10^{-2} \text{ sq. km}) \times (10^4 \text{ sq. km}) \times 0.2 \times 24 \times 365) = 438 \text{ TWh} \quad (2)$$

All other renewable energy sources such as hydroelectric, wind and biomass were estimated to have a potential of

$$791 \text{ TWh} \quad (3)$$

Therefore, the remainder of energy

$$(1 - 2 - 3) = 2171 \text{ TWh} \quad (4)$$

Sukhatme[6] suggested that this remainder energy will be provided completely by nuclear energy after a 100 years, when there are no fossil fuels left.

It is useful to get some indication of the implications of the above calculations.

First, assuming a load factor of 0.9 for nuclear power, a production of 2100 TWh by nuclear plants will require an installed capacity of

$$2100 \text{ TWh}/(0.9 \times 24 \text{ h} \times 365 \text{ days}) = 270 \text{ GWh} \quad (5)$$

For a capacity of 500 MW each, there is a need for a total of

$$(270 \text{ GW}/500 \text{ MW}) = 540 \text{ reactors} \quad (6)$$

Nuclear power plants need a substantial quantity of water and therefore they tend to be located at seashores. It is possible to locate them near internal rivers and water reservoirs, but they may not be able to operate at full capacity during hot seasons; thus, nuclear plants in USA and France had to reduce operation during unusually hot summers due to the heat as well as low water levels[8]. In addition, the internal waterways in India are already severely strained by current human population and agriculture. Note that some recent developments tend to favour smaller modular reactors for easy fabrication and reducing costs[9].

India has a mainland coastal length of ~6000 km, so that the distance between adjacent reactors will be

$$(6000 \text{ km}/540) = 11 \text{ km} \quad (7)$$

Clearly, such a small distance between adjacent reactors would not be socially acceptable. Enhancement in the power of individual reactors and placing several reactors together in nuclear parks would lead to an increase in the spacing between reactors, just as an increase in per-capita energy needs to $\geq$ 5000 kWh (refs 4, 5, 7) would decrease the spacing between the plants.

Although nuclear authorities in many countries claim to have examined the Fukushima disaster and made modifica-

*Based on a presentation to mark the first anniversary of the Fukushima nuclear disaster.

tions to existing plants, one lesson that has not been learnt is the need to avoid placing multiple reactors in one location, as a problem in one reactor can limit access to other nearby reactors, leading potentially to a domino effect and cascading problems. It appears that the nuclear industry has traditionally built two reactors adjacent to each other, perhaps to reduce cost by sharing common facilities and for other logistical and administrative reasons; the Fukushima disaster suggests a need to re-evaluate and possibly discard this historical legacy.

Nuclear reactors in India require an exclusion zone with a radius of 1.6 km and a sterilized zone with a radius of 5 km, with activities being limited to allow only for natural growth in the zone between 1.6 and 5 km. Thus, assuming a circular region with a radius of 2 km around each reactor, the 540 reactors would require a total of ~6800 sq. km. Interestingly, this value is of a similar magnitude to that suggested by Sukhatme[6] for solar energy in open areas.

In view of the possible dangers to health and safety, and the current near impossibility of conceiving evacuation of large numbers of people from near a catastrophic nuclear accident in India, it is not surprising that the NIMBY syndrome is widespread worldwide. Currently, apart from Koodankulam, there is agitation near several other proposed nuclear sites such as Jaitapur. Note that the currently proposed nuclear plants are a small fraction of the 540 reactors that will be necessary. To increase the number of nuclear plants to 540 is likely to see substantial social unrest, especially when several countries are moving towards a consent-based approach, as in restarting nuclear plants in Japan after Fukushima[10] or for long-term nuclear waste storage facilities[11].

Sunny reality?

There are several renewable energy sources available, such as hydroelectric, wind, solar and biomass; the present analysis focuses solely on solar energy. Sukhatme[6] considered a space of 10,000 sq. km available for large-scale solar power plants, with connection to the grid; note that this is substantially less than the 50,000 sq. km considered in the Planning Commission integrated energy policy[12].

Instead of a centralized open-area approach, a distributed rooftop solar possibility is considered below. Assuming a population of 1.7 billion by 2070, and an average household with four members,

the total number of households will be = 425 million. (8)

Calculations for Indian conditions reveal that a 3 kW solar panel can produce ~4.5 MWh of energy in a year[13]. Therefore, the potential total energy from rooftop solar installation is

$$(425 \times 10^6 \times 4.5 \text{ MWh}) = 1900 \text{ TWh} \quad (9)$$

Note that this is similar to the energy required, for which nuclear power was assumed to be inevitable. Since the panels are to be mounted on rooftops, there will not be any additional land area necessary for this scheme. In addition, the rooftop solar panels will overcome the NIMBY stigma associated with the health issues and safety of the nuclear power plants.

A 3 kW solar panel system typically requires about 30 m^2 of space, so that the total rooftop area necessary is

$$(30 \times 10^{-6} \text{ sq. km} \times 425 \times 10^6) = 12,750 \text{ sq. km} \quad (10)$$

Table 1 summarizes the important results from the present analysis.

Surprisingly, the rooftop area necessary for generating 1900 TWh is similar to the value of 10,000 sq. km open area that Sukhatme[6] had used to estimate a solar potential of 438 TWh. This discrepancy is a consequence of the lower value of the effective solar power density (25 W/m^2) used by Sukhatme compared to the realistic values of currently available solar panels (~100 W/m^2), arising perhaps from a consideration of an older technology and the need to allow space between panels or dishes to limit shadowing in large solar fields.

The above calculations suggest that a distributed rooftop solar panel system can provide all the necessary energy projected by Sukhatme[6]. Another advantage of a distributed power system is that it eliminates the transmission and distribution losses of about 30–40% in India, with electrical energy from nuclear and other centralized power plants, so that the distributed rooftop solar system effectively may need to provide only ~80% as much energy as the centralized systems.

It is relevant to note that the above calculations are based on current technology for solar PV, compared to future technologies for nuclear plants that have not ever been successfully employed on a large scale. Technological changes are occurring at a rapid pace for solar energy and it seems reasonable to assume significant improvements over the next decade or two. The lack of consideration for this factor in projections is clear from noting that papers[3,4] in 2005–06 considering energies from various sources available in India did not even list solar energy among renewables, although the current national plans are to develop 20 GW solar capacity by the year 2022, which is what, DAE has projected for nuclear power in the same year.

Finally, it is recognized that 'prediction is very difficult, especially about the future'[14]. However, the above simple calculations demonstrate that there are alternatives to nuclear power, and it is unreasonable to assume that a drastic increase in nuclear power is inevitable. Although there is a widespread agreement on the need for additional energy,

Table 1. Comparison of nuclear and solar futures

Nuclear energy	
No. of reactors (500 MW each)	540
Total energy per year	2100 TWh
Distance between reactors	11 km
Total land area required	~7000 sq. km
Rooftop solar	
No. of households	425 million
Rooftop capacity of each solar panel system	3 kW (~4.5 MWh/year)
Total energy per year	1900 TWh
Total land area required	Nil
Total roof area required	~13,000 sq. km

and there are challenges with all possibilities, there is need for a vigorous debate on the appropriate approach to satisfy this need; policy-makers need to be aware of such information before making decisions on long-term energy strategies that may lock options for the country.

1. Chidambaram, R., *Curr. Sci.*, 2001, **81**, 17–21.
2. http://www.teriin.org/themes/teriday/pdf/2-DarbariSethMemorialLecture2-Full.pdf
3. Srinivasan, M. R., Grover, R. B. and Bhardwaj, S. A., *Econ. Polit. Wkly*, 2005, **40**, 5183.
4. Grover, R. B. and Chandra, S., *Energy Policy*, 2006, **34**, 2834–2847.
5. http://www.dae.gov.in/lecture/iasc.pdf
6. Sukhatme, S. P., *Curr. Sci*., 2011, **101**, 624–630.
7. http://www.niot.res.in/events/events/12-1-presentation.pdf
8. http://www.climatecentral.org/news/in-tennessee-heat-waves-frustrate-nuclear-power/
9. http://energy.gov/articles/energy-department-takes-first-step-spur-us-manufacturing-smallmodular-nuclear-reactors
10. http://www.foejapan.org/en/news/120127.html
11. http://www.nytimes.com/2012/01/27/science/earth/nuclear-waste-panel-urges-consent-basedapproach.html?_r=1
12. http://planningcommission.nic.in/reports/genrep/rep_intengy.pdf
13. http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/International/input-v1_intl.cgi
14. http://www.economist.com/blogs/theinbox/2007/07/the_perils_of_prediction_june

Atul H. Chokshi is in the Department of Materials Engineering, Indian Institute of Science, Bangalore 560 012, India.
e-mail: achokshi@materials.iisc.ernet.in

Groundwater loss in India and an integrated climate solution

Vikram Soni

In the developing world climate change has far more ramifications than can be addressed by controlling just carbon emissions. The developed world has stable populations and landscapes, and is thus affected mainly by the air which spreads democratically without boundaries. On the other hand, the developing world with increasing populations and consumption is depleting its living natural resource base of water, forest, soils and agriculture, and is poised for a far greater catastrophe. In fact, more and more regions in overpopulated Asia and arid Middle East and North Africa are heading into a water crisis. The developing world needs an integrated solution that addresses water, agriculture and forests. We work out such a solution with India as a case study.

NASA's gravity mapping satellite 'GRACE' tracks the local gravity field of an area below it. If we take out a lot of groundwater from such an area, there is a loss of mass and it shows up as reduced gravity. Recent reports[1–4] based on GRACE satellite data show that in a large and fertile area of North India, about 440,000 sq. km, groundwater levels have been going down by 30 cm (or 1 ft) of water a year from overdrawing. A 30 cm (or 1 ft) drop in groundwater level is equivalent to a 4 cm loss of raw water. This area has lost an average of about 18 km^3 of water/yr, which means a loss of 4 cm of raw groundwater per year. Since this has been going on for more than 30 years, over 1.2 m of raw water has been lost. Alternatively, groundwater levels have declined by an average of 10 m. However, this is not the real loss. A lot of the area surveyed by GRACE that is not cultivated, has not lost water. It is in the cultivated area, that accounts for over half of the region that is mapped by the satellite, that the loss is concentrated. In what follows we estimate the water loss for the cultivated area using ground agricultural data.

Water loss in the cultivated area

In the total area monitored by the satellite, the cultivated area accounts for a little over half the area (about 240,000 sq. km). Now we present a more grounded estimate of water loss based on agricultural water use. The cultivated area on the map of this region includes Punjab, Haryana, western Uttar Pradesh (UP) and parts of Rajasthan, which is the granary of the India (western UP has, perhaps inadvertently, been left out in the paper by Rodell *et al.*[1], see Figure 1). It produces much of the irrigation-intensive rice, sugar cane and wheat apart from the less irrigation-intensive pulses, millet, etc.

Rice and sugar cane need over 60 cm of raw water and wheat over 30 cm. Usually, there is a dual cropping pattern of rice in the monsoon season and wheat in the winter–spring. This requires over 100 cm of water annually[5].

From the official data, the water-intensive rice[6–9] and sugar cane[10] growing areas in this swathe of land amount to about 100,000 sq. km. For rice, the division is as follows: 27,800 sq. km under rice in Punjab and 10,800 sq. km under rice in Haryana. All of UP has 46,000 sq. km under rice, of which western UP has the high and medium productivity rice areas ~30,000 sq. km and Rajasthan has 1800 sq. km. Sugar cane is mainly grown in western UP which has 20,540 sq. km under sugar cane[10].

The rest, 140,000 sq. km, grows millet, pulses and wheat[11]. For areas which do not grow rice or sugar cane, the annual water needs are approximately 50 cm/yr.

Thus the weighted average requirement for the area under agriculture is about 71 cm of water/yr. Return flow data[12,13] suggest that of this about one quarter seeps back to the ground.

Now, about 60% of the cultivated area is serviced entirely by groundwater[14,15]. Let us see what are the implications for the groundwater regime once we are armed with this knowledge. In passing, we note that the groundwater table goes down with groundwater draft but goes up from seepage in canal irrigation.

The cultivated area divides into two lots. The area irrigated by groundwater, about 60% of the cropped area,