Thermal power and biodiversity review: Is thermal power going to be the biggest risk to Indian biodiversity this century?

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Abstract

India's 102,000 MW commercial power generating capacity, 69% by thermal power, is the second largest in Asia. India's plans to increase this capacity, largely by thermal power, is one of the world's largest power augmentation programmes.

Over the next half-century, Indian thermal power plants may pose a bigger risk to biodiversity in the Indian subcontinent than all other anthropogenic interferences together did in the past. Sulphur dioxide emissions from thermal power plants will pose the primary risk; and the siting of new power plants closer to river sources, and therefore forests, will pose a secondary risk.

Sulphur dioxide emissions, which are currently 6.5 million tonnes, are estimated to grow at 5.5% per annum to 19 million tonnes by 2020. Nitrogen dioxide emissions, currently 10 million tonnes, are estimated to grow at an even faster rate. The synergistic effect of both these acidic gases will put 35 million Ha, or 55% of India's best forests in the Western and Eastern Ghats, the Himalayas, the Northeast and the Andaman Islands at risk of forest dieback as the soils of these forests have a low buffering capacity and are, therefore sensitive to acidic gas depositions.

To minimize coal transport costs, thermal power plants have largely been located at coalmine pitheads in the major coal belts of India in North-central and East India. However, these areas are also water-stressed. Thermal power plants require large quantities of water. In their search for water, new thermal power plants will locate closer to river sources first close to the Eastern Ghats, then the Himalayas and the Western Ghats. These three hill systems are also forested. As other downstream industry locate close to power plants, the growth centres that are nucleated close to the forests will put them and the biodiversity they host under pressure.

Short-term, medium-term and long-term measures are required to tackle these new threats to biodiversity. The short-term measures include: studying the impact of thermal power on biodiversity, setting up a monitoring mechanism for acidic depositions and their impacts, encouraging the development of green lungs and using bio-indicator plant species to monitor pollution levels around thermal power stations, training bystander populations residing around power plants to monitor the plants, including the cost of externalities in the price of power, formulating environment-friendly power plant siting rules and preparing a toxic release inventory which will put in public domain.

The medium-term measures include: adopting an energy and environment policy, instituting a carbon and sulphur tax, having the signatory nations to the Malé Declaration sign a binding protocol on sulphur emission caps, setting emission standards for power plants, encouraging the use of clean fuels, encouraging emissions control technologies and combined cycle plants, initiating demand-side management by encouraging low energy consuming devices, instituting Pollution Prevention Boards and decentralizing the grant of consent for operations to local self governments, minimizing transmission and distribution losses and encouraging the setting up of renewable energy capacities.

The long-term measure is to substitute carbon-based fuels with hydrogen.

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1.0 Introduction

1.1 About this paper

A National Biodiversity Strategy and Action Plan (NBSAP) is being prepared for India, for which several papers have been commissioned. NBSAP requested the author to review available literature on thermal power and biodiversity.

The impact of thermal power on biodiversity is a little studied subject. The few studies that exist on this subject are primarily on the impact of specific pollutants on certain plant species, usually those of economic importance. Most of these studies are based on laboratory experiments. Field impact studies are few.

Ecosystem risk analysis is a new subject in which work is just beginning. A couple studies have attempted to understand the impact of acidic gas deposition by using models. Though their predictions are yet to be field validated, they provide useful information in understanding future trends in acidification.

Given the relatively low information-base in this subject, this paper should be treated as a preliminary review. However, this does not necessarily detract from the conclusions drawn in this paper.

1.2 Thermal power in India

1.2.1 Power generating capacity

India’s installed power generating capacity in the year 2000 was 102,000 MW. Sixty nine percent of this capacity (70,000 MW) was thermal power (see Table 1.1), 23% (24,000 MW) was hydropower, 5% (5,500 MW) was renewable energy and 3% was nuclear power.

Eighty five percent of India’s current thermal power generating capacity, ie, almost 60,000 MW, is fueled by coal, 14% (about 10,000 MW) by gas and 1% by liquids.

1.2.2 Coal-based thermal power

Coal became the primary fuel for power generation as India’s large coal reserves (206 billion tonnes and expected to last over 200 years more) were well mapped even half a century ago. India mines about 310 million tonnes of coal per annum, ranking as the third largest coal-producing nation in the world.

Seventy five percent of India’s current thermal generating capacity, ie, 53,000 MW, was added in just the last two decades, most of it in coal-based power plants. Several factors aided this dramatic expansion in coal-based thermal capacity. Given India’s coal reserves, planners decided in the late-1960s to locate coal-based plants at pitheads and use pulverized low-grade coal in power plants. The nationalization of coal mining in the early-1970s exited a large number of private mining firms and the consolidated mining operations with a few public sector enterprises. This led to greater investment in the coal industry and consequently its mechanization. Developing large open cast mines and mechanizing the underground ones achieved rapid increase of coal production. Simultaneously, the manufacture of higher capacity power generating equipment in India helped in setting up large coal-based power plants.

Gas finds in last couple of decades in Bombay High and the Krishna-Godavari basin has led to setting up of gas-based power generation.

1.2.3 Growth in power generation capacity

In the last century, total power generating capacity grew at an average of 15% per annum, from 1.1 MW in the year 1900 to 1,363 MW in 1947, to its current capacity (see Table 1.1). During this period, thermal power generating capacity also grew at 12% per annum. In 1900, thermal power generating capacity was 1 MW and a century later, it is 70,186 MW.

The Central Electricity Authority (CEA) estimates peak load to reach 130,944 MW and 176,647 MW by the end of the tenth (2006-07) and eleventh (2011-12) five year plans, respectively. Going by CEA’s estimates, the growth of power generating capacity over the next decade will be approximately 5.4% per annum.

The Ninth Five Year Plan (1996-07 to 2001-02) envisaged that 40,245 MW of additional generating capacity would be added during the plan period, of which 29,545 MW was to be thermal power. However, this was subsequently scaled down to 28,097 MW, a 25% scale down from the original plan. If we were to assume the same scale down to occur during the tenth and the eleventh plans, the annual growth of the power generating capacity would be 4.4%.

The exceptionally high growth rate of power generating capacity in the last century was due to the switchover from non-commercial to commercial power sources and increased demand for commercial power that an industrializing India required. The estimated growth rate for power for the next decade is much lower than what it was earlier, and corresponds to the growth of India's economy.

1.2.4 Power consumption

Per capita commercial power consumption grew at 6.4% per annum between 1986-87 (191 units) and 1998 (384 units). The per capita power consumption of USA and Norway in 1988 was 11,832 and 24,607 units, respectively.

1.3 Impact of thermal power on biodiversity

Thermal power may affect biodiversity at the: a) local (<10 km) and regional scales (<50 km), and b) meso (<500 km) and macro scales (>500 km). Local and regional effects are due to air, water and soil pollution, and disturbance to forests water bodies due to additional human activity—industry, services, and population expansion—around power plants. These effects become visible within 1-2 decades after a power plant is set up, and are confined to a limited area. Meso and macro-scale impacts occur because of acid gas (oxides of sulphur and nitrogen) deposition over large areas downwind of thermal power plants. These effects manifest after several decades, but have the potential to impact a large area.

The effects of air pollution on various levels of ecosystem organization summarized by one writer are:

1. Absorption and accumulation of pollutants in soil, plants and other ecosystem components such as surface and ground water.
2. Injury to primary producers (plants) and consumers (animals) due to pollutant accumulation, eg, leaf necrosis in plants and dental necrosis in animals.
3. Change in numbers, density and diversity of species and shift in competition.
4. Loss of stability and reduction in reproductive ability of species.
5. Degeneration of stands and associations of biotic components.
6. Disruption of biogeochemical cycle.
7. Extension of denuded and eroded areas in the landscape.

2.0 Local and regional impacts

2.1 Air emissions

Thermal power plants are air-polluting industries. Their air emissions include sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM), including fly ash, and mercury.

Typically, a 500 MW unit using Indian coal emits about 105 tonnes per day (TPD) of SO_2 (at 100% power load factor, 0.7% sulphur content in coal), 24 TPD of NO_2 and 2.5 TPD of particulate matter (at 34% ash content, 99.9% electrostatic precipitator efficiency). Use of imported coal may increase SO_2 emissions but decrease fly ash generation, as imported coals tend to have higher sulphur content but lower ash content.

The visible (visually identifiable necrotic foliar symptoms) and subtle (decreased yields and lower plant quality) effects of air pollutants on vegetation are briefly described below.

The visible effects of air pollutants on vegetation may be acute or chronic. Acute injury usually involves necrosis, which develops within hours to days of short exposure to pollutants, and is expressed as fleck, scorch, and bi-facial necrosis. Chronic injury develops after long-term or repeated exposure and is expressed as chlosis, bronzing, premature senescence, reduced growth, etc.

The level of plant injury is determined by pollutant concentration. Pollutant dose does not seem to provide a reliable picture of plant response. The level of plant injury varies with species.

2.1.1 Sulphur dioxide

Of the two major gaseous emissions, SO_2 is more phytotoxic. The major effects of SO_2 exposure to plants are foliar injury, changes in micro-morphology, plant growth and productivity. High level of foliar injury has been observed closer to emission sources, reducing gradually with an increase in distance from the source. Injury is particularly marked along the footprint of pollution plumes.

Sulphur dioxide deposition may cause a lowering of soil pH, a decrease in nutrients—nitrogen and phosphorus, increase in sulphur content, exchangeable potassium and organic carbon. These changes in the soil subsequently lead to changes in the distribution, density and diversity of plant species (see Table 2.1).

Soil injury may be accelerated by precipitation after SO_2 deposition. Precipitation washes pollutants from plants into soil, raising its acidity and increasing the concentration of potassium, calcium and other mineral ions. These ions temporarily become abundantly available to plants; but eventually are leached deeper into the soil, depleting the topsoil layers of them, with consequent harmful effects on plants.

Fruit trees, particularly mango, are quite sensitive to SO_2. Rice and legumes too are fairly sensitive to SO_2. Many tree species are, however, more tolerant to SO_2 exposure.

Vegetation in the vicinity of power plants has been noted to sustain injury at SO_2 concentrations as low as 5-20 $\mu g/m^3$, particularly when other pollutants are also present (see tables 2.2 and 2.3). On the basis of structural and functional changes in vegetation near the Obra power plant, one researcher predicted the possible elimination of various types of vegetation in the vicinity of the power plant. Two other scientists noted that *Melilotus alba* growing close to the Kasimpur power plant had smaller leaf area, smaller roots and shoots and lower biomass compared the same species growing in a relatively pollution-free area. The presence of other factors—strong surface winds and high humidity accentuates plant injury. Several coastal power plants, eg, Kayamkulam, Dhabol, Ennore, Simhadri, are located in humid areas, where vegetation in their vicinity may be at greater risk of injury.

Data indicates that rainfall may play a complex role. Two researchers surmise that SO_2 washed rainfall provides sulphate nutrient. Though rain may wash plants free of SO_2, soil pH may in the short run increase mineral ion availability to plants, but making them scarce in the long run by leaching them beyond the plant root zone.

2.1.2 Nitrogen dioxide

Nitrogen dioxide is less phytotoxic than SO_2, though more so than nitrous oxide (NO). In small doses, NO_2 may even aid plant growth. On its own, NO_2 concentrations need to be high to cause plant injury, but in the presence of SO_2, it accentuates plant injury, even if present at lower concentrations. The importance of NO_2 as a pollutant is primarily because of its participation in photochemical reactions giving rise to ozone and peroxyacetyl nitrate (PAN), both of which being highly phytotoxic secondary pollutants.

Oxides of nitrogen (NOx), which includes NO_2, may injure vegetation even at low concentrations; eg, pinto beans may sustain injury at 3 ppm and sensitive weeds at 20 ppm. These NOx concentrations are observed close to thermal power plants.

2.1.3 Particulate matter

Coal dust, a constituent of PM emissions from power plants, is quite injurious to vegetation, particularly to certain fruit-bearing plants. For example, one researcher observed significant reduction in the fruit yield of mango and lemon plants were exposed to coal dust, and their leaves showed brown necrotic lesions, starting at the tip and progressing down the lamina.

Fly ash, another constituent of PM emissions from power plants, in moderate to large concentrations, affects vegetation, including causing changes in the cuticular pattern of leaves, decreases in the number and sizes of stomata, and increases in the length and density of trichomes. Researchers have reported that fly ash from power plants produce visible damage to certain plants, including severe ill effects to *Cicer arietinum L.*

Alkaline fly ash from stacks can amend the acidic soils. However, fly ash contains heavy metals that may accumulate in soils. Animals grazing grass with fly ash deposition may be affected by ingested heavy metals.

2.1.4 Synergistic effects

Synergistic effect of SO_2, NO_2 and fly ash will affect some plant species more than others. Economically valuable plants such as paddy, mango, chickoo and cashew experience decreased yields, canopy and biomass, leaf size reduction, greater leaf fall and chlorophyll loss. Coconut, being a hardy tree with smooth leaf surface, is likely to be more resistant to pollutants.

2.1.5 Winds

Low wind speeds cause poor dispersion of air pollutants. Consequently, higher ground level concentrations of pollutants around power plants located in low wind speed areas, eg Kayamkulam, will cause greater injury to vegetation.

2.2 Water use and water pollution

2.2.1 Water use

Water use and water pollution associated with thermal power plants do not cause the same degree of impact to the environment as air pollution does. However, the environment could be adversely affected if these two factors are not properly managed.

Thermal power plants consume large quantities of water for cooling. Power plants may use two types cooling systems. A once-through cooling system draws water from a water body, uses it for cooling and discharges it back into the water body. A typical 500 MW plant with a once-through cooling system requires about 1.56 million m^3 of water per day. Such large drawls are possible only from the sea or from water bodies with large flows.

A recirculating-cooling system reuses cooling water in a closed system by bringing down the water temperature to ambient levels with the help of cooling towers. This adds to the cost of the plant but reduces water consumption of the plant. A 500 MW plant with a recirculating-cooling system uses 0.08 million m^3 of water per day.

Given the water scarcity in many parts of peninsular India and competing interests for water by the domestic, agriculture and industry sectors, most power plants in India use recirculating-cooling systems. There was a proposal in the mid-1980s, though, to locate a several power plants on the west coast that were to use seawater in once-through cooling systems.

The large abstraction of water by power plants could impact fish breeding and spawning areas if the intake well is from an estuary. Consequently, the livelihood of fishermen dependent on estuary fishing would be affected. This may have happened if the proposed Mangalore thermal power plant had been permitted to draw water from the Mulki estuary, which is the source of livelihood for about 2,000 fishermen families.

Some small power plants use ground water for cooling, eg the Kutch plant (140 MW, 3,000 m^3/day of cooling water), the Sabarmati plant (430 MW, 32,400 m^3/day). During years of water scarcity, these plants may reduce water availability for domestic and agricultural use.

2.2.2 Wastewaters

A thermal power station’s waste waters are from water treatment plants, condensate cleaners, hydraulic ash disposal system, domestic sewage, used solutions after chemical cleaning of thermal equipment, washings and runoffs from petroleum products, coal yards, coal handling plants, external surface cleanings.

Waste waters will contain unburnt fuel, slime, coarse-disperse particles, organic matter, anti-fouling agents, iron and aluminum compounds, magnesium hydroxide, calcium carbonate, petroleum products, coal particles, chemical solutions used for suppression of airborne particulate matter, corrosion products, ash and soot, coarse disperse substances, acids, organic compounds, detergents, chealates, corrosion inhibitors and domestic sewage. Except for ash and coal particles, the pollutants are usually present in small concentrations and are removed from the wastewaters in an effluent treatment plant (ETP) before discharge.

Ash generated by a power plant is sluiced with water and let into ash ponds. A well-designed ash pond, which is constantly kept under water and is properly biologically reclaimed at the end of its life, should normally not cause any discharge of ash into water bodies. However, ash ponds are invariably badly managed in India, often causing ash to be discharged into waterways. For example, the once pristine Karaka Vagu stream in Khammam district is today completely clogged with ash from the Kothagudem thermal power station’s (850 MW) ash ponds for 20 km downstream, until it meets the Kinnarsani River. Fishing was common in the stream till a few decades ago, but no fishing is done there today. The Ennore power plant (450 MW) dumps about 4,500 TPD of ash as slurry directly into the Bay of Bengal. There is no information on the impact of such dumping on marine life.

2.2.3 Estuary salinity

If a power plant were to either draw or discharge water from an estuary, the salinity levels of the estuary would be altered, and consequently its ecology. An estuary forms a habitat for a variety of fresh and saline water species.

Altered salinity levels would affect the mix of fresh and saline water fish in the estuary. In turn, this would affect fishermen dependent on the estuary for their livelihood.

2.2.4 Thermal pollution

Thermal pollution is caused by power plants that use a once-through cooling system. The discharged water is usually about 10° C above ambient temperature. The Vijayawada thermal power station, which draws and discharges water from the Krishna river for a once-through cooling system, was monitored by the Andhra Pradesh Pollution Control Board (APPCB) to discharge water at 9° C above ambient temperature in July 2001. The discharged hot water will cause a thermal plume in the receiving water body, the size of which depends on the quantity of hot water discharge, flow and surface area available for heat exchange in the receiving water body.

Except marine mammals, nearly all aquatic organisms are thermal conformers or obligate poikilotherms. Behavioral thermo-regulation by water temperature selection in natural gradients is a common feature among fish. They acclimatize themselves to gradual temperature changes over seasons. They take cues from varying seasonal temperature for reproduction, habitat selection, etc. The effect of thermal changes on eco-balance amongst species—predators, competitors, prey animals and plant foods is not yet very well understood. However, there is some understanding of thermal loading and lethal threshold levels of selected species.

Bacteria probably have the widest temperature tolerance range of any group of organisms. Warm waters have been known to attract thermophilic micro-organisms eg, pathogen germs such as Naegleria that can cause meningeo-encephalitis and Hegionella that cause pneumonia. If heated waters are discharged into a water body, harmful bacteria may breed there.

Phytoplankton species diversity decreases in waters heated consistently over 30° C, with a tendency for blue-green algae to dominate if a temperature of over 32° C persists. A 5° C increase in temperature does not have a significant impact on zooplankton, but a higher increase will impact their density and diversity. Tropical benthic organisms live close to their critical thermal limit, and even a 2-3° C temperature increase may be difficult for them to tolerate. Fish will detect and avoid uncomfortable temperatures before they are killed.

Species density and diversity is known to decrease if water temperature exceeds 37° C, and beyond 40-42° C, few organisms survive. A power plant with a once-through cooling system and operating in hot climates would alter the ecology of water body that receives the heated water. If the receiving water body is a river, say 0.5 km breadth (the breadth of most west coast rivers, the water temperature will be 5° C above ambient temperature for a river stretch of 5, 15, 25 km for discharges from a 500 MW, 1,500 MW, 2,500 MW size plant, respectively (see Fig 2. 1). Had the once-through cooling system power plants planned for the west coast been commissioned, the aquatic ecologies of several estuaries would have been altered, as the temperature in these estuaries would have been close to or in excess of 35-37° C.

If heated waters from a once-through cooling water plant were discharged into an estuary, the thermal plume would extend into the sea, as there would probably be insufficient estuary length for complete heat dissipation. If heated waters were discharged to sea, a 10 sq km near-shore area would become a heat island. At least seven plants (Ennore—450 MW, North Madras—630 MW, Tuticorin—1050 MW, Trombay—1337.5 MW, Dahanu—500 MW, Dhruvan—534 MW, Sikka—240 MW) currently use seawater in once-through cooling systems, and discharge the heated water back into the sea. In either case, thermal stratification would reduce species competition for food and habitat. There appears to be little public domain information on the impact of these plants on marine ecologies.

2.2.5 Barge-mounted power plants

A barge-mounted power plant consists of diesel generator sets and liquid fuel tanks mounted on barges. Such plants were originally designed for remote areas that required a temporary power supply. The barge could be towed to the nearest point of the activity and towed away when the activity ceased. Barge-mounted power plants use a once-through cooling system.

In the mid-1990s, there were proposals to set up several barge-mounted power plants in the estuaries of the west coast. One barge-mounted power plant has been commissioned at Taneerbhavi (210 MW) in the Gorpuru estuary close to Mangalore.

Barge-mounted power plants cause vibration, oil spills and thermal pollution, which together have the potential to destroy estuarine aquatic ecologies and economies based on estuarine resources. It was estimated that the proposed barge-mounted power plant in the aquatically rich Tadri estuary in Uttar Kannad district would have caused a loss of income of Rs 40 crores per year to the local economy as the salt pans, low land agriculture, prawn cultivation, horticulture and plantations, estuarine and marine fishery would have been completely or partially impacted by the barge-mounted power plant. The economic benefit to the area because of the power plant, though, would have been only Rs 7 crores. If injury to Tadri's environment—mangroves, forests, flora and fauna, aesthetic beauty—were to be computed, the loss to the area would be much higher.

2.3 Solid wastes

A coal-based power plant generates a very large amount of ash. A 500 MW power plant using Indian coal generates 3,000-3,500 TPD of ash. India generates about 120 million tonnes of ash a year. With only about 10% of it going into ash utilization programmes, the bulk of the ash goes into unlined ash ponds.

Ash is an inert material with about 2% soluble material, mainly as sulphates and heavy metals in trace quantities. The probability of heavy metal contamination of soils and aquifers increases with the presence of each of these factors:

1. The ash pond medium is acidic.
2. The soils under the ash pond are porous, ie, of sandy, sandy-loam or lateritic.
3. The hydraulic gradient of the ground water is high.
4. The aquifers are interconnected.
5. The ground water table is high.

Some or all these conditions are prevalent in many parts of India. All of them, in fact, are prevalent on most of India's west coast, where the coastal power plants were proposed to be located.

Beyond a certain threshold concentration, heavy metal contamination of ground water and soils will be inimical to biota and humans.

2.4 Plant siting

2.4.1 Power plant siting

The three important criteria used for the thermal power plant siting hitherto were: a) minimize fuel transport costs and/or transmission distance, b) locate near water source, and c) locate on the railway network.

Seventy percent of India's coal reserves are concentrated in the states of Jharkhand, Orissa, West Bengal and Bihar and another 20% in Chattisgarh and Madhya Pradesh. To minimize coal transport costs, pithead thermal power plants, eg, Singrauli (2000 MW), Rihand (2000 MW), Korba (2100+1240 MW), Ramagundem (2100+62.5 MW), Neyveli (600 MW), Talcher (1460 MW), etc, are clustered close to coal mines (see Fig 2.2 and 2.3). Ramagundam, Kothagudem (640 MW) and Neyveli, though away from the principal coal reserves, are also pithead plants.

Plants using imported fuels were located close to ports, eg, the Enron plant at Dhabol (695 MW), the proposed Mangalore plant. This minimizes inland transport costs of fuels. Had the proposed Mangalore plant been located close to Bangalore, the load centre in Karnataka state, the cost for hauling coal from Mangalore port to Bangalore over the plant's 30 year life period would have been equal to the cost of the main plant minus some auxiliaries.

Even the new gas-based power plants such as the Spectrum and Snehalata are located close to new gas finds in the Godavari delta, and can use the plentiful water available there.

Invariably most of the larger plants (over 1,000 MW) are located at coal pithead. The smaller state-owned plants, eg, Panipat (650 MW), Bhusaval (482 MW), Gandhinagar (660 MW), which are away from pitheads, are located on railway lines for easy coal transport. A few plants are located at load centres, eg, Trombay (1337.5 MW), Faridabad (180 MW), Badarpur (700 MW), and Southern Generating Station (130 MW).

Most coal deposits in India are located in or close to the deciduous forests of North-central and East India, eg, Chirimiri in Shahdol district, Kothagudem in Khamam district. Coal mines attract pithead power plants, which in turn, attract downstream power consuming industries. Growth centers have thus been formed close to forest areas, leading to their retreat, which can be seen at Ramagundam and Kothagudem.

Power plants are also located at sites where they have easy access to large quantities of water, eg, Mettur (840 MW), Farakka (2100 MW).

2.4.2 Likely changes in power plant siting

In recent years, the landed cost of imported coal is about the same as that of Indian coal. Moreover, imported coal has a higher calorific value and lower ash content, though a higher sulphur content. There has been some deliberation in power utility companies about the use of imported coal. However, with the rupee sliding gradually against the US dollar, Indian coal may in future become cheaper than imported coal. The recent trend to site power plants at ports, eg, Mangalore, Simhadri (Visakhapatnam) will then be reversed in favour of pithead plants.

More importantly, minimizing fuel transport cost may, in future, no longer be the most important consideration for thermal power plant siting. A majority of India's coal deposits are located in water-stress areas (see Fig 2.4). Building new pithead plants in water-stress areas may become increasingly difficult in future. New thermal power plants may then have to move closer to water sources, ie, coastal areas for sea water or close to river sources, even if it means bearing additional coal haulage costs.

Most Indian rivers originate from three major hill systems—the Himalayas (they contribute 320 bcm of utilizable surface water), the Western Ghats (200 bcm) and the Eastern Ghats (100 bcm). Other rivers contribute 70 bcm of utilizable surface water. Locating new power plants on rivers flowing from the Eastern Ghats will be particularly attractive for two reasons—they are close to the main coal fields of India and are well connected by a good railway network. The second preference would be for sites on rivers that flow from the Himalayas, for the same reasons as those for the Eastern Ghats. The only difference being, the relatively greater distance that the Himalayas are from coal fields in comparison to the Eastern Ghats. The Western Ghats rivers will be the least preferred sites as they are the farthest from coal fields and are not well connected by railway lines. If at all new power plants are located close to the Western Ghats, they would be once-through cooling system plants that use sea water.

The impact of coastal power plants on biodiversity has been discussed earlier. The impact of power plants located close to forested river origins on biodiversity will be in much the same way as was described in subsection 2.4.1, ie, they would contribute to forest retreat and loss of biodiversity.

India currently uses 550 billion m^3 (bcm) of water. The demand for water in 2010, 2025 and 2050 has been projected at 700, 950, 1,425 bcm, respectively. However, the maximum quantity of utilizable water is estimated to be 1,100 bcm, which is well short of the projected demand for 2050.

To increase the current quantity of utilizable water, including for use by thermal power plants, there will be pressure to construct dams in the forested hilly areas of the country. Many such dams already exist (Srisailam, Nagarjun Sagar, Bhakra, Tehri, Koyna, Sileru, Machkund) and many are proposed (Mahadayi's tributaries). The reservoirs that these dams create not only decrease forest area, but also cut off wildlife corridors and impact forest ecologies. For example, in the year 2002, an elephant herd from Uttar Kannada district in Karnataka migrated over a 100 km north into the sugarcane areas of Kolhapur district in Southern Maharashtra as they were cut off from their usual range by the Supa reservoir to the south, the steep Western Ghat escarpment to the west and a retreating forest to the west because of land use change. The herd came into conflict with farmers.

Though thermal power plants may not be directly responsible for the impact of dams on biodiversity, they have to share the responsibility for the impact, as they are the beneficiaries of the water impounded in reservoirs.

3.0 Meso and macro scale impacts

Oxides of sulphur and nitrogen are acidic. They are released from various sources, including from thermal power stations, steel plants, fertilizer plants, automobiles, etc, are transported over long distances by the atmosphere and are deposited back to earth along the way as gases (dry deposition) or with precipitation (wet deposition). Because of their acidic nature, wet and dry deposition of SO_2 and NO_2 corrode the atmosphere, soil and water bodies and may consequently cause crop loss, forest dieback, injure aquatic ecology, erode monuments and structures and human health effects.

Wet and dry deposition of acidic gases (thermal power plants are the main source for SO_2 emissions in India) have the potential to impact biodiversity in a manner which far exceeds the damage done so far by other anthropogenic activity, eg, land use change from forest and wet lands to other uses, water pollution, poaching, etc. Yet, this problem has remained unrecognized and unaddressed.

3.1 Emissions

3.1.1 SO_2 and NO_2 emissions and their growth

In the year 2000, India's SO_2 and NO_2 emissions were estimated to be 6 and 14 million tonnes, respectively. Over the last decade, SO_2 and NO_2 emissions grew at 6.7% and 18.9% per annum, respectively. Over the next two decades, SO_2 emissions are expected to increase by 5.5% per annum to 19 million tones in 2020. Estimates for the future growth rate of NO_2 emissions are not available. However, if it is assumed that they will grow at the same rate as they did over the past decade, under a 'business-as-usual' scenario, NO_2 emissions in 2020 will be 440 million tones. The emissions of SO2 and NO2 over the next two decades under a 'business-as-usual' scenario are given below:

SO_2 and NO_2 emissions (million tonnes) under business-as-usual scenario[2]

	2000	2010	2020
SO_2	6.5	11.0	19.0
NO_2	14.0	78.5	442.5

3.1.2 Thermal power plants' contribution to emissions

Thermal power generation contributes to 67% and 6.4%, respectively, of the total SO_2 and NO_2 emissions from India; ie, thermal power plants emitted 4.4 and 0.9 million tonnes of SO_2 and NO_2, respectively in 2000.

Assuming that the percent contribution of thermal power to total emissions remains unchanged, thermal power plants will emit 13 and 28 million tones, respectively, of SO_2 and NO_2 in the year 2020; ie, SO_2 and NO_2 emissions will grow 3 and nearly 30 times, respectively, over the next two decades.

3.1.3 Contribution to SO_2 emissions by fuel

Considering all uses that carbon and hydrocarbon fuels are put to, coal contributes nearly 70% of the SO_2 emission in India, oil--23%, gas--0.5%. Other solid fuels contribute the balance.

3.1.4 Global trends in SO_2 emissions

Global SO_2 emissions due to anthropogenic activities are estimated to be about 150 million tones. Natural sources (volcanoes, oceans) contribute another 25 million tonnes.

In the past, north nations were the major SO_2 emitters. However, with its high economic growth rates, Asia today emits as much SO_2 as North America and Europe together.

China and India together emit about 40% of the world's SO_2 emissions from anthropogenic emissions (see Table 3.1). In the next two decades, these two countries, along with South Korea, Indonesia, Pakistan and Thailand, will become some of the largest SO_2 emitters in the world. Japan, despite its economic size, is expected to keep its emissions low because of fuel choice and emission control technologies.

3.1.5 Emission intensity, per capita emission, emission density

At 16.3 kg of SO_2 emission per US$ 1,000 of value added, India's SO_2 emission intensity is high compared to western countries (~3.8 kg/1000 US$). This indicates that energy intensity (energy used per unit of GDP) of the Indian economy is high, the fuels used are comparatively dirty and that investment in control technologies is inadequate (see Table 3.2). China's emission intensity is significantly higher (71.35 kg/1,000 US$) than that of India.

However, per capita SO_2 emissions (5.99 kg of SO_2 emissions per person) and emission density (emissions per unit area—1.5 T/ km^2) for India is low compared to north nations. For the US, the corresponding figures are 84.27 kg/person and 2.25 T/km^2, and for China they are 22.86 kg/person and 2.79 T/km^2. Based on these figures it may be tempting to argue that India be permitted to increase its SO_2 emissions without restrictions until per capita emissions and emission density are on par with north nations. However, other factors discussed below, need consideration.

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[2] Source: Downing R J, et al, 1997; UNEP, 2000

3.1.6 SO_2 emissions from neighbouring countries

To the west of India, Pakistan and Iran are the only neighbouring countries that have significant SO_2 emissions. They emit a little under one million tonnes each of SO_2 per year. Liquid and gaseous fuels account for 51% and 95% of the primary commercial energy sources of these two countries, respectively. Thermal power plant locations in Pakistan are given in Fig 3.1.

To the northeast of India, China, the Republic of Korea and Japan are large SO_2 emitter—34, 3 and 0.9 million tonnes per annum, respectively. And to the east of India, Thailand and Indonesia emit 1 and 2 million tonnes per annum of SO_2, respectively.

3.2 Pollutant transport

3.2.1 Entrainment of pollutants into atmosphere

Indian power plants have tall stacks. All plants over the size of 220 MW built from the mid-1980s have stacks 220-275 m tall. The heat and momentum flux of the flues carry the pollutants to heights of 500-1500 m, where they are entrained into the atmosphere and carried by winds.

3.2.2 Winds

Winds over South Asia have a distinct pattern. For about 7-8 months of the year, winds blow from West Asia into the northern part of the Indian sub-continent before taking a broad U-turn over Bangladesh and North-east India and blowing into South India from over the Bay of Bengal.

During the four monsoon months—June-September—winds blow from the Indian Ocean, over South India, into the Bay of Bengal, making a broad U-turn over Bangladesh and India's North-east, and moves over the Indo-gangetic plains and into West Asia (see Figs 3.2 and 3.3).

Wind directions determine wet and dry depositions of acidic gases.

3.2.3 Long range transport of pollutants

Once the gaseous pollutants (SO_2 and NO_2) and fine particles (typically, about 70% of particulate emission from Indian power plants are under 15 microns) reach the upper atmosphere (above 1 km), they may be carried long distances, often hundreds or even thousands of kilometers, before being deposited back to earth.

There is inadequate knowledge about the behaviour of atmospheric boundary layers, particularly since the hot climate of the subcontinent increases atmospheric mixing. Modeling the long-range transport of pollutants is therefore difficult and increases the uncertainty of the results.

The high Himalayan Mountains, with peaks above 20,000 m, also play a role in the transport of air pollutants, either blocking or altering their path.

3.2.4 Atmospheric chemistry

Except in certain parts of the country, Indian soils are generally alkaline, particularly in Northwest India. Alkaline dust from edaphic sources entrained into wind appears to neutralize some of the acid gases in the atmosphere. This seems to explain why gaseous pollutant ground level concentrations monitored downwind of specific point sources are less than model predicted values in North India.

Atmospheric chemistry is of recent research interest; hence there is as yet an inadequate understanding of the atmospheric chemistry over the Indian subcontinent.

3.2.5 Pollutant pathway

During the eight non-monsoon months, it is possible for the westerly winds to pick up acidic gas emissions, particularly from power plants located in the northern belt, and deposit them along the way in Bihar, Jharkhand, West Bengal, Nepal, Sikkim, Bhutan, Bangladesh, the North-eastern states, Orissa, Chattisgarh, Madhya Pradesh, Andhra Pradesh, Goa, Maharashtra, Karnataka, Tamil Nadu, Kerala, and northern Maldives islands.

During the four monsoon months, the south-west monsoon winds may pick up acidic emissions from Maharashtra, and Andhra Pradesh and deposit them over Orissa, Bangladesh, the Northeastern states, Bhutan and Sikkim. However, Andhra Pradesh and Maharashtra do not have the same emission loads as North-central and Northeast India. Hence, wet deposition during this period over the above recipient states may not be as significant as dry deposition is during the non-monsoon period. However, the monsoon winds may pick up acidic emissions from the northern belt and deposit them over Bihar, Jharkhand, West Bengal, Nepal, Uttar Pradesh, Uttaranchal, Himachal Pradesh, Haryana, Punjab, Rajasthan and Gujarat.

Wet and dry deposition data for India is scanty. It would be difficult to conclude as yet that any observed impacts of the acidification process may be due to Indian thermal power plants emissions. There is, therefore, a compelling logic for doing further long-term studies on wet and dry deposition and their impact.

3.2.6 Inter-tropical convergence zone

The inter-tropical convergence zone (ITCZ) is a region of deep convection currents, which moves from 5° S latitude 12° N latitude. The ITCZ acts as a barrier for air pollutants from the northern hemisphere, obstructing them from being transported into the southern hemisphere.

3.3 Acidic deposition and its impacts

3.3.1 Deposition monitoring

Time series data for the last three decades for wet deposition monitoring at some locations in India indicates that pH of rain water has been decreasing (see Tables 3.3 and 3.4) and that several sites have recorded acid rain. India is not the only country that has recorded acid rain. Wet deposition monitoring at Horton Plains (see Tables 3.5 and 3.6) and other locations also indicate acid rain episodes in Sri Lanka. Data from India and Sri Lanka indicate that while acid rain is not yet a serious problem, it may become one in future.

3.3.2 Soils and forests

The buffering ability of soils and the response of biota to acidic deposition mark the degree to which terrestrial ecosystems are sensitive to acidic deposition. Well-buffered ecosystems can withstand sustained acidic deposition with little injury, whereas, poorly buffered ecosystems will sustain injury.

Soil weathering, which facilitates the neutralizing of hydrogen ions by soil minerals, is the most important in-soil process that buffers soils against acidic deposition. High cation exchange capacity (CEC) and base saturation are other important attributes which give soil a good buffering capacity and make it insensitive to acidic deposition. A high CEC dampens short-term changes in soil chemistry.

If soil pH decreases below 5, aluminum, which is phytotoxic, is weathered out. Low soil pH also allow hydrogen ions to cause injury to plants, decrease nutrient (phosphates, molybdenum, micro-nutrients) availability, increase the solubility of phytotoxins such as aluminum, manganese, iron, etc, impair the nitrogen cycle and nitrogen fixation, impair mycorrhizal activity and allow increased attack by soil pathogens.

Soil acidification is determined by the rate of wet and dry acidic deposition, base cation deposition and its buffering capacity. Dust from edaphic sources, particularly from arid regions, is usually calcareous and acts as a base cation which neutralizes acidic deposition in the atmosphere and on land. A significant positive correlation has been observed between high dust concentrations at Jodhpur and Srinagar and pH of rain water.

Soil pH values are quite high between 15-35° N latitudes, except between 85-95° E longitude, ie, the Northeastern states, whose soils have low pH. Punjab, Haryana, Uttar Pradesh, Jammu & Kashmir, Rajasthan, Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh and parts of Karnataka and Tamil Nadu have high soil pH (6.5-10.5). Kerala, the Western Ghats, parts of the Eastern Ghats extending into the Sundarbans, Bihar, West Bengal, Himachal Pradesh, Uttaranchal, Sikkim and the North-eastern states have low soil pH (4-6). Vast portions of the Western and the Eastern Ghats and the West coast consist of lateritic soils that are acidic (pH of 4.5-5.9).

In two separate studies, acidification risk modeling was done for South Asia by the Stockholm Environment Institute and the RAINS ASIA project. Both studies map acidic and base cation deposition onto soil sensitivity maps to determine the areas that are likely to exceed critical loads. The conclusions of both studies are quite similar. The areas that are at high risk because of wet and dry deposition of acidic gases are the Western Ghats, portions of the Eastern Ghats extending into the Sundarbans, the Northeastern states and the Himalayan states, including Nepal and Bhutan and a small part of the South Indian tip. Sensitivity analysis for projections of exceedance of critical loads into the future indicates that emission reduction and increased base cation deposition alter the risk of acidification.

The RAINS ASIA model was used for this paper to make an initial assessment of the ecosystem risk posed by acidic gases. A detailed description of the model is available elsewhere and therefore not being provided here. The model results are discussed below.

Figures 3.4 and 3.5 provide spatial information on SOx emissions from India in 2000 and 2030, respectively. Figures 3.6 and 3.7 provide information on SOx deposition due to emissions from South and East Asia in 2000 and 2030, respectively. It can be seen in Fig 3.7 that SOx deposition will significantly increase in the Indo-gangetic belt, Gujarat, coastal Andhra Pradesh and Tamil Nadu.

Figure 3.8, which provides information on critical loads (the maximum load of acidic gas deposition which cause no acidification of soils and no long-term ecosystem changes; exceedance of critical loads occurs when the acidic deposition is greater than the base cation deposition and soil buffering capacity) for SOx deposition, indicates that the most sensitive areas (with the low critical loads) are the Western and the Eastern Ghats, portions of Tamil Nadu, Kerala and Karnataka, the east coast from Tamil Nadu up to the Sundarbans in West Bengal, the Himalayas and parts of Northeastern India. The Thar Desert in Rajasthan has highest critical loads, and therefore is the least sensitive to SOx deposition.

Figures 3.9 and 3.10 indicate that there was no exceedance of critical load in 2000. However, by 2030 there will be exceedance in the southern tip of India, along the east coast and the Western Ghats, in parts of East India, Haryana and Punjab.

Figures 3.11 and 3.12 sum up the modeling by indicating that in 2000 only a small portion of Tamil Nadu, the east coast and the Sundarbans area were unprotected ecosystems. The degree to which the ecosystems were unprotected was small—the percentage of ecosystems with deposition above their critical loads was 1-5%. By 2030, parts of Tamil Nadu, Kerala, the east coast, the Western and the Eastern Ghats, East Uttar Pradesh, Bihar, Jharkand, southern West Bengal, and parts of Haryana, Punjab, Himachal Pradesh, Jammu and Kashmir and Northeast India would have become unprotected ecosystems, and therefore at risk to the ravages of acidification. Moreover, the degree of lack of protection will increase dramatically—up to 80-100% in parts of south, east and west India, and an average of about 25% for all areas that would have become unprotected ecosystems by 2030.

In the 50 years since independence, 5 million Ha of forest land (8% of forest) was lost; 60% of it to agriculture, 11.5% to river valley projects, 4% to industries and townships, 1.5% to roads and transmission lines and 23% for miscellaneous purposes. The loss of dense forest was even greater. Between 1975-95, 22% (10 million hectares) of dense forest (>40% crown cover) was thinned down.

In the first half of this century, wet and dry deposition will put 35 million Ha, or 55% of India's forests in the Western and Eastern Ghats, the Himalayas and Northeastern India and the Andaman Islands at risk to forest dieback. An overlay of Figs 3.8 and 3.13 indicates that critical loads of soils to acidic gases are low in areas that host some of India's best tropical, sub-tropical and alpine forests. Most of the forests at risk are in districts with a high percent of land under forest cover and a high per capita forest area, which indicates that these forests that will now be at risk have so far been less affected by human interference.

These areas probably host 80% of India's 126,000 known species, and may probably have many species that are yet to be identified.

Based on the experience of forest dieback due to acidic deposition in the "Black Triangle" area of Europe (parts of the erstwhile Czechoslovakia, Poland and Germany), it could be said that the biodiversity in Indian forests is likely to be affected. For lack of adequate information, a full discussion on the impact of air pollution on biodiversity in India is not possible in this paper.

Once impacted, these forest areas may not quite recover even if acidic deposition abates, as their acidified soils may no longer be able support good vegetation.

The areas at high risk to the acidification process are also the sources or major catchments for 90% of India's surface water resources. A forest dieback will decrease available water resources for biota in the forests. Moreover, with loss of forest cover, these areas will lose their water retention ability. Rivers flowing from these areas will then experience flash floods during the monsoon months and run dry for most of the rest of the year. Water stress will further impact biodiversity both within forest areas and far beyond them.

Forests diebacks and water scarcity will cause occupation shifts and migration in a significant percent of India's population. Those who will be affected the most by this process will be forest dwellers and others who are dependent on forests for their livelihood.

3.3.3 Water bodies and aquatic ecology

Wet and dry deposition may also cause acidification of water bodies, particularly of inland fresh water bodies by the increased presence of hydrogen ions, which is a result of wet and dry deposition of acidic gases as well as the leaching of these ions from soils.

Acidified water bodies will have altered aquatic ecology. Impact to aquatic ecology starts at a pH of 6 and all normal life stops at a pH of 5. Benthic organisms are the most sensitive and cannot tolerate water below a pH of 6. As waters become further acidic, fish, zooplankton and macrophytes are affected. Below a pH of 4, only certain insensitive insects, plants and a few other species survive.

With their predators gone in low pH waters, certain beetles, dragonfly and other insects will thrive. With a drop in pH to values below 5.5, aluminum concentration increases in water, which can cause gill lesions in fish, causing their decline.

Sweden, which faced the problem of fresh water lake acidification, resorted to liming at a cost of US $ 50 million per annum to mitigate the damage.

Excess NO_2 deposition into water bodies may cause eutrophication of water bodies, including of estuaries and coastal marine waters. Eutrophication depletes dissolved oxygen making it difficult for the water body to sustain normal life. Algal blooms are also associated with excess nutrients in water bodies.

Some of India's islands are rich in coral reefs in shallow waters. While no studies have been conducted to understand the impact of acidic deposition on coral reefs, there is a line of thought that this is an issue worth researching.

If the fish productivity of estuaries and fresh water bodies decreases because of acidic deposition, the livelihood, and consequently the health of several hundred of thousands of fishermen dependent on these water bodies will be affected.

3.3.4 Asian Brown Cloud and climate forcing

Every winter (December through April) a haze, better known as the Asian Brown Cloud (ABC), extends over an area of 10 million square kilometers of the northern Indian Ocean—from the Arabian Sea to the Bay of Bengal and portions of South and South-east Asia. The aerosol cloud, 3 km in height, consists of several inorganic and carbonaceous material—a complex mix of sea salts, sulphates, nitrates, mineral and agricultural dust, soot, fly ash and organic substances (see Table 3.7).

An international scientific team studied the ABC from aircraft, ships and land-based stations about 500 km south-west of the Indian mainland during the period 1996-99. The scientists contend that the black carbon and fly ash found in the ABC are "unquestionably human produced". By comparing concentrations of aerosols in the ABC with those in the very clean air south of ITCZ, the scientists concluded that 90-95% of the sulphate, ammonium and organic concentrations in the ABC and 85% of all aerosol matter found in the ABC north of the ITCZ were of anthropogenic origin.

Though conclusive proof of the origins of the ABC is yet lacking, the track of the non-monsoon winds over the Indian subcontinent and the ABC constituents make it difficult to dismiss offhand the hypothesis that anthropogenic sources, particularly thermal power plants, in the Indian subcontinent may be contributing to the ABC.

The impact of ABC on climate change is yet to be monitored at field level. However, climate change models predict that the ABC may have far reaching impacts. Some of the possible impacts are described briefly below.

Climate forcing is a term used for changes that are caused in radiative fluxes that either heat (positive forcing) or cool (negative forcing) the atmosphere. Aerosols scatter solar radiation back to space, enhancing planetary aldebo. This exerts a negative climate forcing. Scientists estimate that anthropogenic sulphate aerosols, one of ABC constituents, may contribute to negative climate forcing to offset as much as 25% of the effect of greenhouse gases. However, black carbon, another ABC constituent, has the reverse effect.

An increase in atmospheric aerosol concentration, which happens in the ABC, increases cloud size as the aerosols nucleate more cloud drops. If the amount of water vapour remains the same, but the number of drops increases, the drop size decreases, inhibiting the formation of larger drizzle-size drops. This decreases precipitation and increases cloud life and enhances aldebo. The impact of this phenomenon is uncertain, but some scientists estimate that it can be large enough to offset the entire greenhouse effect.

The heating of soot and black carbon, both of which have been found in the ABC, can cause the evaporation of low clouds, resulting in positive climate forcing. The magnitude of this effect may equal or exceed that of the negative climate forcing caused by the scatter of radiation by aerosols.

Climate forcing, whatever be its directions, has the potential to alter temperature, precipitation and the amount of sunshine. The ABC may cause deviations in these three basic parameters over large areas of the Indian subcontinent, which may consequently cause changes in biodiversity composition. It is yet premature to predict the specifics changes in these three parameters and the impact they will have on biodiversity.

3.3.5 Global warming

Indian power plants generate about 3% of the world's carbon dioxide (CO_2) emissions of 35,000 million tonnes, ie, 1,400 million tonnes (India's share of world's emissions is 7%). The impact of CO_2 buildup in the atmosphere is global and principally affects changes in temperature, precipitation and amount of sunshine; which in turn will affect biodiversity. It can be said that Indian power plants currently contribute to global warming only to a small extent. The changes that global warming may cause to biodiversity is beyond the scope of this paper.

4.0 Conclusions

Over the next half-century, Indian thermal power plants may pose a bigger risk to biodiversity in the Indian subcontinent than all other anthropogenic interferences did in the past. Since the study of this subject is at an incipient stage, the above hypothesis is offered as a tentative one. However, because of the gravity of the risk, immediate steps need to be initiated to study this problem thoroughly, and take necessary measures to mitigate the problem.

5.0 Recommendations

To mitigate the possible impact that Indian thermal power plants may have on biodiversity, short-term, medium-term and long-term measures, as outlined below, need to be adopted.

5.1 Short-term

The following measures should be adopted in the next 5-7 years:

1. **Impact of thermal power on biodiversity study:** There is an urgent need for commissioning a small multi-disciplinary scientific group to study the impact of thermal power on biodiversity and write a draft policy paper on this issue for government's consideration. The study should look at all possible existing and possible future impacts at the local, regional, macro and meso scales.

1. **Wet and dry deposition monitoring:** The monitoring of wet and dry acidic deposition and its impact on soils, vegetation and aquatic environments should be begun in India and its neighbouring countries immediately. Under the Malé Declaration, the United Nations Environment Programme (UNEP), South Asia Cooperative Environment Programme (SACEP) and governments of SAARC nations and Iran (Malé Declaration signatories) have initiated a cooperative effort to monitor transboundary pollution and their impacts. A network of eight monitoring station is being setup in the Malé Declaration signatory countries in 2003, which will be expanded to 30 stations in due course. The monitoring methods are available in public domain on a website. The monitoring results, when available, will also be put on a website.

   To monitor acidic depositions and their impacts (in non-transboundary situations), the Andhra Pradesh Pollution Control Board (APPCB) has ordered a group of fertilizer industries and power plants in Kakinada to jointly setup an acidification monitoring station in the Coringa sanctuary. Similar orders have been given to the Kothagudem, Ramagundem and Vijayawada thermal power stations. Many more such stations are required India.

   Using low-cost methods, other stakeholders (educational institutes, NGOs) should also monitor wet and dry depositions and their impacts. The precision of data obtained by such methods may not be as high as that obtained by the UNEP-sponsored programme; but it would be good enough to detect the onset of the acidification process at an incipient stage. The advantages of using low-cost methods are threefold. First, a larger area can be monitored. Second, the participation of other stakeholders will generate public interest in the subject. Third, verification of acidification and its impacts is possible when there are several players who do independent monitoring. The author of this paper is developing low-cost kits for monitoring wet and dry deposition that can be used by education institutions and NGOs.

3. **Green lung:** Green lungs should be popularized for biological control of air pollutants. Air pollutants from a thermal power plant cause the maximum injury to biota within 10-20 km of the plant. Barring for ground level emissions, green belts located at the battery limits of a plant, are not very effective in attenuating air pollution. Plume rise from power thermal power plant stacks, which rise to heights of 500-1500 m, go over the 30 m tall green belt, and cause peak ground level concentrations (glc) at distances 2-20 km from the plant. After doing all that is possible to control emissions at the source, the best way to reduce air pollutant glcs is by using vegetation to absorb the pollutants. This can be done by a green lung, which is an extensive plantation meant to absorb air pollutants.

   Green lung plantations should be developed on wastelands in a 10 km radius around thermal power plants with pollution-resistant species. The Air Pollution Tolerance Index, along with knowledge of hardy local species, should be used to choose plant species. The plantations may have a mix of timber and other species. The cost of the developing the plantations should be borne by the thermal power plants. The management of the plantations may be done for the first 5 years by a committee consisting of the thermal power plant, the Forest Department and the panchayats in whose jurisdiction the plantation area falls. The management of the plantations may be handed over to the panchayats after 10 years.

   The APPCB has ordered all thermal power and cement plants in Andhra Pradesh to do feasibility studies for developing green lungs around their plants.

2. **Bio-indicators:** There are well known bio-indicators for air pollutants. The APPCB has ordered several thermal power stations to plant bio-indicators up to distances of 5-10 km away from the station.

   Industry has been generally resistant to the concepts of green lung and planting bio-indicators, and APPCB has not pursued the implementing of these orders.

5. **Training bystander populations:** The Environment Protection Act should be amended to make it mandatory for populations residing in the proximity of facilities, including power plants, regulated by pollution control boards to receive training to allow them to monitor the compliance of consent conditions put on these facilities.

6. **Cost of externalities:** The cost of externalities must be reflected in the price of products and services, including those provided by power plants and their suppliers and contractors. Else, the cost of environmental injury will remain unaccounted. Government of India should setup an environmental economics commission to establish methods and norms for costing environmental costs, including of thermal power plants.

7. **Siting:** Environmentally suitable sites for thermal power plants should be identified on a war footing. New plants should be located only at these sites. These sites should be such that they cause minimum impact to the four ecologically sensitive areas (Western and Eastern Ghats, the Himalayas, the Northeast). If Government of India does not perform this task, a citizen’s commission should undertake it.

8. **Toxic Release Inventory:** It should be made mandatory for every industry, including power plants, to file an inventory of their toxic and flammable emissions every year. The inventory should provide information on all toxic and flammable releases to air, water, soil and other sinks. The data should compiled by the pollution control boards and put into public domain. On-demand information will then be available on emission quantities from a particular area or from an industry category.

9. **Back stowing of ash into mines:** Back stowing of ash into dis-used mines should be encouraged. The APPCB has requested Singareni Collieries Ltd and the National Thermal Power Corporation Ltd to submit a proposal for doing this. However, Singareni Collieries appears to be reluctant to do this.

5.2 Medium-term

The following measures should be undertaken in the medium-term—over the next 15 years.

1. **Energy and environment policy: The** government should frame and adopt policy paper on energy and environment after circulating a draft for public comment.
2. **Carbon and sulphur tax:** A carbon and sulphur tax, which is proportional to emissions, should be levied on all carbon and sulphur emitters. The sulphur tax should be used to mitigate any damage that acidic emissions may cause. The carbon tax should be used for the protection and conservation of forests and biodiversity in India. It is beyond the scope of this paper to develop these ideas fully.
3. **Emissions protocol:** The Malé Declaration is a non-binding inter-government agreement that seeks to control and prevent air pollution and its likely transboundary effects in South Asia. As a next step, the Malé Declaration signatory nations should sign a protocol that puts ceilings on acidic gas emissions from each country. Such protocols exist in other parts of the world.
4. **Emissions standards:** Except for particulate matter, thermal power plants do not have emissions standards for other pollutants. Emissions standards must be specified for SO_2 and NO_2, and subsequently for other pollutants as well. Possible long-range impact of these pollutants on biodiversity must be considered while setting the standards.
3. **Clean fuels:** Recent global trends indicate a shift away from dirtier solid and liquid fuels towards cleaner gas fuels. In India too, gas-based power plants, which were non-existent earlier, today account for 14% of thermal power generation and 10% of total generation capacity. This trend towards increased use of gas will continue. To accelerate it, gas availability and delivery will have to be improved.
6. **Emissions control:** To meet the new emission standards, several technology options may be encouraged. Pre-combustion control methods include coal washing and the use of low sulphur fuels. Treatment during combustion technologies includes the addition of limestone and the use of low-NOx burners. Post-combustion technologies include flue gas de-sulphurizers and non-catalytic reduction of NOx by adding ammonia and urea to flue gases.
7. **Increasing energy efficiency:** India has already commissioned several liquid or gas-based combined cycle plants. These plants achieve efficiencies of 50% energy conversion as compared to steam generators, which achieve a maximum efficiency of 35%. The setting up of combined-cycle plants may be further encouraged.

   The use of low-grade waste heat from power plants by other industry, domestic and commercial users, will further increase energy conversion efficiency. Government may encourage the use of waste heat.
8. **Demand-side management:** There is considerable scope for introducing standards and using eco-labeling low-power consuming end-use devices. Lighting accounts for 20% and 60% of power consumption by the domestic and commercial sectors, respectively. Refrigeration consumes 20% of the power consumed by the domestic sector. Electrical drives consume 73% and nearly 95% of the power consumed by the industry and agricultural sectors, respectively. Compact fluorescent bulbs consume just 25% of the power consumed by incandescent bulbs. Likewise, switching to more efficient refrigerators can save 25% of the power consumed by older refrigerators. And more efficient drives can save up to 7% of power consumption.

   A switchover to more efficient devices for lighting, refrigeration and drives can save considerable power. Government should encourage such a switchover.
9. **Pollution Prevention Boards:** The present Pollution Control Boards (PCBs) are geared to ‘controlling’ pollution and not preventing or reducing it. A new authority, Pollution Prevention Boards (PPBs), should be created to prevent pollution. They should encourage the use of low-polluting technologies on the supply and the demand side; and use financial incentives and disincentives, including sulphur and carbon taxes, to meet their objectives.
10. **Decentralized grant of consent for operations:** Pollution control boards are responsible for granting consent for establishment (CFE) and consent for operations (CFO) for polluting facilities. One of the reasons for the boards not being able to regulate industry effectively is because they are unable to act as a watchdog over industry. The function of granting CFOs can be better done by local self-governments (panchayats, zilla parishads) as they will be able to perform a watchdog function better because of their proximity to the industry and they would also be more sensitive to bystander populations’ opinions. Local self-governments may be provided suitable training to perform the function of grant of CFO. The transfer of this function may be

effected over a 10 year period. And even after the transfer of this function is effected, the boards may continue to advice the local self-governments on technical issues.

11. **Reducing power losses:** Efforts are already being made to reduce transmission and distribution losses. These must be pursued with vigour.
12. **Encouragement for renewables:** India has a huge potential for tapping renewable energy. However, only a small fraction of this potential has been tapped so far.

Estimated and Installed Capacity in Renewable Energy Sources[3]

	Estimated capacity	**Installed capacity**
Wind energy (MW)	45,000	1,500
Biogas plants (nos)	12,000,000	3,130,000
Biomass gasifiers (MW)	19,500	400
Minihydel (MW)	10,000	210
Solar PVs	20 MW/sq km	60 MW
Solar water heaters (nos)	30,000,000	500,000
Ocean (MW)	50,000	nil
Bagasse-based cogeneration (MW)	NA	3,500

Renewables form only 3% of the installed power generation capacity of India today. To improve India’s renewable capacity utilization, the impediments associated with increasing capacity in renewables, which is beyond the scope of this paper to discuss, should be tackled immediately.

5.3 Long-term

Hydrogen is considered to be the fuel of future—clean and hopefully plentiful. The government should state its position on how India will transit to a hydrogen-based economy in its policy paper on energy and environment.

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[3] Source: Economic Survey, 2002.

Table 1.1 Power Generation Capacity in India (MW)

	Thermal	Hydro	Nuclear	Renewables	Total
1900	1	0.1			1.1
1910	15	16			31
1920	56	74			130
1930	312	287			599
1940	739	469			1,208
1947	855	508			1,363
1950	1,153	559			1,712
1960	2,436	1,917			4,353
1970	7,676	6,383	420		14,479
1980	17,396	11,791	860		30,047
1990	44,910	18,442	1,465		64,817
2000	70,186	23,816	2,680	5,610+*	102,292

* Renewables includes wind energy, biomass gassifiers, minihydel turbines (<3 MW), and bagasse fired cogeneration plants; but does not include biogas plants, solar PV panels and solar water heaters. Figures for previous years not available.

Source: Central Electricity Authority, Central Board for Irrigation and Power, 1997.

Table 2.1 Changes in Soil Samples Collected at Various Distances NE of the Obra Thermal Power Plant

Dist from Plant (km)	pH	Total N (%)	Total S (µg/g)	Available P (µg/g)	Exch'ble K (µg/g)	Organic matter (%)
0.5	5.4	0.042	1156	9.93	216	3.84
1.5	5.4	0.043	1130	10.55	210	3.56
3.0	5.5	0.048	960	13.62	184	3.15
4.5	5.6	0.056	850	14.46	125	3.86
6.0	5.8	0.058	720	15.83	110	2.76
7.0	6.5	0.060	650	16.21	94	2.61
8.0	6.8	0.061	540	16.58	90	2.20
9.5	6.8	0.065	510	18.58	90	1.85
20.0	7.2	0.073	407	22.46	78	1.12

Source: Pandey, 1978 as quoted by Rao, 1985.

Table 2.2 Chlorophyll Content, Weight And Calorific Value Decrease In Three Tree Species Growing 500m From Obra Power Plant

Tree Species	Chlorophyll decrease(%)	Leaf weight loss (%)	Calorific value dec
Diospyros melanoxylon	55.4	34.0	15.2
Lagerstroemia parviflora	43.2	20.7	15.2
Zizyphus nummularis	54.5	17.1	12.2

Note: Figures indicate percent decrease wrt controls 20km from the plant.

Source: Pandey, 1978 as quoted by Rao, 1985.

Table 2.3 Long Term SO_2 Concentrations And Chlorophyll Content Decrease In Four Tree Species Growing 200m From Satpura Power Plant

Tree Species	Chlorophyll decrease(%)	SO_2 Concentration (ppm)		
		Summer	Monsoon	Winter
Diospyros melanoxylon	25.19	0.03	0.02	0.2
Ardina cordifolia	17.46	0.03	0.02	0.2
Buchnania melanoxylon	25.19	0.03	0.02	0.2
Madhuca latifolia	27.64	0.03	0.02	0.2

Note: Figures indicate percent decrease wrt controls

Source: Dubey, 1982.

Table 3.1 Estimated SO_2 Emissions in Asia Under No-Control Conditions

	Sulphur dioxide emissions (kilotons)			Avg annl
Region/Country	2000	2010	2020	growth %
North-east Asia	39,789	55,299	70,714	2.9
China	34,328	47,840	60,688	2.8
Hong Kong	216	290	378	2.8
Japan	997	1,048	1,120	0.6
Korea, Dem Rep	586	878	1,345	4.2
Korea, Rep of	2,802	4,033	5,537	3.5
Mongolia	95	124	168	2.9
Taiwan	765	1,086	1,478	3.3
South Asia	8,630	15,349	27,139	5.9
Bangladesh	165	330	525	6.0
Bhutan	5	7	12	4.5
India	6,594	10,931	18,549	5.3
Myanmar	25	32	40	2.4
Nepal	156	194	247	2.3
Pakistan	1,553	3,684	7,527	8.2
Sri Lanka	132	171	239	3.0
South-east Asia	4,432	7,640	12,112	5.1
Brunei	8	13	18	4.1
Cambodia	40	75	147	6.7
Indonesia	1,085	1,868	3,162	5.5
Laos	5	8	12	4.5
Malaysia	242	342	410	2.6
Philippines	627	1,071	2,037	6.1
Singapore	358	653	1,033	5.4
Thailand	1,901	3,277	4,638	4.5
Vietnam	166	333	655	7.1
Sea lanes	310	397	512	2.5
Total	53,161	78,685	110,477	3.7

Source: Downing, 1997.

Table 3.2 SO_2 Emission Intensity, Per Capita Emissions and Emission Densities in Asia and Selected Western Countries in 1990

Region/ Country	Emission intensity kg/1000 US$ at 1990 prices	Per capita emission kg	Emission density T/km^2
North-east Asia	7.88	22.03	2.58
China	71.35	22.86	2.79
Hong Kong	3.45	23.88	138.50
Japan	0.29	6.90	2.25
Korea, Rep of	6.98	41.29	17.88
Mongolia	24.99	21.93	0.03
Taiwan	3.35	25.38	14.24
South Asia	14.39	5.07	1.11
Bangladesh	4.10	0.77	0.61
Bhutan	7.23	1.33	0.04
India	16.29	5.99	1.50
Mynmar	0.96	0.53	0.03
Nepal	9.05	1.48	0.20
Pakistan	15.74	5.54	0.78
Sri Lanka	3.79	1.79	0.46
South-east Asia	8.18	6.63	0.71
Brunei	1.87	15.26	0.64
Cambodia	12.22	2.35	0.11
Indonesia	6.51	3.85	0.36
Laos	4.84	1.01	0.02
Malaysia	5.02	12.07	0.65
Philippines	9.40	6.78	1.38
Singapore	5.23	70.44	190.89
Thailand	12.93	18.49	2.02
Vietnam	10.37	2.03	0.41
Asia	8.47	13.19	1.86
United States	3.81	84.27	2.25
Germany	3.76	89.96	15.96
France	1.00	21.15	2.17
United Kingdom	3.84	65.84	15.43

Source: Shrestha, 1996, 1997.

Table 3.7 pH of Rainfall at Various Locations

Jodhpur	1976	1977	1979	1996	1997
pH	7.96	8.28	7.16	6.1	5.9

Agra	1963	1984
pH	9.1	6.3

Delhi	1965	1984
pH	7.0	6.1

Sources: Mohan, 1998; Kumar, 2000

Table 3.4 pH Trends at Various Indian Cities

	pH Trends	Acid rain observations
Allahabad	Decreasing	0
Jodhpur	Decreasing	0
Kodaikanal	Decreasing	3
Minicoy	Decreasing	1
Mohanbari	No trend	2
Nagpur	Increasing	1
Port Blair	Decreasing	5
Pune	Decreasing	0
Srinagar	Decreasing	0
Visakhapatnam	Decreasing	0

Source: Mohan, 1998

Table 3.5 pH Value Ranges in Horton Plains During 1995-96

Stream water	5.81-7.45
Rain water	5.37-7.47
Throughfall	5.80-7.57
Cloud water	3.88-6.52

Source: Ileperuma, 1998

Table 3.6 pH Value Ranges at Various Sri Lanka Locations

Stn Code	Min	Max	Avg
AP	4.89	6.97	6.00
BD	6.11	7.11	6.64
BW	5.78	6.72	6.24
CB	5.32	6.68	5.89
GL	5.35	7.90	6.45
HT	5.79	5.99	5.89
KG	4.92	6.67	6.28
MI	5.09	6.54	6.07
NE	4.36	6.96	6.18
PT	6.21	7.31	7.00
RP	5.88	6.49	6.25
UNI	4.68	7.27	6.26

Source: Ileperuma, 1998

Table 3.3 Mean Fine and Coarse Mass Fractions of Aerosols Collected From an Aircraft (34 samples) and from a Ground Station (24 samples) over the Indian Ocean

Compound	**D < 1 micron %**	**D > 1 micron %**
Sulphate	32	25
Organics	26	19
Black carbon	14	10
Mineral dust	10	11
Ammonium	8	11
Fly ash	5	6
Potassium	6	1
Nitrate	<1	4
Sea salt, MSA	<1	12
Rest	2	1
Total mass (um/m3)	22	17

Notes: D—diameter; MSA—methane sulphonic acid; Rest includes magnesium, calcium, oxalate, formate and unidentified material

Source: Lelieveld, 2001.

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