Chapter 11

The Role of Technology in Mitigating Greenhouse Gas Emissions from Power Sector in Developing Countries: the Case of China, India, and Mexico

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Abstract

China, India, and Mexico are the top emitters of CO_2 among developing nations. The electric power sectors in China and India is dominated by coal-fired power plants, whereas in Mexico, fuel oil and natural gas are the key fossil fuels. Spurred by economic development and population growth, demand for electricity in these countries is expected to continue to rise. How this increased demand is met will have a significant impact on emissions of greenhouse gases. While available portfolio of generation and mitigation technologies may not suffice to arrest the growth of emissions, it can help reduce the rate of growth of emissions. To achieve significant reductions, multi-prong approaches are required, such as reduction in demand by adopting end-use efficiency improvement measures, accelerated deployment of renewable and nuclear power, and adoption of cleaner more efficient generation technologies. Retrofitting the existing fleet to meet strengthened environmental standards, and accelerated fleet-turnover, coupled with adop-

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tion of state-of-the-art high efficiency generation technologies, such as supercritical and ultra-supercritical boilers and advanced combined-cycle gas turbines should play an important role in meeting the increasing demand while emitting the least amount of GHG emissions. In parallel, significant R&D efforts will have to be undertaken to adapt off-the-shelf generation technologies to suit local needs. Moreover, in the medium to long term, developed countries will need to provide financial and technical support for these countries and partner with them to develop, design, demonstrate, and deploy end-of-pipe controls for capturing carbon dioxide, and its sequestration.

Introduction

The executive director of the International Energy Agency (IEA), Nobuo Tanaka, underlined the significance of the "huge energy challenges" facing the rapidly growing economies, particularly those of India and China. Given the strengthening science behind the human influence on climate change (IPCC, 2007), he also pointed towards the need to develop a global response to meet this challenge and find ways to mitigate greenhouse gas (GHG) emissions from these growing economies. Within developing nations, China, India and Mexico were among the top emitters of carbon dioxide (CO_2) in 2005 (Marland, Boden et al., 2007). While China and India's power sectors are dominated by coal-fired power generation, in contrast, the Mexican electricity sector relies heavily on fuel oil and natural gas.

In this context, it is instructive to look at GHG emissions within the IPAT[3] framework, where **I**mpact is GHG emissions, **P** is total population, and **A**ffluence is gross domestic product per capita. **T**echnology signifies carbon emission intensity (emissions per dollar of gross domestic product). Economic growth, which broadly increases per-capita consumption, is essential to improve the quality of life. Hence, the key factors by which emissions can be reduced are population growth and the emission intensity of the economy. In this chapter, we focus on the role of power generation technologies in three developing countries—China, India, and Mexico—for managing their GHG emissions. Emissions from power generation play a key role in GHG emissions from these economies.

As a modern energy carrier, electricity is a critical component of energy supply in any country. Thus, the availability of, and access to electricity, is an important element in the effort to increase standard of living. Hence, we present the current status of the power generation sector, prospectus of growth, and its implications for GHG emissions in the three developing nations. These three countries signify a challenge for the whole world, for the way in which they meet

3 The terms in IPAT identity or equation, originally coined by Ehrlich and Holdren (1971), stand for Impact = Population x Affluence x Technology.

their energy challenges will have long-term ramifications for the health of the entire planet. The economies of China and India are particularly challenging, as both heavily rely on coal-fired generation. How the portfolio of generation technologies in these two countries changes over time will play a significant role in their contribution to the global emissions of GHGs. Mexican power sector has undergone significant structural shift in the recent past, which has reduced its GHG emission intensity from the power sector, but total emissions have continued to grow due to increased total energy consumption. Further, energy security concerns have dictated that coal, a carbon-intensive fuel, be considered an important part of the fuel-mix in Mexico.

In spite of significant growth in the generation capacity in these developing countries in the recent past, their per capita electricity consumption is still very low compared to that of developed economies and the world average electricity consumption (Figure 11.1). Per capita electricity consumption in India is less than one-fifth of the global average, and about one-sixteenth of that of members of organization of economic cooperation and development (OECD) countries. Per capita electricity consumption in China and Mexico are similar, and are less than one-fourth of that of OECD countries (IEA, 2008a).To sustain the economic growth and to continue to improve the quality of life of its people, the developing countries would have to undertake massive efforts to add significant amount of generation capacity in the medium to long term.

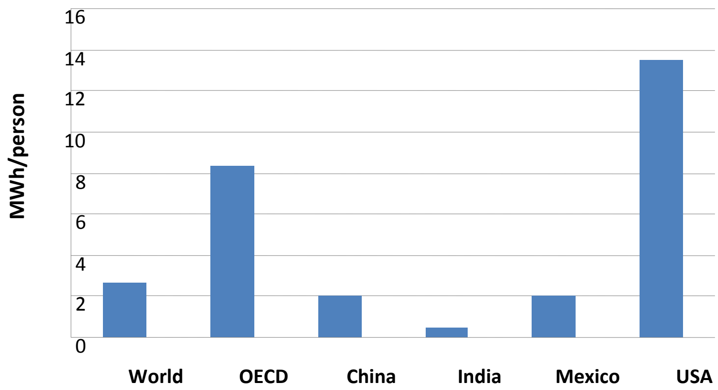

Figure 11.1 Per capita electricity consumption (MWh/person) (2006), Source: IEA, 2008a

While there are some common elements among the three countries, we the structure of the power sector and socio-economic drivers of demand for electricity are very different in these economies. For example, electrification rate in China (~99%) and Mexico (~95%) is very high, whereas it is very low in India (~62%).

Greenhouse Gas Emissions and the Role of Power Sector

In 2006, the total global emissions of GHGs from the combustion of fossil fuel were 28 billion tonnes. U.S. was the single largest emitter of GHG emissions, and contributed slightly over one-fifth of the total global emissions, closely followed by China (20%). India and Mexico contributed 4.5% and 1.5% respectively (IEA, 2008a). Emissions of CO_2 from fossil fuel combustion, cement manufacturing and gas flaring from US appeared to be growing at a slower rate than that of China in 2005. GHG emissions show a sharp rise for China, a steady increase for India, and slow rate of growth for Mexico (Figure 11.2). Some recent studies suggest that GHG emissions from China surpassed that of the US in 2006, and China is now the largest emitting nation (Gregg et al., 2008). Largest share of GHG emissions in China comes from the combustion of coal (Figure 11.3).

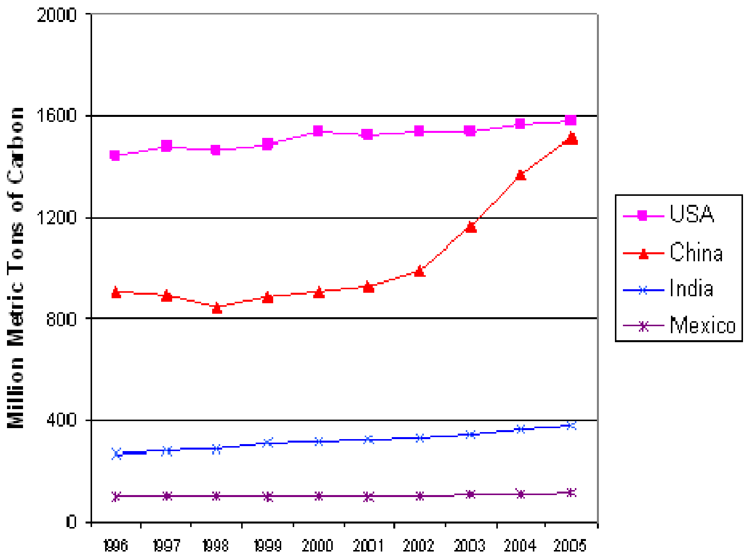

Figure 11.2 National CO_2 emissions from fossil fuel burning, cement manufacture, and gas flaring (1996-2005), Marland et al., 2007

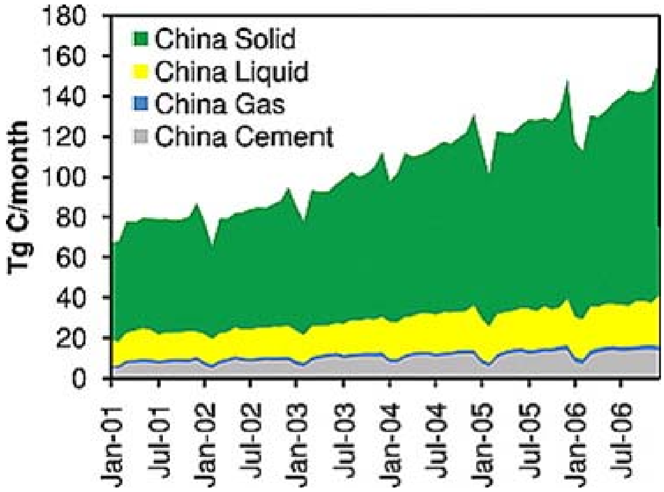

Figure 11.3 Anthropogenic sources of CO_2 emissions in China, Source: Gregg et al., 2008

According to IEA's reference case scenario—which provides a baseline picture of how global energy markets would evolve if governments make no changes to their existing policies and measures—the global primary energy needs are projected to grow by 55% between 2005 and 2030, and China and India alone are expected to account for 45% of this increase (IEA, 2008). Majority of this increase in primary energy demand comes from economic and population growth. A large share of this increase in primary energy demand will be met by increasing the production and consumption of coal for power generation – particularly in China and India. The power sectors are the main consumers of coal in China and India, and are the largest sectors responsible for GHG emissions within respective countries. Electric power generation in Mexico contributed to 31% of the total GHG emissions in Mexico in 2004 (SEMARNAT, 2007). In Mexico the current share of coal in the electricity generation is relatively small. However, in order to diversify its energy supply portfolio and reduce dependence on oil and natural gas, Mexico is also striving to make additions to its coal-fired generation capacity which could further increase its GHG emissions from power generation sector.

In addition to their contribution to global climate change, coal-based power plants also significantly impact the local environment. Direct impacts resulting from construction and ongoing operations include (Chikkatur, 2008):

- flue gas emissions – particulates, sulfur oxides, nitrous oxides, and other hazardous chemicals;
- pollution of local streams, rivers and groundwater from effluent discharges and percolation of hazardous materials from the stored flyash;
- degradation of land used for storing flyash; and

- noise pollution during operation.

Indirect impacts of these plants result mainly from coal mining and include: degradation and destruction of land, water, forests and habitats; and displacement, rehabilitation and resettlement of people affected by mining operations.

Hence, while reducing GHG emissions from these countries is important, it is also critical that the countries reduce the local environmental impacts of their power sectors.

Power Sector in China

The power sector in China has witnessed a phenomenal growth in recent years, led by increased demand in the industrial and household sectors. The demand growth in the power sector is fueled primarily by the very high rate of sustained economic growth—the gross domestic product of China increased at an average of 9.8% per annum since 1980. A significant share of its GDP comes from the industrial sector (~49% in 2006), which relies heavily on availability of electricity for manufacturing and other activities. Furthermore, increases in per capita income and standard of living have resulted in high electricity demand from the residential sector, especially as electricity-based consumer goods and services have rapidly penetrated the domestic Chinese market (IEA, 2007).

In order to meet the steep growth in the demand for electricity, installed generation capacity in China has recently risen at an unprecedented pace. The electricity sector in China has also gone through reforms that have made significant structural changes; these changes have enabled the sector to meet the challenge posed by rapidly growing demand.

Structure of the Power Sector in China

With 713 GWe of installed generation capacity in 2007, China has the second largest electricity market in the world—a market that is now open to participation by private, local and foreign entities (Zhao, 2008; Zhenhua, 2005). The reform process in the Chinese electricity market began in the mid-1980s when non-central governmental entities were allowed to invest in generation. The process of reform was significantly advanced in 2002, when the State Power Corporation (SPC) was split into two transmission and nine-generation companies. Further, private investments by local and foreign players have been increasing under the watchful eye of the State Electricity Regulatory Commission. Central government has been actively seeking the involvement of private and state-owned entities to introduce the elements of market-based incentives to improve system efficiency and obtain needed capital investment to meet the projected growth in power generation sector (Xu and Chen, 2006).

Generation capacity in China is dominated by coal-fired plants, followed by hydropower. The Three Gorges project is the world's largest hydropower project. As such China is the largest producer of renewable energy in the world, despite the fact that solar and wind power have a relatively small share of installed generation capacity. Coal is expected to remain the key source of primary energy for electricity sector in the near future.

Demand and Supply of Electricity in China

The demand for electricity has been growing rapidly in this decade. Electricity generation in China was 2544 TWh in 2005, with an installed capacity of 517 GWe, which grew at an unprecedented rate to 713 GW in 2007. In its reference case, the IEA expects total generation to increase at a rate of 4.9% per year, resulting in 200% increase in the electricity generation in 2030 compared to generation in 2005 (IEA, 2007). The Chinese projections are a bit lower, as China's state energy council expects generation to double from 2005, and installed capacity to increase to 1120 GWe in 2020 (Qiu, 2008). Regional demand and supply of electricity in China is shown in Figure 11.4. Generally, demand in the coastal regions is higher than supply, whereas inland regions have excess supply, with the exception of the Northeast region. Eastern coastal and central inland regions have the highest demand for electricity.

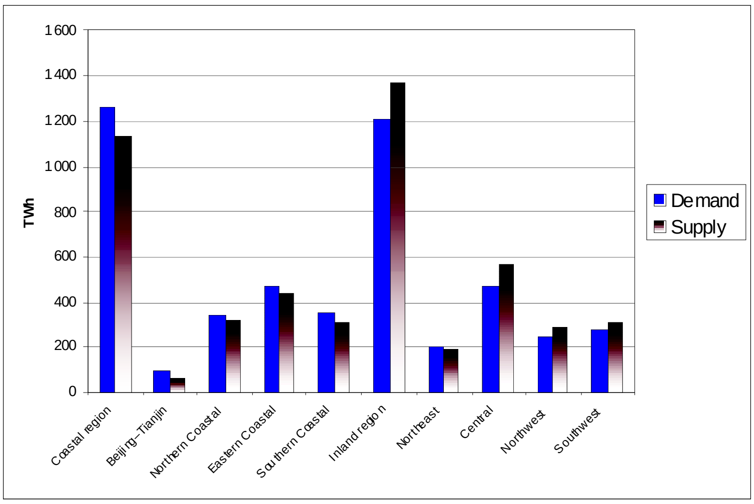

Figure 11.4. Regional imbalances in the Chinese electricity markets, Source: Wang and Nakata, 2009

China's installed generation capacity (Figure 11.5) doubled, in a short span of five years, from 356.6 GWe in 2002 (IEA, 2008b) to 713 GWe in 2007 (Wang and Nakata, 2009). About three-fourth of the total installed generation capacity is based on pulverized coal-fired plants. According to IEA, China added over 105 GWe (almost double the total installed generation capacity of Mexico) to its capacity in the year 2006 alone, of which about 100 GWe is from coal-fired plants (IEA, 2007). While diversification of generation capacity remains a key goal of policy initiatives in China's power sector, coal is expected to remain a dominant source of generation in the near to mid-term.

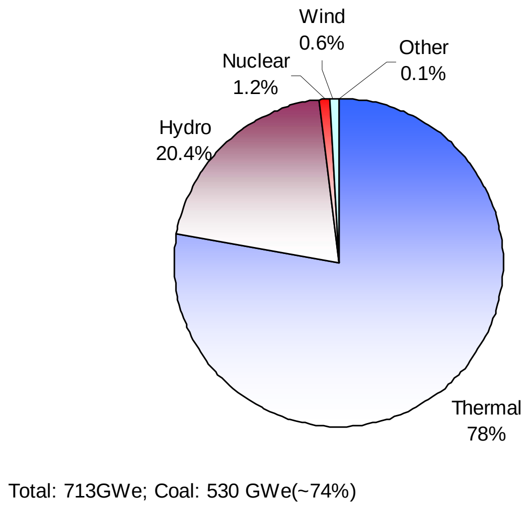

Figure 11.5. Installed Generation Capacity in China (2007), Source: Zhao, 2008

Status of Generation Technology

A large number of small (100-300 MWe) subcritical coal-fired power plants provide the dominant share of China's current coal generation capacity. These plants are generally older, and have low thermal efficiency (IEA, 2007). Fleet turnover of the coal fired capacity, and addition of large more efficient units have improved overall generation efficiency of coal-fired thermal power capacity in China. In the recent past, net plant efficiency has significantly improved, from under 30% in 1997 to over 34% in 2007 (Figure 11.6). The gain in plant efficiency is a result of closing down of small inefficient units (about 14 GWe of capacity), and addition of large more efficient units, and the use of advanced technologies, such as supercritical (SC) and ultra-supercritical (USC) boilers (Zhao, 2008).

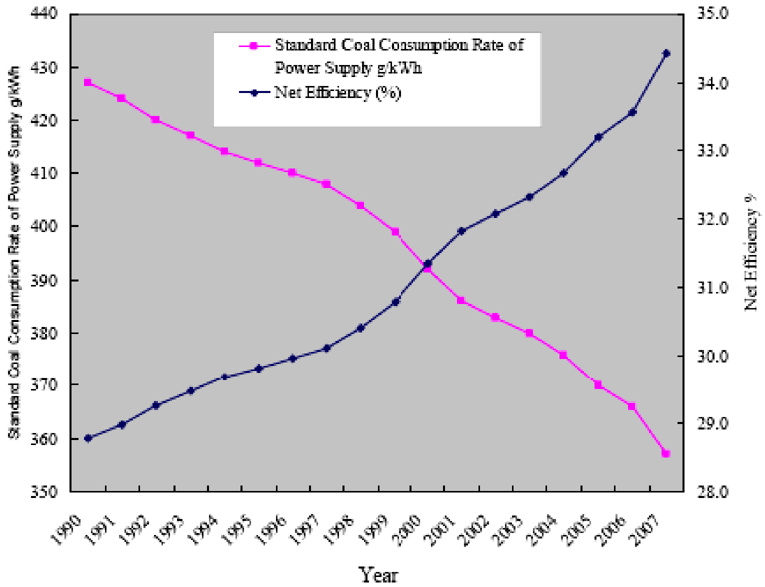

Figure 11.6. Improvement of standard coal consumption rate and efficiency of coal-fired generation capacity in China (1990-2007), Source: Zhao, 2008

Current Chinese fleet of coal-fired generation plants is dominated by subcritical power plants with an efficiency range of 30-36% (IEA, 2007). By 2007, China had added about 8.8 GWe of ultra-supercritical generation capacity (7x1000 MW and 3x600 MW), with an efficiency of about 43%, and is expected to add significant amount of new capacity including supercritical and ultra-supercritical power plants (Zhao, 2008).

Air Emissions from Power Generation in China

China's power sector's heavy reliance on coal results in significant emissions of local air pollutants, SO_2, NO_X, and PM (Yi et al., 2007). Sulfur dioxide emissions from power plants are a result of combustion of naturally occurring sulfur content in the Chinese coal. In 2000, total SO_2 emissions in China were reported to be about 20 million tonnes which increased to 26 million tonnes in 2005 (IEA, 2007). Emissions of SO_2 from coal-fired plants are primarily responsible for acid rain problems in the southwestern cities of China (Qiu, 2008). China has undertaken an ambitious plan to reduce power plant emissions of SO_2 by installing flue gas desulfurization (FGD). In 2003, only about 15 GW (~5% of total installed capacity in 2003) had FGD installations. However, by 2007, over half the generation capacity had FGD installations in place (Qiu, 2008; Zhao, 2008a). Nonetheless, the emission limits on new coal-fired power plants are significantly higher than its European and US counterparts (Zhao, 2008). To improve local air quality, China would have to tighten limits on air emissions from new coal-fired power plants, and deploy end-of-pipe controls and combustion modifications on existing capacity.

NOx emissions in China were reported to be about 12 million tonnes in 2005, with coal combustion having the largest share, followed by industry and transport sector. Most of the power plants have electrostatic precipitators installed, therefore PM emissions from power plants is not a major concern, although emissions of smaller particulate (with diameter less than 2.5 microns) would still be an issue. However, coal combustion in small and village enterprises (without adequate controls) results in large amount of particulate emissions. Mercury emissions from coal combustion, particularly from electricity generation, are also an important environmental concern in China. China is actively pursuing collaborative efforts with US to control mercury emissions from coal combustion.

China's energy related CO_2 emissions in 2005 were estimated to be 5100 million tonnes. Largest share of these emissions came from the power generation sector (Figure 11.7). Almost all of these emissions from power sector can be attributed to the combustion of coal. In the reference case, power sector emissions are expected to grow at an annual rate of 3.7% in 2030. While total energy related emissions are expected to more than double in period 2005-2030, the share of the power sector GHG emissions is expected to increase to 52% (IEA, 2007).

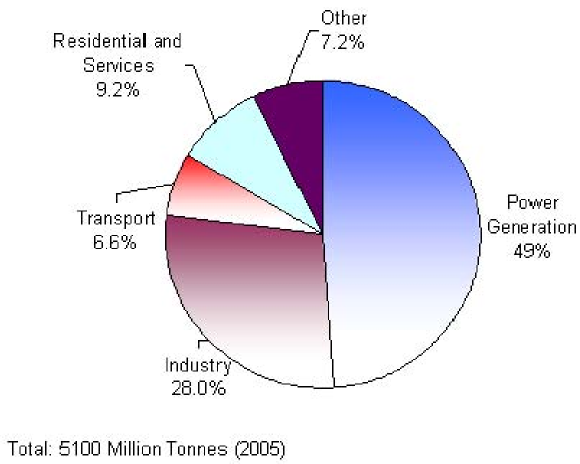

Figure 11.7 Share of CO_2 emissions from energy related sources in China (2005), Source: IEA, 2007

On the supply side, key options to reduce GHG emissions from the power sector include shifting the fuel-mix, accelerating generation fleet turnover, and rapidly deploying cleaner coal technologies. In the national plan for reduction of GHG emissions, China pledged to reduce its dependence on fossil fuel and adopt renewable energy technologies for generation and reduce energy intensity of its economy by 20% in 2010.

Power Sector in India

Per capita electricity consumption in India is relatively low (Figure 11.1) due to a large rural population being not connected to the grid and significant gap in demand and supply of electricity. With increased per capita income and economic growth, the demand for electricity has outpaced supply. India has a significant installed base of hydroelectric power generation. However, fossil-fuel generated power, primarily from coal based thermal power plants, is the key contributor to the total electricity generation in India. As of July 2008, total installed generation capacity of the Indian power sector was 145.6 GW. Fossil fuel based power generation had the largest share (~ 65%) followed by hydro (~25%), other renewable (~8%) and nuclear power (less than 3%). Of the fossil fueled generation capacity, 93 GW, the share of coal fired generation capacity is 83% (77 GW), about 16% natural gas, and remaining oil (MoP, 2008b).

Thermal power plants are a key contributor to the local and global air pollutant emissions in India. In the wake of recent economic growth in the country, and reforms in the power sector, coal-fired power generation is expected to experience a significant growth in the near term. Current Indian coal-fired power plant population is dominated by sub-critical pulverized coal-fired plants, using indigenous high-ash coal. The choice of technology to meet future growth in demand, air pollution control regulation, and adoption of technology will have a significant impact on emissions of criteria and GHG emissions from the power generation sector in India.

Institutional Structure of Indian Power Generation Sector

The Indian power sector remains dominated by government ministries and public sector corporations. The Ministry of Power is primarily responsible for the development of all aspects of electricity generation, transmission, and distribution in India. It is involved in planning, policy formulation, processing of project and investment decisions, project monitoring, human resource development, and implementation of electricity legislation (MoP, 2006).

In the generation sector, although currently about 60 percent of installed capacity is vested in the State sector, National Thermal Power Corporation (NTPC), a Central government-owned utility, has now become a de facto leader in the power sector at the national level. NTPC is now the single largest thermal power utility in the country, accounting for about 20 percent of total capacity (27 GW) and about 28 percent of the total power generated in the country. NTPC also is usually the first utility to experiment with, and deploy, new technologies. For example, the first deployment of supercritical pulverized coal technology is taking place in NTPC-owned plants. It also is actively involved in developing gasification technologies for Indian coal.

Bharat Heavy Electrical Limited (BHEL), also a public sector corporation, is the key player in the electric power technology-manufacturing sector. BHEL manufactured more than 60 percent of the units installed in the 1970s and nearly all of the power plants constructed in the following decade. BHEL units now account for more than 60 percent of all units installed in India (Chikkatur and Sagar, 2007).

Recent Power Sector Reforms in India

The Indian power sector has seen dramatic institutional changes in the past decade and a half. First, in the early 90s, the government promoted the private sector by providing lucrative incentives for Independent Power Producers (IPPs). However, this attempt to bring in the private sector failed, and by 2003 only 5.3 GW of IPP projects were fully commissioned (TERI 2004), and the overall capacity addition in the country slowed down in the mid-to-late 1990s. In the mid-1990s, the World Bank, which had previously engaged with the central utilities and had responded lukewarmly to the IPP policy (Dubash and Rajan, 2001), decided to focus on bringing about changes to the Indian power sector by offering financial support to states that would implement its policies for restructuring their electricity sectors. The main changes were to institute a regulatory commission and split the electricity boards into generation, transmission, and distribution units. In the late 90s, the Central government consolidated these reforms through the Electricity Regulatory Commission Act in 1998 and Electricity Act in 2003.

The Electricity Act 2003 required all state electricity boards to unbundle and privatize, while introducing at the same time wholesale competition, trading and bilateral contracts with regulation. By forcing the unbundling of vertically integrated companies, the Act intended to separate generation from transmission and distribution, with the hope that generation would be subject to market competition. The Act envisioned a new, market-driven framework where electricity would be just another commodity that can be generated, sold, and traded in the market as determined by supply and demand.

The Demand and Supply in India

While installed capacity and electricity generation has been steadily increasing over the years, the peak demand shortage of electricity has been rising in the last five years. Demand-supply gap was reported to be about 9%, the peak demand shortage was reported to be over 15% in the year 2007-08 (MoP, 2008a). A significant portion of the population living in rural area still does not have access to electricity. An ambitious plan to increase rural electrification and eliminate the shortage "Power for All by 2012" envisions installed capacity to increase to 200 GW.

Much of the expected growth in electricity generation in India over the next few decades will likely be based on coal, particularly domestic coal. The demand for utility-generated electricity is projected to more than double from about 520 TWh in 2001-02 to about 1300 TWh by 2016-17, with an annual growth rate of about 6-7% (CEA, 2000). Longer-term scenarios indicate demand to be around 3600-4500 TWh by 2031-32, with the installed capacity (including captive power) to be about 800-1000 GW by 2031-32 (Planning Commission, 2006). Hence, it is clear that India's demand for electricity is projected to rise rapidly in the next 20-30 years.

The projected rapid growth in electricity generation over the next couple of decades is expected to be met by using coal as the primary fuel for electricity generation (see Table 11.2). Table 11.2 assumes that Indian GDP will grow at an average rate of 9%. Other resources are uneconomic (as in the case of naphtha or LNG), have insecure supplies (diesel and imported natural gas), or simply too complex and expensive to build (nuclear and hydroelectricity) to make a dominant contribution to the near-to-mid term growth (Chikkatur and Sagar, 2007). Liquid fuels such as heavy oils have limited use in the power sector for economic and environmental reasons. Prospects for gas-based power are limited by supply constraints, as many of the recent natural gas based power plants in the private sector have been facing fuel supply shortages. India has significant hydroelectricity resources, but there are a number of problems, including shortage of funds, interstate water use conflicts, lack of suitable transmission infrastructure, long gestation periods, geological uncertainty in the Himalayan regions, high environmental impacts, and problems of resettlement and rehabilitation of displaced people (CEA, 1997). The potential for nuclear power development is also not high in the short to medium term, because of limited domestic natural uranium resources and various international restrictions that have held back the Indian nuclear power industry (Gopalakrishnan, 2005). Electricity from renewable sources are relatively small and used mainly in niche applications; even wind power, which has grown significantly in the last decade, is mainly concentrated in a few states in India.

Table 11.2 A “middle of the road” scenario for sources of electricity generation in India

Year	Electricity Generation (TWh)	Hydro (TWh)	Nuclear (TWh)	Renewables (TWh)	Thermal Energy (TWh)	Thermal Fuel Demand		
						Coal (Mt)	NG (BCM)	Oil (Mt)
2003-04	592	74	17	3	498	318	11	6
2006-07	724	87	39	8	590	379	14	6
2011-12	1091	139	64	11	877	521	21	8
2016-17	1577	204	118	14	1241	678	37	10
2021-22	2280	270	172	18	1820	936	59	12
2026-27	3201	335	274	21	2571	1248	87	15
2031-32	4493	401	375	24	3693	1659	134	20

Thus, coal will continue to energize the Indian power sector and its role cannot be understated. Use of India’s significant domestic coal resources for power generation would enhance energy security— which is an emerging priority in the country. India’s domestic oil and natural gas reserves are minimal (about 0.5 percent of world reserves), and over three-quarters of India’s petroleum consumption was met through imports in 2004-05. Based on the Planning Commission (2006) scenarios, coal-based capacity of utility power plants is likely to be in the range of 200-400 GW in 2030, up from about 68 GW in 2005.

The projected high growth of coal power has significant implications for India’s GHG emissions. According to official documents, coal contributed to about 62 percent of India’s total CO_2 emissions of 817 Tg in 1994, with energy transformation (electricity generation and petroleum refining) contributing 43 percent (MoEF, 2004). Contribution of solid fuels (coal) to total fossil fuel-based emissions is now about 70 percent. Given coal power’s rate of growth, it will continue to be the major contributor to carbon emissions from the country (Marland et al., 2007).

Technology, Size, Vintage, and Efficiency of Coal-fired Power Plants in India

Nearly all of the currently installed coal-fired capacity is based on sub-critical conventional steam cycle. Size distribution of the coal-fired installed capacity in 2005 indicates that 77 % of the installed capacity is smaller than 250 MW in size. Only 23% capacity is equal to or larger than 500 MW units (Chikkatur and Sagar, 2007). Further, of the total 386 units, in 2005, about 10% (representing only 3% of the installed coal capacity) were more than 40 year old, and about 20% coal-fired capacity is 25 yr or older. Average net efficiency of coal-fired power plants in India is reported to be 29%. Smaller, old units (less than 200 MW) have very low efficiency (<25%) and plant load factor (PLF) (<70%) (Chikkatur, 2005). The best Indian power plants – 500 MW units – operate with a net efficiency of about 33%. In comparison, the average net efficiency for the 50 most efficient U.S. coal-based power plants is 36%, with the fleet average being 32%.

The current “standard” for coal-power technologies in India is the BHEL 500 MW sub-critical PC unit. These units are based on assisted circulation boilers with main steam pressure of 170 kg/cm^2 (CEA, 2003). Currently, more than 25 of these units are in operation. Many power utilities are now entering the global markets for power plants through their tender process, which has the potential for bringing in new technologies to India. For example, the two NTPC super-critical power plants currently in construction in India are based on Russian and Korean technologies—obtained through a global tendering process.

Air Emissions from Power Generation in India

The ash content in the Indian coal is very high, resulting in high particulate emissions. Run-of-mine domestic Indian coals typically have ash content ranging from 40-50%, moisture content between 4 – 20%, sulfur content between 0.2 – 0.7%, gross calorific value between 2500 – 5000 kcal/kg, with non-coking steam coal being in the range of 2450 – 3000 kcal/kg (Sachdev, 1998; IEA 2002; Visuvasam et al., 2005).

Most of the particulate emissions come from the flue gas, although fugitive dust from coal handling plants and dried-up ash ponds also are significant sources of particulate pollution. Particulate emissions are better regulated than other pollutants, in part because of the use of electrostatic precipitators (ESPs) in all of the plants. Stack emissions of sulfur oxide and nitrogen oxide emissions are not regulated, and only ambient air concentrations are monitored and regulated for these pollutants. Although about 30% of NOx emissions in India derive from power generation, NOx emissions from coal-based plants are not regulated. Finally, the release of trace elements such as mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), etc., from power plants through the disposal and dispersal of coal ash is also a growing concern in India. The concentrations of many trace elements are high in comparison to coals from other countries (Masto et al., 2007).

In terms of CO_2 emissions, India’s emissions from fossil fuels have been increasing at a compounded annual growth rate of 5% from 1990 to 2004 (Marland et al., 2007), although it has decreased more recently (2000 to 2004) to 3.8%--see Figure 11.8. Nonetheless, India’s total emissions in 2004 were still about 4.5 and 3.7 times smaller than U.S. and China emissions, respectively. In per-capita terms, India’s carbon emissions in 2004 were almost one-sixteenth of the emissions of the United States and one-third of those of China.

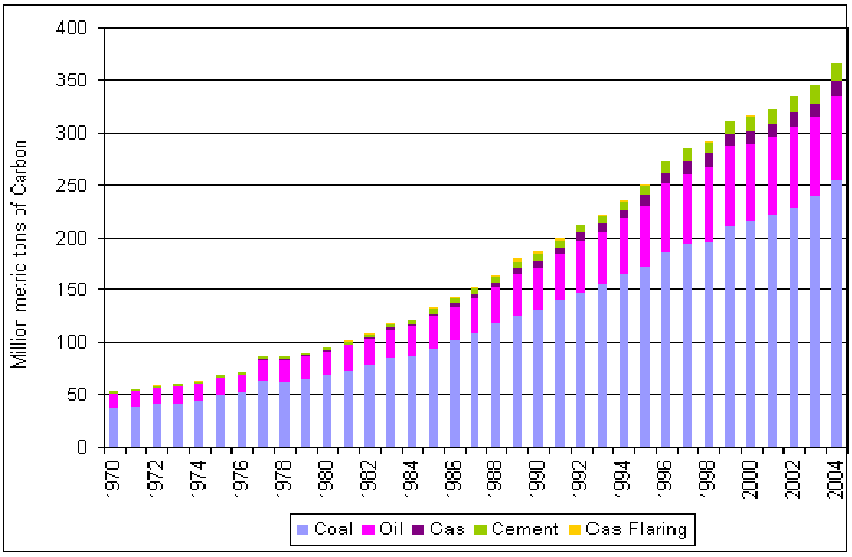

Figure 11.8 Indian carbon emissions from fossil fuel use (1970-2004), Source: Marland et al., 2007

Mexican Power Sector

Mexico is the sixth largest global producer of oil, and has a significant reserve of natural gas. On the other hand, its proven coal reserves are estimated at only 1.3 billion tonnes, and the share of coal in the total energy mix is relatively small (EIA, 2007). Therefore, historically, the Mexican power sector has been dominated by oil—in contrast to coal playing a similar role in China and India. As a result of the reform process that began in 1990s, the Mexican power sector has undergone significant structural changes in terms of its ownership, fuel-share, and generation technology. The changes in Mexico's generation portfolio have had significant impacts on its emissions trajectory from power sector.

Structure of the Mexican Power Sector

Although the Mexican federal constitution limits the participation of non-governmental entities in energy-related activities, regulatory changes starting in the 1990s, have made it possible for the private sector to build, own and operate (BOO) power generation facilities. The regulatory changes leading to this shift can be found elsewhere in the literature (see, for example, Flores-Montalvo, 2005; EIA, 2005; Breceda, 2000). Recent growth in the installed capacity in the Mexican power sector has largely come from privately owned facilities. The structural shift in the Mexican power sector had three components. First, a policy initiative, which allowed independent power producers (IPPs) to make necessary investment in the infrastructure; second, the availability of resource, i.e., natural gas for use in the power sector; and third, the availability and competitiveness of the natural gas combined cycle technology, which enabled the IPPs to quickly install and operate the newer, more efficient generation capacity.

Historically, the Mexican power sector has been dominated by the state-owned public utilities, *Comisión Federal de Electricidad* (CFE), which is the largest state owned utility in Mexico, and *Luz y Fuerza del Centro*[4] (LFC), which is primarily a transmission company operating mainly in the Mexico City metropolitan area. LFC owns some generation assets as well. As a result of the deregulation process, independent power producers (IPPs) have started to play a key role in the power sector, beginning with the first 484 MWe plant in Merida in the state of Yucatán, which came online in 2000. Since then, the first decade of this century has seen a phenomenal growth of the role of IPPs in meeting the electricity demand in Mexico (Figure 11.9). By the end of 2007, IPPs had a share of over one-fifth of the total installed capacity and contributed slightly less than one-third of total electricity generation (Figure 11.10).

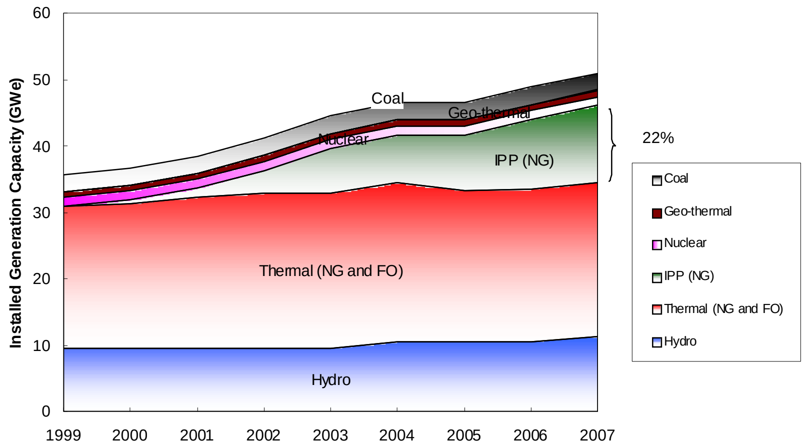

Figure 11.9 Installed power generation capacity in Mexico, Source: SENER, 2008a

[4] In October 2009, in a major move, CFE, the Mexican state owned utility announced take-over of smaller state-owned utility LFC. The key reason cited for this move is inefficiency of LFC's operations (SENER, 2010).

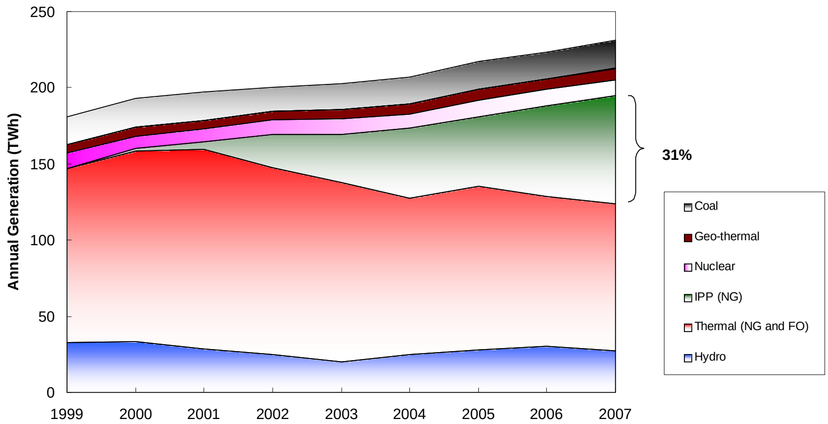

Figure 11.10 Electricity generation in Mexico by fuel type, Source: SENER, 2008a
Source: SENER, 2008a

Demand and Supply of Electricity in Mexico

Increase in population and growth in economic development are the two key drivers for increasing electricity demand in Mexico. Mexico's electric sector planning body estimates that the demand for electricity for domestic consumption will increase at an annual rate of 4.8% from 2007 through 2016. Total consumption of electricity is expected to increase from 197 TWh in 2006 to 318 TWh by 2016. This will require an increase of over 60% in total generation capacity in a decade. It is anticipated that a total of 22.7 GWe new capacity will need to be installed to meet the increase in demand (SENER, 2008b).

Historically, residual fuel oil has been the principle source of primary energy for Mexican power sector. Shares of nuclear and coal have been relatively small. The share of natural gas has been increasing steadily since the turn of the century. While natural gas based combined cycle plants are expected to dominate the portfolio of future new generation capacity, diversity of fuel-mix and energy security concerns have prompted the inclusion of coal as a potential generation source in the future. Mexico has successfully exploited its renewable energy resources in the past: by April 2008, its geothermal capacity was reported to be 965 MWe, and wind power generation capacity was at 85 MWe. According to the recent planning documents and public releases, there is a renewed emphasis on the role of renewables in meeting future demand, especially wind power. Specifically, the Mexican energy regulatory commission has recently set up an inter-institutional task force to enable installation of 1200 MWe wind power generation from the state of Oaxaca (CRE, 2008).

Fuel Shares and Portfolio of Generation Technologies

Until 2000, the Mexican power sector relied heavily on fossil fuels, particularly oil-fired conventional sub-critical steam power plants, with generation efficiency in high twenties to low thirties. However, the IPPs have shifted the structure and fuel-share of the Mexican power sector by rapidly building natural gas fired combined cycle plants.

In 1999, before the first IPP came online, conventional oil-fired thermal plants played a key role in supplying electricity to the country. Fuel oil contributed 61% to the total fuel consumed for power generation, followed by natural gas (19%) and coal (12%), and rest nuclear and diesel (SENER, 2008b). Since then the share of fuel oil has continued to decline in the total fuel-mix (Figure 11.11), and as a result there has been a significant reduction in sulfur dioxide emissions from power generation (see below). For example, units of Jorge Luque and Valle de Mexico located in the Mexico City Metropolitan Area reduced air emissions of criteria pollutants significantly (Molina and Molina, 2002). In addition to being much cleaner and more efficient than fuel oil plants, the gas power plants provide reserve capacity to meet peak demand.

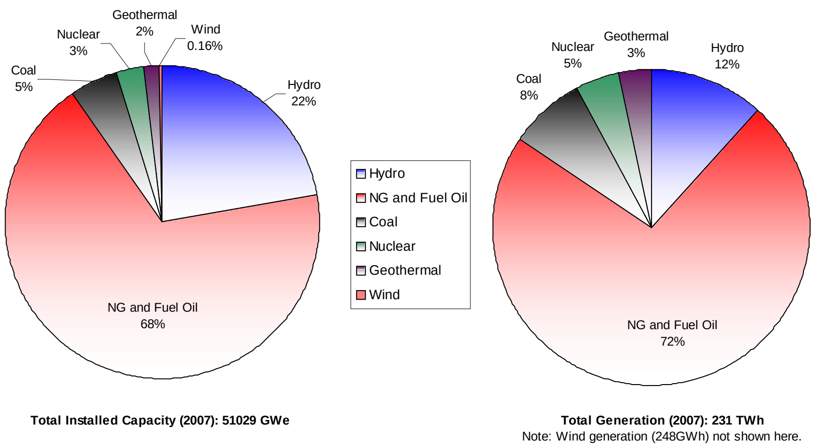

Figure 11.11 Distribution of Installed Public Sector Capacity and Generation in 2007

Structural Shift and its Implications on Air Emissions

As mentioned earlier, the public sector installed capacity in Mexico is dominated by fossil fuels, with coal's share being relatively small. Hydropower generation capacity is the next largest capacity, although its contribution to total generation is relatively small (Figure 11.11). Recent trends in Mexican power sector indicate a sharp decline of fuel oil in the generation mix, primarily driven by local air pollution concerns, and substitution of capacity with IPP-owned natural gas combined cycle plants (Figure 11.12). This shift in the fuel share has had clear impact on emissions of criteria pollutants and GHG emissions from the Mexican power sector.

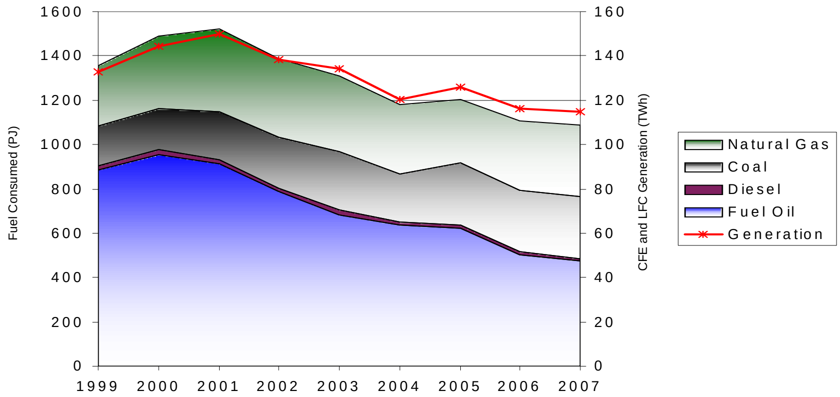

Fig. 11.12 Fossil fuel consumption and power generation trends in Mexican public sector, Source: SENER, 2008a; SENER, 2008b

Electricity generation from the public sector peaked in 2001 and has continued to decline since then, despite the overall generation increasing. Much of this is because of increasing environmental pressure, wherein the combustion of high-sulfur containing residual fuel oil has been frowned upon, especially for plants located near heavily populated metropolitan areas.

The share of IPPs in the installed generation capacity has been steadily increasing in the Mexican power sector. They contributed over one-fifth of the total generation capacity, but were responsible for about one-third of total electricity generation in Mexico in 2007. These IPP plants, however, have significantly lower share of criteria pollutants and GHG emissions from the power sector (Figure 11.13). Overall this structural shift has resulted in decreasing emission intensity from the power sector as a whole. Emission intensity of NO_X, CO_2 and PM has declined between 20-25%, whereas SO_2 emission intensity has seen most dramatic impact, and has decreased by about 40% from 2002 through 2007 (Figure 11.14).

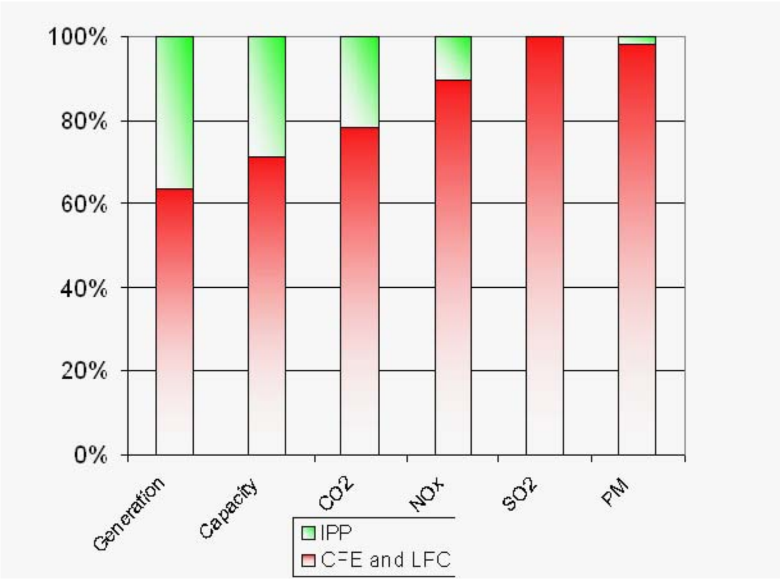

Figure 11.13 Share of installed capacity, power generation, and emissions from independent power producers (IPPs), Source: Vijay et al., 2008

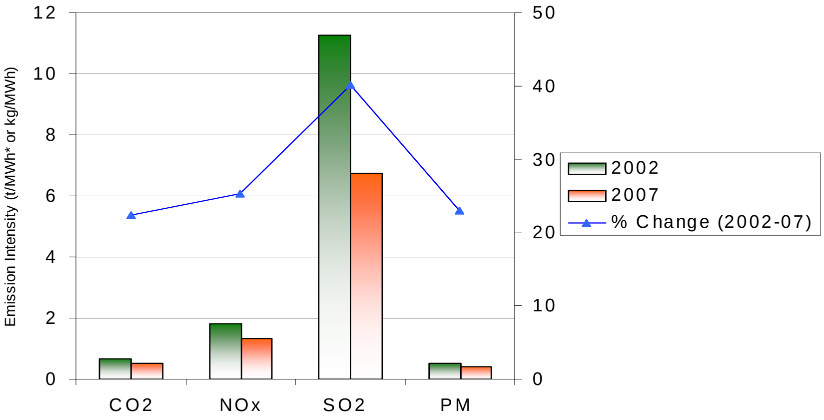

Figure 11.14 Changes in Emission Intensity from Mexican Power Sector (2002-2007), Source: Vijay et al., 2008

Comparing China, India, and Mexico

While all three China, India, and Mexico are developing countries, there are stark differences in their socio-economic characteristics, and the institutional and technological aspects of their power sectors. In this section, we highlight some of the key differences and discuss the implications for technology development and options for GHG mitigation. Mexico's population is less than one-tenth of the population of both China and India, and these two countries have more than 1 billion people each, with the two of them accounting for nearly 40% of global population (IEA, 2008a). Despite its high population, however, China has done relatively well in terms of its economy and its per capita electricity consumption is slightly higher than Mexico (Table 11.3). Per capita income (purchasing power parity adjusted) in Mexico is the highest at about USD 10,000, whereas for China, it is about two-third of that of Mexico (~USD 6,624) and India's per capita GDP is the lowest, at about a one-third of that for Mexico (IEA, 2008a). China has a large industrial manufacturing capacity that has driven its export-based economy, and Mexico benefitted from its participation in North American Free Trade Agreement (NAFTA) which resulted in setting up of manufacturing base across the US border. Indian economy, on the other hand is dominated by the service sector. Contribution of the agricultural production to the total GDP is relatively small, but it still remains the largest provider of employment to the rural population. Manufacturing sector in India contributes about one-fifth to the total GDP. Its service sector, driven by the information technology industry, has seen a significant growth in the recent years. In terms of energy, per capita electricity consumption in China is highest at slightly above 2000kWh; Mexico is only slightly lower than China; and Indian per capita electricity consumption is about one-fourth of those of China and Mexico. Electrification rate is highest in China at 99%, closely followed by Mexico at 95%. India also lags behind in this important indicator with only 62% of its population with access to electricity (IEA, 2008a).

Table 11.3 Key Energy Statistics of China, India, and Mexico

	Population (million)	GDP (PPP[a] 2000$)	Total Primary Energy Supply (MTOE)	Par Capita Electricity Consumption (kWh/y)	CO_2 Emissions (Mtonnes)[b]	Electrification Rate
China	1,312	8,685	1,879	2,040	5,607	99%
India	1,110	3,671	566	503	1,250	62%
Mexico	105	1,030	177	1,993	416	95%

a. Purchasing power parity
b. Fossil fuel combustion only

Source: IEA, 2008; IEA 2008a

With over 120 billion tonnes of proven coal reserves, third largest in the world, China is endowed with the most coal resources among all three countries. However, China's coal production is less than its demand, making it a net importer of coal. Similarly, India imports steam-coal and coking coal, despite having relatively large coal resources (EIA, 2008). Moreover, the quality of coal in India is very poor – with high ash content, which can sometimes be as high as 50%. Mexico also has some coal reserves, but its main energy resource lies in oil and natural gas: it has 12.4 billion barrels of oil, and 14.6 trillion cubic feet of proven natural gas reserves. Mexico imports steam coal for one of its coal-fired power plants, and primarily relies on residual fuel oil from its refineries. Natural gas production has not been able to keep up with demand (driven by industrial and power generation sector), and hence Mexico is now a net importer of natural gas.

The power sector in these countries (as is true in most other countries) is driven largely by the availability of domestic resources. Chinese and Indian power sectors are primarily fueled by coal, whereas Mexican power sector is dominated by residual fuel oil from its refinery capacity and, since 2000, natural gas based combined cycle generation capacity. In the near to mid-term, it is unlikely that there will be major changes in the fuel-mix of the generation portfolio of the three countries. Despite their efforts to add more nuclear and renewable capacity, China and India will continue to rely on coal as primary resource for power generation. Mexico, on the other hand is likely to adopt a more diversified approach: while relying mostly on natural gas combined-cycle (NGCC) plants, Mexico will add more renewables and some oil and coal-fired capacity to its generation portfolio. The overall efficiency of Mexican power sector will also improve as the NGCC plants are much more efficient than conventional oil-fired steam cycle power plants. Mexico's key challenge in the future will be to increase the operating efficiency of its NGCC plants from high 40%'s to high 50%'s. The Chinese power sector has already gained significant experience and expertise in developing and deploying the more efficient coal based USC power plants and the key technological challenge for China is to quickly use the experience gained in installing and operating the USC plants to accelerate its fleet turnover to make itself more energy efficient. The relatively high sulfur content in the Chinese coal would require the installation of FGDs on majority of its new capacity. The technologies in the Indian power sector lags significantly behind China and the main challenge for India is to learn from the experience of China, Japan and other countries to adapt and deploy SC and USC power plants and to accelerate its fleet turnover.

Technology Options for Mitigating GHG Emissions from Power Sector in Key Developing Countries

Economic development and the fulfillment of basic human needs such as education, sanitation, health and communication are dependent on the availability of modern energy services. Indeed, improved standards of living in developing countries are closely associated with an increase in energy demand, particularly electricity. However, the urgent need for a continued and rapid enhancement of the availability, reliability, and affordability of modern energy services, especially electricity, needs to be consistent with sustainable development goals. As such, there are several technology and policy issues associated with reducing GHG emissions from the power sectors in the key developing economies. These issues can be categorized into following four groups: demand management, improving efficiency of existing generation portfolio, new fossil-fired power plants, and non-GHG emitting generation options such as nuclear and renewable. We explore these options and their penetration potential in short (<5 year), medium (5-15 year) and long-term (>15 year).

Efficiency Improvements

In the short term, demand side management (DSM) and improving end-use efficiency by encouraging and enforcing energy efficiency standards and influencing consumer choice through labeling programs are a critical first step in reducing energy demand and GHG emissions. Demand management is especially important in the larger developing economies, as the penetration of electricity-based consumer goods and electricity demand are likely to increase substantially with increased economic growth. China has taken several steps in this direction, and energy efficiency has gained prominent role in policy making in past years. The Chinese energy plan aims to improve energy intensity to reach at “international levels” (IEA, 2007). The Indian Bureau of Energy Efficiency (BEE) has recently taken big steps in providing information to consumers through labeling programs and the agency might also introduce market mechanisms for providing incentives to improve industrial efficiency. Mexico has set up a national commission to conserve energy, known as Comisión Nacional para el Ahorro de Energía (CONAE). CONAE plays the key role in setting up appliance standards for energy efficiency, and promoting technologies such as combined heat and power to improve industrial energy efficiency, in Mexico. While these steps are a good start, consistent and greater efforts in DSM is necessary.

In addition, reduction in transmission and distribution (T&D) losses is another key challenge, especially in India where T&D losses account for a significant loss of revenue and energy. Reducing India’s losses to a more manageable (though still high) 10 percent will release power equivalent to about 10,000-12,000 MW of capacity (CEA, 2007). Such short-to-medium term measures can be very effective in improving efficiency.

Improving Existing Plants

Second, the key developing countries already have a large existing base of power generation technologies, and it is important to consider options to reduce GHG emissions from this existing fleet of power plants. These efforts require relatively smaller capital investment and shorter payback periods, as they are often based on proven and tested technical know-how. As noted in the previous sections, the generation efficiency of existing power plants in all three countries can be significantly improved, especially since there is a large portfolio of smaller, older, and inefficient plants. The efficiency of existing plants can be increased by repowering or upgrading existing facilities and improving energy auditing and management practices. The efficiency gains could yield substantial reduction in primary energy consumption and GHG emissions. In the medium-to-long term, many of the smaller plants need to be retired and replaced with new efficient technologies wherever possible. Such retirements should be particularly targeted at older and more inefficient coal-based power plants. Several power plants in Mexico utilize natural-gas fired steam cycle for power generation, which has much lower efficiency than natural gas fired combined cycle configuration. Conversion of these steam cycle units to combined-cycle plants offer considerable scope to increase fleet-efficiency and reduce natural gas consumption and GHG emissions. Even NGCC fleets introduced in this decade in Mexico and India have the potential to improve efficiency to about 60%, which is the efficiency of the best available combined-cycle plant.

In the short-to-medium term, it is also very important for all three countries to strengthen and strictly enforce the standards for air emissions (particulates, SO_x, NO_x, and mercury)—both for existing fleet as well as for new capacity. Although the control of these local pollutants would slightly reduce net efficiency and capacity, it is critical to prevent socio-environmental problems in all three countries. Furthermore, a clean flue gas is critical for any economic retrofitting of post-combustion carbon capture technologies (Chikkatur and Sagar, 2007). In addition, conservation and efficient use of water is another important aspect for fossil-fuel based power plants, as these plants require large volumes of water for cooling.

Technologies for New Fossil Fuel Plants

In the three countries discussed in this chapter, domestic fossil fuel will continue to remain a key element of power sector. Many developing countries with ready access to such cheap domestic fuel will use them for development, and therefore it is important to consider potential GHG mitigation options for these new fossil fuel-based plants. A key first option, especially for China and India, is to focus on advanced combustion technologies, such as supercritical (SC) and ultra-supercritical (USC) PC technologies. Some of these plants can help replace retire older inefficient plants from the existing fleet. China has already made substantial progress in this direction, and installed 8.8 GWe indigenous USC PC generation capacity. Further, China has embarked on significant future capacity addition based on USC and SC PC combustion technology. According to the IEA, as a result of the introduction of advanced steam cycle plants and the closure of smaller inefficient plants, carbon emissions intensity of coal-fired generation in China is expected to drop by about 25% by 2030. India, however, lags behind China in improving its coal-fired fleet efficiency. Currently there are only two SC

PC plants under construction with imported technology. Given that high ash content in the Indian coal poses specific problems in using off-the-shelf advanced generation technologies, indigenous technology development and adaptation will be the key in the short-term to achieve self-sufficiency in this area. Advanced technology based on imported coal might be an option for India (Chikkatur and Sagar, 2010). Also, given that India has significant lignite resources, RD&D efforts needs to be focused in the short-to-medium term on developing supercritical cycle based on circulating fluidized bed combustion (CFBC) of lignite. In order to diversify its energy portfolio Mexico is embarking on increasing its coal-fired generation capacity. Planning for coal-fired plants based on advanced steam cycle with efficiency as high as 45% can result in significant reduction in resource use and low GHG emissions for Mexico.

According to the reference scenario of 2008 IEA's World Energy Outlook, 75% of the projected global increase in energy-related CO_2 emissions to 2030 comes from China, India, and the Middle East, and electricity-related emissions for non-OECD emissions in 2030 are expected to double from 6.5 Gt in 2006 (IEA, 2008). The business-as-usual projected increase in energy-related CO_2 emissions to 2030, assuming no new global or regional climate policies, is consistent with atmospheric CO_2 concentrations of 660-790 ppm CO_2 by 2100, which can lead to an *equilibrium* temperature rise about 6 degree Celsius above pre-industrial levels (IEA, 2008). Clearly, such high temperature rises would be catastrophic, and hence mitigation of energy-related CO_2 emissions (especially emissions from coal-power plants) in China and India is inevitable over the next few decades.

Hence, the introduction of carbon capture and sequestration (CCS) to new power plants will likely be take place sooner than later in China and India, and perhaps even in the NGCC plants in Mexico. A recent estimate has shown that CCS would be required globally for coal, gas, and oil plants by 2050, with rapid expansion of CCS technologies by 2100. It is estimated that about 70 million tons of CO_2 would be stored by 2020, rising to 600 million tons by 2050 and 6000 million tons by 2100 (Edmonds et al., 2007).

China and India have both taken some initial steps in this direction, particularly in developing and demonstrating new gasification technologies for power generation. China has started construction of three demonstration plants that will use integrated gasification combined cycle (IGCC) technology. It has developed its own gasifiers, with focus on using it for chemicals production. The characteristics of Indian coal prevent the use of standard gasification technologies (Chikkatur and Sagar, 2007) and hence have been developing fluidized bed gasifier that is more amenable to Indian coals. India has plans for a pilot scale facility using these gasifiers in an IGCC plant. Scientists and engineers in both countries are also now beginning to do research on economically viable carbon capture technologies. However, it is unlikely that aggressive efforts will be directed at research, development, and deployment of carbon capture and sequestration (CCS) technology before the demonstration and deploying of CCS in industrialized countries. Even in industrialized countries, full-scale deployment of CCS requires a major effort in demonstration of economic viability of CCS, initiating the development of infrastructure for transport and storage of CO_2, and creating legal and regulatory frameworks (IEA, 2008). Moreover, the timing and nature of a post-Kyoto international climate treaty will determine the pace of CCS deployment both in industrialized and developing countries (Chikkatur and Sagar, 2009) Some of the other key CCS issues for China and India include support for financing and reducing financial cost of CCS, joint research and development of new capture technologies as well as for adapting these technologies to the local context, and detailed assessment of storage sites. Once a viable CCS technology is demonstrated, the manufacturing prowess of China can help bring down the cost of this technology significantly.

The need for detailed storage assessment for CCS is an important issue and needs to be emphasized, as early action is critical for future deployment of CCS. The amount of storage in oil and gas reservoirs is limited and geological underground storage in saline aquifers is currently the most promising option for storing large quantities of CO_2. However, storage in geological media requires detailed assessments of specific storage locations and capacity within these locations. Currently, only broad first-of-a-kind estimates of storage capacity are available in both India and China, and there is a strong need for detailed site-specific assessment of storage mechanisms and capacity in potential on-shore and offshore locations. Furthermore, first-of-a-kind CCS need to be more conservative in their choice of aquifers as a successful and safe first-of-a-kind CCS plants are critical for larger scale deployment in the future. Hence, it is important to embark on such detailed assessments, as well as relevant demonstration projects, as early as possible in order to inform any siting decisions of new coal power plants (Chikkatur and Sagar, 2009).

Non-Fossil Fuel Power Plants

Last, but not least, zero-CO_2 emission technologies such as nuclear and renewables, need to account for a larger fraction of new capacity in order to reduce GHG emissions. The emphasis on these technologies needs to be paramount, and wherever possible substitute for fossil-fuel based plants. Nuclear power can play a key role in meeting the electricity demand without CO_2 emissions. While operating and safety performance of nuclear plants have improved, and new designs offer safer and competitive generation options, public perception of risk and safety of nuclear power, and ultimate disposal of nuclear waste still remain key challenges facing the nuclear industry. Developing countries, China and India in particular, have continued to make additions to their nuclear generation capacity. While China and India will continue to add to their existing nuclear generation capacity, share of nuclear power in Mexico is likely to continue to decline. Mexico’s

Laguna Verde plant has two units totaling 1300 MWe generation capacity and no new unit is planned at this time.

According to the IAEA's power reactor database, by the end of 2008, China had 11 operational reactors (8438 MWe) and 9 were under construction (8220 MWe). India on the other hand has 17 reactors in operation (3782 MWe) and 6 under construction (2910 MWe) (IAEA, 2008). One key difference in the two countries is the unit size and the choice of technology: while Chinese plants are mostly 1000 MWe pressurized water reactors (PWR), Indian plants are smaller in size, and have a mix of PWR, and indigenous pressurized heavy water reactor (PHWR) and a fast breeder reactor (FBR). India does not have abundant natural uranium resources, and has limited technological capability to enrich uranium. Hence, the new nuclear deal with the United States and the International Atomic Energy Agency (IAEA) will clearly help India in importing uranium. India also has vast amounts of thorium reserves, which can be used in combination with fissile plutonium or uranium, to produce nuclear material for power generation. However the Indian nuclear program is far from being able to exploit thorium due to technological and capital limitations. While nuclear power offers significant potential to reduce GHG emissions, public perception of risk associated with nuclear power, lack of standardization of design and capital intensity of nuclear power remain key obstacles in the short and medium term. Nuclear industry still has to find a safe and secure long-term storage of the high-level radioactive waste generated by the nuclear plants.

Contribution of renewable energy in meeting the power demand in China, India, and Mexico has continued to grow. Over 15% of China's total primary energy consumption and about 30% of India's primary energy consumption in 2005 was met by renewable energy. Biomass was the dominant energy source for meeting cooking and heating demand in rural households (IEA, 2008). Electricity generation was dominated by hydropower as the renewable source; it contributed 16% of the total generation. Installed wind capacity is 1.3 GW, and expected to reach 5 GW in 2010 and 30 GW in 2030. In the short to medium term, wind and solar power will remain a marginal source of electricity generation in China. However, in the remote areas where distribution network is unavailable, solar power is likely to provide electricity. By 2030, China's expect solar generation capacity is expected to increase to about 9 GW from about 70 MW in 2005. India plans to add significantly to his hydropower capacity, and it remains one of the fastest growing markets for wind power. Biomass based power generation is also another important source of zero emissions power in India. Although the growth of renewables in the future is expected to be large, they still only provide meet a small fraction of the power demand in the country. Mexico has been exploiting its geo-thermal resources for power generation. Recent renewed efforts to enhance its renewable portfolio are heavily dependent on installation of new wind-farms. However, as in the case of China and India, renewable energy is not likely to amount for large fraction of power generation in the short-to-medium term.

Role of Power Sector Reforms

The power sectors in China, India, and Mexico have undergone a process of deregulation and increased privatization, to varying degrees. The impact of these reforms have been mostly positive with increased competition and independent regulation helping to improve the overall institutional and financial health of the power sector. In India, the liberalization and restructuring of the power sector has to be seen as mixed at best due to poor design of the "reformed" power sector (i.e., not fully suitable for the Indian context), inept management of the reform process, and deficient governance in practice (Dubash and Singh, 2005; Sharma et al., 2005; Singh, 2006; Dubash and Rao, 2007). However, there are signs of hope, including greater scrutiny of the performance of the reforms; better understanding that successful reforms necessarily will require a tailoring to the Indian context; and institutional learning and capacity-building. Regulatory institutions in India will have to be strengthened by giving them greater credibility and enabling the development of their capacity. In addition, regulators themselves must work in a cooperative manner to improve and strengthen regulatory practices and improve stakeholder participation (Dubash and Rao, 2007). While private investors have entered other sectors in India, they have been more hesitant to enter the energy market because of the preferential treatment given to public-sector energy companies (IEA, 2007). It is, therefore, important that a transparent, predictable and consistent investment framework be put in place. Another priority should be to reduce start-up hurdles, such as delays in acquiring land, environmental clearances, and construction permits (IEA, 2007).

Power sector reforms in the Chinese electricity market began in the mid-1980s when non-central governmental entities were allowed to invest in generation, and the process of reform received a boost in 2002, when the State Power Corporation (SPC) was split into two transmission and nine-generation companies, resulting in a dramatic change in the structure and ownership of the power sector. Further, private investments by local and foreign players have been increasing, overseen by the State Electricity Regulatory Commission. Central government has been actively seeking the involvement of private and state-owned entities to introduce the elements of market-based incentives to improve system efficiency. However, to meet the goals of economic growth, power sector reforms will have to be accelerated in China, to meet the needed investment in the power sector, without compromising environmental quality and health of its land and people(IEA, 2006).

While political efforts to introduce reforms in the energy and power sector have often been stalled by the Mexican congress, *de facto* liberalization has already taken place. The liberalization in the Mexican power sector is spurred by changes in the regulations initiated in 1993 to open power sector to private investment (Ibarra-Yunez, 2008). In 2009, power generated by IPPs contributed about one-third of the total electricity generated in the country (SENER, 2010). Given that private sectors contribution was nil only 10-years ago, this indicates a significant shift towards privatization in Mexican power sector, compared to that in China and India. However, the uncertainty in the policy environment and slow pace of deregulation has been a key deterrent to increased participation by the private sector in all aspects of power sector. Specifically, the reform has been slow in other parts of power sector. To summarize, structural reforms are a key component in meeting long term energy demand of the three economies, but the electricity sectors are far from being competitive. Weak institutional framework and lack of clear policy direction are key impediments in achieving regulatory reforms to make the power sector more competitive in these economies.

Conclusion

Technology will play a major role in mitigation and abatement of GHG emissions from power sector in China, India, and Mexico. Reducing the rate of growth of electricity demand by aggressively pursuing end-use energy efficiency measures and improving the operational efficiency and management of the existing generation fleet are the best options to change GHG emissions trajectory in the short-term. In the medium term, deployment of renewables and nuclear power needs to be accelerated. Retrofitting the existing fleet to meet strengthened environmental standards, and accelerated fleet-turnover, coupled with adoption of state-of-the-art high efficiency generation technologies, such as SC and USC boilers and advanced gas turbines should play an important role in meeting the increasing demand while emitting the least amount of GHG emissions. In parallel, significant R&D efforts will have to be undertaken to adapt the off-the-shelf generation technologies to suit local needs. Moreover, in the medium to long term, developed countries will need to provide financial and technical support for these countries and partner with them to develop, design, demonstrate, and deploy end-of-pipe controls for capturing carbon dioxide, and its sequestration. In general, effective GHG mitigation in these three countries requires a common understanding and equitable sharing of costs and benefits among both developing and industrialized countries.

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