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Technology Development Prospects for the Indian Power Sector: The Impact of the Spatial Resource Distribution

Draft for Comment

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Technology Development Prospects for the Indian Power Sector:

The Impact of the Spatial Resource Distribution

Background

The world is facing serious challenges in the energy sector. The global economy is set to grow four-fold between now and 2050 and growth could approach ten-fold in developing countries such as India and China. This promises economic benefits and huge improvements in people's standard of living, but it implies a much greater use of energy.

A global revolution is needed in the ways that energy is supplied and used. Far greater energy efficiency is a core requirement. Unprecedented levels of co-operation among all major economies will also be crucial. In 2008, the IEA published *Energy Technology Perspectives 2008* (ETP 2008). The aim of the book was to explain how to transform the global energy economy over the coming decades. A BLUE Map scenario was elaborated: it explored the energy and technology implications of achieving a 50% reduction in global energy-related CO_2 emissions by 2050, compared to current levels. If fully implemented, the BLUE Map scenario could be consistent with stabilising long-term GHG concentrations in the atmosphere at 450 ppm and limiting the long-term global mean temperature rise to 2.0 to 2.4 degrees Celsius.[1] The analysis indicated that achieving such reductions would require maximum implementation of energy efficiency worldwide and a virtually decarbonised power sector (Figure 1). The decarbonisation of the power sector, in particular, poses a major challenge.

[1] Significant reductions in non-energy CO_2 emissions and non-CO_2 greenhouse gases would also be required to achieve the 450 ppm target.

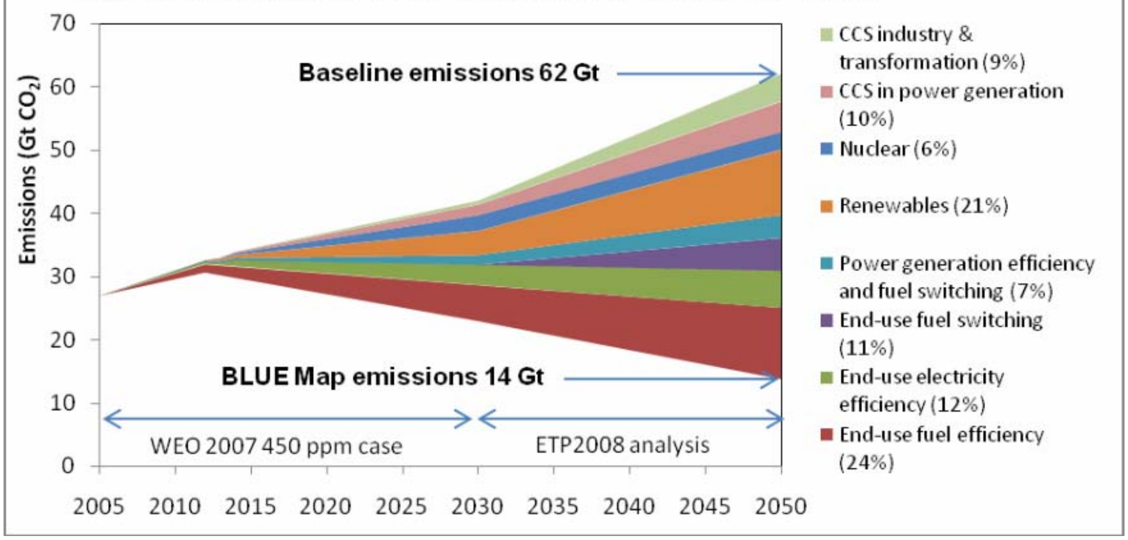

Figure 1: Contribution of emission reduction options, 2005-2050

Source: ETP, 2008.

Recognizing the different challenges faced by different countries, the IEA has selected four countries/regions – India, China, Europe and the United States – for which country specific analysis will be performed in the new ETP publication. The ETP 2010 regional analysis will examine potential technology pathways for each region, taking into consideration the particular energy supply and demand specificities that would be consistent with the goal of achieving a 50% reduction in worldwide energy-related CO_2 emissions by 2050.

This paper, which will be used as an input to the Indian regional chapter in ETP 2010, investigates what mix of technologies are needed to achieve deep CO_2 emission cuts in the Indian power sector while keeping pace with the strong growth in energy requirements that will result from a rapidly growing economy.

Summary of Key Points

Indian electricity supply and demand is projected to increase four to five-fold between now and 2050 (IEA, 2008). This development will require massive investments, but it also creates unique opportunities to dramatically change the CO_2 intensity of Indian electricity supply. However, the expansion of the power sector in India faces many barriers such as a spatially uneven distribution of natural resources, financial constraints and high system losses. Accelerated development of natural resources and more transmission and distribution (T&D) capacity are needed in order to overcome the current problems. Increased competition, additional equipment supply capacity and other actions to increase the private sector interest can help to accelerate investments.

The BLUE Map scenario developed by the IEA has not only CO_2 benefits, it also reduces the need for capacity additions and it enhances supply security. Analysis of the scenario for India indicates that the electricity demand can be limited to 3229 TWh in 2050 despite the projected increase of 5.0% per year between 2007 and 2050 in GDP and 0.8% per year in population, and assuming access to electricity for all. This demand can be met with 734 GW capacity, which implies an expansion by 566 GW compare to 2007/8. In order to reduce the CO_2 emissions of the Indian power sector significantly, while ensuring access for all, a potential technology transition between now and 2050 is outlined that is based on a number of elements:

Technical elements:

- Maximise the efficiency of electricity use and the load factor for capital intensive power plants, notably nuclear and fossil fuelled plants and minimise T&D losses to15%.
- Significantly raise the levels for solar power generation, both photovoltaic (PV) and concentrated solar power (CSP) to achieve a 130 GW capacity by 2050.
- Expand the use of nuclear power by a factor forty, notably in coastal locations, to about 120 GW (more than 100 new nuclear reactors). Additional pumped hydro capacity can be used to deal with rising nuclear power baseload generation.
- Build 80-one GW coal-fired oxyfuel plants and equip them with CCS. Pay special attention to the characteristics of Indian coal for oxyfueling.
- Consider the use of CCS for coal-fired power plants in suitable coastal locations (Mumbai, Chennai).
- Increase the use of natural gas by a factor of eight by accelerating the exploration and developing of offshore gas fields, developing LNG terminals, gas pipelines and natural gas combined cycle (NGCC).
- The use of hydropower can be expanded by a factor four, notably to supply the North. India has enough hydro potential to meet this increase (CEA, 2008a)

The regional natural resource distribution plays a role. The hydro potential is concentrated in the North; wind is concentrated in the South. Nuclear, given its cooling water requirements, will be largely located at the coast. The main CCS potential is in Mumbai and Chennai. New coal capacity should be limited to these regions ("capture ready" concept).

Non-technical elements:

- A policy framework for T&D investments is needed where such investments are rewarded properly. This development should be combined with cost-based pricing and removal of subsidies for certain consumer groups. This is a no-regret option from a national perspective that can ease supply constraints and environmental impacts substantially.
- India will need technology co-operation in the field of nuclear energy, solar, CCS and electricity grids. The Thorium resource, high ash coal reserves, lack of cooling water on inland sites and complex planning problems for hydro projects, mean that India needs dedicated technology development in a number of areas.
- It is imperative to combine CO_2-free supply with maximum efficiency of electricity use. Price incentives, efficient equipment and lightign but also energy efficient building design (avoidance of heat loads, forced ventilation with cold exchange) can help to reduce demand growth.

The development as outlined in BLUE Map results in a radically different coal demand and such a development has consequences for railroad development. In fact, total coal transportation needs would remain constant or even decline as imported coal is economically more attractive in the Western and Southern coast of India (GoI, 2006).

While options such as gas fired plants with CCS, biomass, tidal/wave energy and geothermal can play some role, their contribution will be more limited. The lack of substantial wind and woody biomass resource means that the Indian situation is different than that of China, Europe or the United States. However India is in the possession of world class hydro, solar and thorium fuel resources.

The main challenge for the coming decades is to make an energy transition and to bring in CO_2-free electricity sources online at a sufficient rate to satisfy demand.

A number of issues must be analysed in greater detail:

- Hydropower site issues: the need for and acceptance of relocation, competing water use, competing land use for agriculture and nature, future water flows in a changing climate. Also, development of the hydro potential in the North East (NE) region will require new direct current (DC) line investments for connection to the centres of demand.
- Nuclear: focus on import of uranium-fuelled reactors and development of own Indian production capacity or continued development of thorium fast breeder reactors of Indian design.
- Given the size of the Indian market, it is worthwhile to develop an Indian equipment industry for solar-PV, CSP, T&D equipment. The low labour cost will be beneficial for building integrated installation of PV.

- Indian coal has a high ash content, which makes integrated gasification combined cycle (IGCC) a less attractive option. Development should, therefore, be focused on oxyfueling and coal upgrading (*viz* joint Japan-Australia project for synthetic coal).
- Space cooling is becoming increasingly important in the residential and service sectors. Developments of new technologies and energy savings need to be analysed in greater detail.

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Introduction

The 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC) released in November 2007 concluded that emissions must be reduced by 50% to 85% from 2005 levels by 2050 if global warming is to be confined to between 2ºC and 2.4ºC. Following the publication of the IPCC report, the urgency to address climate change rose significantly. Much deeper CO_2 emission cuts than those previously considered are required; a general guideline is that global CO_2 emissions halving is required.

The BLUE Map scenario, developed by the International Energy Agency (IEA) and presented in the Energy Technology Perspectives 2008 (IEA, 2008) publication, explores the energy and technology implications of reducing global energy-related CO_2 emissions to 50% of current levels by 2050. This scenario could be consistent with the long-term stabilisation of CO_2 concentrations in the atmosphere at 450 ppm.[2] The ETP 2008 BLUE Map scenario indicates that achieving such reductions require maximum implementation of energy efficiency worldwide and a virtually decarbonised power sector. The decarbonisation of the power sector in particular poses a major challenge in the Indian case.

As part of the ETP 2010 analysis, the baseline and BLUE Map scenarios presented in the previous ETP report (ETP 2008) will be elaborated upon for four countries/region - India, China, Europe and the United States. This elaboration will consist of two parts:

- Discussion of IEA's ETP modelling results on a country/regional basis.
- More detailed spatial modelling of the power sector.

The goal is to refine the ETP 2008 scenarios and to assess their viability in greater detail. For example, the potential of high quality renewable energy resources is often concentrated in specific regions. Sitting of nuclear power plants is limited by the availability of sufficient cooling water. Long-range transmission lines can overcome such problems but add to the cost of electricity supply.

This working paper represents a key input to the regional analysis that will be presented for India in the upcoming ETP 2010 publication. The paper investigates what would be the best way to achieve deep CO_2 emission cuts in the Indian power

[2] Significant reductions in non-energy CO_2 emissions and non-CO_2 greenhouse gases would also be required to achieve the 450 ppm target.

system while allowing the Indian economy to continue to grow and alleviate energy poverty. It does so from a techno-economic perspective - building on detailed resource and technology data for India - and identifies the key technologies for India. The intent of this working paper is **not** to analyse how to achieve this technology deployment in India, in which areas technology transfer would be needed, or what technology transfer should look like. However, discussion of generic technology transfer issues will be included in ETP 2010.

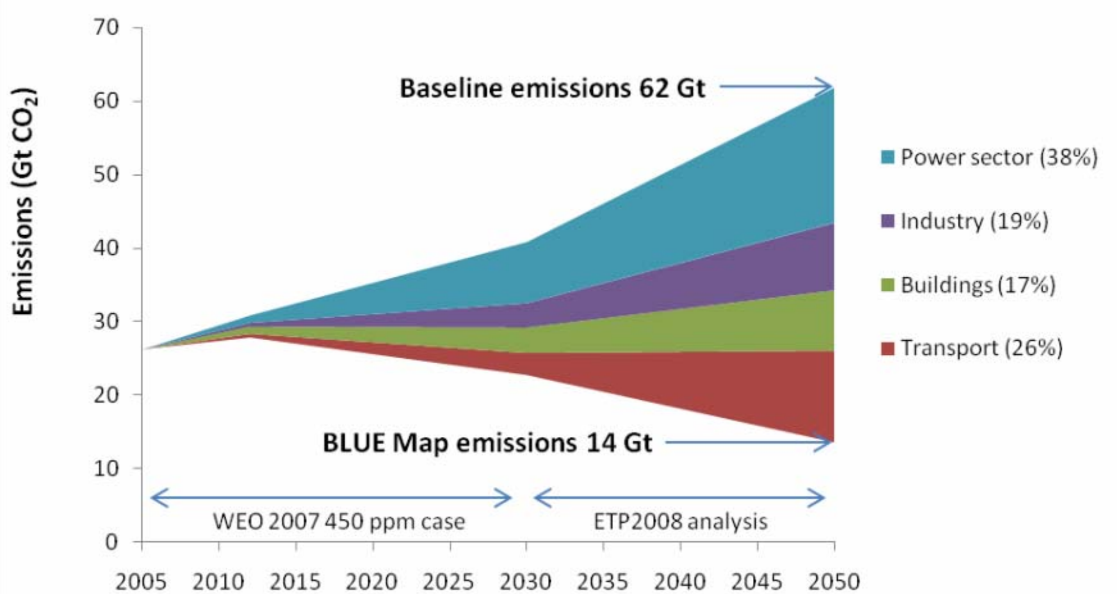
Section 1: Overview of Current Situation

Global Context

Globally, CO_2 emissions from the power sector were 11 Gt of CO_2 in 2007, accounting for 41% of total energy-related CO_2 emissions (IEA, 2009a). This share is projected to increase further with policies in place today, and the CO_2 emissions from the power sector are expected to rise to 27 Gt of CO_2 in 2050 in the Baseline scenario (IEA, 2008). The strong increase in CO_2 emissions in the power sector is mostly attributable to the growth in power generated from coal-fired power plants.

The power sector has a number of features that make it a prime target for CO_2 abatement: centralised large point sources, proven alternative low-CO_2 technology options, and relatively low abatement cost. The IEA estimates that a virtual decarbonisation of the power sector can be achieved with CO_2 prices of between USD 50/t CO_2 and USD 100/t CO_2. In comparison, global emissions halving in other sectors would require options with a cost of up to USD 200/t CO_2. Emissions reduction in the power sector can contribute 18 Gt CO_2 reductions out of the 48 Gt that are needed in BLUE Map compared to Baseline in 2050, a 38% share. This excludes the benefits from end-use electricity savings and widespread use of CO_2-free electricity as a substitute for fossil fuels.

FIGURE 2: Reduction of energy-related CO_2 emissions from the Baseline scenario in the BLUE Map scenario by sector, 2005-2050



Source: IEA, 2008.

The cost and savings potential estimated in ETP 2008 assume a global decarbonisation of the power sector. Without such global participation, it will not be possible to achieve emissions halving, and the cost to reach the same level of emissions reduction will be much higher. Therefore, it is imperative to strive for a global decarbonisation of power generation, also in India. The question of who should pay for this reduction is a different issue and is not addressed in this paper.

The Indian Context

Table 1 compares a number of key energy indicators for the world and the four regions/countries that will be elaborated upon in the ETP 2010. Indian per capita consumption of electricity and oil is significantly lower than in the other regions being considered, and well below the world average.

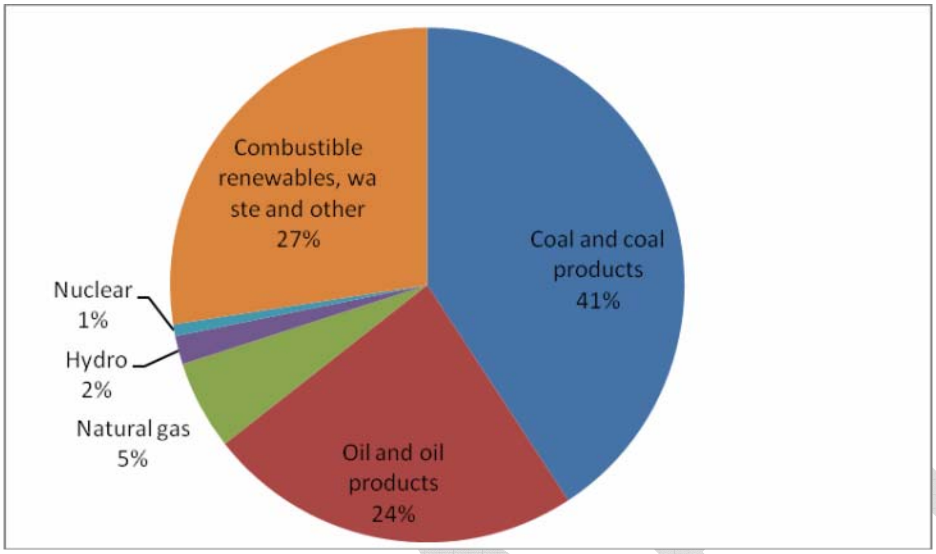
TABLE 1: *High-level energy indicators for the world and four regions, 2007*

	World	India	People's Republic of China	OECD Europe	United States
Energy production (Mtoe)	11 940	451	1 814	1 067	1 665
Net imports (Mtoe)	83	150	194	846	714
Total primary energy supply (Mtoe)	12 029	595	1 970	1 827	2 340
Net oil imports (Mtoe)	80	107	200	495	634
Oil supply (Mtoe)	4,090	141	358	634	910
Electricity consumption (Twh)	18 187	610	3 114	3 387	4 113
CO2 emissions (Gt)	29.32	1.37	6.04	4.10	5.85
GDP (billion 2000 US$ using exch. Rates)	39 493	771	2 623	10 532	11 468
GDP (billion 2000 US$ using PPP)	61 428	4 025	10 156	13 223	11 468
Population (millions)	6 609	1 123	1,327	543	302
Land area (million km^2)	148.94	2.97	9.57	4.95	9.16
Total self-sufficiency	0.99	0.76	0.92	0.58	0.71
Coal and peat self-sufficiency	1.01	0.87	1.02	0.56	1.02
Oil self-sufficiency	0.98	0.28	0.52	0.37	0.35
Gas self-sufficiency	0.99	0.71	0.94	0.53	0.83
TPES/GDP (toe per thousand 2000 US$)	0.30	0.77	0.75	0.17	0.20
TPES/GDP (toe per thousand 2000 US$ PPP)	0.20	0.15	0.19	0.14	0.20
TPES/population (toe per capita)	1.82	0.53	1.48	3.36	7.75
Net oil imports /GDP (toe per thousand 2000 US$)	0.00	0.14	0.08	0.05	0.06
Oil supply /GDP (toe per thousand 2000 US$)	0.10	0.18	0.14	0.06	0.08
Oil supply /population (toe/capita)	0.62	0.13	0.27	1.17	3.01
Electricity consumption /GDP (kWh per 2000 US$)	0.46	0.79	1.19	0.32	0.36
Electricity consumption /population (kWh per capita)	2 752	543	2 347	6 239	13 616

Source: IEA, 2009b; IEA, 2009d.

Figure 3 provides a breakdown of Indian energy supply in 2007. What is evident is the high share of coal, but also a high share of bioenergy. This is largely traditional biomass for heating and cooking purpose in the residential and service sectors.

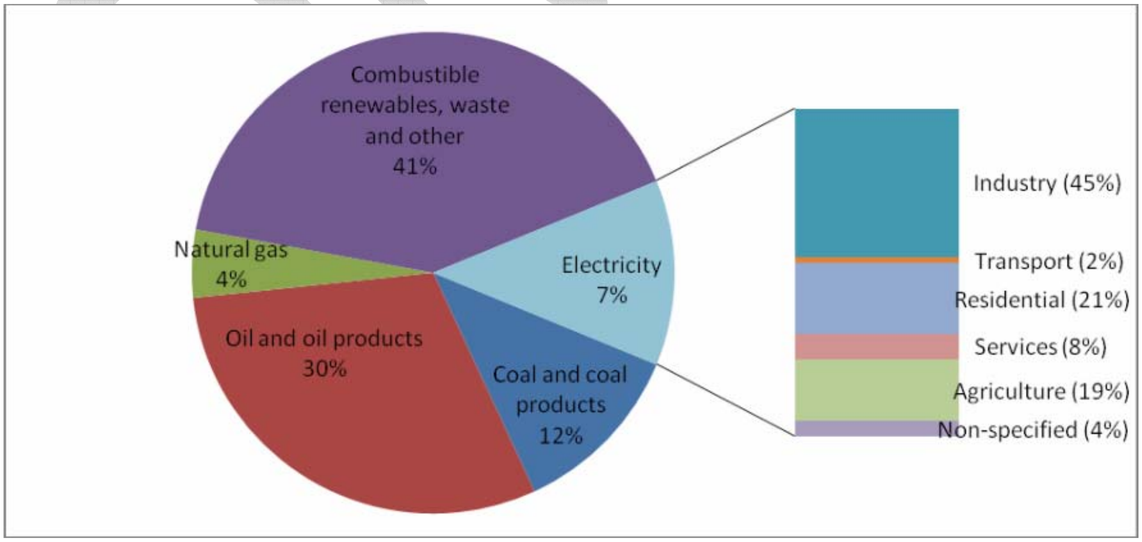
FIGURE 3: *Total primary energy supply in India (595 Mtoe in 2007)*



Source: IEA, 2009b.

Figure 4 provide the breakdown of energy consumption in India by energy source. In terms of electricity demand, agriculture accounts for 19% (largely for water pumps), industry accounts for 45%, domestic use accounts for 21% and the commercial sector for 8% (IEA, 2009b).

FIGURE 4: *Total final energy consumption in India (393 Mtoe in 2007)*



Source: IEA, 2009b.

Industrial development has contributed significantly to economic growth in India over last few decades; however, industrialization has not been uniform. Large and modern urban centres coexist with traditional rural and agrarian economy. The varying sectoral growth rates, consumption patterns and resource endowments have led to widely different regional and sectoral energy consumption and emissions distribution. Regional analyses of CO_2 and GHG data for the year 1995 (Garg et al, 2001) and the year 2000 (Kapshe, M. et al, 2002) suggests that significant differences exist among Indian districts in terms of CO_2 emissions per square metre. The highest emissions occur in a band from Punjab to Calcutta, in the south and along the east coast.

Domestic electricity use also varies by state and territory. It is highest in Delhi with 424 kWh/cap per year and lowest in Bihar with only 18 kWh/cap per year. The average for India is 106 kWh/cap per year (Table 2).

TABLE 2: Domestic electrical energy sales, population and electricity per capita, 2007/08

	Electricity sales to domestic consumers (GWh)	Population (million)	Electricity per capita (kWh/cap)
All India	**120 918**	**1 141**	**106**
Northern Region	39 184	350	112
Western Region	30 483	257	119
Southern Region	35 925	240	149
Eastern Region	13 494	251	54
North Eastern Region	1 833	43	43

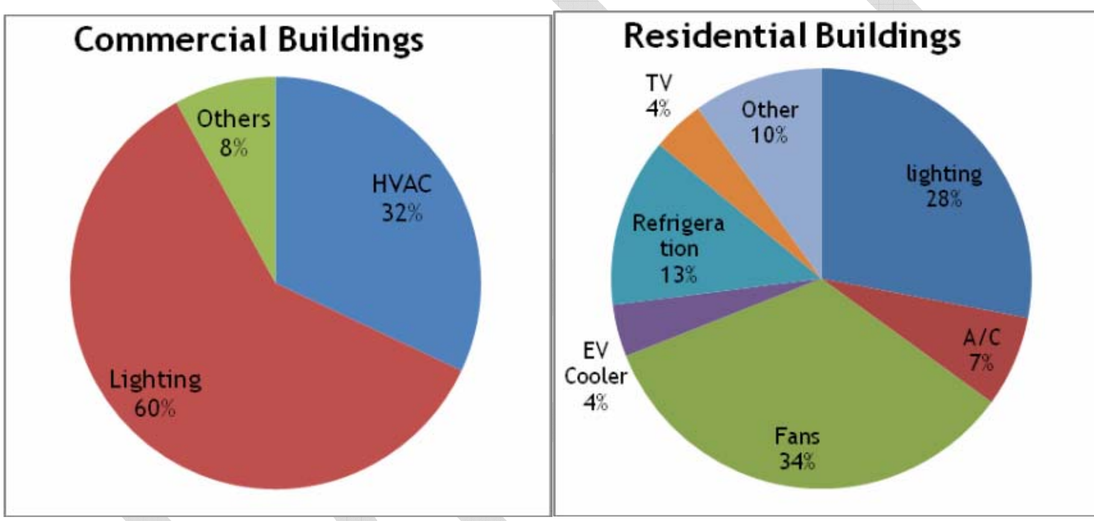
Source: CEA, 2009.

For India, on average, the share for space conditioning (heating and cooling through air conditioning units, fans and evaporative air coolers) accounts for 45% of residential electricity consumption, while lighting account for 28% (BEE, not dated). It is estimated that about 60% of the total electricity is consumed for lighting in a typical commercial building in India, 32% for space conditioning, and 8% for refrigeration (Figure 5).

The Future of Space Cooling

A key question for residential demand is, therefore, what will happen to air cooling. This equipment is not yet widespread in India. Air coolers are, however, more widely applied. These machines use the hot air from within the building to evaporate water. This evaporation cools the outgoing air, and this cold is transferred to the incoming air through a heat exchange. This system can be combined with conventional air conditioning for further cooling. Such hybrid air conditioning systems reduce the energy use by half compared to conventional air conditioners (Oxy-com, 2009). But this system is only suited for dry inland climate conditions, not for the humid coastal cities of India.

FIGURE 5: *Electricity use breakdown in commercial and residential buildings*



Source: BEE, not dated.

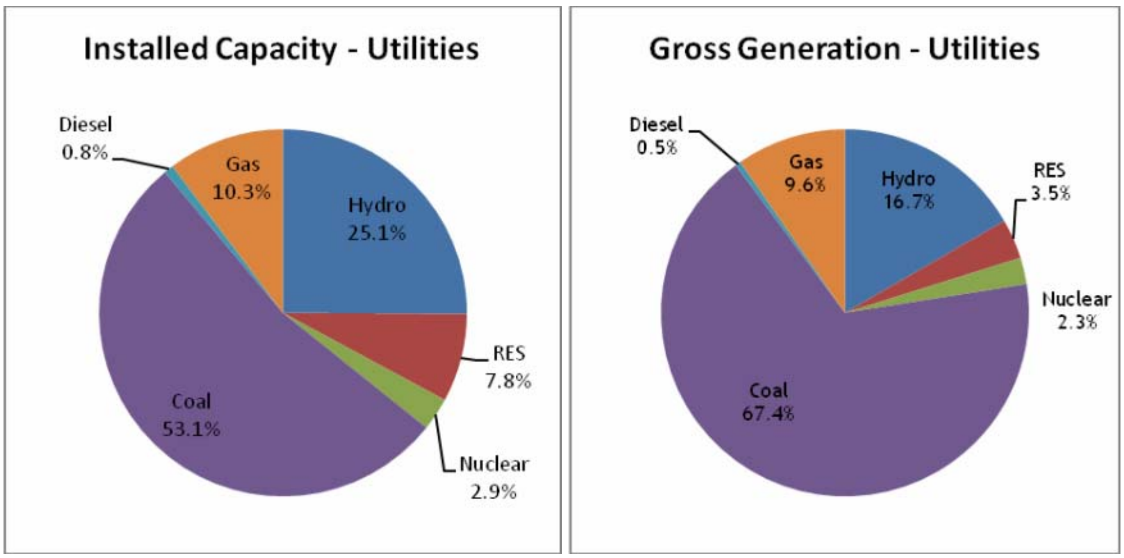
The Indian Electricity System Today

The total generation capacity of utilities stood at 143.0 GW on 31 March 2008; 53.1% was coal, 25.1% hydro, 10.3% gas, 7.8% renewable energy sources[3], 2.9% nuclear and 0.8% diesel. This excludes 25.0 GW industrial captive stations[4]. If industrial captive stations are added, the Indian total amounted to 168.0 GW (CEA, 2009a). Of the captive power plants 47.1% was coal-based (steam), 34.6% diesel, 16.8% gas, 1.2% wind and 0.2% Hydro.

[3] Includes small hydro, wind power, biomass power, biomass gasifier and urban and industrial waste.
[4] Only includes the total capacity of captive power plants having more than, or equal to, 1 MW capacity.

The capacity mix is different from the power supply mix because the load factors are not the same. About two-thirds of all power was generated from coal and lignite fired plants (Figure 6).

FIGURE 6: India Electrical Generation Capacity and Gross Generation by Utilities, 2007/8



Source: CEA, 2009a.

The average efficiency of coal and lignite fired power plants was 32.7% in 2007/8 based on lower heating values (CEA, 2009a). The auxiliary consumption of coal-fired plant ranged from 6% to 13% of total gross power produced, with an average of 8.4%. For gas-based units the average was 2.5% and for nuclear plant 12.7% (CEA, 2008b).

The use of renewable energy sources (excluding large hydro), is elaborated in Table 3. A total of 12.6 GW renewable capacity, grid connected and distributed, was in place as of 31 March 2008 (WEC, 2009). Wind power, in particular, has been growing at a rapid rate. Wind represented 75% of the target renewable power capacity additions (excluding large hydro) in the 11th 5-year plan (Verma, 2008).

Table 3: *Indian renewable power generation capacities, status 31/3/2008*

	Potential	Cumulative achievements
	[MW]	[MW]
Grid connected		
Bio-power (agro-residues)	16881	606
Wind power	45195	8757
Small hydro power (up to 25 MW)	15000	2180
Cogeneration - bagasse	5000	800
Waste to energy	2700	55
Solar power		2
Total grid connected	**84776**	**12400**
Distributed renewables		
Biomass power/cogen		95
Biomass gasifier		100
Waste-to-energy		27
Total distributed renewables		**222**

Source: WEC, 2009.

India has added 27.3 GW between 2002 and 2007, an average of 5.5 GW per year. The projection is to install on average 18.8 GW per year between 2007 and 2012, an increase of the annual capacity additions by more than a factor three (Verma, 2008).

The Indian power sector has a number of important shortcomings (Mathy and Guivarch, 2009):

- Capacity shortages in the order of 15% of peak power demand and 10% of total demand.
- Only 60% of all households connected to the grid.
- Regular blackouts.
- Structural under-investment, rooted between market and institutional failures.
- Average price of electricity sold only covers a portion of the average production cost. The total under-recovery of costs was estimated to 431 billion rupees in 2008, the equivalent of around USD 9.4 billion[5] (GoI, 2008b).
- Low electricity prices result in wastage. Especially in the agriculture sector when free supply results in excessive use of electricity and scarce water resources. This problem is not purely of a technical nature, but other economic and regulatory solutions can reduce demand substantially – to the benefit of the country.

[5] Converted using nominal exchange rate of October 14th, 2009.

While most of these barriers are not technical by nature, they will have an influence on the effectiveness and efficiency of required technology transition.

The Indian Power Grid

Since August 2006, four regional grids have been integrated; the Northern, Eastern, Western and North Eastern grids (the NEWNE grid). Only the Southern grid still operates independently (the Southern grid covers the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and Lakshadweep). The Southern grid is scheduled to be synchronously operated by the end of the 12th 5-year plan (2012-2017). Presently, the Southern grid is connected to the Western and Eastern grid through a high-voltage direct current (HVDC) link and HVDC back-to-back systems. The absolute CO_2 emissions of power generation amounted to 520 Mt in 2007/8, 78% of which are in the NEWNE grid (CEA, 2008a).

Although 80% of the villages are electrified, only 60% of the population has access to electricity. Power outages are common, and the unreliability of electricity supplies is severe enough to constitute a constraint on the country's overall economic development. From 9.9% in 2007/8, power shortage increased to 11.1% in 2008/9. However, it is estimated that the power shortage will be reduced to 9.3% at the end of 09/10 (CEA, 2009b)

India’s transmission and distribution losses are among the highest in the world, averaging 26% of total electricity generation, with some states as high as 62%. When non-technical losses such as energy theft are included in the total, average losses are as high as 50%. The billing efficiency is 55% and the collection efficiency only 41%. As a consequence, power producers make losses.

Losses in distribution power lines also depend on the geographical spread of the system. In extreme cases, such as in rural India, these losses may exceed 30% (Suresh and Elachola, 2000). In such systems, a larger number of lower-capacity substations, together with the conversion of single-phase supply to three-phase supply, would reduce these losses substantially. During periods of peak load, today’s losses may even exceed 45%, so designing systems with sufficient “slack capacity” is also important. Obviously, this slack capacity adds to the upfront investment cost, and a trade-off between investment and distribution costs is needed.

India’s grid is in need of major improvements. This situation has accumulated in a variety of system failures:

- Poorly planned distribution networks;
- Overloading of system components;
- Lack of reactive power support and regulation services;
- Low metering efficiency and bill collection;

- Unmetered use.

An improved grid should be a top priority in mitigate power supply constraints.

Section 2: India Energy Technology Strategies and Development Activities

India Energy Technology Strategies

A number of plans and strategies have been developed in recent years by the Government of India and its Agencies and Institutes that have relevance of power sector technology planning. Their key points will be discussed in this section.

In 2006, the Government of India has released an Integrated Policy document (GoI, 2006). The broad vision behind the Integrated Energy Policy is to reliably meet the demand for energy services of all sectors including the lifeline energy needs of vulnerable households with safe and convenient energy at the least cost in a technically efficient, economically viable and environmentally sustainable manner (GoI, 2006). More specifically, the document states that:

Coal:

- Coal will remain the dominant energy source for India until 2031/32 and possibly beyond.
- In-situ gasification should be developed to tap the vast coal reserves.
- Coal production should be raised through competition and coal import facilities should be built along the Western and Southern coasts.
- Coal washing should become the norm.
- Increasing amounts of coal should be auctioned on the Internet.
- Environmental externalities should be treated uniformly and internalised.

Efficiency:

- Aggregate technical and commercial losses should be reduced (automated meter reading, Geographic Information Systems (GIS), separation of feeders and agricultural pumps).
- It is possible to reduce India's energy intensity by up to 25% from current levels.
- The average gross efficiency of power generation should be raised from 30.5% to 34%.
- All new plants should adopt technologies that improve their gross efficiency from the prevailing 36% to at least 38 to 40%.

Renewables:

- Electricity should be generated through wood gasifiers or by burning surplus biogas from the community bio-gas plants.

Planning capacity:

- India needs to substantially augment the resources made available for energy related R&D and to allocate these strategically.
- Energy policy modelling capability should be improved and the different modellers should be brought together periodically in a forum to address specific policy issues.
- International collaboration on RDD&D is required.

The Indian National Action Plan on Climate Change (GoI, 2008), hinges on the development and use of new technologies. Eight national missions form the core of the national action plan:

National Solar Mission;

Solar thermal generation
Solar photovoltaic generation

National Mission for Enhanced Energy Efficiency;

National Mission on Sustainable Habitat;

Promoting building energy efficiency
Management of Municipal Solid Waste
Promotion of Urban Public Transport

National Water Mission;

National Mission for Sustaining the Himalaya Ecosystem;

National Mission for Green India;

National Mission for Sustainable Agriculture;

National Mission on Strategic Knowledge for Climate Change.

Especially the solar and efficiency missions have relevance for the present power sector analysis.

TERI has published a National Energy Map for India (TERI, 2006). The study constitutes and integrated assessment of different technological options to examine possible energy pathways and their impacts over time. This study concludes that:

- ultra-supercritical boilers and IGCC are key technologies for the power sector in India.
- Coal exploration and mining needs upgrading.
- Natural gas exploration and production and imports need to rise.
- Hydro investments should be accelerated, despite a low load factor of only 30%.
- Nuclear investments should be stepped up; especially Thorium fed fast breeder reactors.

- Investments should be made in energy efficient industrial plants, lighting, rationalise electricity pricing for the agricultural sector.
- T&D losses should be reduced.

In 2008, TERI published a study showing energy scenarios for 2031/2032. According to this recent analysis (TERI, 2008):

- Total power capacity would rise to 750-1200 GW.
- The share of solar thermal would rise to a level of 31% to 61% of total power generation, depending on the scenario analysed.
- Hydro-power generation capacity will rise to 150 GW.
- Nuclear power is projected to rise to 100 GW.
- Coal capacity would be limited to 50-180 GW (without CCS).
- Gas NGCC capacity would be 25-50 GW.

The study concludes with following key modelling results:

- India does not have enough degrees of freedom in its fuel technology choices to be able to significantly change its energy development pathway till 2017 (end of 12th Five-year Plan) at the earliest. However, it can start influencing its infrastructure investment choices such that is does not lock itself into a high carbon pathway.
- It would be possible to provide 90% of all electricity from CO_2-free sources.
- India needs international co-operation for supply of enriched uranium and re-processing of spent fuel. This would be essential to accelerate the operationalisation of India's three-stage nuclear programme, while sharing of technologies for disposal of highly radioactive waste will address concern about nuclear safety.
- Biomass could play a more important role in the relatively short term, especially in meeting the energy needs of the rural population.
- Early introduction to the PV technology would be essential to pave the way for a near-term acceleration of this technology.
- Solar thermal can play a role as baseload capacity.
- India needs access to large 5 MW wind turbines and offshore turbines.
- India needs to accelerate the tapping of its hydropower potential of 150 GW.
- Given the shortcomings of the grid infrastructure, it may be worthwhile to develop decentralised power generation technologies, notably solar and biomass.
- Importing natural gas seems not an economic option, but exploration of offshore basins based on horizontal drilling would be attractive and could result in more gas availability for the power sector.

- Manufacturing plants for energy-efficient equipment should be built in India or the technology should be licensed to India.

India's current and planned technology development activities

India is working on supercritical coal-fired power plants (660/800 MW units), eight of them under execution by National Thermal Power Corporation (NTPC). These units operate at 247 bar, main stream temperature (MST) 565 degrees Celsius and hot reheat temperature (RHT) 593 degrees Celsius. They achieve 41.6% net efficiency (lower-heating value based). About 1.2 percentage point's loss compared to similar plants in the United States or Europe cannot be avoided due to the Indian climate conditions and the coal quality (NTPC information).

Supercritical technology is mandatory for Ultra-Mega Projects (4 GW each). Three of these projects have been awarded. Many more supercritical units are in the pipeline. Also, retrofit of existing plants is considered to increase the load factor and the efficiency of older units. The retrofit of the Badhapur plant resulted in a reduction of the fuel consumption by about 6% (NTPC information).

Bharat Heavy Electricals Ltd. (BHEL), an Indian company established by the government, is the supplier of the bulk of the coal fired power generation equipment. The company has a 65% market share in India, 10 to 15% of its production is aimed for export. Recently Mitsubishi Heavy Industries (MHI) has started a joint-venture together with Larsen & Toubro Ltd, an Indian firm. The joint-venture will build 500-1000 MW supercritical boilers in India for the Indian market. The goal is to raise sales to USD 690 million in five years (MHI information).

Ultra-supercritical technology is under development, 700 degrees technology is expected to be commercialised by 2025.

A Future for Ultra Clean Coal in India?

The high ash content of Indian coal poses multiple problems. Research in India, Australia and Japan is aiming for ash removal using chemicals such as sodium hydroxide. The product is an ultra clean coal with less than 0.2% ash content that can be burned directly in a gas turbine. This allows the use of combined cycles and results in a major efficiency gain of the power plants.

Ultra Clean Coal (UCC) Energy has constructed a pilot plant in Cessnock, New South Wales, Australia which is capable of processing 350 kg/h of coal. Trials performed by Mitsubishi Heavy Industries in Japan gave results that proved the use of this coal to be very beneficial. Similar testing was undertaken by Idemitsu Kosan in Japan.

After modification of their gas turbine, which had, to date, predominantly used natural gas as the fuel source, Mitsubishi directly injected the prepared coal. Analytical tests of the same sample revealed an ash value of less than 0.2%. This impurity level should not cause major problems in the gas turbine.

However, this process is not yet proven on a commercial scale. It is unclear if the economics of this approach are favourable. Initial estimates indicate that cost in Australia would be ASD 5 to 8 cents per kWh. Cost may come down as the technology develops. It is unclear if the higher ash content of Indian coal constitutes an incentive or a barrier for this type of technology development.

http://www.skmconsulting.com/knowledge_insights/The+Case+for+Ultra+Clean+Coal.htm

Circulating fluidised bed combustion is a niche technology for high sulphur lignite, 10 125 MW units and one 250 MW unit are operating or under implementation or under installation (Verma, 2008).

A 6.4 MW Integrated Gasification Combined Cycle (IGCC) pilot unit has been operating by BHEL since 1989, based on Siemens and Alstom technology. A Memorandum of Understanding (MoU) has been signed between Andhra Pradesh Power Generation Corporation Limited (APGENCO) and BHEL to set up a 125 MW IGCC plant. A 250 MW unit is planned by BHEL and NTPC. The Indian high ash coal requires use of fluidised bed gasifiers, which is a difference compared to hardcoal-fired units.

CCS technology is rather controversial as there are no other benefits apart from CO_2 reduction. Therefore the technology is considered less suitable for India in the short-term.

Section 3: Power Sector Scenarios

Electricity Demand Projections

Between 1975 and 1995, the elasticity of primary commercial energy to GDP was equal to 1.4, and the elasticity of electricity consumption to GDP was more than two. Between 1995 and 2005, even if the energy decoupling increased, the elasticity of total primary energy supply to GDP remained close to one, while the consumption of electricity kept growing faster than GDP (Mathy and Guivarch, 2009).

The Indian economy is projected to grow at a faster rate than China, Europe or the US during the coming four decades. As a result, India's share in the world economy will rise considerably. A consequence of this ascent is a significant increase of energy use and associated CO_2 emissions in absolute and relative terms. In the ETP 2008 Baseline scenario for India, GDP increases 10-fold, primary energy use quadruples and CO_2 emissions increase 5.4-fold between 2005 and 2050. The share of India in total global CO_2 emissions is projected to double from 5 to 10%. The power sector plays an especially important role as electricity demand is projected to rise 6.5-fold. Within the power sector coal-fired power generation is the dominant source of emissions.

Table 4: *Comparison of GDP projections for India (index, 2005=100)*

	2005	2010	2020	2030	2040	2050
CEA	100	147	317	685	1014	1501
CIRED	101	142	255	415	639	982
IEA	100	142	266	467	665	947

Sources: Verma, 2008; Mathy and Guivarch, 2009; IEA, 2008.

Different projections on the growth of the Indian economy in the next decades are available from several organisations. Three different GDP projections from the CEA/Indian government (Verma, 2008), the Centre International de Recherche sur l'Environnement et le Développement[6] (CIRED) (Mathy and Guivarch, 2009) and the IEA regional analysis (ETP 2010) are compared in Table 4. The Indian projections of the GDP level in 2050 are more than 50% higher than the CIRED and IEA projections. CEA projections for the average annual growth rate in GDP for the 2005/2030 period are about 2 percent point than the other two projections (8% per year for CEA vs. about 6% for the two other projections). For the 2030 to 2050 period, the projected growth rates are similar (4% for CEA and about 3.5% for the

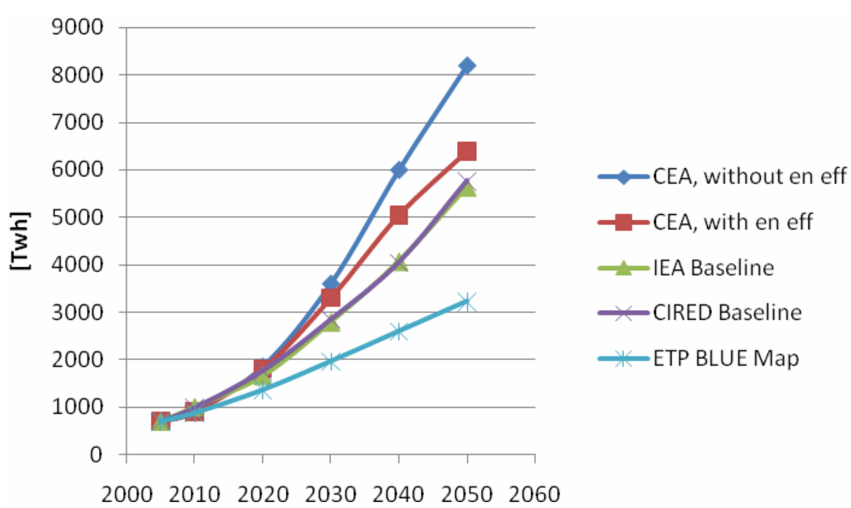
[6] International Research Centre on Environment and Development.

other). Because energy demand growth is closely related to GDP growth, this has a major impact on the energy demand projections.

Figure 7 shows electricity demand projections for India from the three different sources.

- The two projections from CEA (Verma, 2008) refer to the Baseline, but in one scenario the demand elasticity of electricity declines from 0.95 to 0.725, while in the second scenario it reduces from 0.95 to 0.5. This affects the demand in 2050 significantly. Both projections are considerably higher than CIRED and IEA.
- The two projections from the IEA, the Baseline and the BLUE Map, are based on a bottom-up system engineering model. A nine-fold increase of electricity demand between 2005 and 2050 is projected in the Baseline scenario. Demand is reduced in BLUE Map to the level of 3245 TWh.
- The projection from CIRED is based on a top-down general equilibrium model. As for the IEA baseline scenario, a nine-fold increase of electricity demand is projected between 2005 and 2050. The projections from CIRED and IEA baseline match closely.

Figure 7: *Electricity demand projections 2005-2050*



Source: Verma, 2008; Mathy and Guivarch, 2009; IEA, 2008.

Total Indian electricity demand stood at 717 kWh/capita (based on UN practice[7]) in 2007-2008 (CEA, 2009a); an increase of 6.7% over the previous year. For the domestic sector, electrical energy sales to domestic consumers amounted on

[7] UN practice for the per capita electricity consumption is worked out on the basis of the gross electricity generation during the year

average to 106 kWh in 2007-2008, with a range from 18 kWh/capita in Bihar to 424 kWh/capita in Delhi.

Comparing these levels of electricity use to those of other countries in similar climate zones provides clues regarding potential future domestic demand development in India. Singapore, Malaysia and Thailand are countries in a similar climate zone but with much higher income levels. Their domestic demand suggests a clear relation between per capita residential electricity demand and income levels (Table 5). Given a projected GDP per capita growth of factor 6.5 between 2007 and 2050 in India, one would expect the growth of residential electricity demand per capita by a similar amount - to over 800 kWh/cap per year in 2050.

Table 5: *Comparison of residential electricity demand levels in India and emerging economies in the same region, 2007*

	Population	**Per capita income**	**Residential electricity demand**[8]	
	[million]	[USD 2000 (PPP)/cap]	[ktoe]	[kWh/cap]
Singapore	4.6	29 603	587	1 795
Malaysia	26.5	10 934	1 598	858
Thailand	63.8	8 585	2 412	477
India	1 123.3	3 583	10 408	125

Source: IEA, 2009b.

To put this into perspective, it would imply that the average residential electricity consumption per capita in India would reach nearly twice the current Delhi per capita residential electricity demand level in 2050. The demand would be at a similar level as Malaysia today, but still well below the level of Singapore today. In combination with a 50% population growth, this would result in a residential electricity demand of 1330 TWh, twelve times the demand level of 2006/7.

Table 6 provides a breakdown for all demand categories in the IEA BLUE Map scenario. On the production side (industry, commercial and agriculture), significant changes are expected as the economy grows nearly ten-fold. This implies a massive expansion of the commercial/services sector by a factor of almost 10, a significant expansion of manufacturing activity, and more limited growth of activity in agriculture. However, water needs to be pumped from increasing depth and this is the main electricity demand category in the agriculture sector. The projections for industry are based on IEA analysis (IEA, 2009c). The projection for agricultural demand is based on TERI (2006).

[8] Based on data from IEA statistics, 2009.

Table 6: *Final electricity demand breakdown in India and projection for individual categories for BLUE Map, 2050*

[TWh/yr]	2006/7	2050
Domestic	111	1330
Commercial	40	354
Light industry	36	176
Heavy industry	205	934
Traction	11	220
Agriculture	99	174
Other	23	41
Total	526	3229

Source: IEA, 2009b; IEA, 2008; IEA, 2009c; TERI, 2006.

In the ETP 2008 BLUE scenario, which look at the electricity sector for the country as a whole, the electricity demand grows from 60 Mtoe (692 TWh) to 390 Mtoe in 2050 (4536 TWh). When taking into account the regional differences for the generation capacity potentials and electricity demand, the regional BLUE Map scenario shows an increase only to 279 Mtoe (3229 TWh) in 2050. So the new demand projection is slightly higher than the previous one published in the ETP 2008 book.

Power capacity and generation projections

Assuming that the transmission and distribution losses can be reduced to 15% in 2050, about 3700 TWh of electricity production is needed in BLUE Map in 2050. At full load 114 GW can generate 1000 TWh per year. However, in practice plants operate on average far below the maximum load. This is partially related to the energy resource availability (e.g., for variable renewables) and it is partially related to the fluctuations in demand during the year.

India had about 168 GW installed capacity in 2007/8. Based on these numbers the average load factor was 63%. Table 7 shows the power capacity in the ETP Baseline and BLUE Map scenarios in 2050. Total capacity in 2050 is similar in both scenarios (around 700 GW), four to five-fold the installed capacity in 2007/8. However, the mix of resources used is quite different.

Table 7: *India power generation capacity in the ETP 2008 scenarios (not taking into account regional differences)*

	Power gen share Baseline	Power gen share BLUE Map	Load factor	Capacity	2050
				Baseline	BLUE Map
	[%]	[%]	[%]	[GW]	[GW]

Nuclear	5.0	20.3	95	27	79
Oil	0.5	1.6	50	6	12
Coal	77.4	0.0	90	444	0
Coal + CCS	0.0	21.2	90	0	87
Gas	9.6	15.6	40	124	144
Gas + CCS	0.0	2.9	65	0	17
Hydro	4.1	4.6	56	38	30
Bio/waste	2.9	3.4	50	30	25
Bio + CCS	0.0	3.3	65	0	19
Geothermal	0.0	0.1	85	0	1
Wind	0.4	3.7	30	7	46
Tidal	0.0	6.2	50	0	46
Solar	0.1	13.9	30	2	171
Hydrogen	0.0	3.4	50	0	25
Total	100.0	100.0		677	700

Source: IEA Analysis.

Table 8 provides a breakdown of the power production and the capacities for the individual model regions. This analysis combines the regional resource potentials with the regional demand. Total capacity would amount to 734 GW. The full potential of biomass, geothermal, wind and tidal energy would be used. For hydro, two-thirds of the potential would be developed. Total coal-fired capacity would be roughly at today's level, but all this capacity would be equipped with CCS. For solar a significant expansion is assumed, from near zero to 130 GW.

Table 8: *Power capacities by region in BLUE Map, 2050*

	Srinagar	Delhi	Bhopal	Ahmadabad	Mumbai	Hyderabad	Bangalore	Trivandurum	Chennai	Calcutta	Varanasi
Demand [TWh]	61	872	243	190	363	286	198	95	234	351	247
Nuclear[GW]	0	10	0	20	20	10	10	20	20	10	0
Coal[GW]	0	0	0	0	0	0	0	0	0	0	0
Coal + CCS [GW]	0	0	0	10	20	0	0	20	30	0	0
Gas[GW]	0	50	0	0	0	0	0	0	0	50	50
Hydro[GW]	30	0	0	0	4	5	16	0	0	0	0
Bio/waste [GW]	2	2	2	2	2	2	2	2	2	2	2
Bio + CCS[GW]	2	2	2	2	2	2	2	2	2	2	2
Geothermal [GW]	5	2	2	2	0	0	0	0	0	0	0
Wind[GW]	0	18	0	5	10	5	5	5	0	0	6
Tidal[GW]	0	0	0	5	5	5	5	5	5	5	0
Solar[GW]	10	25	25	10						20	10

Total[GW]	49	109	31	56	63	29	40	54	59	89	70

Source: IEA Analysis.

Air Cooling: an option for India?

For any power plant, once-through cooling systems using fresh water and seawater are less costly to build and more energy-efficient than systems using wet recirculation through cooling towers or ponds. Thus, the sitting of coal and nuclear power plants on coastlines is usually preferable where other considerations allow.

For inland locations without suitable cooling water availability, other solutions do exist. Acting as part of a consortium, Siemens has built a coal-fired power plant in the Australian outback at Kogan Creek that operates with almost no cooling water. By means of a special air-cooled condenser, the plant uses air instead of water to cool the hot steam from the plant turbine, so using 90% less water than conventional plants, an ideal solution for coal-based power generation in arid regions.

Kogan Creek, which is about 300 kilometres west of Brisbane, is the largest power plant in Australia, with an output of 750 megawatts. Moreover, with its 45% efficiency, it is also one of the most efficient power plants in the country. Two low-pressure turbines emit hot steam at 60 to 80 degrees Celsius, which flows through large heat exchangers. Fans nine metres in diameter blow air against the metal sheets from below and cool the steam, which in turn condenses. Five hundred litres of water per second flow into a collector at the lower end of the heat exchanger and then into a tank, from where pumps feed it back into the power plant to generate steam.

The power plant cannot operate entirely without fresh water, however. Water drawn from deep bores replenishes losses in the steam cycle of the turbines and serves as cooling water for the electrical equipment, which cannot be cooled with air alone. Nevertheless, with its water savings rate of 90%, Kogan Creek far outperforms comparable power plants when it comes to economy of water use. That offers extra reserves in extremely dry periods, when water-cooled power plants are forced to scale back their output. At Kogan Creek, water can be sprayed beneath the condenser surfaces for additional cooling. This enables the plant's operators to run it at its full capacity of 750 megawatts even at temperatures well over 40 degrees Celsius, or tease out a few more megawatts when there are bottlenecks in the grid.

The whole power plant then uses less than 10% of the water required for a wet-cooled plant (about 0.25 l/kWh), but a lot of power (around one to 1.5% of power station's output) is consumed by the large fans required.

In Australia Kogan Creek (750 MWe supercritical) and Milmerran (840 MWe supercritical) coal-fired power stations use dry cooling with air cooled condensers (ACC), as do Matimba and Majuba plants in South Africa. South African experience puts ACC cost as about 50% more than recirculating wet cooling. An air cooled condenser (dry cooling system) typically requires an investment of USD 60-70 /kW.

Sources:
http://www.siemens.co.za/en/news_press/news2008/index/june132008.htm
http://www.world-nuclear.org/info/cooling_power_plants_inf121.html
http://www.world-nuclear.org/uploadedFiles/org/reference/pdf/PS-cooling.pdf

The analysis suggests that the picture does not change dramatically if the regional potentials are taken into account. However, some differences can be noticed:

- The nuclear potential has been revised upward by more than 41 GW;
- Hydropower has been revised upward by 70 GW;
- Geothermal has been revised upward by 9 GW;
- Tidal has been revised downward by 11 GW;
- Solar has been revised downward by 40 GW;
- Hydrogen has been deleted (25 GW).

If these projections are compared with CEA/Verma (2008), significant differences emerge. Verma (2008) projects capacity needs of 1335-1854 GW by 2050. However, this assumes a much higher electricity demand (6698-8679 TWh, vs. 3700 TWh). The difference is accounted for by a combination of much higher economic growth rates (two-thirds of the gap) and lower efficiency gains (one-third). The lower demand means that nuclear and renewables can gain a higher share in the new IEA scenarios and therefore, deeper CO_2-cuts seem feasible. However, it should be stressed that this depends on scenario assumptions that are inherently very uncertain. It is evident from this analysis that deep CO_2 reduction in power generation in India will be very challenging.

Investment Needs

Table 9 provides an overview of the investment needs for Baseline and for Blue Map. It includes all investments from fuel production to power generation, electricity transmission and distribution and end-use equipment. The cost for coal and gas supply have also been included, as far as they would incur within India. For end-use equipment, only the additional cost compared to Baseline have been quantified in the case of electric equipment.

Total investment cost in Baseline are USD 2.2 trillion. In BLUE Map this increases to USD 2.5 trillion in investment terms for two radically different scenarios. Given the uncertainty ranges the numbers suggest no significant differences. In comparison, the Indian GDP (PPP based) would amount to 72 billion for the period between now and 2050. So total power system investments equal 3.4% of total GDP. Based on market exchange rates of today its share would amount to nearly five times as much.

Table 9: *Global Investment needs for Baseline and BLUE Map*

	Baseline [Mt]	BLUE Map [Mt]	Baseline [GW]	BLUE Map [GW]	Investment cost [USD/kW]	Baseline [bln USD]	BLUE Map [bln USD]
Nuclear			30	120	1875	56.25	225
Oil			0	0	2000	0	0
Coal			556	0	1250	695	0
Coal + CCS			0	80	2000	0	160
Gas			230	150	650	150	98
Gas + CCS			0	0	1400	0	0
Hydro			55	96	2000	110	192
Bio/waste			28	28	2000	56	56
Bio + CCS			0	28	3500	0	98
Geothermal			0	11	5000	0	55
Wind			10	56	1250	12.5	70
Tidal			0	35	4000	0	140
Solar			2	130	2000	4	260
Efficient lighting						23	29
Efficient equipment							457
Efficient motor systems						22	29
Electricity transmission grid investments						500	400
Electricity storage				50		0	25
Gas offshore fields	145	95			500	145	95
Gas LNG terminals	145	95			50	7	5
Gas pipelines	290	189				40	26
Coal mines	1670					111	37
Coal harbours	1670					50	0
Coal railroads	1670	561				244	2
Total						2225	2457

Source: IEA analysis.

Conclusion: Towards a Power Sector Decarbonisation Strategy

The Indian power sector has a number of characteristics that make it very different from those in the other three regions that are analysed (China, Europe and the United States). First, the demand growth in percentage terms will be much higher than in the other regions, which means that virtually the whole power system must be planned from scratch, which opens up interesting opportunities. Second, while coal is an important indigenous energy resource, the coal quality is much lower than elsewhere. This means that Indian coal is not per se the most economic supply option. Coal imports or other power supply options are often cheaper. Third, the Indian renewables resources are limited, compared to the demand growth that is forecast for the coming decades. Solar is the only option with a huge technical potential, but its use is starting from a very low level of installed capacity.

Nuclear and coal with CCS are two alternative CO_2-free supply options.

The prospects for nuclear have brightened with the 2008 United States-India deal and the consent of the nuclear suppliers group. However, India will need to develop Thorium reactors if it wants to expand its nuclear production capacity to levels significantly higher than 100 GW. This requires a different type of nuclear reactor and it will raise a different type of fuel management issue. But, it is evident that nuclear must play a crucial role in a CO_2-free electricity supply.

Finally, coal with CCS is a new concept. Development of a technology suited for Indian coal will require special attention. The complexity of this technology and its impact on electricity cost make this an "option of last resort" for India. But, the urgency of CO_2 reduction is increasing and if a full decarbonisation is needed, coal with CCS must be part of the solution.

As a strategy, maximisation of nuclear and renewables investments can play an important role on the short and medium term. The ambitions level for solar needs to be raised – both PV and CSP. It is recommended to investigate the potential of oyxfueling and to accelerate the work on IGCC for Indian coal, as a preparatory step towards CCS that can also generate some benefits such as higher efficiencies.

Maximisation of the transmission and distribution efficiency, together with maximum end-use efficiency, should be a priority. One way to achieve this is to make sure that prices reflect the supply cost. Electricity access for the poor rural areas may be improved through decentralised solar systems with storage and other types of decentralised renewable supply options. A combination of proper electricity pricing and subsidised energy efficient equipment and lighting may result in substantial savings and reduced demand growth.

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Annex A: Energy Resource Availability in India

Thermal

Coal

India has geological resources of 264 billion tonnes (bt) of coal, proved resources of 101 bt (status 1 April 2008). At prevailing prices and technology, experts' estimate that only 21% of the 'in-place' resources can be recovered (in-place resource to mineable reserve ratio of 4.7:1). Recoverable coal reserves are, thus, about 55 bt. Depth-wise 80% of the proved reserve is at a depth of less than 300 m and 61% of the total resources (proved+indicated+inferred) is at a depth of less than 300 m. Together states of Jharkand, Chhatisgarh and Orissa account for 70% of the coal resources. Only 13% of the coal resource has coking quality. The remainder is high ash steam coal (CEA 2008b).

Coal India Ltd. (a public sector undertaking of the Indian Government) has the plan to raise coal production from 453 Mt in 2006 to 750 Mt by 2012. One of the biggest barriers facing the coal industry is the resource geography. The coal beds are often in remote areas where safety is an issue and access rights are not guaranteed. Also, large populations are living on top of the coal reserves. Mine allocation between state and central government can delay development by a decade or more. Given these barriers the expansion target seems challenging, and the government has sanctioned increased coal imports. Four 4000 MW coastal power plants are being built that will use imported coal.

Cumulative ETP baseline coal demand would be 47 Gt coal equivalent in 2050, close to the total recoverable resource. As a gradual rise and fall of indigenous supply is likely, based on the bell-shaped supply curve that has been observed elsewhere. The ETP baseline scenario would imply massive coal imports, in the order of 25% to 50% of total supply in 2050. Imports are already rapidly increasing today. India is projected to import 40 Mtcoe of coal in 2008, about 8% of total coal supply. The rapid increase in imports can, in part, be explained by:

- indigenous coal production has not kept pace with demand.
- supply cost of indigenous coal on the West coast are higher than for imported coal.
- the indigenous coal is of low quality (up to 50% ash), which is detrimental for the efficiency and power production capacity.

Box: Cost of coal imports vs indigenous supply

Of the proven non-coke coal resources superior grades (namely A, B, C, D) contributed one third. The rest were inferior grades (E, F, G) which is typically used for power generation.

India's hard coal reserves are concentrated in the East, in a band that stretches from Chhattisgarh over Orissa, West Bengal, to the Bangladesh border. This band continues further Northeast in Assam. The typical transportation distance to Delhi, Mumbai or Chennai from the Western part of this band is 1500 km. 66% of all coal was transported by rail in 2005 to 2006 (Ragurham and Gangwar, 2005/2006). About 88% of all coal transported by rail originated in mines, 12% came from harbours (total 313 Mt in 2006/2007). Only 20% of all steam coal that arrives by ship is transported by rail.

Total freight revenues of Indian Railways amounted to 41 716 crore Rupiah (USD 9 million) in 2006/2007. Coal accounted for 41% of these earnings. Based on this number it can be calculated that the average coal transportation cost amounted to 550 Rupiah per tonne, about USD 12 per tonne.

Rail transportation cost over such a distance are typically 1 500 Rupiah per tonne of coal (USD 32/t). Multi-handling at various locations can raise these cost above 2 000 Rupiah per tonne. In addition, the mine-mouth cost of coal are in the range of USD 15/t to USD 20/t. The energy content of washed Indian coal for power generation is typically 4300 kCal/t, vs. 6200 kCal/t for imported coal. As a consequence in harbour locations on the West and South coast, imported coal may cost USD 2/GJ, vs. USD 4/GJ for indigenous coal. For more inland locations, both are closer to parity, while on locations in the East indigenous coal is cheaper. The policy of the Government of India stipulates use of only washed domestic coal by power plants located at distances of 1 000 km or more from coal mines. However, availability of washed coal is limited.

Rail transport capacity poses important constraints. 3 500 trains loaded with coal crossed the country daily in 2007, 44% of all freight transport in tonnes, 39% in tonne-kilometres (tkm) and 41% in earnings. The average transport distance for coal was 579 km in 2005/6. Coal and other freight transport is subsidising passenger transportation, actual freight cost are about one-third below transportation prices. If coal transport would expand in line with the Baseline scenario, a massive ramp-up of rail transportation capacity will be needed as total freight volumes would triple (an increase of 2.7% per year). As other freight transportation will also increase, a 5% to 6% growth per year will be needed. Typically about 200 km of track has been added per year in the past 20 years (0.23%/year), and about 250 km per year of track doublings (0.29%/year). This can be compared to a total track length or 85 389 km. The gross freight-km per track-km have increased by nearly 50% between 1999 and 2006, a trend that cannot continue indefinitely. Between 2006/2007 and 2011/2012, freight transportation is to increase from 726 to 1 100 Mt, and from 469 to 702 billion tkm (Ragurham and Gangwar, 2008). This represents an annual increase of 8.4% per year. Sea transportation may ease the inland transportation problem but harbour charging and discharging capacity needs to expand if water transportation should ease the logistic problems.

CO_2 Capture and Storage

India has some potential for CO_2 capture and storage. It can be split into on the one, hand the depleted oil and gas fields and saline aquifers in sedimentation basins and on the other hand the volcanic rocks Deccan traps.

The first category includes in the West coast potentials in Rajahstan along the Pakistan border, the Cambay basin North of Ahmedabad, and the offshore Mumbai basin. Along the East coast the Cauvery and Godavary basin have significant potential (South and North of Chennai). Finally, Assam has a significant potential. The total storage potential in this category is estimated to amount to 65 Gt. The potentials are regionally concentrated. As a consequence Mumbai, Chennai and Ahmedabad can store significant amounts of CO_2 while other areas such as Delhi and Calcutta lack this option.

The second category of storage sites (basalt) is much more speculative. It is a fact that a large area of about 500 000 km^2 between Mumbai and Bhopal and in Gujarat is covered by thick basalt layers. If basalt is a suitable cap rock, it is estimated that this would allow storage of 300 Gt CO_2. This options could be a topic for sensitivity analysis.

Natural gas

India consumed 35 billion cubic meters (BCM) of natural gas in 2007. Consumption is growing at a much faster rate than production (12% and 3% per year, respectively). Gas accounted for 9% of total fuel supply in 2008. This is projected to double between now and 2015. Total gas demand is projected to increase from 35 BCM in 2007 to potentially 150 BCM in 2025. Gas use for power generation would increase at an even faster rate, from 14 in 2007 to 65 BCM per year in 2025. The remainder would largely go the fertiliser making and other industrial use (Kaushal, 2008).

Indigenous gas will come from the coal fields in the East (coal bed methane), the offshore KG basin (halfway between Chennai and Calcutta on the East coast), Mahanadi and Konkan. Pipelines exist from Ahmedabad to Delhi, Calcutta to Delhi and from the KG basin to Mumbai. New pipelines are planned from the KG basin to Chennai and to Calcutta (Kaushal, 2008).

It is projected that about 30 BCM can be delivered from existing fields, 40 BCM has to come from new fields yet to be discovered and 30 BCM can be LNG imports. This gives a total of 100 BCM (3.5 EJ/year). A more rapid increase would require a rapid expansion of LNG imports (Kaushal, 2008).

This analysis project a maximum gas use of 300 BCM by 2050. 250 BCM would have to come from LNG imports. This would imply an eight-fold increase of LNG imports between 2015 and 2050, or 18 new very large 10 Mt/year LNG regasification facilities. Construction of pipelines and imports may reduce the need for LNG. Of these 300 BCM, at most 175 BCM would be available for power generation. This is sufficient gas to sustain 125 GW baseload gas combined cycles with 85% load factor and 55% efficiency.

Hydro

India has 30 GW installed hydro capacity, with 13 GW under construction. The total potential capacity is nearly 150 GW or 84 GW at 60% load factor (600 TWh/year). In practice the average capacity factor of hydropower in India was 43% in 2007. Future higher electricity prices will make a larger share of the total potential economically viable. Nearly 90% of the total remaining hydro potential of 105 GW is in the Himalaya mountain region (CEA, not dated). Development of this potential only makes sense if transmission capacity is developed to transport the electricity to the main markets.

Table A1: *India Hydropower potentials*

	Feasible Installed Potential at 60% Load Factor	Feasible Installed Capacity in MW	Potential in billion kWh per year	Pumped Storage Feasible Installed Capacity in MW	Small Hydro (up to 15 MW) Potential in MW
Northern	30155	53405	225	13065	3180
Western	5679	8928	31.4	39684	661
Southern	10768	16446	61.8	17750	801
Eastern	5590	10965	42.5	9125	530
North Eastern	31857	58956	239.3	16900	1610
Total	84044	148700	600	95524	6782

Source: *Indian National HydroPower Association, 2005*

The pumped hydro potential is about two-thirds of the total hydro potential, around 100 GW. This capacity can be used to balance variable renewables.

India has 256 projects with 761 dams in operation. In 2002, more than 695 dams were constructed with 25.2 GW capacity. A further 400 hydropower schemes can yield 107 GW (CEA, 2002). Under the 50 GW Initiative in May 2003, programme feasibility reports of 162 new projects with an aggregate capacity of 47 930 MW were prepared, including cost estimates for these projects. 73 schemes with an indicative tariff below Rs 2.5 were selected for detailed project reports and subsequent implementation, amounting to 33 GW.

Typical specific investment cost for projects completed between 2000 and 2010 are USD 1450/kW, with a wide range of USD 540 to USD 3700 per kW. India has a small hydro potential (up to 25 MW) of nearly 10 GW distributed over 4 000 sites. It is estimated that there is still an unidentified potential of almost 5 GW. Nearly 1.5 GW of the potential has already been tapped and projects amounting to around 0.6 GW are under construction (ADB, 2007).

In order to augment the hydro generation and improve the availability of existing hydro power projects, the Government of India has put emphasis on Renovation, Modernisation & Up-rating (RM&U) of various existing hydropower projects in the country. RM&U of the existing/old hydro electric power projects is considered the best option, as this is cost effective and quicker to achieve than setting up of green field power projects. The cost per MW of a new hydroelectric power project works out to about INR 4 to 5 Crores whereas the cost per MW of capacity addition through up-rating and life extension of old hydroelectric power project works out to about 20% of that of new capacity. Further, the RM&U of a hydro project can be completed in one to three years depending upon scope of works as compared to gestation period of five to six years for new hydro projects.

Nuclear

India has 17 pressurised heavy water reactors in operation. In 2008, the total installed capacity of Nuclear Power plants was 4 120 MW which contributed about 3% to the total installed capacity in India. 3160 MW is under construction. Contracts with Russia have been signed for another four light water reactors of 1 GW each (Ramesh, 2009). In 2007 to 2008, total electricity generated by nuclear was 16.9 TWh. India's nuclear reactors are operating at just 45 to 55% capacity due to low uranium supplies.

However, India has abundant Thorium resources that can be used. The nuclear co-operation agreement signed with the United States provides a considerable boost to the nuclear power prospects for India and has resulted in a shifting emphasis from developing the use of Thorium to imported Uranium.

As part of the eleventh five-year plan (2007-12), Nuclear Power Corporation of India Ltd (NPCIL) will start site work in 2009 for 12 indigenously developed reactors, including eight 700 MW PHWRs, three 500 MW fast breeder reactors and one 300 MW advanced heavy water reactor (AHWR). NPCILs augmentation plan includes construction of 25 to 30 light water reactors of the 1 and 1.65 GW type by 2030. The target is to increase nuclear power capacity to 63 GW in 2030. Based on these plans the IEA projects a potential capacity of up to 120 GW in 2050. The bulk of these reactors will be located along the coast because of the cooling water requirements (Kanwarpal, 2009).

The Indian Department of Atomic Energy has more optimistic projections with 250 GW nuclear power generation in 2050. India has an ongoing programme on 220 MWe PHWRs, a reactor system that is competitive in terms of capital costs, safety performance and unit energy cost. This system is well suited to the needs of countries with small electricity grids, especially those in the developing world. India has reached world leadership in this area. Nearly 55% of all scientific publications for PHWRs area were Indian in 2006, and India is also leading the research in fast breeder reactors (Kakodkar, 2008).

Indian PHWR reactors are about 15% to 30% cheaper than those elsewhere (USD 1700/kW). Future PFBRs cost nearly RS 70 thousand per kW, around USD 1250/kW (Kakodkar, 2008).

Renewables

Indian Renewables Potentials

The renewable energy resource in the four regions that will be further analysed in ETP 2010 differ considerably (Table A2). While India has a good hydropower resource, its potential in other renewables is more limited. Solar is not included in this list because the resource is not the limiting factor in any of these regions. However, India has a good quality solar energy resource that could be considered as renewable “backstop” option.

TABLE A2: *Renewable energy resource potentials*

[GW]	United States	OECD Europe	China	India
Wind Onshore	1230	900	250	45
Wind Offshore (<60 m water depth)	170	140	750	15
Wind floating (<100 km distance, >60 m water depth)	225	100	?	?
Large hydro	121 (+217 Canada)	280	400	150
Biomass (primary) (assuming 50% use for PG)	50 (200 Mtoe)	35 (150 Mtoe)	50 (200 Mtoe)	20 (80 Mtoe)
Geothermal	<80	<25	<10	<10
Tidal & wave	2100 TWh			15

Sources:
http://www.awea.org/newsroom/releases/AWEA_second_quarter_market_report_072809.html
www.windpoweringamerica.gov/pdfs/workshops/2005_summit/musial.pdf
www.offshorewindenergy.org/ca-owee/indexpages/downloads/Brussels01_Resources.pdf
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VTT (2007)
Chan (2008)

Biomass

India shares 16% of the world population, while its land is only 2% of the total geographical area of the world. Naturally, the pressure on the land is often beyond its carrying capacity. Therefore, the productive lands, especially the farmlands in India are in the constant process of various degrees of degradation and are fast turning into wastelands.

In order to map and tap this potential, the Indian government has developed a 'Biomass Atlas', utilising satellite data as input for geographical information systems. Wastelands statistics indicated that about 55.3 million hectares, which account for 16.8% of the total geographical area (328.7 million hectares) could be categorised as wastelands in India in 2003. About 34% is land with or without scrub. Another 20% is degraded forest. 10% is unsuited for cropping (barren rock, snow cover and glaciers). About 20 million hectares of these wastelands are in use for agriculture today, but the yields are low.

The current assumption is that 20 million hectares of these lands (one third) are accessible and will be yielding around 5 tonnes of additional woody biomass per hectare per year if the productivity is restored, with an average lower heating value of 17 MJ per kilogram, which can be converted in biomass power plants with an efficiency of around 30%. Assuming a load factor of 60%, this biomass can sustain 25 GW biomass power generation capacity.

Apart from wastelands, agricultural residues can be used. Sugar production residues represent the single most important category. With the establishment of new sugar mills and the modernisation of existing ones, the technically feasible potential for bagasse cogeneration is estimated to be around 5 GW (USDOE, 2009). Another 18 GW can be obtained from other agricultural and plantation residues. The total biomass potential in India is, therefore, estimated to be around 50-55 GW.

TABLE A3: *State wise – category wise wastelands that could be suited for energy production in India – 2003*

	Land with scrub	Land without scrub	Degraded forest	Degraded forest agricultural use	Degraded pastures/grazing land	Total
Andhra Pradesh	1.6	0.2	2.0	0.3	0.0	4.1
Arunachal Pradesh	0.3	0.3	0.0	0.0	0.0	0.6
Assam	0.2	0.0	0.2	0.4	0.0	0.8
Bihar	0.0	0.0	0.3	0.0	0.0	0.4
Chhattisgarh	0.3	0.1	0.3	0.0	0.0	0.7
Goa	0.0	0.0	0.0	0.0	0.0	0.0
Gujarat	1.2	0.5	0.1	0.0	0.0	1.8
Haryana	0.1	0.0	0.1	0.0	0.1	0.3
Himachal Pradesh	0.2	0.0	0.1	0.0	0.6	1.0
Jammu and Kashmir	0.0	0.0	0.7	0.0	0.1	0.8
Jharkhand	0.2	0.0	0.7	0.1	0.0	1.0
Karnataka	0.4	0.1	0.5	0.1	0.0	1.1
Kerala	0.1	0.0	0.0	0.0	0.0	0.1
Madhya Pradesh	2.7	0.2	1.8	0.4	0.0	5.1
Maharashtra	1.9	1.0	1.2	0.2	0.0	4.4
Manipurß	0.8	0.0	0.0	0.0	0.0	0.8
Meghalaya	0.1	0.2	0.0	0.0	0.0	0.3
Mizoram	0.0	0.0	0.0	0.0	0.0	0.0
Nagaland	0.2	0.0	0.0	0.0	0.0	0.2
Orissa	0.8	0.1	0.5	0.2	0.0	1.6
Punjab	0.0	0.0	0.0	0.0	0.0	0.0
Rajasthan	3.0	0.7	0.9	0.1	0.9	5.5
Sikkim	0.0	0.0	0.1	0.0	0.0	0.1
Tripura	0.0	0.0	0.1	0.0	0.0	0.1
Tamil Nadu	0.5	0.1	0.8	0.0	0.0	1.4
Uttarranchal	0.2	0.0	0.1	0.0	0.1	0.5
Uttar Pradesh	0.3	0.1	0.2	0.0	0.0	0.6
West Bengal	0.0	0.1	0.1	0.0	0.0	0.2
Delhi	0.0	0.0	0.0	0.0	0.0	0.0
Total	15.1	3.7	10.8	1.8	1.9	33.4

Source: NRSA, 2005

TABLE A4: *Residual biomass availability and power generation potentials*

State	Area (kha)	Crop Production (kT/Yr)	Biomass Generation kT/Yr	Biomass Surplus (kT/Yr)	Power Potential (MWe)
Andhra pradesh	2540	3232	8302	1173	150
Assam	2633	6076	6896	1398	166
Bihar	5833	13818	20442	4286	530
Chattisgarh	3816	6143	10124	1908	221
Goa	156	555	827	130	16
Gujarat	6513	20627	24164	7506	1014
Haryana	4890	13520	26161	9796	1261
Himachal pradesh	710	1329	2668	988	128
Jammu & kashmir	369	649	1199	238	32
Jharkhand	1300	1509	2191	568	67
Karnataka	7277	38639	23767	6401	843
Kerala	2042	9750	9421	5703	762
Madhya pradesh	9937	14167	26500	8033	1065
Maharashtra	15278	51343	36804	11804	1585
Manipur	73	159	319	32	4
Meghalaya	0.8	14	42	8	1
Nagaland	27	88	149	27	3
Orissa	2437	3633	5350	1163	147
Punjab	6694	27814	46340	21267	2675
Rajasthan	12538	93655	2E+05	35531	4595
Tamil nadu	2454	24545	15977	6659	864
Uttar pradesh	12628	46801	50417	11726	1478
Uttaranchal	66	136	160	52	7
West bengal	5576	21063	23316	2960	368
Total	**1E+05**	**4E+05**	**5E+05**	**1E+05**	**17982**

Source: *MNES, 2005*

A large amount of land in India is indeed degraded, but it is not lying "waste". There is substantial dependence on such lands for fuel, fodder, wild foods and other survival resources by millions of poor people.

Apart from the production of bioenergy, the government has a target of 33% forest cover. On the other hand, tens of millions of hectares of degraded forest lands have been regenerated and conserved by communities across India, either on their own, or under joint forest management (JFM) processes.

The new environment policy of the government sets an ambitious target of achieving 33% green cover over the geographical area of India by 2012 from that of 23% forest cover in 2007. To cover 33% under tree cover actually means bringing 34 million hectares under plantation. The investment required to afforest this land is nearly Rs 60,000 crore (USD 13 million).

In conclusion, the total primary biomass supply potential is around 180 Mt, which equals around 80 Mtoe.

Wind

The on-land wind potential of India is estimated to amount to 45 GW. Some studies put this potential even higher, at 60 GW. In any case, the potential is relatively modest compared to the projected growth of electricity demand in India. Most of the wind potential is in the South.

Under the National Wind Monitoring Programme, wind data are obtained from 54 coastal locations. The western coastline has modest potential. While the Gujarat coastline has reasonable potential, it is prone to severe cyclone. So far, two locations at Rameshwaram in Tamil Nadu and Mundra at Gulf of Kutch have shown good potential, where we have wind power density of about 350 to 500 watt per square metre. In comparison, most of the offshore wind power projects in Europe are being set up at locations which possess wind power density beyond 800 watts per square metre (twice as much), which is considered economical to invest in offshore wind power.

The total installed wind power capacity in India amounted to 8.8 GW in 2008/9, about 6% of the total installed generation capacity and about 1.6% in terms of total electricity consumed in the country. The investment cost used to be around 1000 USD/kW, but has risen in recent years to USD 1500/kW. However, this rise can be attributed to supply bottlenecks and cost may come down again because of the economic recession.

Inadequate power transmission infrastructure is one of the barriers to wind power development. In Tamil Nadu, wind farms are often shut down in peak season due to inadequate grid capacity to transport the power.

Despite the high installed capacity, the actual utilisation of wind power in India is low because policy incentives are geared towards installation rather than operation of the plants. On average, across the country, the PLF of wind energy has increased marginally from 13.5% in 2003 to 2004 to 15%, but there are states such as Gujarat and Andhra Pradesh, where wind energy is functioning at a plant load factor of less than 10%. The government is considering the addition of incentives for ongoing operation of installed wind power plants (OneWorld, 2008).

Solar – CSP and PV

Indial announced a target of generating 20 GW of electricity from solar energy by 2020 under its national solar mission.

Solar owner capacity is still very small. India had 2.74 MW grid connected PV systems and 1.9 MW stand-alone systems in 2008 (Bannerjee, 2008). On top of that there were about 400,000 solar street and home lighting systems, and 7000 agricultural pumps driven by PV. Some studies are modest in terms of PV growth, to around 100 MW in 2022 (Bannerjee, 2008). Others are more ambitious and project a potential for 1.8 GW solar PV in the next five to six years (ISA, 2008). Generally, a shake-out is expected in this industry with prices that continue to come down rapidly. It is essential to account for such learning effects.

Thanks to a major initiative by Indira Gandhi, an SPV R&D programme was started by Central Electronics Ltd (CEL), as early as 1976. India has now a large and diversified PV industry consisting of ten fully vertically integrated manufacturers making solar cells, solar panels and complete PV systems, and around 50 assemblers of various kinds. Between them these companies make and supply around 200 MW per year of 30 different types of PV systems in three categories — rural, remote-area and industrial.

India has also good CSP potential, notably in Rajasthan, with a Solar Insolation of (2400 kWh/m^2) and Max. no. of sunny days. The land requirement for 100 GW is 3600 sq. kms. In comparison, Rajasthan has more than 175000 sq kms of desert land.

A recent development is introduction of PV based lighting systems, a TERI initiative. For USD 250 investment a family gets 2 LED lamps. This scheme has proven to be successful and it is rapidly expanding in rural areas without grid access (Srivastava, 2009)

Geothermal

The geothermal energy potential of India is concentrated in the Himalaya, Sohana, Sonata and Cambay basins. The total potential is around 10 GW.

Wave and tidal energy

Tidal power is a form of hydropower that converts the energy of tides into electricity. A water turbine is placed in a tidal current, which turns an electrical generator, or a gas compressor that stores the energy until needed. The identified economic tidal power potential in India is about 8000-9000 MW. The most potent sites to produce tidal energy include the Gulf of Cambay (7000 MW approx.) and the Gulf of Kachchh (1200 MW approx.) on the west coast (GEDA, 2003).

Wave power systems convert the motion of the waves into usable mechanical energy, which in turn, can be used to generate electricity. These systems can be floating or fixed to the seabed offshore, or may be constructed at the edge on a suitable shoreline. It is estimated that the theoretical annual wave energy potential along the Indian coast is about 60 GW (between 5 MW to 15 MW per metre for a coastline of 6000 km). However, the realistic and economical potential is likely to be considerably less.

Annex B: Power Sector Options for India

India has built on power plant production capacity in recent decades. Bharat Heavy Electricals Limited has been set up to deliver power plants. The company builds the majority of the coal-fired power plants in India. Other players are entering the market.

Also India has a strong position in wind turbine manufacturing. Other equipment such as nuclear power plants and gas-combined cycles are imported.

Table BB1: *Characteristics of power generation options for India (TERI, 2006)*

	Availability factor [%]		Characteristics	Capital costs [USD/kW]	Annual O&M [USD/kW]	Life [years]	Efficiency [%]
Coal-fired plant - old (before 1980)	0.58	Base Load	Centralized	Sunk costs	24	10	22.7
Coal-fired plant - old (after 1980)	0.58	Base Load	Centralized	Sunk costs	24	30	29.5
New coal plant (sub-critical)	0.85	Base Load	Centralized	942	24	30	32.3
Retrofit coal plant (first built before 1980)	0.85	Base Load	Centralized	357	24	30	30
Retrofit coal plant (1980-2000)	0.85	Base Load	Centralized	298	20	30	32.2
CFBC	0.85	Base Load	Centralized	1087	27	30	39
IGCC (refinery residue)	0.85	Base Load	Centralized	1256	27	30	46
IGCC (Coal	1.85	Base Load	Centralized	1256	27	30	44
Coal supercritical	0.85	Base Load	Centralized	1014	25	30	37.7
Coal pressurized bed combustion	0.85	Base Load	Centralized	1087	27	30	43
Coal ultra-supercritical	0.85	Base Load	Centralized	1217	32	30	44
Lignite power plant (existing subcritical tech)	0.58	Base Load	Centralized	952	24	30	29.5
Small generator set (2 kW)	0.2	Base Load	Decentralized	643	17	10	25
Existing open cycle gas based	0.9	Standard	Centralized	Sunk costs	12	20	28
Existing combined cycle gas based plant	0.9	Base Load	Centralized	Sunk costs	10	25	44.1
New open cycle gas based plant	0.9	Standard	Centralized	380	6	20	39
NGCC (new)	0.9	Base Load	Centralized	524	8	25	53.8
NGCC (new high efficiency)	0.9	Base Load	Centralized	643	10	25	60
Hydro reservoir - new	Fixed capacity	Standard	Centralized	952	14	50	32.3
Small hydro-grid connected	Fixed capacity	Standard	Centralized	2143	32	40	32.3
Heavy water reactor 1 (using natural uranium)	0.9	Base Load	Centralized	1429	36	25	21.4
Light water reactor 1 (using enriched uranium)	0.9	Base Load	Centralized	1875	47	25	17
Decentralized electricity from fuelwood	0.2	Standard	Decentralized	643	17	15	21.7
Solar PV with battery bank	0.29	Standard	Decentralized	7143	107	25	0
Solar PV without battery bank	0.29	Standard	Decentralized	4762	24	25	0
Grid interactive solar photovoltaic power	Fixed capacity	Standard	Centralized	5952	30	25	0
Wind turbines	Fixed capacity	Standard	Centralized	905	14	20	0

Annex C: India Electricity demand by Region and by Sector

Table C1: *Electricity demand 2006/7 (CEA, 2008)*

	Domestic [%]	Commercial [%]	Industrial power (M&L voltage) [%]	Industrial power (HV) [%]	Public lighting [%]	Traction [%]	Agriculture [%]	Public water works & sewage pumping [%]	Miscellaneous [%]	Total [%]	Total energy sold [GWh]
Haryana	17.68	5.59	5.8	25.5	0.3	2.39	38.77	2.18	1.79	100	17727
Himachal Pradesh	21.68	6.61	3.3	56.76	0.26	0	0.6	7.43	3.36	100	4375
Jammu & Kashmir	39.34	5.29	20.06	0	0.59	0.19	5.01	11.07	18.41	99.96	4033
Punjab	20.83	5.85	6.87	32.19	0.47	0.39	30.28	1.17	1.95	100	27182
Rajastan	16.2	5.42	4.11	36.86	0.57	1.21	28.7	4.52	2.41	100	23202
Uttar Pradesh	32.89	8.52	4.27	31.04	1.07	1.54	16.89	1.98	1.8	100	41249
Uttarkhand	26.08	12.29	3.59	42.76	0.94	0.15	8.31	4.54	1.34	100	4321
Chandigarh	36.64	29.26	12.55	13.16	1.51	0	0.14	0	6.74	100	1066
	43.41	31.65	15.6	1.17	1.99	2.25	0.36	0.63	2.93	99.99	14678

Delhi											
ST (NR)	26.51	9.68	6.63	28.5	0.83	1.3	21.31	2.63	2.61	100	137831
Gujarat	11.9	4.96	12.13	47.38	0.37	0.94	20.3	1.67	0.35	100	55490
Madhya Pradesh	16.89	3.83	2.81	37.93	0.64	5.74	29.79	2.28	0.09	100	23591
Chhattisgarh	9.78	1.82	2.26	70.31	0.35	3.94	8.48	0.51	2.54	99.99	16603
Maharashtra	21.38	10.48	7.53	39.6	1.01	2.98	14.62	2.38	0.02	100	66676
Goa	20.55	6.41	4.99	61.93	1.23	0	0.64	4.26	0	100.01	2446
Daman & Diu	4.16	2.13	12.08	80.48	0.36	0	0.26	0.08	0.44	99.99	1166
D&N Haveli	1.67	2.14	13.64	81.67	0.42	0	0.28	0.19	0	100.01	2750
ST (WR)	16.07	6.63	7.96	46.24	0.68	2.68	17.47	1.92	0.39	100.04	168722
Andra Pradesh	19.9	4.79	5.37	30.7	3.39	2.83	32.7	0	0.33	100.01	49937
Karnataka	17.28	8.77	4.69	28.89	2.17	0	33.21	4.64	0.37	100.02	33752
Kerala	44.55	10.81	8.23	29.26	1.95	0.62	1.88	0.83	1.87	100	11749
Tamil nadu	22.54	8.16	9.96	34.79	0.75	0.84	18.97	1.48	2.51	100	54593
Puducherry	16.46	5.97	5.82	65.16	0.72	0	4.66	1.2	0	99.99	2168
	70.62	22.3	1.61	0	5.46	0	0	0	0	99.99	24

Lakshadweep											
ST (SR)	22.13	7.36	7.09	32.14	2.02	1.28	25.11	1.64	1.23	100	152224
Bihar	33.26	8.51	3.04	19.94	0.55	10.03	20.58	4.08	0	99.99	3827
Jharkand	7.92	1.38	0.8	82.69	0.57	5.74	0.46	0.44	0	100	14737
Orissa	15.29	3.26	1.46	74.18	0.31	2.42	0.79	0.84	1.46	100.01	18190
West Bengal	26.74	11.7	7.95	42.84	0.99	3.62	3.86	1.92	0.39	100.01	24390
A&N islands	47.19	24.4	4.49	0	5.56	0	0	0.43	17.93	100	137
Sikkim	24.62	12.84	33.96	0	0.81	0	0	0	27.76	99.99	212
ST (ER)	19.28	6.56	4.09	59.99	0.67	4.15	3.16	1.37	0.72	99.99	61491
Assam	30	9.02	1.69	46.91	0.21	0	0.48	1.12	10.56	99.99	3488
Manipur	66.67	5.81	3.18	0.75	1.97	0	0.04	4.6	16.98	100	217
Meghalaya	23.12	4.65	2.35	53.14	0.75	0	0.05	2.96	12.98	100	863
Nagaland	62.04	8.69	8.49	0	2.92	0	0	0.97	16.88	99.99	156
Tripura	56.29	9.22	5.83	0	4.94	0	2.26	3.45	18.01	100	395
Arunal Pradesh	34.66	12.64	8.66	0	5.16	0	0	4.95	33.94	100.01	139
Mizoram	65.79	4.89	1.58	0	4.48	0	0	12.92	10.33	99.99	145

ST (NER)	34.31	8.18	2.53	38.8	1.03	0	0.48	2.14	12.52	99.99	5403
Total India	**21.12**	**7.65**	**6.85**	**39.04**	**1.11**	**2.05**	**18.84**	**1.97**	**1.38**	100.01	**525671**

Annex D: The IEA Power Sector Model for India

Figure D1: *Map of India. Location of major cities*

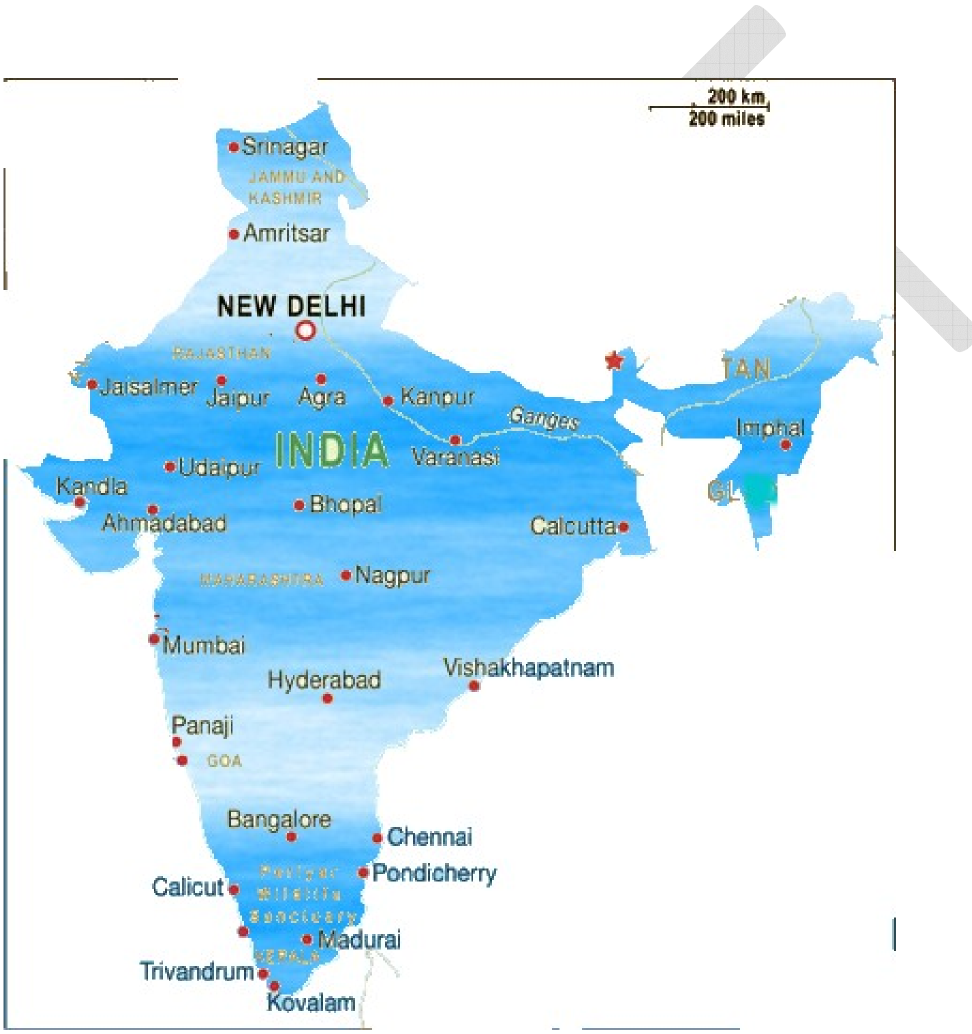

Figure D2: *Map of India. States*

Figure D3: *Map of India. Model Structure*

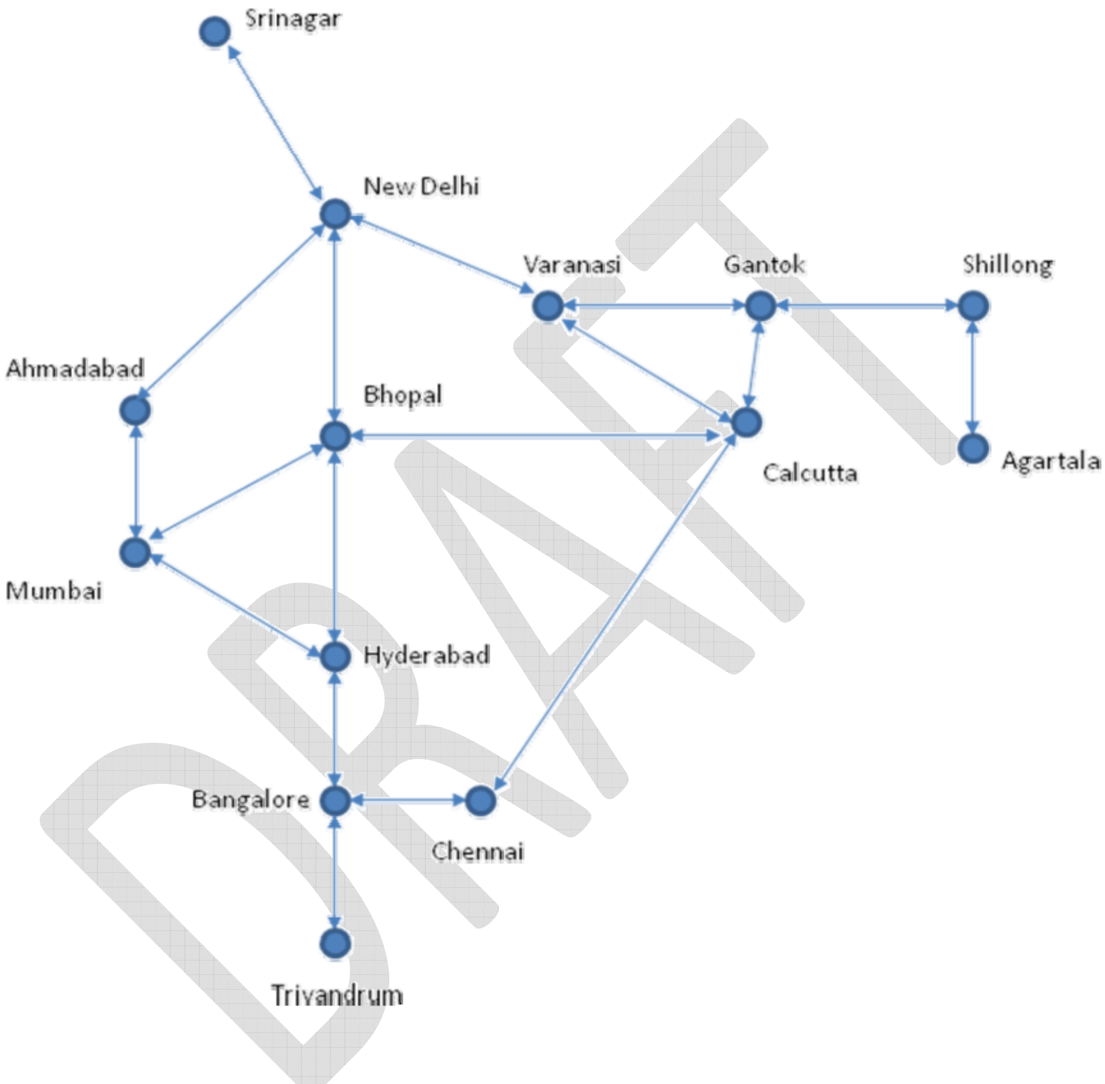

Figure D4: *Map of India. Distances in kilometres*

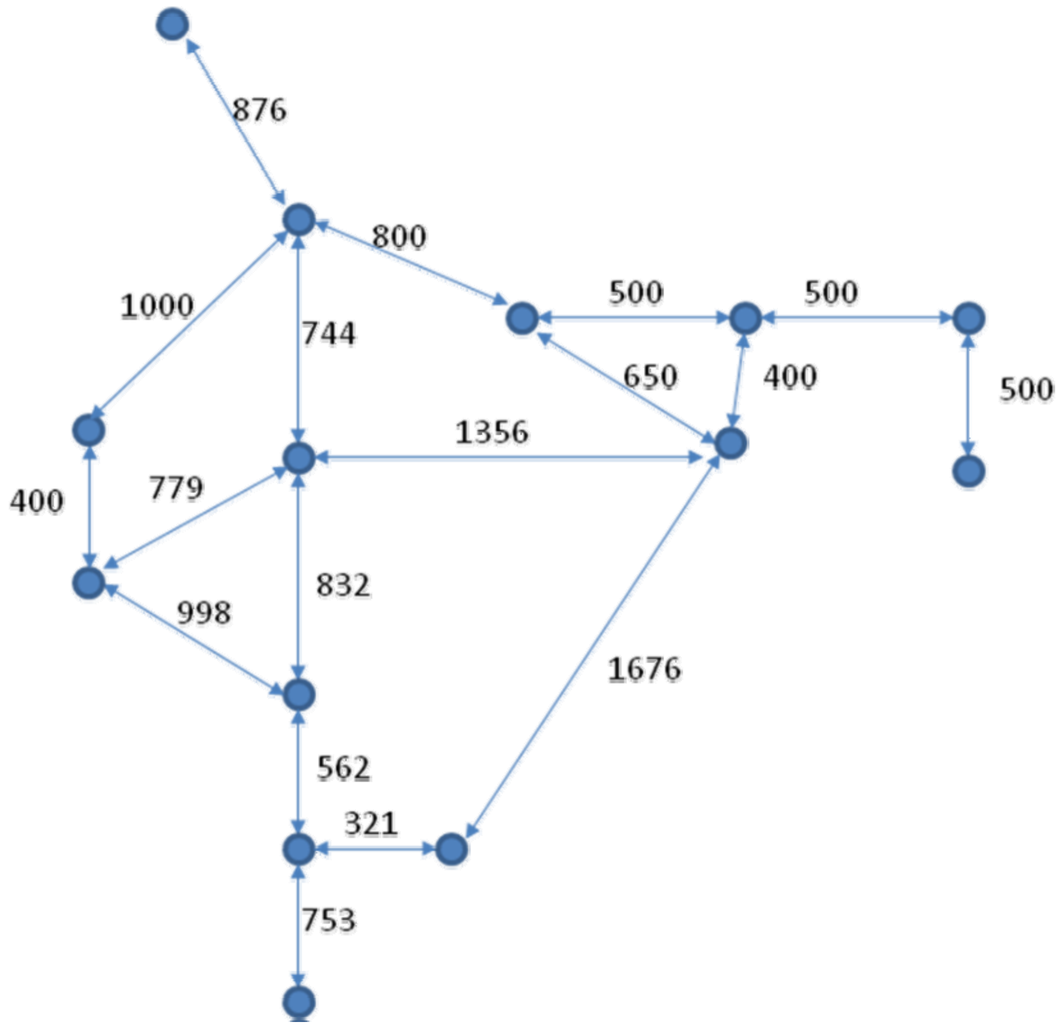

Figure D5: *Map of India. Large Hydro Potentials in GW*

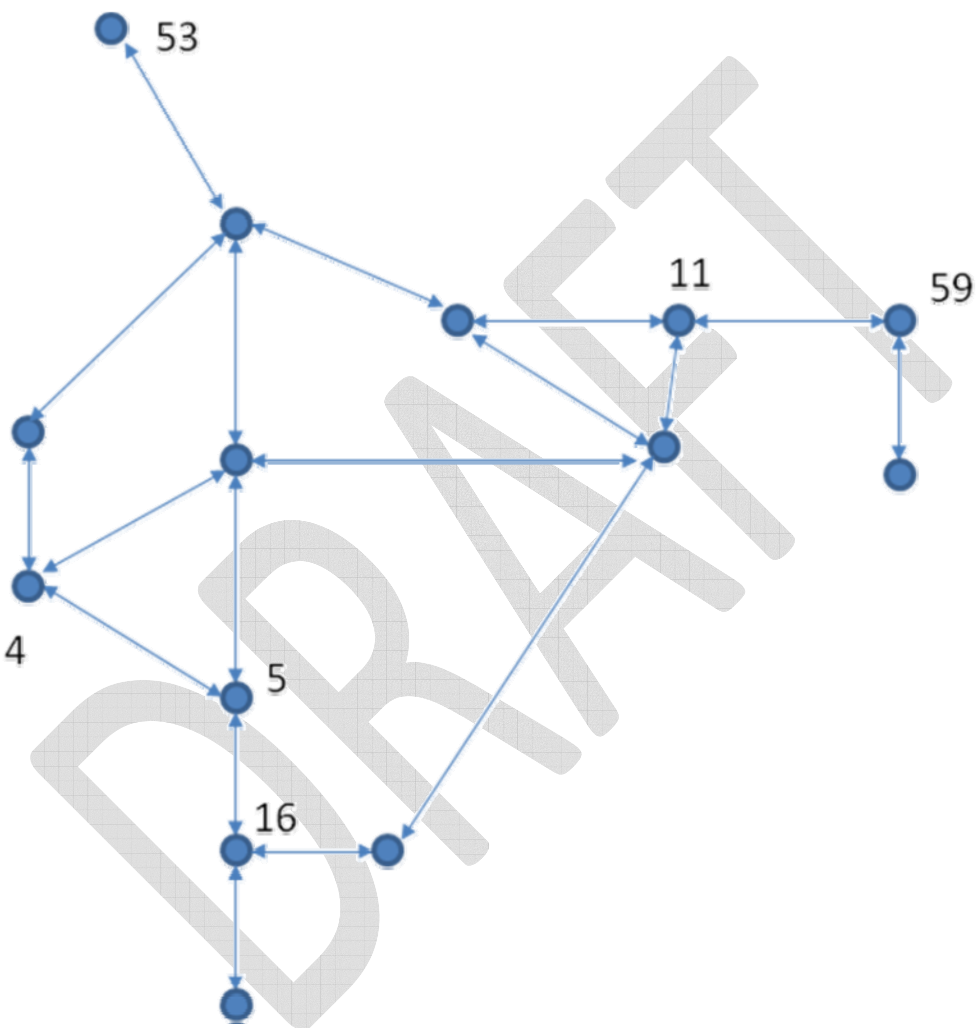

Figure D6: *Map of India. Onshore wind potentials in GW*

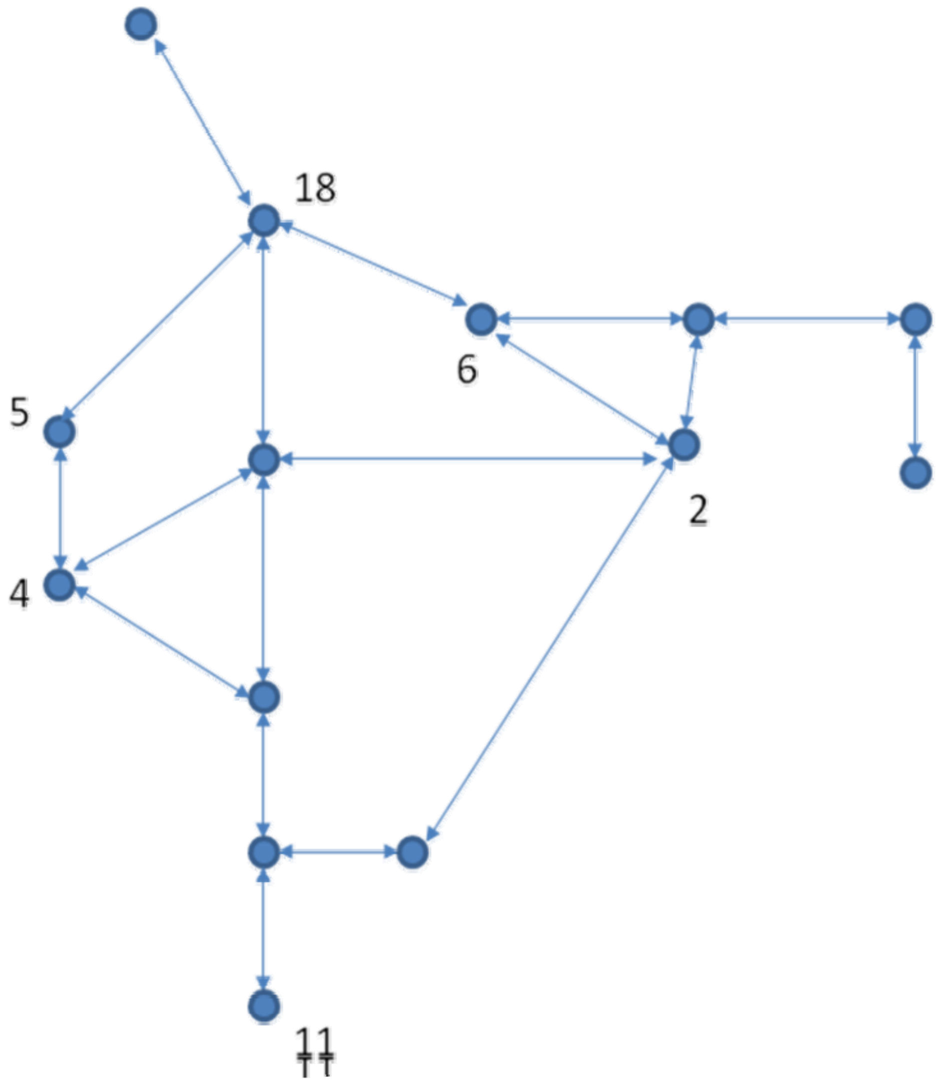

Figure D7: *Map of India. CO_2 Storage Potentials in Gt (excluding Deccan Basalt Plateau)*

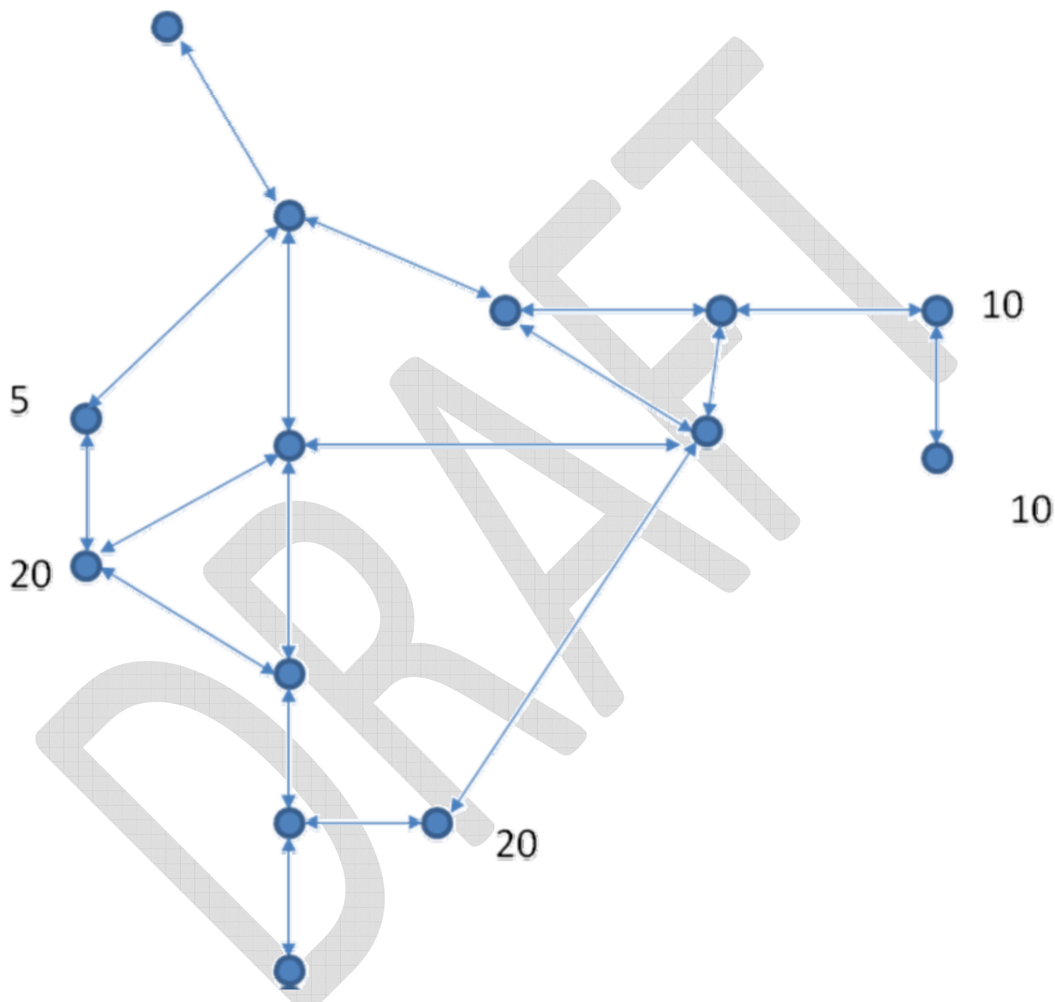

Figure D8: *Map of India. Deccan basalt plateau storage potentials in Gt*

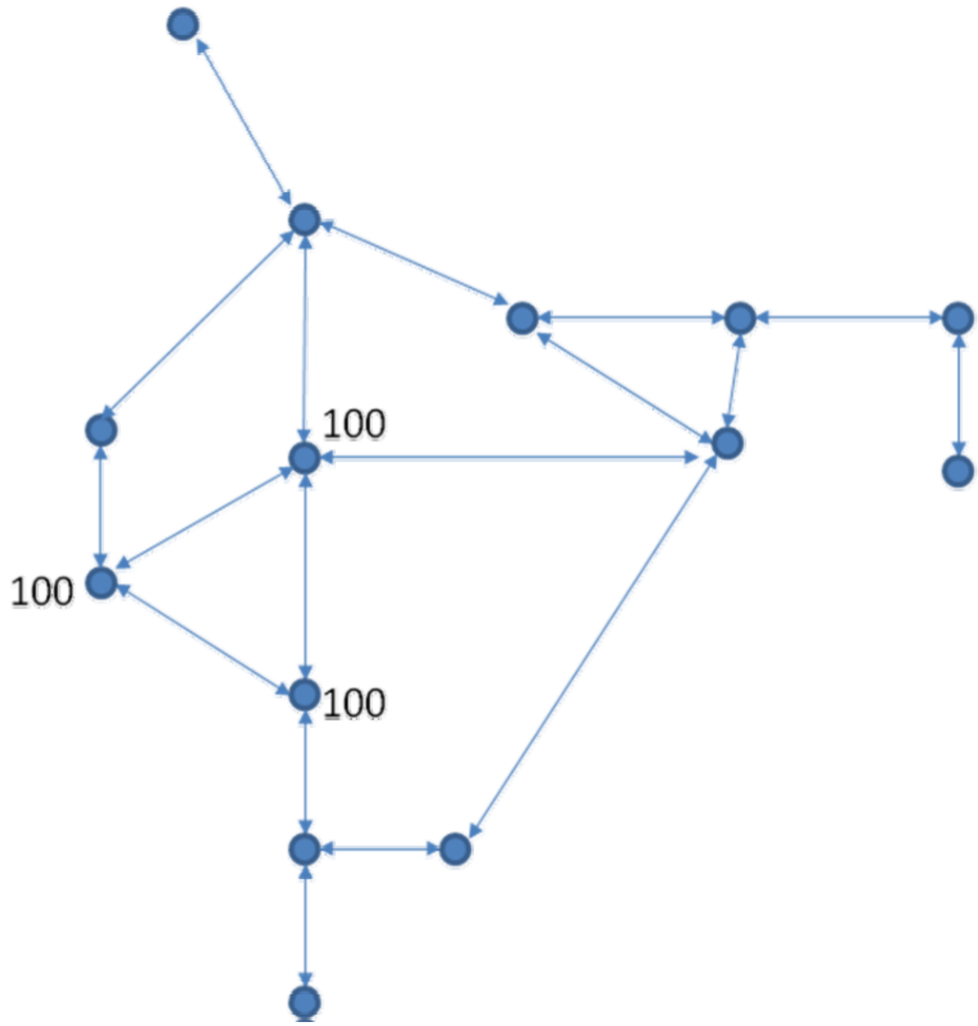

Figure D9: *Map of India. Geothermal potentials in GW*

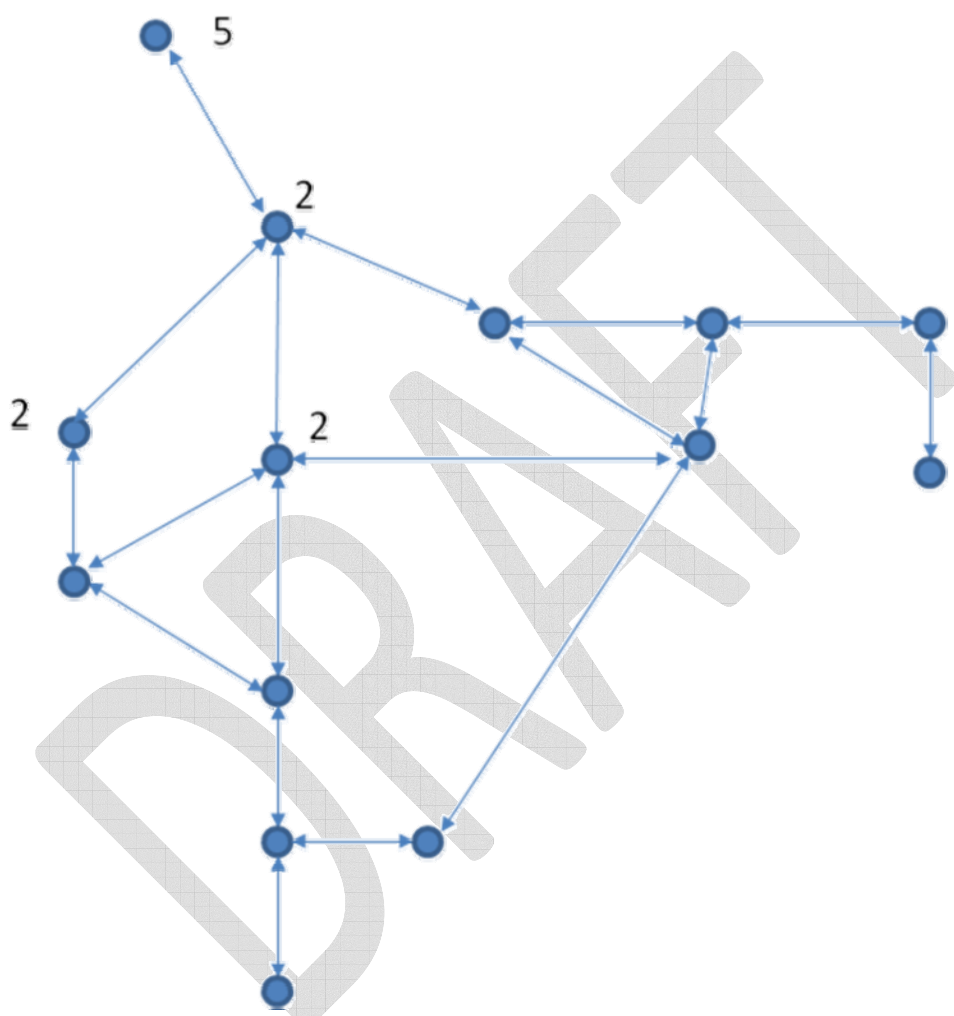

Figure D10: *Map of India. Nuclear potentials in 2050 in GW*