Pathways to Adoption of Carbon Capture and Sequestration in India:

Technologies and Policies

by
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Submitted to the Engineering Systems Division
and the Department of Civil and Environmental Engineering
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ABSTRACT

India is the world's second most populous country with a rapidly growing economy and increasing emissions. With the imminent threat of anthropogenic climate change in the coming decades, helping to control India's emissions will have to be a global priority.

Carbon capture and sequestration (CCS) can play a pivotal role in reducing India's emissions in the future, given India's reliance on coal power and the large coal reserves. The motivation for this dissertation is the need to ascertain the current situation and conditions relevant to carbon capture in India so as to help guide the processes to prepare for large scale adoption if desired in the future. For carbon capture to be undertaken at a significant scale, various pieces will have to fall in to place in sync with each other. The technological capability would have to be complemented by adequate geological capacity under the umbrella of the right policies. Adoption of carbon capture would need a tailored approach for each country and for a diverse country the size of India, these approaches may need to be customized even locally to each region.

The objective of this thesis is to increase the understanding of the opportunities, issues and challenges amongst the stakeholders regarding CCS in India regarding the capacity, political structures and policies.

To address the objective, this dissertation analyzes the current power and coal sector situations, geological capacity for sequestration in India, the political decision making structures and the current views of the relevant civil servants in this field. At the end, there are some recommendations for the government of India and the international climate and CCS community to make conditions conducive for CCS in India.

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To my rocket fuel, Naman and Namrata.

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1 Introduction and Roadmap

1.1 Introduction

India is the world's second most populous nation with a rapidly growing economy. Its greenhouse gas (GHG) emissions are growing at an increasing rate. A significant portion of the country's emissions come from coal burning power plants. Controlling the growth of these emissions and then reducing them will be imperative for reducing India's climate burden.

This dissertation explores the possible role of carbon storage in the Indian coal power sector. Rapid adoption of carbon capture and sequestration (CCS) would depend just as much on the technologies as the local geological situations, policies and the corresponding economics. This is an effort to understand the local geological situations, policies and economics that would affect and influence the adoption of CCS in India.

1.2 India: A brief introduction

India is the largest country in the Indian Subcontinent, bordered on the south and west by the Indian Ocean and on the east by the Bay of Bengal. It shares land boundaries with Pakistan, China, Nepal, Bhutan, Bangladesh, Myanmar and Afghanistan. It has a total area of 3.3 million $km^{2,}$ of which around 3 million km^2 is land and the rest is water. For comparison, it is slightly larger than one third the size of US (CIA 2007). It extends from 8°4' to 37°6' in the Northern Hemisphere and from 23° to 95° in the Eastern Hemisphere (CIA 2007). The mainland extends around 3200 km from north to south and around 3000 km east to west. Figure 1: Political map of India: (India 2004) gives a political map of India.

Figure 1: Political map of India: (India 2004)

It is the seventh largest country by land area, with approximately 2.4% of the world's land area and the second most populous nation with an estimated 1.1 billion people with a population density of around 330 persons per square kilometer. The local geography, with water bodies in the South, East and West and the Himalayan range in the North and North East, gives India a distinct geographical entity which set it out apart from the rest of Asia.

India has a Gross Domestic Product (GDP) of around $900 billion with a per capita income of around $800 (Economist 2007) per year but this figure does not represent the huge disparities in incomes. The economy is diverse with significant share of agricultural and service sectors. The agricultural sector employs close to three-fifths of the population (CIA 2007). The recent growth in the economy has been led by the knowledge industries in the service sector.

There is a large economic disparity between the rural and urban populations. This disparity is manifest in widespread illiteracy, corruption, poor public health services and poor human development indicators which again feed into poverty, creating a vicious circle of poverty and low human development.

India is a parliamentary democracy federal union with 28 states and 7 centrally administered territories, as shown in Figure 1. Most of the states have their own distinct identities with significantly different languages, culture and traditions in each. The country has 18 national languages. There is a multitude of religions and ethnicities in the population. It has a legal system based on English Common Law with the world's largest constitution and a robust judiciary which overlooks the legislature and executive.

1.3 Approach and research methodology

This dissertation was written keeping in mind two major objectives: (a) A first-order estimation of the geological sequestration capacity and (b) Defining the direction in which policies will need to be instituted by the Government of India (GoI) as well as the international climate community to encourage adoption of CCS in India. The approximate capacity was estimated using a variety of literature sources as well as independent analysis. The geological capacity maps were prepared with the help of Geographic Information Systems (GIS) data as well as historic maps available publicly.

For the survey of opinions of the policy makers and civil servants in the Government of India, interviews were conducted in the month of January 2007, as detailed in Appendix A. The information from these interviews was taken in context of the policy making structures of the Indian governments. The recommendations were discussed with various stakeholders and researchers for their viability and robustness.

Recommendations are made keeping in mind the nature of the Indian decision making structure and the interactions with the international efforts to adapt carbon mitigation technologies like CCS.

1.4 A Roadmap for the dissertation

In the six chapters that follow, **Chapter 2** focuses on an appraisal of the Indian coal and power sectors, most relevant to CCS. It delineates the various challenges that the power sector faces which may be hindrances or opportunities as and when a carbon restraint policy is adopted.

Chapter 3 gives a broad outline of the political decision making structure of India. It focuses on the Union government since the authority over the power sector and other relevant sector relies more with the Union than the states.

Chapter 4 analyzes the expected impact of anthropogenic climate change on India. India stands out even amongst the developing world as one of the most vulnerable countries due to its reliance on the monsoon cycle of the Indian Ocean for its rainfall.

Chapter 5 gives an approximation of the geological sequestration capacity in India. With very little information available currently, this estimation is good to an order of magnitude.

Chapter 6 encapsulates the current views on the adoption of climate change mitigation and adaptation strategies and policies in the Union government, with focus on CCS as a viable option in the middle and long term. It also outlines the involvement of India in the climate change science and pertinent international negotiations.

The **final chapter** sets out some recommendations for policy directions for the government of India as well as the international climate community in the short, medium and long terms. Recommendations about covering the additional costs as well as technology transfer are explored in detail.

2. India's Energy and Emissions Situation

2.1 Recent Growth

The economy of India has been growing at a rate of close to 6.5% annually over the last decade, mostly due to economic liberalization and other economic reforms which started in 1991.

The economy is expected to grow at a similar or even faster rate for the coming years. In the final quarter of 2006, the index of industrial production grew by 14% per annum while the economy as a whole grew by 9.2% per annum. Many publications (McKinsey 2001; MIT 2007) discuss further rapid increase in the rate of growth of the Indian economy.

This growth would have to be accompanied by a growth in the energy consumption. The Planning Commission expects that to sustain growth at 8% per annum till 2031, the primary energy supply would have to grow by 3-4 times and the electricity supply 5-7 times the levels of current consumption (Parikh 2006).

2.2 Energy statistics for India

The per capita consumption of primary energy in India in 2004 was 15.3 GJ[1] as compared to 360 GJ per capita in the US. This corresponds to a total national primary energy

[1] 1 GJ = 10^9 Joules

consumption of around 19 EJ[2] per year, compared to around 104 EJ for the US (EIA 2007). The primary energy supply is dominated by fossil fuels, a large share of which is coal, as shown in Figure 2.

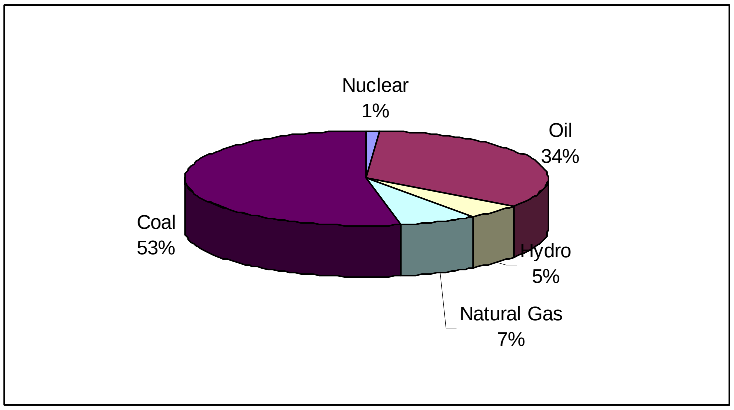

Figure 2: India's primary energy supply by source (IEA)

The Indian government expects this mix of energy sources to remain approximately stable in the near term, till 2024-2025, (Parikh 2006) as shown in Figure 3.

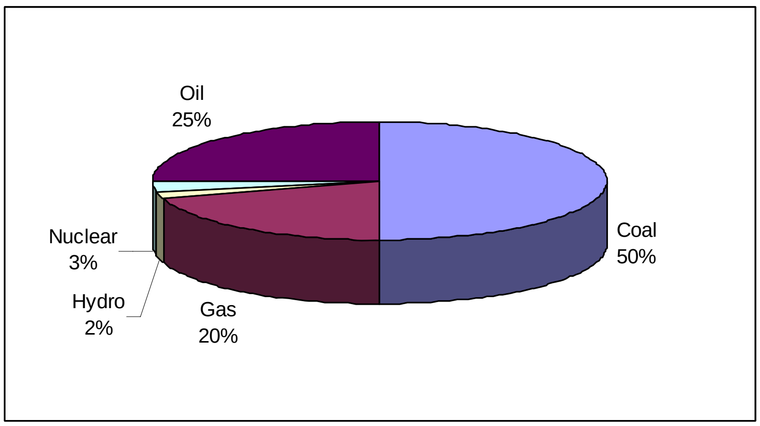

Figure 3: Projected Primary Energy mix in India 2024-2025, source: Ministry of Petroleum and Gas: Hydrocarbon Vision 2025 (IndiaStat 2006)

[2] 1 EJ = 10^{18} Joules

2.2.1 Power

India has an installed power generation capacity of about 126 GW [CEA 2006]. Thermal power plants account to about 50% of the installed capacity, and close to 67% of the *generated* electricity, as shown in figure 4.

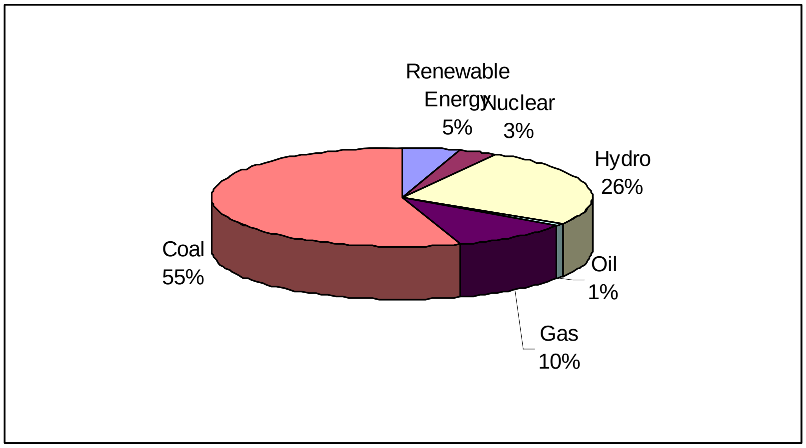

Figure 4: Electricity generation capacity mix in India 2005, source: IndiaStat 2006

The per capita consumption of power in India is ~612 kWh/year, (IndiaStat 2006) as compared to the global average of 2400kWh/year (RFF 2006).

In 2003, India consumed around 556 billion kWh of electricity, of which just 1.4 billion kWh were imported (CIA 2007). Of these, 407 billion kWh came from consuming close to 289 million tonnes of coal and lignite in more than 80 large utility-scale power plants (Chikkatur 2005). The Central Electricity Authority (CEA 2006) estimates that an additional 41GW will be added in the Tenth Five Year Plan period between 2002-03 and 2006-07. Close to a third of this new capacity is expected to be coal [CEA 2005, Chikkatur 2005].

The difference in installed capacity and supplied electricity mentioned earlier shows that coal is used as the fuel for the base load and is more reliable than other sources and shoulders a larger portion of the burden.

2.2.2 Disparity in consumption

According to the Ministry of Power [CEA 2006], just 60.2 million of a total of 138 million households are electrified. There is wide disparity in electricity consumption with 44% of the rural households and close to 70,000 (out of around 95,000) villages still unelectrified (Ailawadi and Bhattacharyya 2006). What is more relevant here is the number of rural households electrified and not the total number of villages as even if a village is counted as electrified, supply may be restricted to the local school or collective area etc. The villages counted as electrified also may not be getting electricity to fulfill the demand. By personal experience, even rural areas nearby cities often have supply for just a few hours a day.

2.2.3 Estimates of Growth

Ghosh [2005] and various other authors estimate that the electricity consumption in India will double between 2004 and 2025. The demand for power has been recently increasing at a compounded annual growth rate of 9% per annum (Ghosh 2005). The rate of increase of demand is foreseen to increase or at the very least, stay the same for a long time to come.

2.2.4 Shortfalls

One interesting piece of statistics is that of the peak power demand of 86 GW in 2003, just about 76 GW was met, with a shortfall of 10GW (about 11.5% of the peak power demand)

(IndiaStats 2006). There was a shortfall of about 10% in the month of June and close to 13% for the period between April and June.

These figures show that there is a considerable shortfall in the capacity of the electric power system to supply power. This shortfall is manifest in considerable and regular load-shedding in most urban areas with erratic power supply in the rural areas. The supply to industrial areas is still 'rationed' in some states like Rajasthan, and in other states, the hours in which power is available are rotated daily and annually. This shortage creates extra pressures on industries. In the increasingly competitive environment of global manufacturing, this drawback does not allow Indian industries to perform at their best. In personal experience, this is manifest in the regular power supply cuts that most households face. People often plan their schedules around these power cuts which are usually known well in advance.

If this excess demand need is to be fulfilled without laying an excessive burden on the planet's atmosphere, a comprehensive energy policy will have to include the maximum possible from most of the energy options like coal, nuclear, renewable as well as oil. Each of these options has their own particular merits and demerits. In this dissertation, I will not discuss all of these options, but focus mainly on coal.

2.3 Coal power in India

India is the third largest coal producer and consumer in the world, after China and the US, respectively. As we have seen earlier, a large portion of the total primary energy supply as well as a significant share of the electric generation comes from coal.

2.3.1 Coal reserves in India

Most data sources (Mathur, Chand et al. 2003; EIA 2007) show that India has total resources of about 250 Gt and recoverable reserves of around 92 Gt, corresponding to a reserve-to-production ratio of 230-250 years at projected consumption levels. The Indian Coal Ministry designates coal reserves in three categories (Figures of reserves as on 1.1.2006, Coal Ministry, all figures in metric tonnes):

- Proven: ~96 Gigatons (Gt)
- Indicated ~120 Gt
- Inferred: ~38 Gt
- Total: ~253 Gt

Many recent publications have cast serious doubt on these figures. Due to outdated methods of estimation of remaining coal reserves and inconsistent analysis used conventionally, some authors like Chand and Sarkar (2006) and Chikkatur (2005) doubt this figure. Most detailed studies report that the discrepancy in expected reserves comes due to the different method that the Indian Coal Ministry follows. This method does not confirm to the internationally accepted methods and hence overestimates the reserves. According to some commentators (Chand and Sarkar 2006), most of the economically recoverable resources have been projectized, leaving a meager 18 Gt of virgin reserves. However, according the Draft Report of the Planning Commission Expert Committee on Integrated Energy Policy, (Parikh 2006), finds it likely that more coal reserves would be found in India with better exploration of deep seams. The Central Mine Planning and Design Institute Ltd (CMPDIL) reported total extractable reserves for India in 2005 as 52 Gt, which is just a fifth of the total geological resources. This leaves the expected lifetime of coal resources about 50 years (Chikkatur 2005), as opposed to around 200 years understood in most studies. Nevertheless, this is a large amount of coal that can serve the needs of a large country for close to half a century. As we shall see later, this may come along with serious repercussions for the climate problem.

2.3.2 Quality of coal in India

Indian coal is a typically low quality coal. It has high moisture content as well as very high ash content. These are the following characteristics (IEA 2000):

- Over 80% of coal has an ash content of 30% to 50% with low iron content
- Negligible toxic trace elements and low sulphur content of 0.2 to 0.7%
- High moisture content between 4% and 7% with the "as received" content between 7% and 13%.
- Low gross calorific value, 12,000 to 20000 KJ/kg (Ghosh 2005)

It has good reactivity that aids combustion as also a favorable base/acid ratio. Due to the high ash content, just 15% of the coal can be used for coking and most of the coking coal has to be imported.

The high ash content causes technical difficulties at power plants (IEA 2000). The costs of transportation also increase due to ash since beneficiation is not practiced widely. High ash means that a lot of energy is spent just transporting useless ash. It reduces availability for coal power plants due to recurring need for maintenance and cleaning. The poor quality of coal and the subsequent high costs of transport lead to a conundrum that it is cheaper to import higher quality of coal from Australia and South Africa. An order of the Ministry of Environment and Forests (MoEF) regulates that for power plants more than 1000 km from the mine-mouth, not more than 34% of the coal should be ash. With the large amount of ash in the domestic coal, this regulation is met by blending it with better quality foreign coal.

2.4 Coal usage in India

Figure 5 shows the trend of coal usage in India from 1980 to 2004.

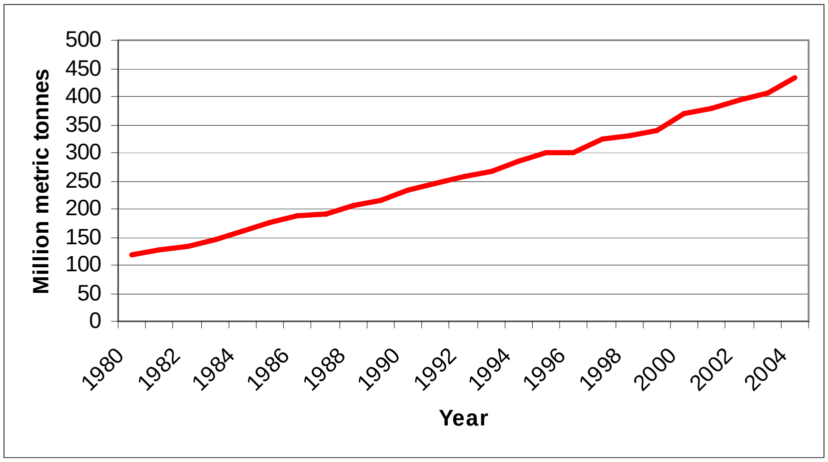

Figure 5: Historical coal usage and emissions in India (EIA 2006) Source: EIA 2006 and IndiaStat 2006

Due to difficulties in procuring good quality coal domestically, imports from Australia and South Africa have been increasing steadily.

According to World Energy Council [2006], the Indian coal is used in different sectors as shown in Figure 6. A majority share is used in the production of electricity.

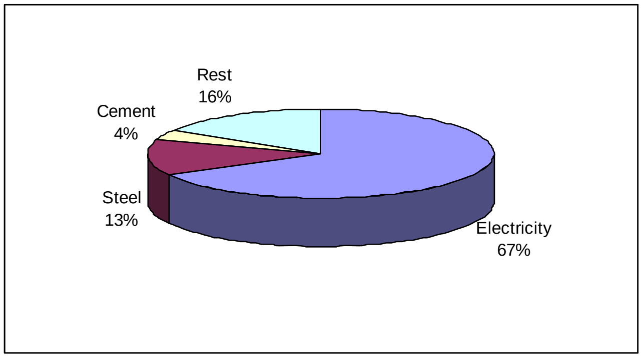

Figure 6: Distribution of coal usage in India (WEC 2006)

2.4.1 Projected coal usage

The historical and projected coal consumption in India is shown in Figure 7:

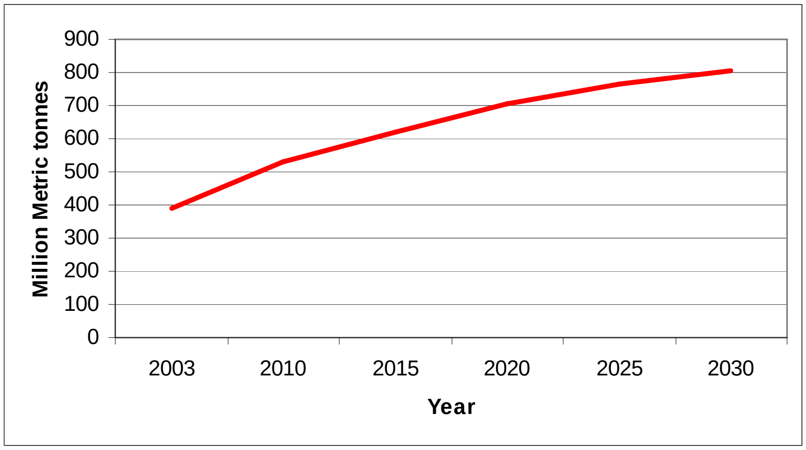

Figure 7: Historic and projected coal consumption in India [EIA IEO 2007]

This trend in the use of coal is further expected to continue, leading to large increase in emissions from India.

2.5 Emissions from India

India's carbon dioxide emissions due to consumption of energy were 1.1 Gt , of which emissions from combustion of coal were 0.7 Gt of carbon dioxide in 2004 (EIA 2007). Between 1990 and 2000, the overall increase in CO_2 emissions has been at a rate of 4.2% per annum and 5.1% between 2000 and 2005 (Shukla 2006). Figure 8 shows the trend in growth of emissions in the recent years in India, due to use of fossil fuels.

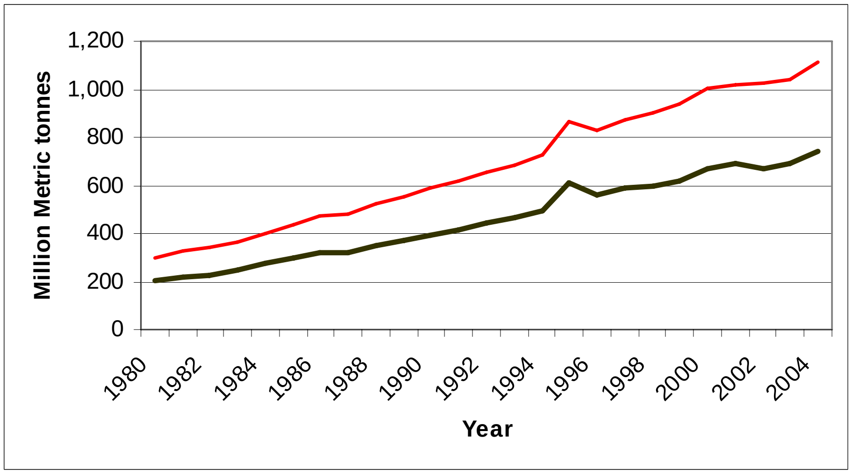

Figure 8: Historic emissions from the use of fossil fuels in India

India's emissions are relatively small compared to the industrialized countries. Figure 9 shows the total carbon dioxide emissions from the consumption of energy from some prominent countries (and Europe) in 2004.

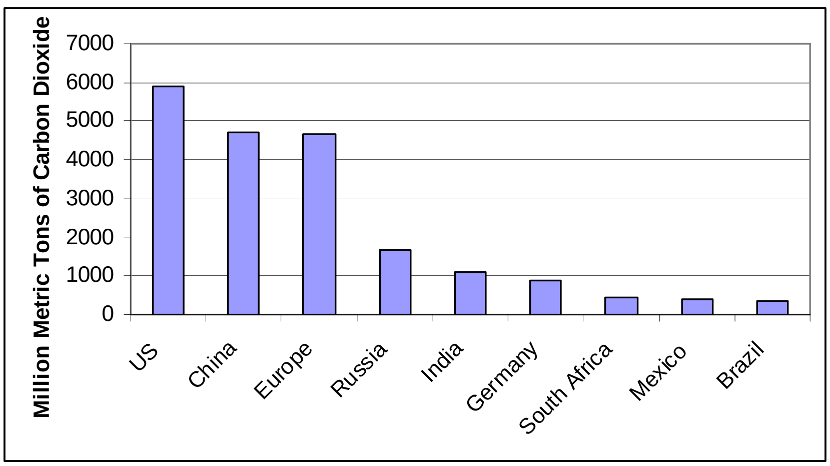

Figure 9: Carbon dioxide Emissions from the consumption of energy in 2004 (EIA)

On a per capita basis, India's emissions are remarkably low, even compared to other developing countries like Brazil, Mexico and China. Compared to the developed countries, India's emissions are a fraction, as shown in Figure 10.

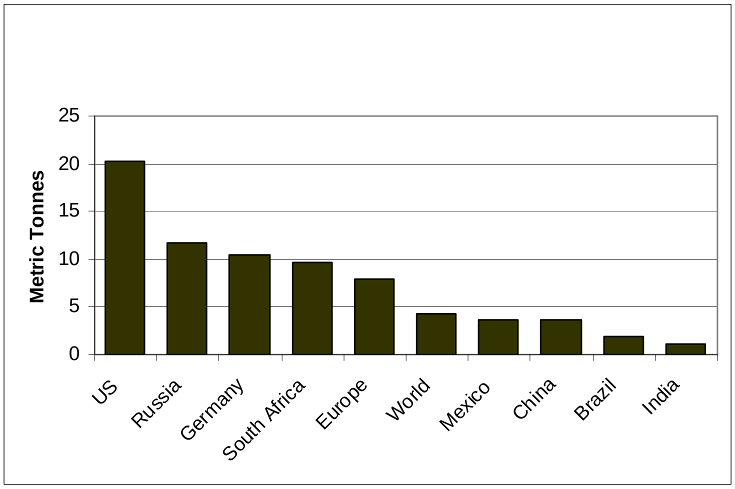

Figure 10: Comparison of per capita emissions from different countries and the world in 2004 [IEA 2007] Note: Europe includes Germany but not Russia

Even though India's emissions are small as compared to the OECD countries, it would be worthwhile to attempt reducing the coal usage in India or to sequester the carbon dioxide emissions due to the large population.

As for non-carbon emissions, it is estimated that the coal power plants in the country produce 100 million tons of ash a year (CEA 2005), which contributes to local air and water pollution and large amounts of land are required to dispose of the fly ash from the coal power plants. Mathur *et al* (2003) calculate that 44% of the costs of coal in India come from transportation costs as opposed to 27% for US since a higher fraction of ash is transported. This becomes more important given the fact that almost two-thirds of the coal mined in India is transported across distances beyond 500 km (Ghosh 2005). Current laws require the implementation of electrostatic precipitators (ESPs) for suspended particulate matter (SPM). The operation of these ESPs is not up to the 99.9% mandated. This happens due to low quality of coal as well as poor maintenance of the systems. The emissions of SO_x and NO_x

due to coal combustion have caused problems of acid rain and poor air quality but were tackled to some degree of success by executive as well as significant judicial action in the past decades.

There are no current requirements for mercury emissions control [Ghosh 2005] but only non-binding guidance from the Central Pollution Control Board (CPCB) based on ambient air quality standards. Since the content of mercury in Indian coal is low [CSE 2006], mercury is not a major concern as of yet but high amounts of usage may change the situation.

2.6 Problems with the current Indian Power Sector

The problems of Indian power sector are widespread and diffused throughout the system, technical and political. As mentioned earlier, there are serious shortfalls in the supply. There is no one specific part of the process where the entire blame can be placed but neither is any part of the system free of some kind of issues.

On the generation and transmission side, the problems range from old plants and low capacities to high losses in transmission. The comparatively inefficient older thermal power plants are inherently connected to a higher intensity of emissions of greenhouse gases.

According to Ghosh (2005) and Chikkatur (2005), the problems of coal power plants are many and varied. The plants are often producing at a lower general efficiency than the expected due to reasons like:

- Poor quality of coal

- Lack of proper operation and maintenance at power plants
- Bad grid conditions
- Low plant load factor (PLF)
- Aging technology and machinery
- Low emphasis on efficiency during operations and maintenance of the power plants.

The technology is not new. There are still no supercritical plants in operation today (Chikkatur 2005). Although, one National Thermal Power Corporation (NTPC) plant with 3 super critical units is currently under construction.

According to McKinsey, the Total Factor Productivity (TFP)[3] in generation for India was 34 with the US productivity indexed at 100 (McKinsey 2001). The biggest culprits of this low productivity were low capacity utilization, inefficient deployment of manpower, shortage and poor quality coal as well as high ash content of coal.

The entire country suffers electric outages which were estimated to be 26% of the total annual capacity of generation. The McKinsey report attributes these outages to the following:

- Breakdowns in boilers, generators and turbines, 42% of the total losses
- Breakdowns in auxiliary equipment, 15% of the total losses
- Problems in coal quality, 19% of the losses

[3] The Total Factor Productivity (TFP) is a relative index that measures the output for a given set of inputs in different factories, or in this case, countries. The measure scales and normalizes the expected output given some localized conditions. This TFP is used to compare the productivity of different producing entities.

- Other miscellaneous reasons, 23% of the total losses.

The problem is more serious when we look at the transmission and distribution system. The TFP is indexed at 4 as opposed to 100 for the US and 86 for the rest of the OECD countries (McKinsey 2001). These losses are attributed to:

- Thefts and improper billing – Close to half of the electricity is lost to power theft or distribution losses. There are also political reasons for improper billing and free electricity to politically strong groups etc.
- Poor organization of functions and tasks
- Unviable investments
- Low demand per consumer – This leads to greater losses per unit of electricity consumed by each end user.
- Unsustainable cross subsidies (Parikh 2006)
- Legacy linkages between coal mines and power plants that do not allow for trading or flexibility across mines, increasing costs and reducing efficiency in plants away from the coast (Parikh 2006)

Till the late 1990s, and early 2000s in some states, electric power was produced, transmitted and distributed by state-owned and regulated electric utilities called the State Electricity Boards (SEBs). These SEBs were used as political tools and functioned not just on economic criteria but were influenced by politics. Free power to the large voting constituency of farmers has been a popular electoral concession in state elections over the years (McKinsey 2001; Khanna 2004).

In the last decade, most of these SEBs have been disbanded and divided up into various generation, transmission and distribution companies. This unbundling came about as a result of the huge losses incurred by the SEBs over many years. The disbanding is still in initial stages and its relative successes and failures are yet to be seen reliably.

2.7 Energy mix options for a rapidly developing country

As we see in the previous sections, there is a large capacity shortfall that needs to be addressed to fulfill the energy needs of the Indian people. Not being a energy resource rich country (Parikh 2006), India will have to maximize returns from the resources that it has as well as secure other viable sources.

Meeting this requirement will need all the options that are available. Nuclear power, large hydroelectric, thermal power as well as renewable energy will have to be harnessed for a comprehensive energy mix that addresses the issues of:

- Fulfilling energy needs
- Energy security
- Climate effects
- Local pollution

Each of the options have has relative strengths and drawbacks. A relative decisive comparison that decides the policy would undoubtedly be based to a significant extent on the costs and attended benefits, though social and political factors would also play key roles in deciding India’s energy mix. In the context of carbon capture and storage, this cost-benefit analysis may prove to be a hurdle since CCS would be amongst the more expensive options available.

With most of the energy market not fully open to the private sector yet, the role of the central government in developing energy sources will be a major determinant in the direction that India takes.

There is a lot to be gained from the efficiencies brought about by market forces (Parikh 2006). This potential has not been gained yet and it will be a few years before such large changes can be made (Parikh 2006).

Currently, the government has a clearly outlined view of its priorities for harnessing energy sector improvements. This priority order emerged in the same form in discussions with various policy makers as well as government policy papers (Ghosh 2007; Shahi 2007). The Integrated Energy Policy (Parikh 2006) also mentions these four sectors for growth in the Indian energy services:

1. **Efficiency improvements in generation, supply and consumption**
2. **Hydropower at large and small scale**
3. **Nuclear energy**
4. **Distributed Generation**

This report on Energy Policy is discussed in detail below.

2.7.2 The new Indian Energy Policy expert panel report

The Report of the Planning Commission Expert Panel on Integrated Energy Policy was issued in August 2006. This report is likely to heavily influence any new laws relating to energy as also energy-related ordinances, planning, and policies set out by the government. This Expert Panel comprised of various senior civil servants, academics, researchers and industry representatives (Parikh 2006).

The stated aims of the charge given to the Panel were to recommend policies that help India achieve, with as little harm to the environment as possible:

- Access to energy for all by 2012
- Available and efficient energy services
- Affordable energy at the right prices
- Sustainable Development

The report focuses considerably on increasing efficiency in the Indian energy systems and markets, which it finds excessively poor. It states that to achieve sustained growth at 8% through 2031, India's primary energy supply will need to grow by 3-4 times and electricity supply by 5-7 times the current levels.

This report discusses dominant role that coal plays in the Indian Energy mix and stresses the fact that this role is not about to be diminished before 2031-32. The Panel emphasizes need for efficiency in all sections of the coal industry, from production to transmission to distribution and then final consumption. There are also recommendations on introducing the market mechanism to help the over all sector achieve efficiency, to break the old linkages between specific coal mines and power plants, regulated privatization of coal mines, etc.

2.8 Conclusion

From the preceding analysis, it is apparent that while the Indian economic growth is accompanied by a strong growth in demand for energy, the current system is highly inefficient and will be unable to keep up with the increase in demand. The emissions from India, though very low currently, will increase to be a significant share of the global emissions soon, due to the rise in incomes as well as population.

3. Energy and Environmental Policy Decision Making Structures in India

3.1 Introduction

Given the fact that in the short term, CCS is expected to be undertaken either by the government itself or with a significant government support worldwide, it is important to understand the decision making process in the energy and environment sector of the Government of India (GoI).

3.2 India and its Democracy: The Decision Making Process

India is a federal republic with a written constitution. It has 28 states and 7 union territories. India is a vibrant multi-party democracy with often different parties at both central and state levels. The Constitution tilts towards a strong central government. All legislatures, central and provincial, are elected on the basis of a multi-party first-past-the-post[4] multi-candidate election. Each legislature is elected for five years at a time and most provinces have their elections at the same time as the central government. The executive is formed from the body of elected legislators by the party or coalition receiving a simple majority in the legislature. Voting rights are available to every citizen over the age of 18 years.

[4] First-past-the-post is the system of popular election where the winner is decided on the basis of the maximum number of votes polled by any candidate, without any run-off elections or proportional representation.

Close to 36% of the Indian population is illiterate and close to 80% of the rest received only primary education. Less than 9% of the population passes high-school. This kind of status in literacy and education imparts significant hurdles to well-informed decision making during elections. Consequently, the polls are often decided on the basis of the religion, caste or familial association of the candidate or even very trivial issues. Representation of rural areas is often uniformly decided on the basis of local affiliations to castes etc. The politicians are notorious for having links with the crime world and often are un-convicted criminals.

This analysis of the Indian political set up is the subject of various books and lends itself to various other such analyses. However, this analysis is also important in our discussion to give a background on the way decisions are made, later in the chapter.

3.2.1 Federal Structure and division of powers

The federal structure allows a division of powers between the states and the central government through the Seventh Schedule of the Constitution of India. Given the diversity in cultures, religions and languages among the states, it is very important to have clearly delineated division of powers. The Seventh Schedule of the Constitution sets out three different lists of legislative jurisdiction in India:

- **Union List**: 97 subjects on which only the central legislative body, the Indian Parliament can make laws – Subjects of national importance like defence, national security, international affairs, railways, atomic energy, post, banking etc.
- **State List**: 66 subjects on which the state legislatures, called the state assemblies can make laws – Criminal affairs, police, public health and sanitation etc.

- **Concurrent List**: 47 subjects on which either of the central or state legislatures can make laws but in the event of a normative conflict, the central laws prevail – Subjects like trust, bankruptcy, local government, local judiciary etc.

The Union of India retains all residual powers about subjects not mentioned in the Seventh Schedule. Relevant to our discussion, energy does not occur in any of the lists as an independent entity, though atomic energy is mentioned in the Union list. Amendments to this list are rare.

Of interest to climate change and related issues, it is notable that electricity, forests and economic planning are mentioned in the Concurrent list while mining is listed in the state list. Even though the original Seventh Schedule does not mention the environment *per se*, with its correlation to forests, both levels of governments are assumed have the authority to make laws regarding the Environment. This power is seen in the presence of pollution control boards (PCBs) in both the state and the central levels.

The central government's Ministry of Environment and Forests (MoEF) has the Central Pollution Control Board (CPCB) while most of the states have their own respective PCBs. These boards are authorized to make rules and implement laws pertaining to pollution control. Most of these powers are limited to toxic pollution, ranging across air pollution, water pollution and solid waste management. Climate change regulations and negotiations are not part of the mandate for the CPCB. The agency's website[5] (CPCB 2007) mainly focuses on toxic population, without any significant mention of climate change. This is relevant as it

[5] Website: http://envfor.nic.in/cpcb/ (Accessed March 2007)

shows that the government does not treat climate change like just any another pollution problem.

For climate change, the lead has been taken by the MoEF. The MoEF coordinates the climate change negotiations and all other international interactions for India (CDM 2007). The National CDM Authority acts as the Designated National Authority, required of all signatories of the Kyoto Protocol. This authority is expected to make all decisions on the international cooperation aspects of climate change. This body is also expected to oversee the implementation of Clean Development Mechanism (CDM) aspects of projects which have undertaken to reduce emissions.[6]

3.3 Government officials

3.3.1 Ministers

The Indian executive at the both the central and state levels are divided into ministries. Each ministry is headed by a minister, often supported by other junior ministers. These ministers have to be elected members of the legislature and if nominated by a new government, have to seek popular election within six months to avoid losing their position. Each ministry has overarching control over the implementation of most laws pertaining to a specific area. For example, the union government has ministries like the Defence ministry, the Law Ministry, the Ministry of Home Affairs, the Ministry of Foreign Affairs etc. All ministers of a government together form the Cabinet, the highest decision making body in the executive branch. The

[6] It is notable that the CDM Executive Board is headed by the head of the Indian National CDM Authority, Mr. R.K. Sethi (http://cdm.unfccc.int/EB/index.html) while the IPCC is headed by another India, Dr. Rajendra K. Pachauri.

Cabinet at the state level is headed by the Chief Minister who heads the government while at the Central level, it is headed by the Prime Minister.

These ministers are usually chosen to head a specific ministry without any due consideration of their background in the field, though it is not unusual to see certain individuals staying connected to some areas for a long period.

3.3.2 Civil Servants: The Steel Framework

The Indian elected executive is supported by a cadre of career civil servants, members of the Indian Administrative Service (IAS). These civil servants are selected through a rigorous and extremely selective 2 year long selection procedure and do not have to seek re-election with every new government. These civil servants then work in different departments, ministries and capacities often in tenures of three to five years each. At the Central level, senior IAS officers tend to specialize in specific fields towards the end of their career. Again, as with the ministers, the appointment of these career civil servants is done without consideration to their prior training or education. These civil servants are often called the *Steel Framework* of the Indian administration since they retain the institutional memory, despite changing of governments.

These civil servants are usually the real rule makers in the Indian policy making. With their experience in administration, most IAS officers set out the different policy options available to the government, out of which the elected officials choose those that serve the government's political objectives. The broad policy direction for each ministry is set by the elected politician but these policies are implemented by the civil servants.

As mentioned earlier, most of the climate change negotiations are handled by the Ministry of Environment and Forests. In my meetings with the Secretary of this ministry (Ghosh 2007), it was apparent that just a handful officials in this ministry were responsible for deciding the direction to be taken ahead. In my experience working with the think tank and research organization, The Energy and Resources Institute (TERI)[7], the guidance from these few senior officials was considered the final word on the general governmental policy direction. On specifics related to such scientifically complex issues like climate change, the elected official often relegates policy making powers, unofficially, to the trusted ministry civil servants.

3.4 Decision making in energy and environment sectors

Policy decisions in the Indian governments, state and Central, are made on the basis of the ideological underpinnings of the current party in power. The policies depend on the political principles of these leaders. These policies are then put in action by the civil servants, who have a major control over particular policy details.

There is considerable politically influenced decision making in the environmental sectors, which are yet not considered priority in the Indian national political discourse. With other pressing problems like unemployment, inflation and international affairs dominating the national discussion, environment, and climate change more specifically, are usually not debated. Due to this lack of awareness in the general public, government decisions are often not closely scrutinized in the media or the public discourse, enabling concentrated decision

[7] It is notable that this Indian think tank TERI is headed by Dr. Rajendra K. Pachauri, also the head of the Intergovernmental Panel on Climate Change (IPCC)

making. There is also lack of accountability in the decisions of the civil servants, except to the elected politicians. Despite this lack of accountability, the upper echelons of the policy making apparatus are viewed by most to be working with India's best interests in mind.

Corruption in the middle and lower levels of government in India is a well documented and chronic problem. Often, critical decisions are made based not on any cost-benefit analysis or careful scrutiny but by the possibility of personal profit of the decision maker. This problem confounds any other organizational and institutional problems.

Khanna (Khanna 2004) discusses the lack of cost-benefit analyses within the decision making process in the state electricity sector in India. The average revenue from 1955-1996 electricity generation was estimated to be 18% lower than the average cost of production, due to the subsidies and free power to various agriculture sectors. This led to disincentives to saving power and no significant conservation measures {Khanna, 2004 #16}

Similarly in the environmental pollution control field, good legislation and noble intentions of politicians and judiciary are often frustrated by rampant corruption amongst the officials in the grassroots. Though there are yet to be any strong climate change specific regulations, similar problems might to be expected. Much like problems in China and its coal power sector that pervade all levels of government and power companies (MIT 2007), the problems in any climate change regulation in India will have to be anticipated and tackled at various levels.

3.5 Conclusions

Given the above analysis, it is apparent that the decision making structures in the environmental field will have to be influenced for any shift towards a CCS friendly policy. The concentration of decision making powers in a few hands would make it easier for faster decisions to be made by a few informed people, a critical point to be kept in mind when negotiating with the Indian government. The specter of catastrophic climate change demands swift and committed action by all countries. It will be necessary to leverage the current administrative structures to achieve the goal of reducing GHGs.

Chapter FOUR

4. Climate change impacts on India

4.1 Continental position

India lies partially in the Temperate, Tropical and Arid and Semi-Arid regions of Asia, as shown in the map in Figure 11. It has a variety of climates with a desert region, mountainous climates, tropical regions and many more.

India is a poor country with 36% of its population still living below the poverty line. Close to 68% of the population is dependant on agriculture for its subsistence. India also has a fast growing population, expected to overtake China by 2030/31. A larger population places an increasing strain on the natural resources of the country.

India is extremely vulnerable to climate change because of its reliance on the monsoon for irrigation of a majority of its crops and our particular place in the globe with influence of various climatic systems.

The impact of climate change on India's environment, politics, society and the economy merits an independent detailed study. There is a remarkable lack of such a detailed study for such a large and important country.

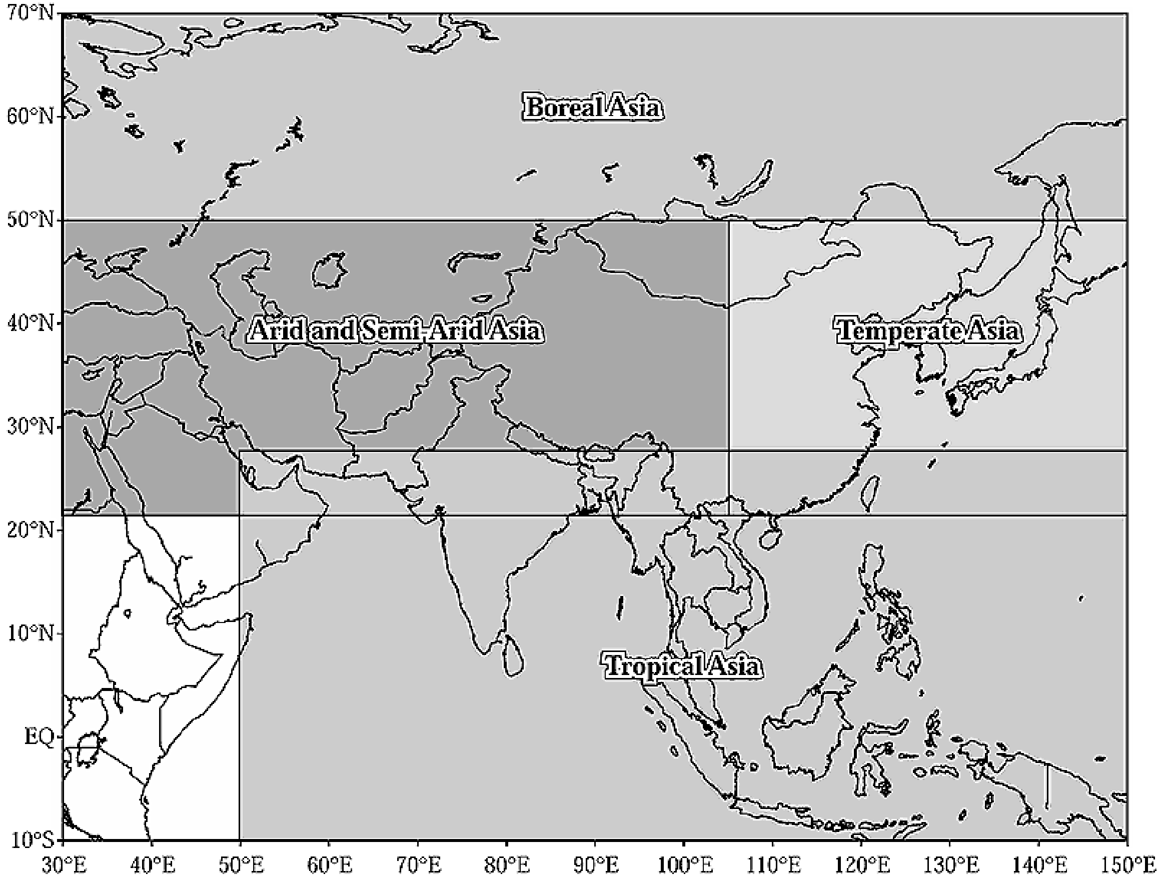

Figure 11: Geographical Domain of Asia and its sub-regions (Source: IPCC TAR, Asia, pg 540 (IPCC 2001))[8]

Though this investigation is well beyond the scope of the present project, in this chapter, I briefly look at the impacts that a moderate range of climate change would have on Indian economy as well as socioeconomic changes. I chose to take the moderate range of climate change since the Inter-governmental Panel on Climate Change (IPCC) report has the greatest confidence at that range. Consequently, it would be appropriate for India to design its policies keeping that range in mind.

[8] *This map does not represent the territory of India accurately, according to the Government of India. The State of Jammu and Kashmir is an integral and indivisible part of India in its entirety, including the Northern regions and Aksai Chin, not shown as parts of Indian Territory in this map.*

4.2 Monsoon cycle and Agricultural output

Within Asia, India has the largest area under cultivation (IPCC 2001). However, in 1997-98, just 38.2% of Indian agricultural land was provided by irrigation facilities (IndiaStat 2007), leaving more than 60% of the Indian irrigation vulnerable to the vagaries of the rains, mostly the monsoon system. India is expected to experience a greater disruption in rainfall patterns, with more droughts and floods (IPCC 2001). As the following map, derived from a simulation by the Hadley Center and presented as part of the report of Working Group on Impacts, Adaptation and Vulnerability of the Third Assessment Report of the IPCC, shows the Indian subcontinent is expected to experience considerable changes in the rainfall. More extreme rainfall events are expected. This shows that there will be an increase in the inter-annual variability of daily precipitation in the summer monsoon over time(IPCC 2001). With the large variation of climates across the country, extreme climates are expected to become more extreme. With an increase in temperature, more glacial melting in the early part of the century would lead to a higher volume of flow in the rivers, followed by major reduction as glaciers disappear (IPCC 2001). There is expected to be an increase in rainfall in the eastern areas while decrease in rainfall in the already arid western regions. Enhanced drainage from soil is expected to lead to higher runoff and consequently, lower soil moisture. Soil moisture is closely related to the agricultural output in un-irrigated areas and hence needs to be understood in context of India's large areas which are still not served by canal irrigation.

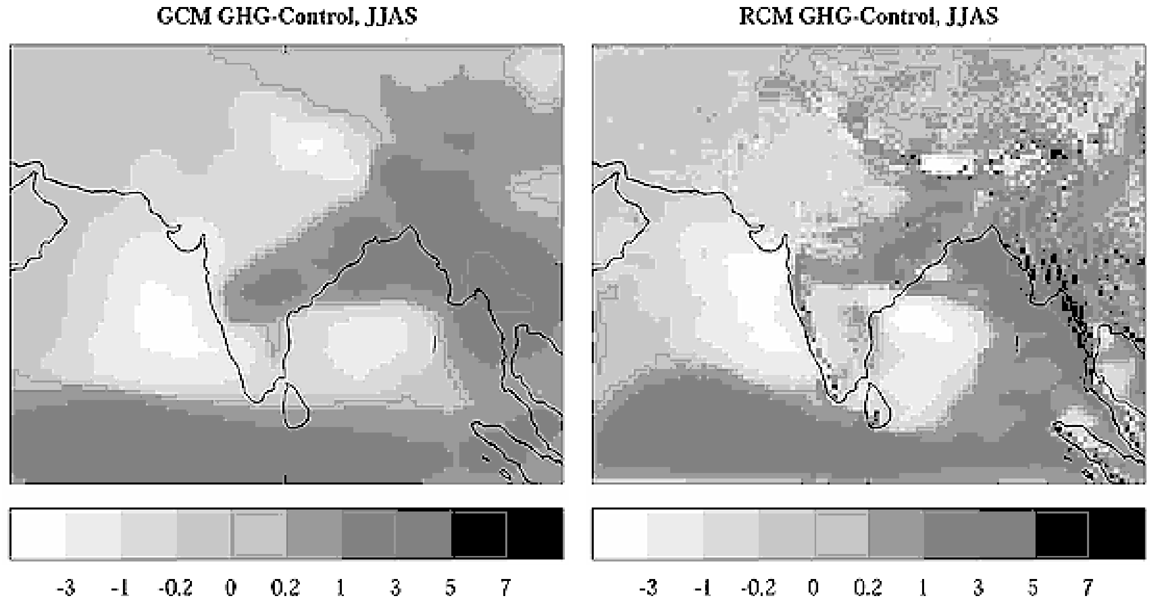

Figure 12: Spatial distribution of changes in monsoon rainfall over Indian subcontinent as simulated by Hadley Centre's global and regional climate models at the time of doubling of CO2 in the atmosphere --- Source: (IPCC 2001)

4.3 Agriculture and politics

Due to higher productivity of fields which have canal irrigation facilities as compared to rain-fed fields, a higher proportion of the population dependent on agriculture subsists on un-irrigated land than on canal-irrigated land. Close to 70% of the agriculture does not have access to irrigation and depends on the monsoon (IndiaStat 2007). This low irrigation manifests itself into lower productivity, reflected much lower per area production of grains as compared to China, which has a smaller area under cultivation but twice the production.

With a large agricultural sector dependant on rain, any disturbances to the monsoon cycle or rains can have catastrophic effects for India and its economy. Any significant impact on Indian agriculture has the potential of having far-reaching social, economic and political effects. Based on personal observations, it was very evident in Indian politics that the will of the farmers takes the strongest precedence and the political clout enjoyed by them is incomparable to any other group. The reasons why this clout does not correlate to development is probably worthy of an independent thesis.

4.4 Agricultural impacts

In this century, the area under cultivation for food in India is expected to go down due to decrease in productivity owing to climate change.

Agricultural impacts are broadly divided into two sectors by most authors (Bhadwal, O'Brien et al. 2003):

- Direct effects from changes in temperature, precipitation, or carbon dioxide concentrations
- Indirect effects due to changes in soils or changes in the incidence of disease or pest infestation

Though a detailed discussion of the impacts of climate change on Indian agriculture is beyond the scope of the present work, it is worthwhile to present condensed figures about the possibility of climate impacts in aggregate.

Early on in this century, models predict an increase in soil moisture in most of India, except for the eastern regions, due with higher rainfall. Over time, there would be a considerable decrease in the soil moisture throughout the country. Correspondingly, this would lead to significant losses in crop production. This might lead to loss of grain sufficiency, which currently stands at 90% (IPCC 2001).

(Nordhaus, Mendelsohn et al. 1994) and (Adams 1999) estimate severe impacts on the Indian monsoon-fed agriculture within the first half of the century. The average soil moisture in India is expected to take a heavy hit due to higher ambient temperatures, leading to lower agricultural productivity.

It is widely accepted that a 2.5°C global warming range will lead to about a 5% drop in agricultural output for India (Nordhaus 2000; Saseendran and al 2000). At a similar scale, wheat yields could decrease upto 28% without considering carbon fertilization effects (Kavikumar 2004). (Saseendran and al 2000) estimate that each one degree rise in temperature will reduce the yield of rice by 6%. With both these crops being the staple grains for India, we see India's frightening vulnerability to climate change.

Such catastrophic decrease in agricultural productivity relates to a 9% average reduction in farm revenues in real terms, by 2025 (Kavikumar 2004). This range of reduction in revenues would increase poverty.

4.5 Agricultural productivity and the society

With close to 70% of the population dependant on agriculture in one way or the other, such significant reductions in output can also mean various unsettling social and economic changes. Though the discussion of these effects is outside the scope of this dissertation, it is important to note that the some of the most long lasting impacts may be social in nature.

(Bhadwal, *et al.* 2003) discuss the extremely low adaptability of the Indian poor towards effects of climate change. The poor not only spend a significant share of their incomes on food, leaving little for anything else, their economic subsistence is most dependent on the vagaries of nature. This means that the poor in India will face the worst consequences from a changing climate. Poverty always leads to greater environmental degradation when the poor are forced to forage for fuel-wood or even food. This environmental degradation further weakens the resilience of the nature to insults, leading to a vicious circle of poverty and environmental degradation of the local area.

Lower productivity in the agricultural sector leads to migration of laborers to urban centers, leading to further poverty and urban overpopulation. This creates greater pressures on the urban infrastructure, stressing the facilities. Concentration of economically disadvantaged people in distressing conditions is ideal for social unrest, a particularly unwanted development in a multi-cultural country with a history of communal strife.

Cities and towns are also not untouched by impacts of climate change. India is one of the most commonly cited examples of intense urban heat island effects in developing countries, due to its peculiar global position as well as tropical climate (Devi 2005). The growth rates in urban areas are close to four times (IPCC 2001) the rate of growth of the population, leading an explosive expansion in the size of the cities. Some of the most intense heat islands are found around Delhi and Mumbai (IPCC 2001). Further growth leads to more energy consumption, more air-conditioners running and more heat concentration in the cities. These heat island effects coupled with rise in temperatures would make living in the cities more difficult. Growth in urban areas leads to further increase in concreted surfaces of streets and homes, leading to an increase in surface rainfall runoff, causing a greater strain on the groundwater resources. This effect, worthy of an independent thesis, is expected to lead major intra-national conflicts, as often already seen. The water resources come under further stress due to over-extraction (Bhadwal, O'Brien et al. 2003) for underground reservoirs and inadequate replenishing from rainfall. Indian cities have faced critical water shortages for the past few decades and further urbanization or a decrease in the water supply can exacerbate this problem. The elections in cities like Delhi already feature water availability as a major issue and with greater surface run-off, this problem is expected to get worse.

There is not much published information about the effect of climate change on cities in India; yet, the direction of changes is invariably negative.

4.6 Water Resources

The preceding analysis talks about losses due to change in rainfall patterns and availability of water. India is expected to have one of the most significant shortfalls in water supply due to climate change (IPCC 2001). Just as much as agriculture, this problem is expected to affect the rural people the most.

4.7 Coastal Resources

Climate change impacts on coastal areas around the world are well documented. India's low lying regions are densely populated and are agriculturally fertile (ADB 1994). Various large states have dependence on coastal resources like fishing etc. Change in sea levels can have catastrophic effects on these regions (Kavikumar 2004). The ADB country study for India (ADB 1994) estimates the effects of a one meter rise in sea level. Close to 7 million people are expected to be displaced while 5,764 km^2 of land would be lost and some 4200 km of roads would be lost.

The impacts of any increase in the frequency and intensity of extreme events, such as ocean surges, could be disproportionately large in terms of the heavily populated coastal areas.

The 1999 tropical cyclone that hit Orissa resulted in deaths of around 10,000 people and this figure demonstrates the extreme significance of impacts related to climate variability. The intensity of such cyclones is expected to increase (Emanuel 2005) due to climate change and India will have to face an increasingly violent hurricane season. The 2005 flooding of the financial capital Mumbai resulted in deaths of close to a 1000 people and economic losses of around Rs. 3000 crore (~$600million), further proving the vulnerability of our coastal regions.

4.8 Forests

India lies mostly in the tropical region, with large forest areas. Moderate climate change will have a major impact on forests in the long term[9] in terms of decrease in productivity as well as greater exploitation from the surrounding communities which are pressed for resources. The eastern forests are expected to lose productivity, leading to social and economic losses (IPCC 2001). These forests have already come under anthropogenic pressure and loss of tree cover leads to runoff, further exacerbating the problem and leading to a reinforcement of the vicious loop of deforestation and runoff. There is not enough published data about the probable effects of climate change in India, yet, the comprehensive models talk about a decline in forests later in the century.

4.9 Biodiversity

The IPCC expects considerable strain on the biodiversity in the South Asian region, comprising of the Indian subcontinent. There is expected to be a considerably change in the feeding habitats for most tropical species, leading to a stress on their ability to survive (IPCC

[9] Some authors discuss the possibility of an increase in forest productivity in the short term due to carbon fertilization effects but there has not been any independent study on India's forests in this regard yet.

2001). As many as 1,256 higher plant species are threatened in India (IPCC 2001). This loss of biodiversity would be a loss to the entire world as this region has a large number of species unique to it.

4.10 Adaptability and Vulnerability

With a considerably large population living below the poverty line and a huge reliance on rain-fed agriculture, India's vulnerability to climate change is high while adaptability is very low. The poor are expected to face the biggest burden of climate change and it is they who have the least capacity to adapt (Bhadwal, O'Brien et al. 2003).

4.11 Conclusion

Due to its location and economic system, India is particularly vulnerable to climate change impacts. These impacts are imminent and will be a major issue for the people to handle in the coming years.

The Indian government will not be able to neglect these negative effects for a very long time. The defense that our emissions played a very small part in the current buildup stands true, as does the fact that India is expected to be one of the biggest sufferers from effects of climate change. Coupled with our low adaptability and high vulnerability, climate change is set to become one of the biggest national issues in the decades to come. It is imperative for India to move quickly and effectively in the short term.

5. Geological Capacity for Sequestration in India

5.1 India and its geology

India is a large granitic and metamorphic massif surrounded by sedimentary basins (MIT 2007). It is divided into three major regions based on distinguished characteristics as shown in Figure 13 (Garg, *et al*. 2006):

- Indo-Gangetic Alluvial Plains
- Peninsula Shield
- Extra-peninsula

These three regions exhibit different physical features and structures.

These important geological provinces are detailed below.

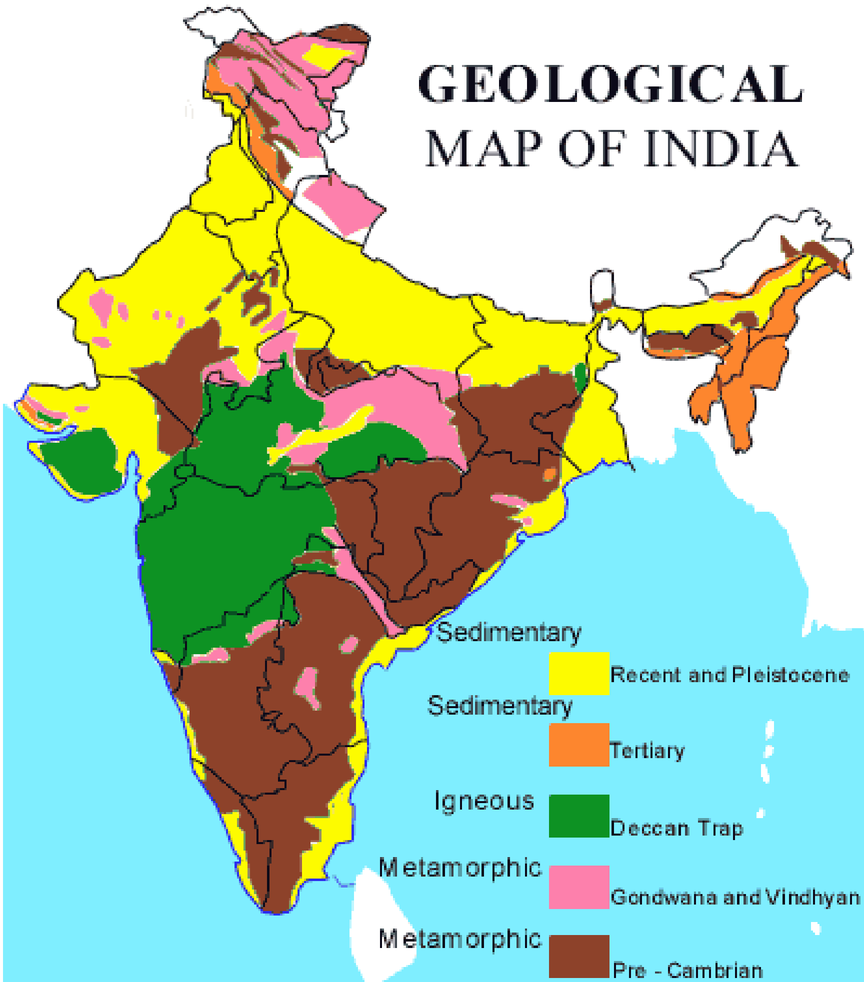

Figure 13: India Geological Provinces with broad classification (IndiaMaps 2007)

5.1.1 Indo-Gangetic Alluvial Plains or the Ganga Basin

The Ganga basin is the largest sedimentary basin in the world, with alluvial depths of thickness of 5000m and beyond (Bhandari, Sarin et al. 2007). This basin lies in China, Nepal, India and Bangladesh, with the largest portion in India. In the north, it is bordered by the Himalayas and the Deccan traps in the south. It is often also considered to be a part of the

Indus-Ganga-Brahmaputra drainage system (Bhandari, Sarin et al. 2007). This basin has 580,000 square kilometers of arable land, which supports close to half a billion people in India. It is drained by several rivers and is one of the most fertile regions of the world.

5.1.2 The Peninsular Shield or the Deccan Traps

The Deccan Traps are exposed in Western India and cover an area of approximately half a million square kilometers. It is one of the largest continental flood basalt volcanic provinces of the world (Garg, Singh et al. 2006; Kumar, Charan et al. 2007) with basalt thickness ranging from a few hundreds to a few thousands of meters. It is broadly divided into the Rajmahal and Deccan regions. It contains flat-lying basalt lava flows varying in thickness of more than 2000m and also contains inter-trappean and infra-trappean sedimentary beds of thickness ranging around 15m. Peninsula shield is composed of geologically ancient rocks of diverse origin (Garg, Singh et al. 2006). Over these ancient rocks lie few areas of pre-Cambrian and later sediments and extensive sheets of horizontally bedded lavas of the Deccan trap formations. Mesozoic and Tertiary sediments are found mainly along the coastal regions (Garg, Singh et al. 2006). The volume of basalt is estimated to be around 512,000 km^3.

5.1.3 Extra-peninsular regions

The regions around those mentioned in the previous two sections are collectively called the extra-peninsular region. This incorporates the northern Himalayan mountains and the eastern lower Himalayas, the Thar desert in the west and the outlying islands. These regions have not been studied extensively due to their low populations and comparatively very few thermal power plants.

5.2 Sequestration Capacity in India

Before any steps are taken to adopt CCS in India at a large scale, it is essential to understand the capacity for sequestration in its territory. There has not yet been a detailed assessment of India's sequestration capacity, although there have been some initial estimates made by Garg, Singh et al (2006). The International Energy Agency and the UK Department for Environment, Food and Rural Affairs have sponsored a project which is underway for detailed estimation of the sequestration capacity in the Indian Subcontinent, which is expected to be completed in Fall 2007. Even though the official Indian position (Shahi 2007) does not emphasize an assessment of the potential of CO2 storage in geological formations in India or even "agree" to cooperate on capacity assessment in the short term, other arms of the Indian government are involved in this project, like the National Geophysical Research Institute and the Central Mining Research Institute.

5.2.1 Current Estimates

Garg *et al.*, (2006) estimate a total sequestration potential of geological formations in India to be 572Gt of carbon dioxide. Of this, 360 Gt would come from onshore and offshore deep saline aquifers, 200 from the Basalt formations in the Deccan and Rajmahal traps. 5Gt and 7Gt capacity are estimated to be in unminable coal seams and depleted oil and gas reservoirs, respectively.

As this is an initial estimation, it is reasonable to expect that after a detailed estimation of capacity, this figure would be changed considerably. However, it would still be considerably high as compared to the current levels of emissions as well as projected emissions in the near future.

At current levels of production of around 1.1 Gt CO_2 a year, that is a considerably large capacity (Raghuvanshi, *et al.* 2006).

5.2.2 Deep Sea Sediment Capacity

According to researchers at the Harvard Kennedy School of Government, the offshore sequestration capacity in deep sea sediments in India's exclusive economic zone is a further 15,600Gt (Bielicki and House 2006). This kind of sequestration is yet to be proven in a real experiment and will take time to develop. If it is implemented, it would probably come at a later stage, when geological sequestration has been successfully adopted onshore and there is considerable need to increase the capacity. Deep sea sediment sequestration is not the focus of this dissertation, and the focus in this dissertation is exclusively on onshore sequestration.

5.2.3 Saline Aquifers

Due to lack of any historical financial interest in their development, deep saline aquifers are not as well studied as other geological formations (Bhandari, Sarin et al. 2007). However, from a CCS point of view, they have the largest potential storage capacity for CO_2. CO_2 can be stored hydrodynamically in the formation waters for tens and thousands of years and longer (Garg, Singh et al. 2006). They have the largest capacity in India also. The Gangetic sedimentary basins of India vary considerably across short distances (Garg, Singh et al. 2006).

This paper gives an estimated capacity of 360Gt of carbon dioxide in these formations across India.

5.2.4 Basalt Sequestration

Home to some of the largest volcanic basalt provinces, India is already exploring options in this kind of geological formations. There is a study being carried out by the (Indian) National Geophysical Research Institute alongside US Batelle Pacific Northwest Laboratory, the National Thermal Power Corporation and the Department of Science and Technology of India (Kumar, Charan et al. 2007) to estimate the feasibility. Garg, *et al.*, (2006) estimate a capacity of around 200Gt of CO_2 in the Deccan and Rajmahal traps.

Thus, it is reasonable to say that, theoretically, there is sequestration capacity in most of India. In the coming years, more and more power plants will be opened which would need sequestration facilities if a carbon restraint policy is undertaken. If there is a strong government policy favoring CCS in the future, the siting of new plants may be influenced by the geological capacity in the vicinity of the proposed sites.

5.3 Siting of coal power plants for CCS

Although there is no specific policy regarding siting of plants taking into account CCS capacity yet, it is expected that most of these new plants would be nearby large consumption centers like cities. As discussed earlier, a considerable share of the rural population (see Chapter 2) still does not have access to power. Where there is access in rural areas, the average per consumption is a fraction of the urban average (McKinsey 2001). A McKinsey Global Institute study shows that close to 4% of the total efficiency loss in the Indian power sector is due to low average consumption as well as transmission and distribution losses are a further 27% (McKinsey 2001). To reduce this loss, new power plants would be located closer to the major load centers. This is also done currently as the following map shows. The circles represent major coal-fired power plants and there are various plants near Delhi, Calcutta and Chennai, three of the four largest Indian metropolitan cities. Mumbai, the largest electricity market in India, has a nearby nuclear power plant and thus does not appear to have many coal plants around it. Despite this fact, with the growing demand of electricity from consumers in these cities, a significant share of the power also comes from plants distant from the cities.

Figure 14 shows the distribution of coal thermal power plants in India. The four metropolitan cities of Mumbai, New Delhi, Chennai and Kolkata have a number of large point sources around them. In the map in fig. 14, it is apparent that even though large coal power plants are spread throughout the country, a large number of these plants lie in the Indo-Gangetic plains. There is a reasonable proximity between a large number of the point sources and the sedimentary basin. As seen above, this basin is also expected to be the largest reservoir. Hence, a significant share of the plants would need retrofits to reduce the emissions. The MIT Coal Study (MIT 2007) discusses the infeasibility of retrofit due to extremely higher costs and correspondingly, it is unforeseeable that India would go in for such retrofits without considerable external aid.

Figure 14: Indian[10] coal power plants, with the size of the circle showing the relative size of the plant.

5.4 Coal deposits in India

India is the world's third largest producer as well as consumer of coal in the world. The coal deposits are mostly found in the eastern part of the country. Some of the power plants in

[10] *This map does not represent the territory of India accurately, according to the Government of India. The State of Jammu and Kashmir is an integral and indivisible part of India in its entirety, including the Northern regions and Aksai Chin, not shown as parts of Indian Territory in this map.*

India are mine-mouth power plants. The map in Figure 155: Coal Deposits in India (IndiaMaps 2007) shows some of the major coal fields in India:

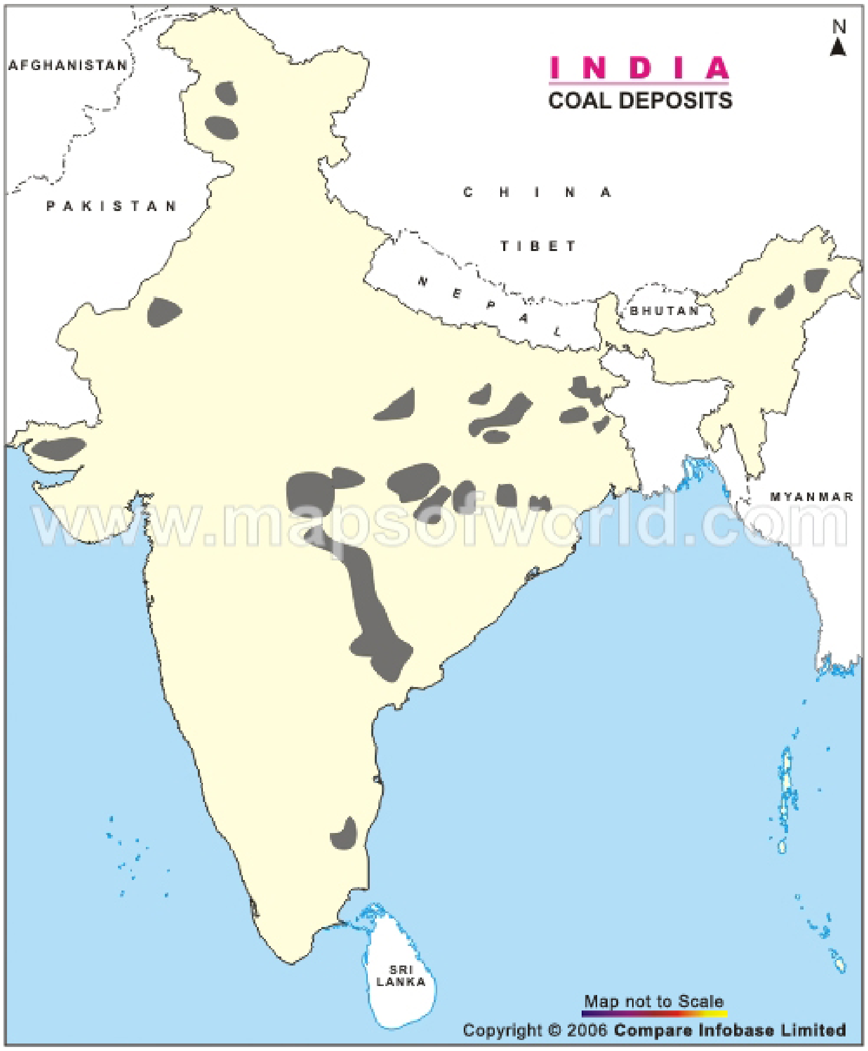

Figure 155: Coal Deposits in India (IndiaMaps 2007)

5.4.1 Unminable coal seams

Nearly 72% of assessed Indian coal resources are within 300m of the surface, another 25% between a depth of 300-600m and the remaining 3% between a depth of 600-1200 m (Garg, Singh et al. 2006). Due to the mostly shallow depths of India's coal reserves, the capacity for sequestration in unminable coal seams is comparatively low, around 5Gt. This estimation is further expected to decrease with greater detailed assessment as Indian coal seams have been extensively punctured and would not be suitable for long term sequestration of carbon dioxide.

5.4.2 Sequestration in depleted oil and gas fields

Due to very small oil and gas reserves in India, the capacity for sequestration in depleted reservoirs is not large. It is estimated to be around 7 Gt.

5.5 Conclusion

Despite considerable uncertainty, Current estimates indicate that India's territory has a large capacity for geological sequestration of carbon dioxide. It will not be constrained by geology or geography if it chooses to adopt CCS.

6. Indian views about CCS

6.1 India's Involvement in climate change mitigation efforts

India has been an active participant in climate change mitigation activities for a long time. It was one of the earliest signatories of the United Nations Framework Convention on Climate Change (UNFCCC). It signed and ratified the Kyoto Protocol on August 26th, 2002, under which as a developing country, it has no obligatory emission reduction commitments. It hosted the 8th Conference of the Parties of the UNFCCC in 2002 (COP 2002). The IPCC is currently headed by a notable Indian, Dr. R.K. Pachauri. India has consistently been one of the top countries with the most number of Clean Development Mechanism (CDM) projects under consideration or accreditation.

India is a founding member of the Asia-Pacific Partnership on Clean Development and Climate along with Australia, China, Japan, Republic of Korea, and the United States. This is a multi-lateral partnership between the governments of these countries to make a framework to "meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction" (APPCDC 2007).

India is also a member of the Carbon Sequestration Leadership Forum and hosted the Fifth CSLF meeting in Delhi in April 2006. Its representatives are key members of the various panels in the CSLF.

India, along with South Korea, is one of the two countries involved in the FutureGen project, contributing $10 million to the project. Even though this amount is not a significant share in the $1 billion costs of the project, the contribution is expected to get India some participation in the technology transfer. The government officials involved in the negotiations (Sonde 2007) expect more to come for India on the training and knowledge exchange side than the technology exchange.

Despite these partnerships in the international arena, it is notable that all Indian input has an underlying current of ensuring that we do not have to face a carbon restraint. In multi-party non-binding talks, Indian representatives pledge their commitment to clean energy but do not commit to any talks on restraints (BBC 2007) and if that becomes inevitable, India drops out officially. The official position is that it "*is outrageous that the US has not accepted any restraints and expects the developing countries to do so*" (BBC 2007; Ghosh 2007; Shahi 2007). It is also notable that some sections of the often-misinformed Indian polity, much like sections in the US (BBC 2007), feel that climate change is a hoax brought upon India by the developed world to stunt our growth. Based on personal interactions with low-level politicians in the state of Rajasthan, it is clear that there is either absolute ignorance of the issue or a feeling of hostility towards "western attitudes to Indian development". Despite the fact that these politicians may not have much of a say or any influence in national agreements, they still represent the popular view and they will likely influence the national debate in case of a reduction commitment.

6.2 India, Climate Change and Development

India has consistently maintained a position that climate change is a severe problem and the world will have to take urgent action to prevent major losses. It has had a long standing policy of involvement in the research and design of policy without taking any obligatory emissions reductions, but a commitment towards clean development. The recurring official Indian stance is that India's developmental needs are more important than our obligations to reduce emissions. Our development is paramount and since most of the current emissions accumulations were not the responsibility of the developing countries, we should not shoulder the burden of reductions. This stance is a recurring theme in various forums and in the views of important policy makers.

Despite its significant vulnerability to significant climate change (see chapter 4), the government is not ready to undertake any changes in policy to reduce emissions which can hamper the possibility of rapid economic development. As seen in an earlier chapter (chapter 2), India's access to energy is very low by international standards. Taking up any kind of a carbon constraint can make it even more difficult for a large share of the population to get a step on the first rung on the developmental ladder.

The government emphasizes on the aspects of human resource development as well as research in its actions on climate change. In discussions with the senior policy makers of relevant areas, it was apparent that the government's initial focus is more on the research and human resource development aspect than actual mitigation or adaptation plans. It is apparent that no binding obligations to reduce emissions would be acceptable to either the political leaders or the people.

It also affirms its faith in clean energy. A complete ministry in the central Government of India, called the Ministry of New and Renewable Energy, is entrusted with developing our clean energy options. According to the website of the ministry, *"..present emphasis is on reduction in cost and increase in efficiency"* of renewable energy systems (MNRE 2007).

According to Mr. R.V. Shahi, Secretary, Ministry of Power, (Shahi 2007) the order of priority for expanding energy options and reducing greenhouse gases in India is:

1. Energy efficiency and demand side management
2. Hydropower
3. Nuclear Power
4. Distributed and Renewable generation
5. Clean Coal

This order of preference seems to be based on a consensus in the policy making elite of India. This priority order also matches the attendant goals of poverty alleviation, energy security as well sustainable development (Parikh 2006). A number of high ranking officials mentioned these four options and their relative importance. According to the statement presented by Mr. Shahi on *India's position on Carbon Capture and Storage Technology in the context of Climate Change* (Shahi 2007), the Ministry of Power has put in steps to harness around 150,000MW of hydropower. Coal is mentioned as the "*mainstay of our power supply*" in the report of the expert panel on Integrated Energy Policy (Parikh 2006).

Various people have also noted a need for foreign direct investment in clean technologies in India and especially, in carbon capture and sequestration activities.

The usual justifications from the Government of India to not invest in major greenhouse gas reduction programs range from India's primacy to development needs to the fact that most of the current increases in CO_2 emissions were not caused by the developing countries.

In the coming years, emissions from a majority of the Indian population, which might be comparable to those from developed countries, would mean a tremendous increase in the global emissions. Such an increase would make it very difficult, if not impossible, for the world to stabilize CO_2 emissions at twice the pre-industrial levels.

Most Indian policy-makers and viewpoints emphasize India's needs for development and the necessity to generate more power for impoverished masses. This development is seen as antithetical to emissions constraints, given the large share of electricity from coal in our energy supply.

Amongst the key policy makers for the Indian policy on energy and climate change would be the Secretary of the Ministry of Environment and Forests (MoEF). Mr. Ghosh, the current Secretary of MoEF, believes that the relative positive returns in climate change mitigation, especially CCS, to India would be overwhelmed by the costs in development and growth that would have to be borne by the already disadvantaged sections of the Indian population (Ghosh 2007; Sethi 2007). This view is shared by a large section of the influential climate change community in the Indian government. This aversion to spending precious Indian resources to fight long term climate change when the returns will be incommensurate is likely to prevail for the foreseeable future. My discussions with the policy-makers bring me to the conclusion that the belief in the higher Indian establishment is that any mitigation costs would have to be borne by the international community, more specifically, the OECD countries.

6.3 Views on Carbon capture and sequestration

The standpoint of key Indian policy makers on CCS is not very different from their views on other carbon mitigation technologies. Moreover, this view is part of the greater policy towards climate change mitigation strategies which would cost significantly. CCS is seen as a very expensive solution to a problem that India did not create.

According to the key representative of the Indian power industry who has been a member of the negotiating team for Indian participation in the FutureGen project, Mr. RR Sonde (Sonde 2007), the penalty imposed by CCS on power supply from plants and hence costs, does not look justified given the returns to India. Given India's geological history, he felt that there will have to be a few demonstration projects before India makes it a part of the official policy. Since India does not have the capacity like the formation in Sleipner at Norway, it would be more difficult for India to be convinced of geological feasibility.

He felt that since most of the decisions are ultimately based on economics, CCS does not look promising by itself in the near future. However, new technologies that make it cheaper would be more helpful in getting it adopted quickly. Also, given low resources in oil, enhanced oil recovery (EOR), can not be a bridge for ultimate adoption in India.

Other senior civil servants also felt that the way to reduce Indian emissions would be led by efficiency and better technology paths, rather than CCS (Ghosh 2007). The expectation is that the near term steps would be restricted to efficiency and biomass while nuclear and CCS would be brought in at later stages.

6.4 Technology and climate change mitigation efforts

Given the reliance on coal and the need for rapid capacity expansion, the emphasis is on technology duplication and replication instead of innovation. Harvard Kennedy School of Government researchers focusing on coal power in India (Chikkatur and Sagar 2006) discuss the institutional and technology lock-in and the need to increase indigenous capacity in the coal power sector. Even though there is enough awareness about the need to move towards more efficient generation facilities, constraints of available technology, resources and know-how do not allow implementation of cleaner technologies. Even if the lack of financial resources can be overcome through international loans etc, the factors of human resources and technology can not be overcome in the short term. This kind of capacity building will require sustained efforts, starting soon. These efforts can come around in the way of collaboration in technology development as well as transfer. Mr. R.R. Sonde, the Executive Director (Energy Technologies), NTPC (Sonde 2007), believes that our expectation from the investment in this project is of technology collaboration as well as research on Indian coals for usability in such plants. Many senior officials, including Mr. Ghosh (2007) and Mr. Sonde (2007) talked about the need for research to be conducted on appropriate technologies for Indian coal. Indian coal, with its rather singular properties, has not been extensively tested. Due to the lack of relevant expertise in India (Sonde 2007), a major barrier to adoption of better technologies can be overcome by research on Indian coal and its adaptation to the new technologies. Secretary Ghosh (2007) commented on the similarity in the issue of intellectual property rights between HIV/AIDS and climate change. In both these issues, the patents are held by western countries while the most affected live in the developing world. Just like the HIV/AIDS issue, where patent regime was relaxed or not exercised as strongly in Africa, he believes that technologies to counter harmful CO_2 emissions should be made available right now to developing countries to prevent major technological lock ins. For CCS as well, a similar approach is advocated, with transfer of technology to India in the near term (Shahi 2007).

6.5 CDM and CCS in India

The Kyoto Protocol's Clean Development Mechanism (CDM) was designed to reduce the costs of emissions reductions by allowing non-Annex I (developing) countries to undertake sustainable development projects that reduce emissions, the credits from which can then be used by the Annex I countries to meet their emissions reductions targets.

India has had a strong presence in CDM and there is considerable institutional capacity to support CDM projects. There are a large number of new projects which are considering to apply for the CDM credits by using clean energy. In my own experience working on CDM in states of India during an internship at The Energy and Resources Institute (TERI) in Delhi, there is growing awareness in the investor and promoter community regarding the potential of CDM as a revenue stream. In my personal experience, outside the climate community in India, CDM is the most closely related term to climate change. If CCS can be linked to CDM, then it might lead to a faster adoption of the technology in India.

However, there are various hurdles. There is still no widely accepted methodology for CCS projects which is approved by the CDM Executive Board, though one is expected by the end of 2007 (Shackley 2007). With the inherently bureaucratic and tedious process associated with the adoption of new methodologies, it is difficult to foresee such a process being speeded up.

The official government position, as stated by Secretary Ghosh (Ghosh 2007), opposes adoption of CCS into the CDM fold. According the Ghosh, social development being one of the four pillars of CDM projects in developing countries, it is difficult to justify just another power plant as a CDM project. India would not support CCS being considered for CDM projects.

Furthermore, with the importance that the GoI and MoEF attaches to CDM (Ghosh 2007), this position is difficult to change. The other, unmentioned, reason for this opposition could be regarding the possibility of flooding of the CDM market with CCS credits, due to the much larger size of CCS projects as compared to most other CDM projects.

Hence, a concerted effort that removes the doubts about linking CCS with CDM is necessary before India allows for the adoption of CCS in the CDM umbrella.

6.6 Global Climate Change and International Cooperation

Global Climate Change policy, due to its inherent dependence on various countries, economic sectors and its effect on large populations, will have to face a string of problems of immense Commons, free riders and enforcement. Any global carbon constraint policy applicable universally is likely to pit the developed countries versus the developing countries in a political and economic battle. The issues of equity and efficiency will persist, with the developing countries counting on their need for growth and the developed countries reliant on their new technologies to bargain for more favorable emissions allowances. This kind of a battle will make it extremely difficult to get cooperative solutions which are acceptable to all the major stakeholders.

In an elegant and comprehensive game-theoretical treatment of the problem of emissions allowance distribution between developed and developing countries using a two-stage, two-player, non-cooperative, complete information game, Shah (Shah 2004) treats the world as made up of two distinct regions, North and South, corresponding to the developed and developing countries, respectively. The two stages correspond to the short term and long term. The paper mathematically proves that under any global carbon constraint policy, unless there are significant foreign investments in clean energy in developing countries in the short term, there will be no incentive for either the developed or the developing world to invest in clean energy in the future due to the lock-ins in technology as well as manpower. The profits of the group that takes the carbon policy would be considerably reduced due to the non-cooperative nature of the game. He concludes that to break the chicken and egg problem of emissions lock in due to underinvestment followed by further capacity addition, there have to be adequate incentives from the developed world in the short term.

India's leading climate modeler, Prof. P.R. Shukla of the Indian Institute of Management, Ahmedabad, argues for a growth strategy that goes hand in hand with the stabilization targets (Shukla 2006). He talks of significant changes in the global and Indian domestic economic system that allows for growth along side climate constraint policies. This paper talks about the inevitability of long term lock-in of emissions from large power plants unless a strong carbon emissions policy is put in now. Inevitably, this kind of a proposed policy would run into severe political and social opposition due to its high costs and relatively minor returns in the near term. There are various low-hanging-fruit policy options that India can take up to reduce its carbon footprint, most of which rely on increasing efficiency of its generation and distribution systems.

This kind of analyses is not yet used by the Indian representatives in dialogues and meetings pertaining to climate efforts. However, the argument is almost always about India's low per capita emissions as compared to the developed world.

This conundrum of development versus climate action can only be broken by committed action from all the stakeholders.

6.7 Conclusion

Given the above analysis, prospects for adoption of carbon capture and storage technologies in India look bleak in the near future. However, there are various steps that the international climate community can take to remove these deadlocks and prevent carbon lock-in in India. I discuss some of these possible ways in brief in the next chapter.

7. Conclusions and Recommendations

7.1 The Challenges

From the earlier chapters, it is evident that there are many hurdles for deploying carbon capture and storage technologies in India. The most significant problems are:

1. **High cost of CCS –** One of the most important objections of the Indian government officials to suggestions of implementation of CCS in India were the factor of high costs (Ghosh 2007; Sonde 2007). Most officials objected to the high costs both in terms of loss of power and high capital costs that India will have to face to implement CCS.
2. **Technology customization and adoption –** There is widespread belief (Sonde 2007) that the IGCC and CCS technologies have not been extensively tested and customized for Indian conditions. Even worldwide, there are only a small set of projects that have been functioning for a long time, which is often cited as a reason for the perceived unreliability of this technology. Since India has not been involved with any of the current projects, the understanding of the technology and its adaptation in India is low.
3. **Government Opposition and Apathy –** There is considerable opposition from the government due to the above reasons as well as economic reasons stemming from

the belief that since the current accumulation of greenhouse gases is not of India's doing, and so it should not have to bear the costs of emissions reductions.

4. **Lack of cooperation –**There is still a lack of understanding about the technology at various levels in the Indian government. Proper cooperation can lead to solving this problem, as discussed later. The Carbon Sequestration Leadership Forum (CSLF) includes India but the capacity building contact is currently limited to the central environment and science and technology ministries. The cooperation would have to reach the organizations putting up the plants as well as the relevant state governments.

The problems of government opposition due to high costs and lack of incentives for the utilities will need to be solved for any forward movement in this direction. These problems straddle various spheres of government and international relations. Commensurate with the current environment, the solutions to these problems can be worked out not by the independent silos of different bodies of the Indian government or the international community but across all of these, together.

Recommendations

Given the hurdles and problems enumerated above, cooperative effort by various parties will have to be undertaken if India's emissions from thermal power plants are effectively reduced through he adoption of capture and storage. In the following analysis, I have delineated the following recommendations according to the intended audience and different stakeholders. It is worthwhile to demarcate the recommendations on the basis of different time frames as considerable preparation would be required before large scale adoption can happen.

7.2 Short Term Recommendations

The entire world has an interest in curbing Indian emissions without harming its economic growth. The efforts to reduce greenhouse gas emissions are spearheaded by bodies like the Intergovernmental Panel on Climate Change (IPCC) and the Carbon Sequestration Leadership Forum (CSLF). These bodies have the authority and mandate to influence and guide the international efforts to reduce climate change and promote CCS. Some ground-work would need to be done by these bodies as well as the government of India so that the systems and capacity is in place before the adoption occurs.

Recommendations for the International community

Following are some recommendations for the multilateral agencies to kick-start the process of adoption of CCS in India:

1. **Cooperative R&D** on Indian coal – A common refrain from various stakeholders representing the relevant bodies of the Indian government is about the lack of adequate research on Indian coal. Accepting the lack of viable research in India, most officials (Ghosh 2007; Sonde 2007) recommend cooperative research and development on Indian coal for IGCC and CCS. Indian coal, as discussed in chapter 2 earlier on, has rather low sulphur but very high mineral ash, making it unsuitable for some combustors

and gasifiers. Optimization of the new technologies for Indian coal will be a good starting point. This improvement should not be limited to just the coal sector, but also the power sector.

2. **Technology Transfer –** The technologies involved in long term carbon capture and storage have not been researched in India. With its extremely small reserves of petroleum, enhanced oil recovery with CO_2 has not been used. The technological capability to undertake CCS at a large scale is missing and will have to be brought in from the countries which already have proven projects. This technology transfer will need to be on economically favorable terms. One senior official (Ghosh 2007) suggested an intellectual property rights regime similar to that now being exercised for HIV/AIDS retroviral (ARV) therapy in the Africa, where the Western companies have agreed to not exercise their patent rights to enable availability of drugs to a large number of people. Some drug patents have also been bought out by the states for the same purpose. A similar regime might be considered seeing the global nature of the problem and urgency that needs to be shown to implement effective remedies. Despite the lack of a completely analogous nature in the comparison between ARV therapy and power systems since ARV drugs cost higher in research but lower marginally, while power systems have higher per equipment cost, the principle of a patent regime that aims to face an international challenge cooperatively still applies.

3. **Increased cooperative training of Indian personnel to build capacity –** Just as important as the technologies is the build-up of human capacity. For an effective and rapid deployment of the technologies in India, the necessary manpower, at all levels, needs to be trained. There are some mechanisms for cooperation in the Science and

Technology fields between the US, like the Indo-US Science and Technology Forum, which enable joint research. However, seeing the gravity of this issue, an independent organization needs to be set up which allows exchange of science and technology personnel. The Indian government expects this kind of an exchange to be an outcome of its participation in the FutureGen project but it needs to be systematic and planned.

4. **Higher interaction** with the Indian coal power system – Apart from research on the coal quality, the entire system of the power plants and thermal generation will need to be optimized to get the most power with the least emissions. This issue is relatively politically explosive with huge financial and labour interests involved, but still merits attention. The labour of the coal sector is a considerably large political power and in case these reforms lead to job losses, these unions may not allow for quick reforms. Adding on the requirement or mandate for CCS in an otherwise inefficient system will not get any significant returns but only marginal ones. Research on optimization of the entire supply chain and the plants should be undertaken to make the sector more effective and ready to adopt CCS.

For the Indian Government

1. **Create a legislative mandate to allow carbon capture in the future –** Accepting the fact that India will have to adopt carbon restrictions in the near or distant future, as part of obligations to a multilateral agreement or under international duress, India should start to create a legislative mandate that facilitates this move. There have already been executive moves to reduce the impact, like the National CDM Authority at the MoEF but none at the legislative front. Given the relatively slow pace of legislation in India, it

advisable that there is a move towards creating a publicly acceptable and transparent legislation aimed towards guiding and regulating CCS. It is foreseeable that the mandate for CCS would come under a broader act that aims to limit India's GHG emissions.

2. **Delineation of a regulatory authority –** Given the different spheres of activity that will be affected by CCS adoption, it is advisable that an independent and responsible central authority be installed that would have all relevant powers to regulate CCS enabled thermal power plant. This agency should not create an additional level of government bureaucracy but be the "one-window" approval body that handles all aspects of CCS in India. The proposed agency should also be responsible for liaison with international agencies and research centers.

3. **Embed engineers and designers –** It is advisable to embed scientists and engineers in the ongoing CCS projects around the world to create a body of trained engineers and scientists who can be called upon to implement India's CCS. This would provide the trained manpower that can be called upon at short notice to implement a large scale CCS system. Participation in projects like FutureGen and forums like the CSLF should be leveraged to get Indian scientists as observers or partners in the upcoming projects.

4. **Storage capacity assessment –** It is important to get a quick and accurate storage capacity at the local-level to get a perspective about the absolute capacity for carbon in the long term. The IEA GHG program is currently involved in this and a cooperative program between the GoI and the IEA can get cheap and quick results. The capacity

mentioned in this dissertation is a first order estimation. Even though this would go against the grain of the policy stated by Secretary Shahi of the Ministry of Power (Shahi 2007), this assessment is critical before any long reaching policy is designed.

7.3 Medium and Long Term Recommendations

International Community

1. **More demonstration projects** in the developed countries **–** One drawback of the quest to promote CCS in developing countries is the lack of any significant number of carbon storage projects at a large scale in developed countries. A large number of projects that have been reliably functioning with sustained monitoring and without leakage events for a considerable period of time are absolutely necessary for countries to come forward to accept this technology. Before India and other developing countries take up something so risky, there is an expectation that the developed countries adopt this in their own land beforehand. There is an underlying fear in the Indian public about being treated as guinea-pigs in global experiments. Such concerns are further reinforced by the brouhaha over the drug trials being run by some multinational drug companies in India. This issue can cause a public relations debacle if India moves forward to adopt such an expensive and 'unproved' technology without it being adequately tested elsewhere. Hence, the OECD countries need to implement a few CCS projects in a short time frame as proof of technology.

For the Indian Government

1. **Provide corresponding guarantees on IP Rights** - The Indian government should provide guarantees to those governments and companies that provide technology that their patents will not be undermined by Indian companies but will be used only to reduce India's carbon footprint. This kind of a reciprocal guarantee is essential to induce any company to part with its proprietary technologies that may be essential to the process.
2. **Create a more streamlined permitting process** than the current CDM process – The current process to approve CDM projects to be sent to the Executive Board in Cologne, Germany, is long drawn out and expensive for project promoters to undertake. Therefore, the proposed authority should be less bureaucratic and efficient.

7.4 Financial recommendations and incentives

It is well understood and accepted that CCS is a relatively expensive technology for a developing country like India. The energy penalty is unacceptably large with a country for such significant shortfalls in the supply to meet the demand, as seen in the second chapter. Given the relatively small per capita emissions of developing countries in the past and even in the years to come, it is not reasonable to expect them to restrain emissions at the cost of development. For the sake of reducing global emissions, the new capacity being built in these developing countries should be adaptable to capture and this can happen only with the correct incentives in the short term.

Even though the discussion about the correct financial incentives can be enough material to merit an independent dissertation on the topic, I attempt to tackle the question at an elementary level.

1. **Compensation Mechanisms -** Mechanisms to **compensate India** for the additional costs of CCS and/or IGCC –Any recommendations for India to mandate CCS to accompany new power plants is incomplete without a recommendation to pay for the additional costs. All developing countries would have to be compensated for the additional capital as well as production costs due to adoption of CCS.

   It is easy to mistake this compensation for a transfer payment from the developed countries to the developing countries. This compensation should instead be seen as a cost effective and cheap way to reduce greenhouse gases. To prevent a public backlash in the OECD countries against this payment to countries which are increasingly being seen as looming threats, these compensations may be packaged as long term loans to a facility like the Marshall Plan for Europe—an idea that was brought forward by the former US Vice President, Al Gore in his testimony to the US Senate Committee on Public Works and the Environment (2007). The Marshall Plan was brought as a developmental plan to help the European countries get back in the economic system and to prevent further wars in Europe. Similarly, given the rising military and economic power of some developing countries like India and China as well as their increasing emissions, these loans to promote CCS should be seen as a new Marshall Plan in which the OECD countries stand to gain from also. In the distant future, when Indian incomes are equal to those in the developed countries, it could then help other developing countries in the same way, making it a kind of a rolling fund. The initial inertia of the system can be overcome by IPCC or the CSLF or the World Bank's Global Environmental Facility, which already supports environmental projects on a smaller scale.

CDM process for compensation

It is notable that the government of India would not be ready to accept this compensation under the rubric of the CDM. CDM is now widely understood in the Indian climate change community and India has a strong presence in the CDM market. Secretary Ghosh (2007) believes that given the developmental focus of CDM, it is hard to justify a plant with CCS as aiding development directly. According to him, the pillars of CDM of sustainability, development, social suitability and local adaptability should not be tinkered with.

This view is understandable given India's stakes in the continuation of the CDM process. Large CCS projects can overwhelm the market and small projects that the government has continually supported in the recent years. In my own experience at TERI, the MoEF puts in a lot of effort to supplement and strengthen the CDM process in the states of India with a view to expand the range of projects that can be provided revenue through CDM. Hence, it is apparent that an independent mechanism will be needed to compensate India for the costs of CCS.

2. **Adoption of risks** of the new technology for Indian projects by the international community – Given the doubts attached to the viability of the technology amongst the senior decision makers of the government of India and other countries, one innovative solution could be to assume the risks of the implementation of CCS. This adoption of

the risk would come in the form of an indemnity that allows India to move forward. In case of any untoward incident, the compensation could be made from a fund proposed above.

7.5 Conclusion

The analysis in this dissertation does not paint a very exciting picture of the possibility of adoption of CCS in India in the near future. The road to significant reductions from a large number plants or a mandate to implement CCS in all new plants is long and arduous. Due to the perception of extremely high costs of adoption of CCS, the efforts will need cooperation of various countries, companies and multi-lateral organizations. It is unforeseeable to have many Indian CCS plants in the short term but in the long term, this can be achieved if we start taking the right steps now. Many bodies will have to alter their present positions and be more flexible in looking for a mutually acceptable solution. India would have to start designing a responsible and efficient regulatory authority while the international community would urgently need to find a mutually acceptable way to pay for the incremental costs of CCS.

Like all other aspects of the problem of climate change, the road is hard and challenging, but the goal is worthy enough to merit our best attempts. The solutions will need cooperative action across nations, states, blocs and groups and yet the human race will need to overcome a lack of trust to work together to leave a sustainable world, better than we found it from ancestors. Mitigating climate change is the challenge of our times and we as a species have to come together to face it and come out ever stronger.

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Appendix A

List of Interviews conducted during India Trip

Date	Interviewee	Designation	Organization	Venue
3rd Jan 2007	**Dr. Prodipto Ghosh**	Secretary	Ministry of Environment and Forests, Government of India	Paryavaran Bhawan, CGO Complex, New Delhi
3rd Jan 2007	**Mr. R.K. Sethi**	Director, Climate Change, and Head, National CDM Authority	Ministry of Environment and Forests, Government of India	Paryavaran Bhawan, CGO Complex, New Delhi
4th Jan 2007	**Dr. P.K. Dadhich**	Area Convenor	The Energy and Resources Institute (TERI)	India Habitat Center, New Delhi
11th Jan, 2007	**Dr. R.R. Sonde**	Executive Director (Technology)	National Thermal Power Corporation (NTPC)	Hyderabad
11th Jan, 2007	**Dr. Balesh Kumar**	Deputy Director (retired) and Advisor, CCS	National Geophysical Research Institute (NGRI)	NGRI, Hyderabad
11th Jan, 2007	**Dr. Malti Goel**	Scientist 'G' and Adviser, STAC	Department of Science and Technology, Ministry of Science and Technology, Govt. of India	NGRI, Hyderabad
11th Jan, 2007	**Mr. R.V. Shahi**	Secretary (then)	Ministry of Power, Government of India	NGRI, Hyderabad

Appendix B

List of Acronyms

ADB	Asian Development Bank
ARV	Anti-retroviral
CCS	Carbon Capture and Storage (or Sequestration)
CDM	Clean Development Mechanism
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CMPDIL	Central Mine Planning and Design Institute Limited
CPCB	Central Pollution Control Board
CSE	Center for Science and the Environment
CSLF	Carbon Sequestration Leadership Forum
EIA	Energy Information Administration
EJ	Exajoule (10^18 Joules)
EOR	Enhanced Oil Recovery
ESP	Electrostatic Precipitators
GDP	Gross Domestic Product
GHG	Greenhouse Gas(es)
GIS	Geo-Informatics Systems
GJ	Gigajoule (10^9 Joules)
GoI	Government of India
Gt	Gigaton (10^9 tons)
GW	Gigawatt (10^9 Joules)
HIV/AIDS	Human Immune Virus/ Acquired Immunodeficiency Syndrome
IAS	Indian Administrative Service
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hour
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment and Forests
NOX	Nitrogen Oxides
NTPC	National Thermal Power Corporation
OECD	Organization for Economic Cooperation and Development
PCB	Pollution Control Board
PLF	Plant Load Factor
SEB	State Electricity Board(s)
SOX	Sulphur Oxides
TAR	IPCC Third Assessment Report
TERI	The Energy and Resources Institute (formerly Tata Energy Research Institute)
TFP	Total Factor Productivity
UNFCCC	United Nations Framework Convention on Climate Change
WEC	World Energy Council