Carbon Counting

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India may reject proposals for mandatory cuts in carbon dioxide emissions, but it has to consider meeting a reasonable proportion of its growing energy supply from carbon-free technologies. What could these be?

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The Intergovernmental Panel on Climate Change (IPCC) recently released its *Fourth Assessment Report* and the United Nations published its *Human Development Report 2007*.

Both these reports gave a stern warning on the serious dangers of climate change facing the world and linked it to human activity. Depending on the amount of carbon emitted, the IPCC report estimates a global temperature rise of 1.8-4 C and sea level rise of 18-59 cm by the end of the century. Further, the impacts could be abrupt and irreversible.

The IPCC report calls for deployment of renewable or carbon-free technologies that are currently available or will be commercialised in coming decades. This requires moving away from the coal and oil based economy to one in which a "significant" fraction of energy supply comes from carbon-free technologies such as solar, wind, nuclear, biofuels, hydroelectricity, fuel cells, batteries, hybrid cars, carbon capture and sequestration, etc. There are also some outlier suggestions such as building giant space mirrors to reflect solar radiation back into space.

Should India be concerned with the problem of global warming at all? The UN report calls for developed countries to cut carbon dioxide (CO_2) emissions by 80 per cent by 2050 and developing countries by 20 per cent from 1990 levels. India has strongly objected to this since most of the build-up of CO_2 is due to industrialisation of the west and India has low per capita CO_2 emissions.[1] However, global warming is not going to be selective. If anything, it will affect the countries near the equator far more than those in higher latitudes and the poor will be the worst affected. Moreover, India's CO_2 emissions are growing rapidly and it is poised to become the world's third largest emitter by 2030 (after China and the US). Consequently, there will be growing pressure on India for proactive action. Since India has rejected mandatory CO_2 cuts, what are the other options? As we see presently, carbon credit trading and carbon-free technologies are other opportunities.

Can India develop carbon-free technologies to meet a part of its future energy requirements? India's present total commercial energy supply is about 4,000 billion kwh.[2] The Planning Commission estimates it to grow to 20,000 billion kwh by 2030.[3] How India achieves this steep growth is in itself a challenge. It is further compounded by the fact that a "reasonable" fraction of this energy should be from carbon-free sources. How much is "reasonable"? Coal, oil and gas presently supply 97 per cent of

India's commercial energy and many new carbon-free technologies are still to become mature for large-scale implementation. It is therefore, nearly impossible to make a major switch. In one possible scenario, India could plan to meet 15 per cent of its future energy needs from carbon-free technologies.[4] This implies by 2030, carbon-free sources contribute about 2,500 billion kwh out of 20,000 billion kwh. (Of course, no technology is totally "carbon-free" since there are CO_2 emissions over the total life cycle of any technology.)[5]

In this article, we examine the potential from several energy sources. We estimate the maximum possible potential from these options and so the actual may turn out to be lower.

Wind

Wind power is a reasonably mature technology and India with its installed capacity of 7,600 MW, is the fourth largest in the world. Wind power potential in India is estimated at 45,000 MW. However, wind power is location specific and intermittent. This intermittency is now causing some scarcity of electric power in Tamil Nadu, which has a sizeable fraction of wind energy. Wind speeds in India are in general lower than those in Europe and the US and consequently wind turbines operate at less than 20 per cent load factor. If India achieves the estimated potential of 45,000 MW, wind can generate about 100 billion kwh, which is less than 1 per cent of India's desired energy supply of 20,000 billion kwh.

Biofuels

Oil bearing crops such as jatropha, pongamia pinnata and mahua can be used to produce biodiesel, which is an effective substitute for diesel. Likewise, ethanol can be produced from sugar cane juice, molasses and sweet sorghum. An enticing option would be to produce fuel from any cellulosic biomass such as wood chips, rice husk and sugar cane bagasse though the technology is yet to be commercially proven. However, as shown by recent experience in US, Mexico and Thailand, large-scale biofuel production requires careful planning. Use of land for biofuels should not in any way compromise with production of foodgrain or animal feed. Diversion of agricultural land for producing fuel should therefore be discouraged.

India has an estimated 30 million hectares of cultivable wastelands out of a total area of 328 million hectares. It is debatable whether to plant such a large area with biofuels given the pressures of population. However, if all of this is used to grow biofuel producing crops, India can produce about 40 million tonnes of oil, equivalent to 525 billion kwh of energy.[6] India could also produce up to 10 billion litres of ethanol, (50 billion kwh) if it develops cellulosic ethanol technology and improves yield of sugar cane using drip irrigation and fertigation technologies.[7] The total contribution of bio-fuels will then be about 3 per cent of India's energy supply.

Hydroelectricity

India's hydroelectric potential is estimated to be 84,000 MW (at 60 per cent load factor). Present generation capacity is about 34,000 MW operating at an average 29 per cent load factor. Most of the untapped potential is in Arunachal Pradesh and it is not clear how much of this can be tapped given the social problems of rehabilitation and resettlement of people affected by large hydro projects. If India can achieve the full potential of 84,000 MW, it will generate about 400 billion kwh, 2 per cent of the desired total energy supply.

Therefore even in the most optimistic scenario, wind, hydro and biofuels contribute about 1,100 billion kwh, which is effectively the upper limit from these sources (see the table, p 15). This is less than 6 per cent of India's expected commercial energy by 2030 and therefore it appears that these sources will remain marginal in India's future energy mix. Bulk of carbon-free energy will have to depend on sources such as coal (with carbon capture), nuclear and solar.

Coal (with Carbon Capture)

India has abundant and cheap coal reserves and coal accounts for 51 per cent of the present commercial energy supply. Therefore, coal will continue to dominate the energy mix in near future. However, every kwh of electricity from coal also releases about 1 kg of CO_2 into atmosphere. An emerging option is therefore to capture the CO_2 from coal power plants and bury it deep underground. This sequestration technology requires modern coal gasification and combined cycle power plants.[8] All these ancillaries will make coal power expensive, almost doubling the cost of electricity. At present there are only a few pilot plant experiments for sequestration underway in North America. A major research programme is necessary to prove CO_2 capture and sequestration for Indian conditions. If we assume that 40 per cent of India's future energy is from coal then annual coal-based CO_2 emissions would be about 2,500 million tonnes. Out of this, at least 400 million tonnes of CO_2 would have to be captured and sequestered annually and this is a huge challenge. It will require successful commercialisation of the technology and proper site selection for long-term sequestration.

Table: Projections of Future Energy Supply Potential from 'Carbon-Free' Sources

Energy Source	Energy Generation Potential by 2030	Assumptions
Wind	100 billion kwh	45,000 MW capacity operating at 20% load factor
Biofuels	575 billion kwh	30 million hectares of land planted. Oil yield of 1.5 tonnes per hectare. Ethanol production of 10 billion litres from cellulosic feedstock
Hydro	400 billion kwh	84,000 MW operating at 55% load factor
Coal (with carbon capture)	Depends on how soon India develops carbon capture and sequestration technologies and identifies sites for long-term sequestration.	
Nuclear	260 billion kwh	35,000 MW of nuclear power, 24,000 MW from light water reactors. Large-scale breeder and thorium reactors start after 2030 and hence share of nuclear could grow significantly after 2030.
Solar	Depends on how soon India develops utility scale solar PV and thermal technologies.	

Nuclear

India's installed nuclear power is 4,120 MW and contributes less than 3 per cent of the electricity generation. Domestic uranium reserves being limited, India is pursuing the three-phase programme with the objective of developing breeder reactors using plutonium and later thorium derived reactor technology. The proposed Indo-US nuclear agreement provides the opportunity for importing light water reactors with fuel. India could then add up to 24,000 MW from this route by 2030. Large-scale deployment of breeder reactors is still at least several years away and depends on a successful demonstration of the prototype reactor presently being built. It also depends on building of large-scale spent fuel reprocessing facilities since every 500 MW breeder reactor requires 3 tonnes of plutonium that has to be reprocessed from spent fuel from the reactor. Given international collaboration, it is possible for India to install 35,000 MW of nuclear power by 2030, which will generate 260 billion kwh, 1.3 per cent of total energy supply. However, the crucial point is that this is just the beginning; the fruits of breeder and thorium reactors will be realised only in the years after 2030.

Solar

Most parts of India receive a good average daily solar radiation of 5-6 kwh/m^2. Therefore, if solar generation technologies are deployed on 20 million hectares, India can generate about 24,000 billion kwh even at a modest 10 per cent efficiency. This is more than India's expected total energy supply and several times the desired carbon-free energy. Solar energy evidently is a crucial option for a long-term solution to the climate problem. It is a more efficient option than biofuels since the latter utilise sunlight indirectly through photosynthesis. The overall efficiency of making biofuel from sunlight is less than 1 per cent.[9] As against this, the efficiency of present generation silicon cells is about 20 per cent. Unfortunately, these continue to be expensive and the challenge is to make them cost competitive. Solar thermal power using concentrators is another attractive option for utility scale power generation. A single stretch of land measuring 20 km × 20 km, say in sun-drenched Ladakh, can generate over 20,000 MW of electric power contributing 50 billion kwh of energy (equivalent to eight coal power plants).

India's total commercial energy supply is expected to be 20,000 billion kwh by 2030, out of which 2,500 billion kwh is desired from "carbon-free" sources. Wind, biofuels and hydro will be marginal players contributing less than 6 per cent of India's future needs even if they are developed to the maximum potential.

This analysis suggests that India must use all the resources discussed here and technologies to the limits of their potential to generate a "reasonable" fraction of carbon-free energy. Wind, hydro and biofuels have limitations and can contribute only to an extent. Nuclear, solar and coal (with carbon capture and sequestration) are vital for India's long-term energy security in a climate-friendly manner.

A large number of research and development programmes are required to prove several of these technologies for large-scale implementation. While India has a large and ongoing nuclear power programme, a similar major effort is lacking in solar energy and carbon capture and sequestration. Indian R&D investments in these areas are still modest and have to be scaled up dramatically, almost on a war footing.

Germany, despite not being so blessed with solar radiation leads the world in grid-connected solar PV systems mainly because of government subsidies and investments for R&D. Japan also has sizeable subsidies. India's experience is limited to solar water heating systems and solar PV panels for niche applications. It is befitting for India to initiate major programmes in utility-scale solar power generation involving government, industry and the scientific community. Efforts should also be made to make these projects attractive for talented and qualified research scientists and engineers. If India develops some of these technologies, it will enable other developing countries to adopt these as well in their effort to combat climate change.

NOTES

1 India's total CO_2 emissions are 1,342 million tonnes, fourth largest in the world after US (6,045), China (5,007 and Russia (1,524). India's per capita emissions are 1.2 tonnes, well below the US (20.6) and the world average of 4.5 tonnes.

2 This is the total primary commercial energy supply to the economy and includes energy sources such as coal, diesel, petrol, kerosene, LPG, naphtha, coke, natural gas, hydroelectricity, nuclear power and renewables. It excludes non-commercial energy sources such as firewood, dung and other biomass used for cooking.

3 'Integrated Energy Policy Report', Planning Commission, government of India, August 2006.

4 This is just one of the several possible scenarios. The purpose of this article is to assess the potential of carbon-free technologies in powering India's growth.

5 On a life cycle basis, CO_2 emissions of wind energy are estimated at 7-120 grams per kwh, solar PV (13-730), nuclear (2-59), hydropower (2-48), natural gas (389-511) and coal (790-1182).

6 Normally 2000-3000 jatropha trees are planted per hectare. The average seed yield is 1 to 2.5 kg per tree and seeds contain about 30 per cent oil. This translates to an oil yield of about 1 to 1.5 tonnes per hectare.

7 Present ethanol production is about 2 billion litres, out of which just about 5 per cent is available for blending with petrol. Drip irrigation and fertigation and increase sugarcane yield to almost 150 tonnes per hectare.

8 Coal gasification produces a combustible gas which is burnt in the gas turbine. Gasification is amenable for CO_2 capture because it is captured pre-combustion.

9 If one hectare of land is planted with a biofuel producing crop, it produces about 1.5 tonnes of oil; equivalent to 17,500 kwh energy per annum. If solar PV panels are installed on the land, the expected energy output is about 1,000,000 kwh per annum assuming solar radiation of 5 kwh/m2, 10 per cent efficiency and 200 days of sunshine.