Report No. 54607-IN

Energy Intensive Sectors of the Indian Economy

Path to Low Carbon Development

Energy, Environment, Water Resources
and Climate Change Units
Sustainable Development Department,
South Asia Region
The World Bank

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PATH TO LOW CARBON DEVELOPMENT

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and Climate Change Units
Sustainable Development Department,
South Asia Region
The World Bank

ESMAP
Energy Sector Management Assistance Program

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Abbreviations

BEE	Bureau of Energy Efficiency
CD	compact disc
CEA	Central Electricity Authority
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
g	grams
DVD	digital video disc
GDP	gross domestic product
GHG	greenhouse gas
GOI	Government of India
GW	gigawatts
IEA	International Energy Agency
kWh	kilowatt-hours
MW	megawatts
NAPCC	National Action Plan on Climate Change
NPV	net present value
PLF	plant load factor
SME	small- and medium-size enterprise
T&D	transmission and distribution
TWh	terawatt-hours
VCR	video cassette recorder

All currencies are U.S. dollars unless otherwise noted.

All years are financial years in India (April to March), unless indicated otherwise, with the year indicating the first year of the financial year. For example, 2007 represents financial year 2007/2008, or April 2007 to March 2008.

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The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank that assists low- and middle-income countries to increase know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth.

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Executive Summary

Initiated in 2005, this study was requested by the government of India to: (a) develop the analytical capacity required to help identify low-carbon growth opportunities, up to the end of the 15th Five Year Plan (March 2032), in major sectors of the economy; and (b) facilitate informed decision-making by improving the knowledge base and raising national and international awareness of India's efforts to address global climate change.

India is at a unique juncture in its development. Prior to the recent global economic and financial crisis, its gross domestic product (GDP) grew at more than 9 percent annually between 2003 and 2007, with high rates of investment and savings and strong export growth. This rapid economic growth generated substantial potential for public and private investments in infrastructure development. As outlined in India's 11th Five Year Plan (April 2007– March 2012), the government of India is aiming to double per capita GDP over 10 years. Achieving such rapid income growth for a country as populous as India will require transformative changes in all sectors, including in the energy sector.

Accordingly, carbon dioxide (CO_2) emissions are set to grow rapidly if the government's growth and development objectives are to be met. However, during the run-up to Copenhagen, where the international community was striving to come up with a comprehensive agreement to combat climate change, India made a significant announcement that it intends to reduce 20 to 25 percent of its carbon intensity by 2020 against a 2005 baseline. With its relatively low carbon footprint and a steadily declining carbon intensity over the last decade, India will further its contribution to reduce climate change by this voluntary target.

India has the tremendous challenge of meeting the energy needs of its growing economy while also connecting and providing lifeline electricity to about 400 million people who currently do not have access and to address chronic energy shortages within the context of tight fiscal constraints and limited availability of low-cost, lower-carbon energy resources.

The scale of the growth of energy demand in India raises obvious questions about the time path of the country's CO_2 emissions, which has strong global implications: according to the International Energy Agency (IEA 2009), India's CO_2 emissions from fuel use in 2007 were less than 5 percent of the world total; however, as mentioned above, its global share of emissions is projected to increase with economic development. India relies heavily on coal for its commercial energy demand (53 percent of installed generation capacity) but lacks other domestic energy resources, and is increasingly dependent on imports of fossil fuels to meet demand. The reduction in the growth in total CO_2 emissions will depend on the extent to which total growth in energy use is offset by a combination of: (a) further reduction in energy intensity of GDP, allowing growth and development goals to be met with less growth in energy use and associated CO_2 emissions than currently projected; and (b) a further reduction in the CO_2 intensity of energy use through greater increases, where possible, in the share of energy demand met by lower-carbon or even carbon-neutral energy resources.

This collaborative study by the World Bank and the government of India uses an innovative bottom-up model and examines CO_2 emissions from energy use in India beginning in 2007 through the 15th Five Year Plan, ending in March 2032. The report focuses in particular on power generation; energy consumption in six energy-intensive industries (iron and steel, aluminum, cement, fertilizer, refining, and pulp and paper); energy consumption in nonresidential buildings; electricity consumption by households; and fuel use in road transport, all of which are estimated to contribute significantly to India's future CO_2 emissions.

The findings reported represent India's potential "carbon futures"—how total emissions might evolve to 2031 under different assumptions about the drivers of energy supply and demand, in particular the potential evolution of total emissions from several sectors of the economy in the scenarios considered. The study does not in any way recommend a future carbon trajectory; that decision is for India itself to make based on national development considerations and the process of international negotiations on greenhouse gas (GHG) mitigation. Nor does it provide a cost-benefit analysis of alternative measures to limit the growth of CO_2 emissions, because of the limited knowledge of associated transaction costs.

The report is divided into seven chapters. Chapter 1 discusses India's current carbon footprint, the drivers that will contribute to growth in GHG emissions, the objectives of the study, and the scope and methodology of the analytical approach. Chapter 2 provides an overview of each of the sectors covered by the study, along with their respective specific challenges and past performance, and the modeling approach adopted in the study. Chapters 3, 4, and 5 provide the specific assumptions and findings of the three scenarios:

(1) Scenario 1, alternatively called Five Year Plans scenario, assumes full implementation of the Five Year Plans and other projections and plans by the government of India

(2) Scenario 2, alternatively called delayed implementation, more closely follows historical performance in implementation of the Five Year Plans

(3) Scenario 3, or all-out stretch scenario, adds to scenario 1 additional steps to increase energy efficiency and low-carbon energy sources

Sensitivity analysis is conducted on each scenario. Chapter 6 provides a brief comparison of the results of the three scenarios, and chapter 7 concludes with a brief description of the challenges of low-carbon development in India.

All scenarios and their sensitivity analyses show emissions of CO_2 equivalent (CO_2e) from the sectors studied increasing from 1.1 billion in 2007 to between 3.2 and 5.1 billion tonnes of CO_2e in 2031. The overall carbon intensity of the sectors studied is set to fall against a 2007 baseline in scenario 1 by 19 percent by 2020 and 32 percent by 2031, whereas an all-out effort on the technical, financial and institutional fronts in scenario 3 would result in a reduction in carbon intensity of 29 percent by 2020 and 43 percent by 2031. This is consistent with the government's voluntary target of reducing carbon intensity by 20 to 25 percent by 2020 against a 2005 baseline, which was announced immediately prior to the Copenhagen negotiations in December 2009.

With respect to electricity generation and supply, three major findings emerge from the modeling exercise. First, the model estimates that coal-fired generation plants are likely to continue to dominate energy supply to the grid despite considerable efforts to increase the share of less carbon-intensive sources of power. The share of total power generated derived from coal increases from 73 percent in 2007 to 78 percent in scenario 1 (Five Year Plans). The increase in coal's share of generated power is a consequence of the lack of significant alternative natural resources in India, lack of availability of lower-carbon technologies such as solar at affordable prices, and the abundance of (global and domestic) coal and its relatively low prices. Should the Five Year Plan scenario experience significant delays in implementation, as observed in the last three Five Year Plans (April 1991 to March 2006), the share of total power generated from coal increases to 84 percent (scenario 2) and total emissions increase at a higher pace. Only in scenario 3 (all-out stretch) does the share of coal decline slightly to 71 percent.

The amount of CO_2 emitted per kilowatt-hour (kWh) varies markedly from scenario to scenario. Compared to 2007, CO_2 emissions per kWh of grid electricity in 2031 are about 19 percent lower under the all-out stretch scenario, almost 13 percent lower under scenario 1 (the Five Year Plan scenario), and just about 3 percent lower under scenario 2 (delayed implementation scenario). Compared to the all-out stretch scenario, CO_2 emissions per kWh of grid electricity in 2031 are almost 20 percent higher under scenario 2 and 8 percent higher under scenario 1. By far the most carbon-intensive is scenario 2, because of the delay in the reduction of technical transmission and distribution losses, and halving of the rates of construction of new supercritical power plants and renewable power generation compared to scenario 1.

Another finding of the model is that reducing technical transmission and distribution losses remains one of the most cost-effective means of improving power sector performance while simultaneously reducing CO_2 emissions. Reducing technical losses is in fact equivalent to adding new capacity with no increase in CO_2 emissions. For example, by accelerating the implementation of the transmission and distribution loss reduction programs by 10 years, and assuming that the same amount of grid electricity as in scenario 1 is supplied to end-users, there is a reduction in CO_2 emissions of 568 million tonnes (equivalent to the total emissions of the power sector in 2005) and of 94 billion 2007 rupees (equivalent to US$2.1 billion) in investment in new plants and renovation of existing plants between 2007 and 2031.

Finally, results show that scenario 2 lowers capital expenditures for grid electricity by about 14 percent on the basis of net present value (NPV) compared to scenario 1. In scenario 2, captive generation covers the unmet electricity demand created by delayed implementation, giving a temporary relief to the public sector but imposing higher costs to society as a whole: over the medium term, a portion of investment in the power sector is shifted from the grid system to privately owned, smaller-scale power generators throughout the economy running mainly on diesel. In sensitivity analysis *B* where delayed implementation affects only 20 percent—rather than 50 percent—of generation plants using lower-carbon technology, the capital expenditures for grid electricity are lowered by about 8—instead of 14—percent on a NPV basis.

With regard to household use of electricity, the model confirms that adopting energy efficiency standards for household appliances significantly trims down the electricity demand. Results for scenario 1 show that the amount of electricity used for space-cooling and water-heating makes up slightly more than one third of total electricity consumed, but rises to nearly half by 2031 as household incomes increase. In scenario 3 where there are tighter mandatory energy efficiency standards, the share of electricity consumed for space-cooling and water-heating exceeds 60 percent by 2031, but the total amount of electricity consumed is lowered by almost a third. The largest reduction in electricity consumption occurs with lighting: in 2031, the total amount consumed is 70 percent lower in scenario 3 than in scenario 1.

For nonresidential buildings, the model indicates similar trends as in the residential sector. To assess those trends, consumption of electricity, diesel used for additional power generation, and use of liquefied petroleum gas (mainly for heating water and also for cooking in restaurants) were calculated for six categories of buildings, two of which were separated further into public and private. The model confirms that meeting tighter energy efficiency standards for electric appliances lowers consumption by about 10 percent. In both scenarios 1 and 3, retail stores have the highest share of electricity consumption among the nonresidential buildings. Retail and private offices realize the largest reductions in electricity use in scenario 3. All measures for tightening energy efficiency standards to achieve these reductions are estimated to have real rates of return of 10 percent or higher.

With respect to the transport sector, the model calculates that CO_2e emissions will increase by a factor of 6.6 in scenario 1 and 5.4 in scenario 3 between 2007 and 2031. Emissions from road transport were dominated by those from heavy-duty commercial vehicles (buses and trucks) in 2007, constituting as much as 60 percent of the total. Their relative share declines over time and the share of passenger cars increases rapidly in scenario 1. The model forecasts private ownership in India of 86 cars per 1,000 people in 2031, a level that is significantly lower than the 300 to 765 per 1,000 observed in most high-income countries today. In scenario 3, where tighter CO_2 emission standards for passengers and light-duty commercial vehicles are imposed and modal shifts from private to public transport are promoted, the growth of emissions from passenger cars is substantially curtailed. Emissions from heavy-duty commercial vehicles in scenario 3 exceed those in scenario 1 because of much greater use of buses for public transport.

Shifting passengers from private to public transport reduces congestion and, where the shift is from cars to buses, CO_2e emissions. Shifting passengers from motorcycles to buses, however, does little to reduce overall CO_2e emissions. This is because emissions per kilometer traveled of motorcycles are an order of magnitude lower than those of buses. When converted to CO_2e emissions per passenger-kilometer, there is essentially no difference between the two. Incremental cost calculations show that the technology options to lower CO_2e emissions by 35 percent give a real rate of return of 10 percent or higher for most light-duty vehicles, although tighter CO_2e emissions standards for some vehicles result in lower rates of return. Higher global oil prices in the future could increase the rate of return in each case.

For the total CO_2 emissions of the sectors covered in this study, the model shows that: (i) the largest share of CO_2e emissions continues to come from the power sector (captive generation and grid supply), which in 2031 is estimated to make up 50 percent of the total in scenario 1, 53 percent in scenario 2, and 52 percent in scenario 3. The potential for reducing aggregate emissions in 2031 by implementing all the demand-side and supply-side measures in scenario 3 is estimated to be 815 million tonnes of CO_2 relative to scenario 1. While the largest *volume* of emissions reduction is from the power sector, the highest *percentage* of reduction is from industry.

The study also asked what additional capacity of carbon-neutral generation would need to be added to stabilize CO_2 emissions in the power sector by 2025 with no further growth. Replacing 130 gigawatts (GW) of coal-based and 2 GW of gas-based power generation with carbon-neutral generation capacity beyond scenario 3—for example, adding more nuclear—was found to achieve this stabilization target. By 2031, these measures nearly halve CO_2 emissions relative to scenario 1 in the power sector and reduce the overall CO_2e emissions to 2.8 billion tonnes, which is 2.5 times the 2007 level. It is important to point out that these calculations say nothing about the feasibility or cost of such massive additional introduction of carbon-neutral generation.

CONCLUSIONS AND IMPLICATIONS

Expansion needs for power generation during the study period are vast, with estimated increases from fourfold to as much as sixfold. During the same period, demand for fuel used in road transport may increase more than fivefold. These increases are a natural consequence of income growth and greater availability and delivery of basic services. They occur even with investments that improve supply-side energy efficiency—such as greater thermal efficiency in new power plants and reduced technical losses in transmission and distribution—and demand-side efficiency improvement through adoption of efficient household appliances, continued industrial modernization, higher-fuel-economy vehicles, and other means.

According to this study, electricity consumption of Indian households will remain relatively frugal, with even the richest third of urban households in 2031 consuming only about one third of the average current electricity consumption in the European Union. For the six energy-intensive industries, per capita consumption in India even in 2031 is forecast to be no higher than per capita world production in 2006, despite a significant increase in outputs to support India's growth.

All major sectors of the energy system can contribute to a lower-carbon development and this would require comprehensive and large-scale changes in sector investment, performance, and governance; particularly in the power sector. A crucial first step would be for India to substantially improve upon its past performance in achieving its targets. Unless India allocates financial, technical, institutional, and skills-based resources more efficiently, new power generation capacity addition may continue at half the planned rate as in the past three Five Year Plans. Meeting the targets for the power sector, contained in the 11th and subsequent Five Year Plans, will require coordination and an enhanced performance of institutions across all levels of government—federal, state, and municipal. If grid electricity continues to fall short of demand, then captive generation relying on diesel could expand, resulting in higher costs to the economy and higher overall CO_2 emissions.

In addition to a streamlined regulatory framework, the development of solar power, nuclear power, and other lower-carbon energy sources beyond existing ambitious plans would require significant structural changes, including access to new energy sources and technologies, better delivery mechanisms, and widened access to a skilled workforce. The likelihood of success also depends on putting in place a monitoring and evaluation system to detect any systemic slippages during program implementation and to ensure that early corrective measures are taken.

By 2031, India's urban population is expected to double, placing substantial stress on existing—often insufficient—transport infrastructure, both for long-distance freight and the movement of people within cities. Developing extensive and better mass transit in cities, investing in the shift of freight transport from road to rail, and improving facilities for nonmotorized travel to meet some of this inevitable growth in demand for transport would pose both institutional and technological challenges. It would also be critical that new vehicles entering service have high fuel economy—regardless of what might happen sometime in the future in development of low-cost, low-carbon, and environmentally sound biofuels. At the same time, tighter tailpipe emissions standards for local pollutants are required such that the growth in the in-use vehicle fleet does not further impair air quality.

Ultimately the scope of this study does not allow making conclusive statements about the costs of achieving different future carbon trajectories. While there are capital cost increases because of the switch to costlier technologies, these outlays, however, are only part of the total cost of achieving such ambitious GHG reductions. The speed of the hypothesized carbon-neutral capacity investments in sensitivity analysis *D* for scenario 3 (in which additional fossil-fuel power generation is replaced by carbon-neutral generation capacity) is estimated to increase costs considerably—more than 25 percent—and infrastructure and other investments for substantially reducing transport sector emissions would be very large.

There are possibilities in many sectors for significant improvements in energy efficiency, with low or potentially negligible costs. However, those opportunities depend on accomplishing various policy and institutional changes noted above, which constitutes a challenge. Other barriers include competition for limited funds from projects with higher risk-adjusted rates of return and constraints on financing availability for covering up-front costs. A well-known example of the former in industry is the tendency for a growing firm to choose production capacity expansion over energy efficiency improvement to increase its market share, even if both energy efficiency improvement and capacity expansion give positive rates of return.

Aside from the possibilities discussed to this point, what are the options for truly dramatic reductions in GHG growth, even as energy use expands? One option is to promote international cooperation and regional trade in lower-carbon energy sources and allow India, under appropriate conditions, to have access to natural gas in neighboring countries. Another option is adoption of emerging new carbon-neutral energy sources—beyond wind and hydro, which are already assumed to be maximally exploited in our scenario analysis—providing that they are acceptably safe and relatively affordable. Much international attention has been given to the future role of carbon capture and storage for use with fossil fuels. Aside from the fact that this technology is still precommercial, India's geology does not seem particularly hospitable. Current estimates indicate that India's oil and gas fields plus coal fields have less than 5 billion tonnes of CO_2 storage capacity. This could store national emissions from large point sources for only five years (IEA 2008).

Given the limited outcome of the Copenhagen negotiations, the financing of additional costs for the higher-cost carbon-neutral resources through sales of CO_2 reduction credits or other carbon finance mechanisms has become uncertain. But given the large amounts of carbon-neutral investment needed in scenario 3 and even more so for emission stabilization, unless the carbon-neutral technologies were fairly cost-competitive the carbon finance costs would be staggering.

Ultimately, India needs to decide what steps it will take to meet the continuing energy and economic development needs of its people, taking into account the costs and risks of various options. India also shares with the rest of the world an interest in limiting disruptive and costly climate change. The findings in this study underscore the challenge of meeting energy access, energy cost, and global environmental objectives within the menu of technological options currently available. Where there are synergies between cost-effective efficiency improvement and demand management on the one hand and reduction of carbon intensity on the other, they should be pursued as a top priority.

In addition, if efforts in the non-energy sectors like agriculture and forestry (which the Bank study did not examine) are also sustained, trends indicate that India could achieve its voluntary target while meeting its priority development objectives. Several improvements in technologies and practices in these sectors are known to help reduce carbon intensity, such as the reduction of methane emissions from irrigated rice production and livestock, the reduction of nitrous oxide from the use of fertilizers, afforestation, as well as reforestation.

I. Introduction: India's Current Carbon Footprint and Challenges for Future Development

CONTEXT

In 2005, the government of India requested a study examining strategies for low-carbon growth to: (a) identify low-carbon growth opportunities, up to March 2032, in major sectors of the economy in ways that enhance national growth objectives, relative to baseline conditions; and (b) facilitate informed decision-making by strengthening the knowledge base as well as raise national and international awareness on India's efforts to address global climate change.

India is at a unique juncture in its development. Between calendar 2003 and 2007, before the onset of the global financial crisis, India experienced high rates of investment and savings and strong export growth and its gross domestic product (GDP) grew annually at more than 9 percent. This rapid growth generated substantial public and private resources for investment and development programs. The objectives of the government, as outlined in India's 11th Five Year Plan, are to achieve an annual GDP growth rate of 9 percent and double per capita GDP within 10 years.

For India, the overarching priority is to maintain its economic growth and lift millions out of poverty while providing them with access to modern energy. Although India is the world's fourth largest economy it faces significant challenges in meeting the Millennium Development Goals, as it is home to a third of the world's poor and a quarter of the world's poor without access to electricity (about 400 millions in 2008). In addition, electricity supply is both inadequate and unreliable and more than two-thirds of all Indian households relied on traditional use of biomass as the main source of cooking fuel and one-thirds of households on kerosene for lighting in 2004–05 (NSSO 2007).

Recent World Bank analysis (World Bank 2008a) shows that the number of people who live below a dollar a day in 2005 dollars valued at purchasing power parity—a threshold that is close to the official poverty line—came down from 296 million in calendar 1981 to 267 million in calendar 2005. However, the number of people living under US$1.25 a day increased from 421 million in 1981 to 456 million in 2005. This indicates that in India there are many millions of people living just above a dollar a day and their numbers are not falling.

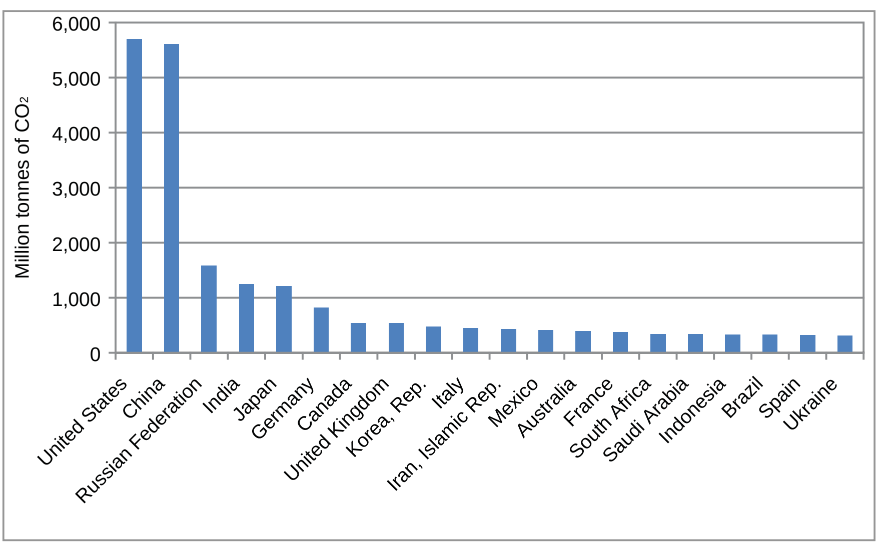
As with China in the past decade, the scope and speed of India's transformation are key questions for the next decade. Should India maintain high economic growth in the coming decade and beyond, it may succeed in lifting millions out of poverty within a generation. But according to a recent IDA Review (World Bank 2009a), India has made less progress than other countries in reducing poverty and resentment about the unequal distribution of the benefits of growth contributes to social discontent. For these reasons, the challenges of inclusive, sustainable growth and service delivery are at the center of the government's priorities.

At the same time, such economic growth would call for increased demand for energy and ensuring access to reliable energy for all to address human development issues. According to India's Planning Commission, "the energy challenge is of fundamental importance to India's economic growth imperatives" (IEP, 2006). If India were to grow annually at 9 percent to 2031, it is likely that India's primary energy supply would need to triple or quadruple and electricity supply would need to increase fivefold or more. Along with quantity, the quality of energy supply also has to improve, with implications for future carbon emissions.

Historically, the Indian economy has a relatively low carbon footprint on a per capita basis. Though India is ranked among the top ten emitters (Figure 1.1) due to the size of its economy and population, the level of its per capita CO_2 emissions from fuel combustion, at 1.2 metric tonnes in calendar 2007, was a fraction of the global average of 4.4 (Figure 1.2). In the same year, India's CO_2 emissions intensity per unit of GDP, valued at purchasing power parity, was at the world average (IEA 2009; World Bank 2009b) (Figure 1.3).

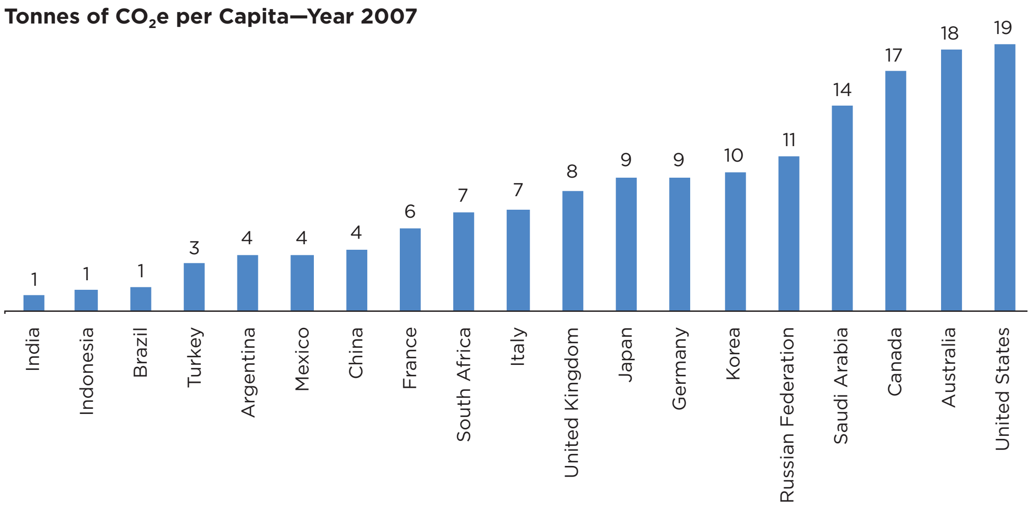
A recent World Bank cross-country comparison (Kojima and Bacon 2009) examined the change in CO_2 emissions from fossil fuel combustion between calendar 1994 and 2006 in 123 countries by separating them into changes in five factors: the carbon intensity of fossil fuels consumed, the share of fossil fuels in total energy used (fossil fuel intensity of energy), the energy required to produce a unit of GDP (energy intensity), GDP per capita, and population. The study defined an offsetting coefficient: the ratio of the negative value of the sum of the changes in emissions of the three factors sensitive to energy policies—fossil fuel mix, fossil fuel share in total energy, and energy intensity—to the change in emissions related to GDP growth (product of the last two factors). During the study period, India offset one third of CO_2 emissions due to GDP growth. India's performance for the full period was comparable to the world average, but

Figure 1.1 | Top Twenty Countries Ranked by CO_2 Emissions from Fossil Fuel Combustion in Calendar 2007



Source: IEA 2009.

Figure 1.2 | India's Per Capita CO_2 Emissions Compared to Other G-20 Economies (2007)



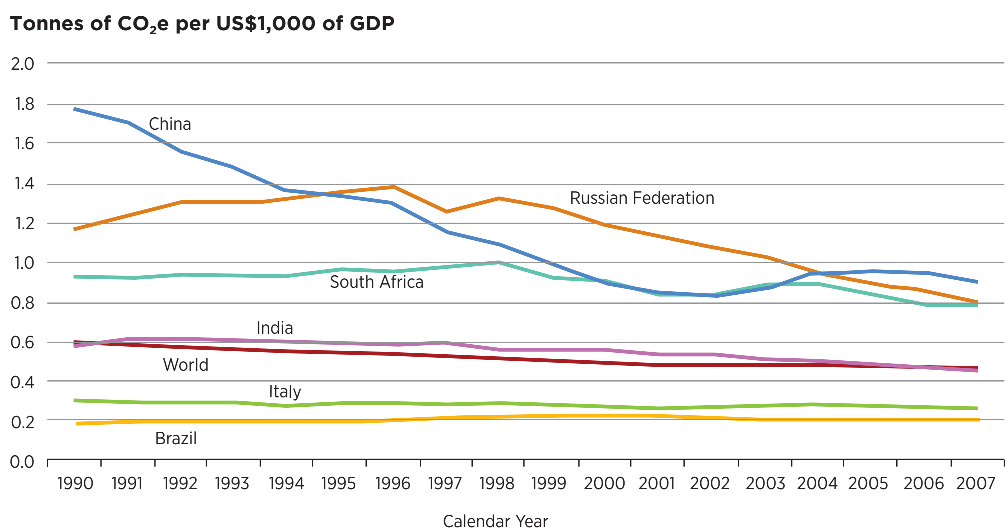
Source: IEA 2009; World Bank 2009b; and authors' calculations.

its offsetting coefficient of 43 percent the second half of the study period was markedly higher than the world average of 18 percent.

The study also identified India as one of the twenty countries in which CO_2 emissions intensity declined successively from the first half to the second half of the study period, with larger declines in the second half. Similar to the world average, the decline in CO_2 emission intensity in India occurred from a relatively low initial level.

India's relatively low carbon footprint can be attributed to several factors. The large numbers of people who still lack access to electricity and modern commercial fuels, and low energy con-

Figure 1.3 | CO_2 Intensity of India Compared with Select G-20 Economies



Sources: IEA 2009, World Bank 2009b, and authors' calculations.

Note: GDP is valued at purchasing power parity in 2005 US$.

sumption of the poor, contribute to low per-capita emissions. Another factor is the change in the composition of GDP with economic modernization since 1990.

More importantly, service and industry sectors reduced their respective energy intensities significantly, with services as a whole registering a greater reduction. Both industry and service sectors have increased their share of GDP at the expense of agriculture, and service more than industry. Because the service sector has lower energy intensity than industry, although higher than that of agriculture, there is a small overall reduction in total use of energy for a given amount of GDP. Increased competition arising from the liberalization of the economy, the increase in energy prices, and the promotion of energy efficiency schemes with the introduction of the Energy Conservation Act in 2001 have contributed to reductions in the energy intensities of the service and industry sectors.

CHALLENGES AHEAD

In the years ahead, however, India faces formidable challenges in meeting its energy needs and providing adequate energy of desired quality in various forms to users in a sustainable manner and at reasonable costs. Any meaningful exploration of India's future economic development and CO_2 footprint must include, as a point of departure, the expansion of modern energy availability to the poor, the reduction in chronic energy shortages, and the government's poverty reduction targets.

Keeping these challenges in mind the government announced an Integrated Energy Policy in 2006. The broad vision behind the policy is to reliably meet the demand for energy services of all sectors including the lifeline energy needs of vulnerable households, in all parts of the country, with safe and convenient energy at the least cost in a technically efficient, economically viable, and environmentally sustainable manner.

As India moves along its current growth trajectory, the pattern of industrialization will also determine its energy demand and hence carbon emissions. In addition to the power sector, energy-intensive industries are other major contributors of CO_2 emissions in India. Interestingly, on the industry side, India's heavy industry sector has recorded more energy efficiency improvement than any other sector since the late 1980s, resulting in reduction of carbon intensity. In addition, total industrial primary energy consumption has increased at a slower rate that the sector's value added since the mid-1980s, demonstrating some decoupling of energy consumption and sectoral GDP. However, a large number of energy efficiency projects with strong financial rates of return remain unrealized in India, in particular in small and medium enterprises. The essential factor hampering the development of these potential energy savings continues to be the underdeveloped state of project delivery mechanisms. Only a fraction of the potential has been tapped using the traditional investment delivery mechanisms operated by local financial institutions.

Another sector of importance to India's growth is the transportation section. Emissions from the latter, which constitute 8 percent of the total GHG emissions of India in 2007, are the fastest growing of any sector. About 90 percent of these were from road transport, compared to a global average of 72 percent. This is one of the consequences of the growth of the vehicle population in the country. Annual growth rates of 5–15 percent, depending on the class of vehicle, have been recorded, and the transport sector faces a number of challenges to cope with the rapidly expanding vehicle fleet population.

There have been major initiatives at the domestic level to deal with energy security, which invariably address carbon emissions. On June 30, 2008, India's first National Action Plan on Climate Change was released, outlining existing and future policies and programs addressing climate mitigation and adaptation (Government of India 2008). The plan identifies eight national missions running through 2017 and directs nodal agencies to submit detailed implementation plans to the Prime Minister's Council on Climate Change. The Prime Minister's Council has already approved the Energy Efficiency Mission, which target 5 percent reduction in annual energy consumption by

2015 compared to a business-as-usual trajectory, and the National Solar Mission, which has set a target of installing 20 GW of solar power by 2020. Prior to the Copenhagen Climate Change Conference, the government also announced that India will cut its carbon intensity by 20–25 percent from 2005 levels by calendar 2020. A group led by the Planning Commission has been set up to develop a strategy for India as a low-carbon economy to feed into the 12th Five Year Plan process.

In the words of Prime Minister Manmohan Singh, India's ability to secure a reliable supply of energy resources at affordable prices will be one of the most important factors in shaping its future energy consumption. In addition to pursuing domestic oil and gas exploration and production projects, India is also stepping up its natural gas imports, particularly through imports of liquefied natural gas. This will require the government of India to maintain and increase the momentum for improving efficiency in the supply chain and developing and tapping into renewable energy at both the national and regional levels to the fullest extent possible.

OBJECTIVES OF THE STUDY

Against this backdrop, the objective of this report is to describe the possible trajectory of GHG emissions out to 2031, under different sets of assumptions organized into particular scenarios described below. To that end the report presents the results of the bottom-up model that was constructed as part of the low-carbon growth study. These results cover the GHG emissions of the 11th, 12th, and subsequent Plans in the power generation, transportation, residential, nonresidential buildings, and industrial sectors until 2031. These five sectors covered 75 percent of GHG emissions from energy use in India in 2007 (IEA 2009), which is the base year for the study.

This report, which is informed by extensive sector dialogue, also offers an opportunity for policy-makers to reassess the validity of sector plans and other proposed actions under the National Action Plan on Climate Change, given the triple constraints India faces—(1) availability of reliable and affordable energy sources; (2) availability of financing; and (3) institutional capacity, including availability of adequate human resources—to carry out these ambitious programs. As the report concerns actions to be taken until 2031, the modeling did not take into account technologies that are not yet commercially viable but that are likely to form part of a low-carbon growth strategy in the longer term, such as carbon capture and storage.

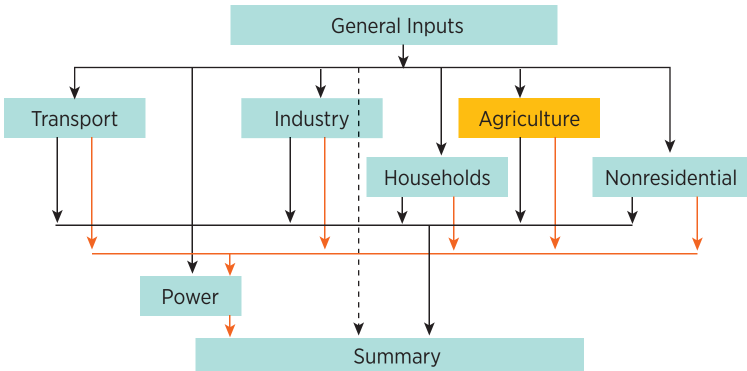
The Government has been an active partner in the analysis, with specific interest in energy efficiency options. Data was collected across several sectors—power supply, household appliances, transportation, industry, and buildings—resulting in a flexible model that has generated interest among various stakeholders in India. Even now, the Indian Government is seeking ways to use this modeling framework as an energy-sector planning tool.

SCOPE AND METHODOLOGY

To compare different carbon futures for India, the study team developed an engineering-based bottom-up model to project future energy demand in sectors of important consumption and expected growth. The model enables comparison of different options for the electricity supply mix to meet those demands, and calculation of associated CO_2 emissions under different scenarios. Although a small fraction of the total emissions computed, the model also includes process-related non-CO_2 GHG emissions in industry and from vehicle tailpipes. The model was developed with the clear intention of transferring ownership and use to institutions selected by the government of India for its future maintenance, updating, and use. It is expected that the government of India will continue to refine the model and populate the necessary data to better reflect the country's reality.

The model outlined in Figure 1.4 includes the following sectors of the economy:

Figure 1.4 | Low Carbon Development Model Structure



Source: Authors.

Notes: Agriculture is not yet included in the model. Industry covers six energy-intensive industries, excluding small- and medium-size enterprises except for iron and steel manufacture.

Supply

- Electricity generation, both grid and captive, and transmission and distribution

Demand (covering energy consumed by end-users)

- Several energy-intensive industries with significant potential for future expansion: (1) iron and steel, further separated into large integrated steel plants and small-scale plants; (2) aluminum; (3) cement; (4) fertilizer; (5) refining; and (6) pulp and paper
- Nonresidential buildings
- Residential electricity use
- Road transport, comprising vehicles ranging in size from two-wheelers to heavy-duty trucks and buses

The underlying approaches and assumptions are given in Annexes 1 and 2. The model calculates:

- future demand within the model based on exogenous variables,
- GHG emissions throughout the supply chain and from consumption,
- the change in investments and operating costs needed to reduce GHG emissions, and
- the net present value (NPV) of future expenditures on reducing GHG emissions.

The power supply portion of the model covers the entire economy; for consumer categories not covered in the study, demand is based on assumed income elasticities and GDP growth. The five sectors studied accounted for about three quarters of CO_2 emissions from energy use in India in 2007 (IEA 2009), which is the base year for the study. Agriculture, an important part of total GHG emissions today, is not included due to non-availability of data, but its relative share is expected to decline as the Indian economy continues to modernize and grow. Detailed recommendations on data collection are included in the background report on agriculture (IFPRI 2009), and once reliable data are available, adequate modeling for the agriculture sector could be conducted.

On the supply side, capacity addition in the power sector—both technology type and unit size—is based on exogenous scenarios derived from Five Year Plans and others discussed with the government of India. New plants are built as needed to cover the required system expansion and the technological choices associated with these new plants are varied under different supply-side scenarios. At any given time, electricity is dispatched from grid-connected power plants to meet projected demand on a merit order basis, minimizing costs.

Although the model focuses primarily on electricity production and use, it also includes on the demand side direct use of petroleum products, natural gas, and coal for industry, and of petroleum products in transport and nonresidential buildings. Household fuel use is excluded because of difficulties in modeling, and diesel use for irrigation and powering agricultural equipment is also not studied for lack of data. Electricity generated from smaller units by households, shops, and others is also not included. Captive power covers electricity generation from a minimal unit size of 1 MW and uses mainly diesel, except in industry, where other fuels may be used. This leaves out the amount of electricity generated from small generators fueled by gasoline or diesel.

Projections for future ownership of vehicles and electric appliances by households are based on assumed GDP and population growth rates, household size, distribution of household income (using expenditures as a proxy), and urbanization. Vehicle fuel use and electricity are projected based on the vehicle size or appliance, technology, kilometers traveled (for vehicles) and hours of use (for electricity). Other demand projections, including industrial commodity sales and building floor space, are based primarily on GDP and population growth, and associated energy consumption on the technology for each application.

This study takes three scenarios and conducts sensitivity analysis on each. The three scenarios take full implementation of future Five Year Plans as a starting point and investigates likely outcomes if there are delays as well as accelerated progress beyond what is planned:

Scenario 1 | Five Year Plan. Full implementation of Five Year Plans.

Scenario 2 | Delayed Implementation. Delayed implementation of Five Year Plans, halving the pace of installation of power generation capacity and a delay of five years for reducing technical losses in power transmission and distribution.

Scenario 3 | All-Out Stretch. Full implementation of Five Year Plans, coupled with accelerated pace of implementation and expanded use of low-carbon and carbon-neutral technologies.

The scenarios and basic assumptions are provided in Table 1.1. GDP growth rates vary across the study years and average 7.6 percent per year in the three scenarios. Sensitivity analysis *A* examines the impact of lowering annual GDP growth to an average of 6.6 percent. Scenario 2 considers delays in both the addition of new generation capacity (with captive power generation making up the shortfall) and in the technical loss reduction program. New capacity addition for certain types of generation reaches only half of the targets set in Five Year Plans—this achievement rate is similar to the historical performance in the past three Five Year Plans. Sensitivity analysis *B* considers increasing the achievement rate from 50 percent to 80 percent. The technical loss reduction program takes five years longer than planned in both scenario 2 and sensitivity analysis *B*. Scenario 3 is the most ambitious of the three, carrying out more energy efficiency measures in all sectors than in scenario 1 (including rehabilitating existing plants to higher efficiency), advancing the date of achieving 15 percent technical losses by 10 years to 2015, and adding more solar and imported hydro power to the energy mix. Sensitivity analysis *C* considers accelerating the loss reduction program by 5 years instead of 10, and sensitivity analysis *D* considers replacing a certain amount of fossil-fuel-based power generation with carbon-neutral generation.

There exists an extensive literature on electricity demand projection, and different approaches are found. One approach makes use of aggregate macro data at the country or sub-national/state level (Bose and Shukla 1999; CEA 2007a). Essentially, this approach aims to estimate the income elasticity of electricity consumption by econometric analysis of the relationship between electricity consumption and its key determinants, such as GDP per capita and electricity price, over a relatively long period of time. Another approach, which may be referred to as a microeconomic

Table 1.1 | Summary of Scenarios

ASSUMPTION CATEGORIES	SCENARIO 1 Five Year Plans	SCENARIO 2 Delayed Implementation	SCENARIO 3 All-Out Stretch
Average annual GDP growth in 2009-2031	7.6%	7.6%	7.6%
Grid generation life extension and efficiency enhancement	As defined in Five Year Plans	Same as scenario 1	Enhanced program
New grid generation capacity expansion	As defined in Five Year Plans	50 percent slippage in new capacity addition for higher-efficiency coal, hydro, wind, and biomass	Additional 20 GW of solar and 20 GW of imported hydro
Technical loss reduction in transmission and distribution	From 29% in 2005 to 15% in 2025	Delayed by 5 years to 2030	Accelerated by 10 years to 2015
Industry, household, nonresidential, transport	Projected based on historical trends and government energy efficiency targets	Same as scenario 1	Additional energy efficiency measures in each sector
Sensitivity analyses	***A.*** As scenario 1 but with a GDP growth rate of 6.6%	***B.*** As scenario 2 but with 20 percent slippage in new capacity addition for higher-efficiency coal, hydro, wind, and biomass	***C.*** As scenario 3 but with only 5 year acceleration (to 2020) of technical loss reduction in transmission and distribution. ***D.*** Additional fossil-fuel power generation replaced with carbon-neutral generation capacity relative to scenario 3.

Source: Authors.

approach, uses micro-level data that reflect individual and household behavior. This approach enables analysis across different heterogeneous household sub-groups and takes a number of household characteristics into account.

This study uses variant of the microeconomic approach and is sometimes referred to as an end-use or bottom-up approach. As with the microeconomic approach, the end-use approach makes use of micro-level data. While the former aims to analyze income-electricity demand relationships through reduced-form equations, the latter examines the ownership and the use of household electricity-consuming devices and considers efficiency scenarios from an engineering point of view, as opposed to micro-economic/econometric.

A key advantage of end-use over other approaches is that it allows the assessment of efficiency scenarios for electrical appliances, their usage, and electricity conservation, as well as the impact of other economic (GDP growth, prices), demographic (population growth, urbanization), and geographical (e.g., rural/urban and regional/state dummies) factors.

II. Sectoral Overview and Study Approach

This chapter provides an overview of the sectors studied and more detailed information on assumptions and the methodology used in each sector. The issues and challenges in these respective sectors have been discussed in greater detail in separate papers published earlier (Rogers 2008; Rogers and Suphachalasai 2008; Sathaye *et al.*, 2010).

POWER GENERATION, TRANSMISSION, AND DISTRIBUTION

The power sector in India is one of the largest emitters of CO_2 in the country accounting for about one half of the total emissions (MoEF, 2010). The share of the power sector CO_2 emissions in the total CO_2 emissions in India is higher than the global average of one-third, the corresponding share of 18 percent in Russia (McKinsey and Co., 2009), of 34 percent in the USA (US EPA 2008), of 42 percent in China (University of Alberta 2008), and of 46 percent in Australia (McKinsey and Co. 2008). The main reason for such a high share is the power sector's heavy reliance upon coal. At the end of calendar 2008, the grid-connected generation capacity was about 147 GW, consisting of 63.3 percent thermal (mainly coal), 24.9 percent hydro, and 11.8 percent other energy sources (CEA 2008a). About 73 percent of the total power generation supplied by the utilities was from coal. Coal-based generation appears likely to remain the linchpin of the Indian power sector at least for the next few decades, given the large domestic coal resources and the absence of any other significant affordable domestic energy sources in the country (Chikkatur and Sagar 2009). The challenges in the power sector are daunting, given the magnitude of the investment requirements to increase the reliability of supply and expand access, the coordination requirements both within the power sector and with institutions outside the sector, and the complexity of the political economy issues.

The state of the power sector in India is currently characterized by an inadequate level of generation capacity, a high level of transmission and distribution losses, poor reliability of supply, and limited electrification rates. Power supply infrastructure and service quality have been identified as among the most binding constraints to economic growth. Power outages are frequent and affect growth. In 2007, the country faced a peak power shortage of 16.6 percent and an energy deficit of 9.9 percent. As a result, more than 60% industries rely on captive power plants (Rud 2009) and the captive generating capacity connected to the Grid was 19.5 GW at the end of March 2007 (CEA 2008a), which represents about 13.3 percent of the overall installed capacity in India. A recent study by the Manufacturers Association for Information Technology (MAIT) and Emerson Network Power India (ENPI) reveals that corporate India may have lost Rs 43,205 crore (about US$9.9 billion) in 2008 as a result of the high occurrence of power outages, both scheduled and nonscheduled. Such losses amount to 1 percent of GDP, and have almost doubled since 2003.

Although unevenly distributed and high, the average level of aggregate technical and commercial losses has been decreasing, from 34.3 percent in 2004 to 32.1 in 2006 (CEA 2009). Reducing those losses further to 15 percent, as currently envisaged under the government-sponsored Accelerated Power Development and Reform Program, will generate additional revenues of about US$4.4 billion and help ease some of the supply constraints.

Addressing the issues above has been rather difficult. India's performance in meeting its plans has consistently been poor, as it has achieved only about 50 percent of its generation capacity expansion targets in the past three Five Year Plans (Table 2.1). According to the Centre for Monitoring Indian Economy, the trend continues as power generation capacity addition is 68 percent below target in 2009. The "White Paper on Strategy for 11th Plan," prepared by the Central Electricity Authority and the Confederation of Indian Industry (CEA and CII 2007), recognized that the power sector is poised for long-term capacity additions and pointed to a number of reasons for slippages in the 10th Plan (in order of decreasing importance): (a) shortages of raw materials and supplies; (b) difficulties in reaching financial closure; (c) delay in deploying supercritical technology; (d) non-availability of natural gas; (e) delay in implementation of hydropower projects due to technical, environmental, and social issues; (f) delay in procurement, in particular for state projects; (g) delay in investment decisions in hydropower projects; and (h) legal issues. The surprising findings were that slippages were more common in private sector projects (only 27.1 percent of the 10th Plan target was achieved), and slightly higher for thermal-based projects (47.6 percent achievement rate) compared to hydropower projects (54.8 percent achievement rate). This trend points to the need for an improved investment climate for private sector players. In addition, the White Paper suggests that a substantial augmentation of the existing domestic manufacturing capability in thermal and hydropower generation and transmission could help reduce project delays.

India has limited options to increase the overall contribution of renewable energy in the grid at current prices and levels of technology development. The government of India has one of the largest programs in renewable energy in the world, covering a wide spectrum of resources such as wind, solar, biomass, and small hydro. Of these, wind has been the most successful program, as India has the fifth largest installed capacity in the world at 9,755 MW in 2008 (MNRE 2009). However, the intermittent or variable nature of wind power, coupled with the moderate wind regime (with low load factors of 20 to 25 percent) in India, limits the capacity of wind power to provide baseload energy, especially in the absence of large energy storage capacities. Hydropower is a promising technology and India already plans to develop full technical capacity by 2031. Even with the development of the entire renewable energy potential (Figure 2.1), the electricity needs of the Indian population would not be met.

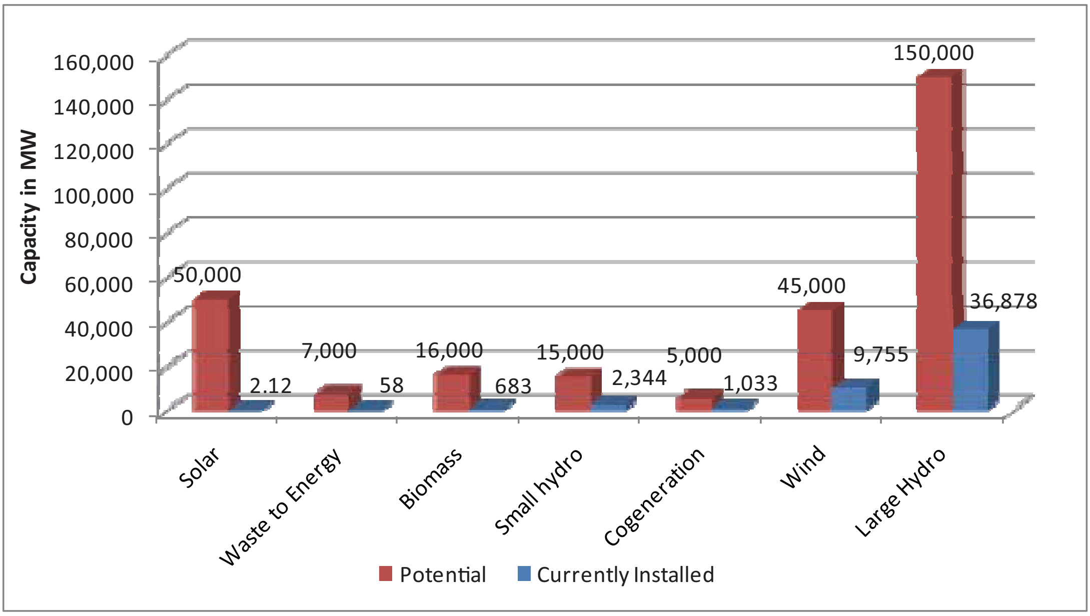
While expanding the generating capacity, the government has also been focusing on supply-side energy efficiency, with mixed results. Nearly all coal power plants in the country rely on one tech-

Table 2.1 | Performance of Power Sector Targets in Five Year Plans

PLAN#	PLANT PERIOD	TARGET (MW)	ACHIEVEMENT (MW)	% ACHIEVEMENT
8th Plan	1992-1997	30,538	16,422	53.8%
9th Plan	1997-2002	40,245	19,015	47.2%
10th Plan	2002-2007	41,110	21,180	51.5%

Source: CEA and CII, 2007.

Figure 2.1 | Renewable Energy Installed Capacity (2008) Compared to Potential in India



Source: 11th Plan proposal MNRE, Government of India (As on January 31, 2009).

nology (steam-based subcritical pulverized coal) (World Bank 2008b). According to CEA (2009), the national average efficiency on gross calorific value of the entire fleet of coal-fired power plants in the country has remained around 32 percent over the period 2004-2007, while the average plant load factor (PLF) has increased from 73.6 to 78.6 percent over the same period. These relatively poor performance and low efficiency of the coal-fired power plants are linked to the poor quality and under-pricing of coal. In general, inferior grades of non-coking coal are used for power generation in India. According to the government's Integrated Energy Policy (Government of India 2006), the properties of coal used for power generation are generally not conducive to high combustion efficiency. The gross calorific value of coal burnt in India's power plants is only about 3500 kilocalories per kilogram and generally lower than those of imported coal, the mineral matter (ash) content is in the range of 27–42 percent, the moisture content ranges from 7–20 percent, the volatile matter content ranges from 15–25 percent, and the sulphur content is generally very low. The low calorific values and high ash content lead to higher specific coal consumption (in comparison with imported coal), high un-burnt carbon losses, higher auxiliary power consumption, and low overall efficiency.

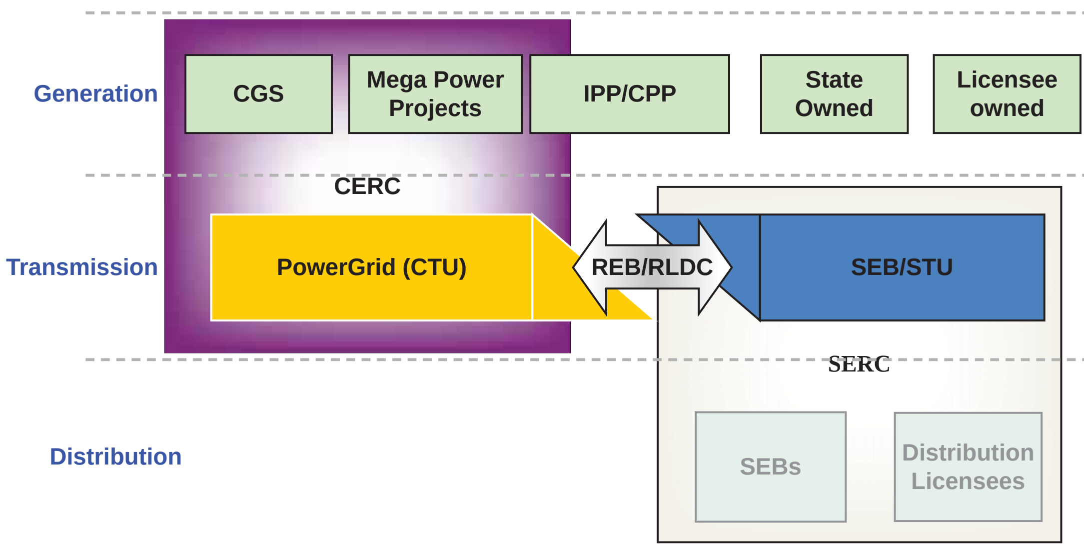
In addition to these technical characteristics, pricing and coal supply chain issues make it difficult to ensure higher efficiency in coal-fired plants. According to the government expert committee report, "Road Map for Modernization of the Coal Sector" (Ministry of Coal, GOI, 2005), and the Integrated Energy Policy, there is a strong need for regulating coal prices in light of market realities, where hard sub-bituminous steam and metallurgical coals are produced largely through two public sector companies, Coal India Limited and Singareni Collieries Company Ltd. The power industry uses coal because its prices are low and are anticipated to remain lower than natural gas prices. As noted in the government expert committee report, establishing a market mechanism for pricing coal in India is not simply a matter of having multiple producers and consumers with minimal entry barriers. Competition and the price determining the demand-supply balance for coal and its alternatives is intricately tied to this regulatory environment. Domestic gas is seeking import parity pricing (as most products in the petroleum sector) even whilst power prices to end-users are regulated. Transport costs for both fuels (rail and port infrastructure for coal, and shipping, port, and pipeline infrastructure for gas) are an important part of the equation.

The "Road Map for Modernization of the Coal Sector" (Ministry of Coal, GOI, 2005) and the Integrated Energy Policy recommend that prices of coal for power generation be distinguished from those for other sectors—which use higher-quality coal—and regulated. The regulation of coal price has to differentiate the pricing for power generation, since it consumes 80 percent of the domestic production and the quality of coal it consumes is too low for the steel and cement sectors. Further, the power sector has to be serviced with long-term contracts and special investments in coal rail transport. Other problems in the coal supply chain need to be addressed to further enhance the quality and quantity of coal supply to the power stations, thus enabling efficiency enhancements. These include lack of availability of coal reserves, large demand-supply gap, low productivity and ageing manpower, and failure to augment exploration capacity and increase underground operations. These problems have led to growing import dependence.

Nuclear power plants currently provide approximately 2 percent of India's electricity, and plans are in place to double that capacity by the end of the 11th Plan (to 7.28 GW). Although development in this area has been hampered by India not being a signatory to the Nuclear Non-Proliferation Treaty, India recently signed the U.S.-India Nuclear Cooperation Approval and Nonproliferation Enhancement Act in October 2008, which allows India to purchase nuclear fuel and technology from the United States. Other nuclear agreements have been signed with several countries since, but challenges remain in the nuclear equipment supply chain because of the limited availability of suppliers.

In the network segments, although on a declining trend, the technical transmission and distribution (T&D) losses remain relatively high. Across the country, they have decreased from an average 31.3 percent in 2004 to an average of 26.9 percent in 2007 (CEA 2009). According to the Ministry

Figure 2.2 | Indian Power Sector: Institutional Framework



Source: Authors.

CGS = central generation station, IPP = independent power producers, CERC = Central Electricity Regulatory Commission, CPP = captive power plants, CTU = central transmission utility, REB = Regional Electricity Board, RLDC = Regional Load Dispatch Centre, SEB = State Electricity Board, STU = state transmission utility, SERC = State Electricity Regulatory Commission.

of Power (MoP 2010) the high T&D losses are the result of ageing and overloaded networks due to inadequate investments in transmission and distribution, improper load management, inadequate reactive power compensation, and uncontrolled expansion of sub-transmission and distribution networks with large-scale rural electrification through long 11-kilovolt and low-tension lines.

Several states have launched with relative success different programs to curb the technical losses such as the use of aerial bunch cables, high voltage distribution systems, and segregation of feeders to have dedicated supply to agriculture consumers. Reducing technical transmission and distribution losses is one of the most cost-effective means of improving power sector performance while simultaneously reducing CO_2 emissions. Reducing technical losses is in fact equivalent to adding new capacity with no increase in CO_2 emissions. This study examines the impact of varying the pace of reducing technical losses in across the scenarios.

The difficulties in addressing energy shortages and improving the efficiency of the power sector are further compounded by the multiplicity of actors in the sector. As shown in Figure 2.2, the electricity sector is handled both at the central and the state levels, since power is a concurrent subject (shared jurisdiction) under the Constitution.

While many progressive policies have been recently enacted at the central level, the state actors remain the main implementation agents, with significant interfaces with the end-users. The states have the responsibility for managing the distribution sector, where the political economy issues have the highest bearing on sector performance. As a result, more than six years after the enactment of the Electricity Act (2003) and associated policies, inadequate electricity service delivery mechanisms remain a critical constraint on India's growth, its economic competitiveness, private investment in energy-dependent industry, and poverty alleviation efforts.

In the power module, the model starts building new power plants in 2012 and continues to build as required to meet demand (with plant mix defined on a scenario basis), according to government of India plans, adjusted as necessary under each scenario. Demand is estimated separately for households, nonresidential buildings, and energy-intensive industries, excluding small and medium-size enterprises (SMEs) except for iron and steel manufacture. Outside of these sectors, demand is based on an elasticity with respect to GDP that declines from 1 in 2006 to 0.67 in 2023 and remains constant thereafter (CEA 2007d).

In thermal generation, new plants are added and, for the existing coal-fired plants, the lowest-performing plants (in terms of thermal efficiency and utilization) are rehabilitated or retired. New additions as well as the renovation and modernization of coal-fired power plants follow the strategy set by the government of India. The model considers captive demand based on historical performance and stabilizes its use once grid supply increases sufficiently to meet new electricity demand (situation of no shortage or surplus). The model subtracts captive generation from total demand to arrive at the demand met by the grid. Technical transmission and distribution losses are added to the grid-based demand and shortages/spinning reserves are considered to calculate the gross electricity supply needed for the grid. Transmission and distribution losses are built in the model in accordance with plans to reduce them over time based on the scenario considered. In the case of hydropower, a similar process to thermal generation is followed, taking into account government of India plans. Besides large-scale hydropower, the model adds renewable energy, including wind power, biomass, and small hydro, according to government of India plans, adjusted as necessary under each scenario.

Table 2.2 shows construction costs of new representative power plant units used in the study and their associated CO_2 emissions per kWh of electricity generated. The emission levels in the table are for new plants and increase over time with plant usage. For each existing plant, the CO_2 emissions per kWh were derived from the Central Electricity Authority's (CEA's) database for 2007-08 (CEA 2008). The total CO_2 emissions for grid electricity are computed based on plant type, size, technology, and age; fuel type; operating conditions; and the dispatch order minimizing variable costs.

Table 2.2 | Costs and Emission Characteristics of New Power Plants

TYPE	SUB-TYPE	CAPACITY (MW)	INVESTMENT IN PLANT & EQUIPMENT (US$/kW)[a]	FUEL	CO_2 EMISSIONS (g/kWh)
Hydro	Large storage	[b]	1,325	—	0
Hydro	Run of river	[b]	1,104	—	0
Nuclear	Heavy water reactor	220	1,435	—	0
Coal	Subcritical	500	883	Domestic	980
Coal	Subcritical	250	930	Domestic	1,000
Coal	Low supercritical[c]	660	945	Domestic	949
Coal	High supercritical[c]	800	969	Domestic	919
Coal	Ultra supercritical	1000	1,041	Domestic	874
Coal	Subcritical	500	844	Imported	957
Coal	Subcritical	250	890	Imported	977
Coal	Low supercritical	660	910	Imported	928
Coal	High supercritical	800	942	Imported	898
Coal	Ultra supercritical	1,000	984	Imported	854
Natural gas	Open cycle	250	662	—	492
Wind	—	100	993	—	0
Solar	CSP with storage	15	6,071	—	0

Sources: Central Electricity Authority 2007; Mott and McDonald 2007; and Authors.

a. Costs provided in rupees in 2007 and converted to U.S. dollars at a rate of 45.3 rupees to the dollar.

b. Costs independent of size.

c. Low and high supercritical refer to low and high steam temperatures and pressures.

— Not applicable.

HOUSEHOLD ELECTRICITY CONSUMPTION

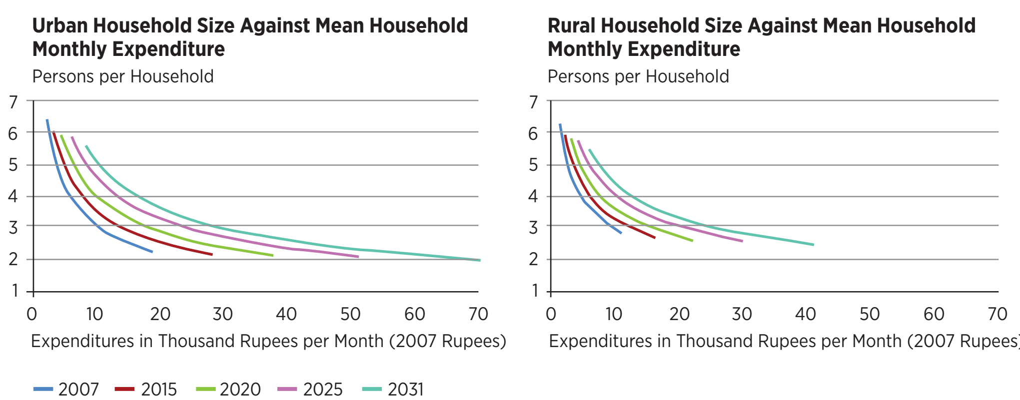
Household electricity consumption in 2007 represented approximately 21 percent of the total electricity demand in India. As with all sectors, household electricity consumption is slated for significant growth. According to the Census of India, India's total population will reach 1.4 billion by 2026, and this, coupled with increasing urbanization (urbanization rate is projected to rise from 29 percent in 2006 to 33 percent in 2026), decreasing household size, and increasing household income and expenditure, is expected to drive greater ownership and use of electrical appliances.

Against this background, the objective of the Standards and Labeling Program of the BEE is to enable the consumer to assess the cost-saving potential of the marketed appliances and equipment and make an informed choice about energy savings. The program is expected to affect energy savings in the medium and long run while positioning domestic industry to compete in markets with mandatory energy efficiency standards. The program was launched in May 2006 and currently covers frost free refrigerators, direct cool refrigerators, tubular fluorescent lamps, air-conditioners, pump sets, ceiling fans, electric geysers and color television sets.

According to a limited survey conducted in this study, lighting accounts for approximately 30 percent of total residential electricity use in 2007, followed by fans, refrigerators, electric water heaters, and televisions. Approximately 4 percent of total residential electricity used was for standby power—the apparently small amount of power that many modern appliances consume when they are turned on. Appliance penetration, particularly of refrigerators and air conditioning units, is expected to be the main driver of growth of residential energy demand by 2020 (McKinsey Global Institute, 2007). In order to build an aggregate of household electricity demand, the appliances that were considered included fans, air-conditioners, air coolers, refrigerators, radios, television sets, washing machines, compact disc (CD) players/video cassette recorders (VCRs), computers, lighting, electric water heaters, ovens, toaster, microwave ovens, and booster pumps.

The study projects household size and expenditure (as a proxy for household income) to 2031 by location (urban, rural) (Figure 2.3). For each location, households are further separated into centiles containing an equal number of people. The study forecasts the number of new electrified households and their expenditure levels for each year based on historical data, and appliance ownership and usage patterns of electrified households as a function of location and household expenditure. Modeling of appliance ownership was based on data from National Statistical Survey Rounds 58 and 61, the survey conducted by the National Council of Applied Economic Research in 2004, and the survey of 600 households conducted in 2007 as part of this study. New appliance sales are derived from the overall annual growth in ownership and the replacement of appliances in service that have been scrapped during that year. The appliance ownership calculation by location and centile—combining the number of households owning each appliance with the number of appliances per household—and assumptions about appliance usage yield the aggregated household electricity demand.

Figure 2.3 | Household Size Distribution, Urban (left) and Rural (right), against Mean Household Expenditure



Sources: National Statistical Surveys and Authors' calculations.

Note: Study projects household size and expenditure as a proxy for household income.

NONRESIDENTIAL BUILDINGS

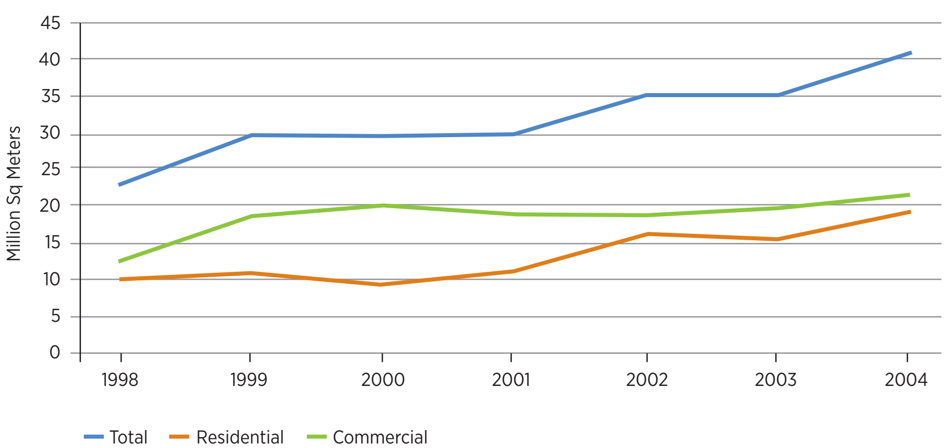
India has historically seen a near-consistent 5 percent rise in annual energy consumption in the residential and commercial sectors. Building energy consumption increased its share from 15 percent in the 1970s to nearly 33 percent in 2004. This growth has been particularly marked in the commercial sector with a growth rate of 8 percent, and the 17th Electric Power Survey forecasts an annual growth of 10.5 percent in the commercial sector over the next five years.

The Construction Industry Development Council estimates that the total new construction floor space added in the commercial and residential sectors was about 43 million square meters in 2004, of which about 23 million square meters was in the commercial sector. The new construction trend shows a consistent annual growth rate of about 10 percent. Gross fixed capital formation shows a similar trend, with more than 18 percent annual growth in the nonresidential buildings sector between 2000 and 2005, with the bulk of the growth taking place in the private sector (MOSPI 2008). Figure 2.4 shows this historical trend in new construction.

Energy use in buildings is affected by the physical characteristics of the buildings, including building design, structure, and layout, location, equipment efficiency, and the occupants' energy-related behavior. Specifically, the two most important parameters that determine the energy use in this sector are the building floor space and the end use technologies in place. These two measures provide different aspects of commercial building use, which allow energy analysis to focus on the characteristics of building use as they relate to either the building stock or the amount of floor space. Energy use is also driven largely by the number and type of energy-using equipment in use and the hours of operation of the building. An additional factor is the difference between the energy consumption patterns in existing buildings and those in new stock.

Of the total commercial floor space in India, about 30 percent is public sector. The distribution further indicates that warehouses, offices, and schools account for the largest share of total floor area, followed by health care and other services. Schools are primarily in the public sector while offices and health have an equal proportion in the public and private sectors. Across all these groups, annual electricity use for lighting and cooling in new construction currently is 173 kilowatt-hours (kWh) per square meter, 27 percent higher than the current average of 137 kWh per square meter for the existing stock. While aggressive efficiency measures in lighting and cooling can reduce power consumption growth in new construction, they are likely to be fully offset in the existing

Figure 2.4 | Historical Trends in New Construction



Source: Sathaye, et al., 2010.

stock by the increased level of appliance use due to modernization of the buildings, both in terms of building renovation and of purchase and use of more electric equipment.

The model considers retail stores, government and private offices, schools, government-owned and private hospitals, hotels, and others. Electricity use for lighting, cooling, fans, and other activities are considered. Three technologies are considered for lighting and six technologies for cooling.

INDUSTRIAL SECTOR

With 35 percent of final energy consumption, the industrial sector in India is particularly energy- and carbon-intensive. Industrial value added grew at an annual average rate of 5.6 percent in the 1990s and 7.3 percent during 2000 to 2005. Industry contributed 26 percent of GDP in 2005 (MOSPI 2007).

The industrial sector can be broadly defined as consisting of energy-intensive industries (such as iron and steel, fertilizer, petroleum refining, cement, aluminum, and pulp and paper) and light industries (for example, food processing, textiles, wood products, printing and publishing, and metal processing). The energy-intensive industries accounted for 66 percent of the energy consumed in the sector in 2005 and this report focuses on these industries: (1) iron and steel, including large integrated steel plants and small-scale industries; (2) aluminum; (3) cement; (4) fertilizer; (5) refining; and (6) pulp and paper.

India has nearly 3 million SMEs, which constitute more than 80 percent of the total number of industrial enterprises in the country. The Indian Institute of Foreign Trade estimates that approximately 60 percent of the country's GDP comes directly or indirectly from such enterprises. Numerous sector-specific studies have confirmed that energy intensity in industry can be reduced with the widespread adoption of commercially available technologies, but SMEs have fallen behind larger Indian industry benchmarks in productivity, technology modernization, and energy efficiency. The SMEs are facing high and rising energy costs and increasing global competition. In the past, wide-ranging governmental fiscal incentives and other interventions have been offered to SMEs to upgrade technologies and improve efficiency, but they have not resulted in large-scale replication.

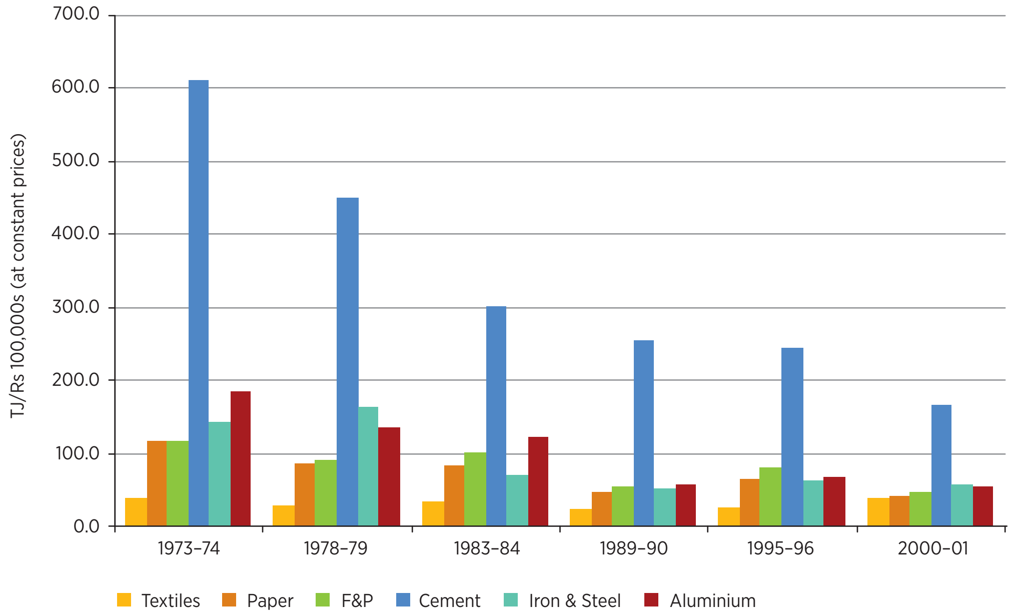
Industry has recorded greater energy efficiency improvement since the late 1980s than any other sector in India (Roy 2007). In addition, total primary energy consumption in industry has increased at a slower rate than the sector's value added since the mid-1980s. Many factors account for this trend, including greater competition following the liberalization of the economy in the early 1990s, rising energy prices starting in the late 1990s, and the promotion of energy efficiency schemes through the BEE since the introduction of the Energy Conservation Act in 2001. However, if barriers to energy efficiency improvements in India can be overcome, there appears to be significant, potentially exploitable energy- and emission-saving opportunities in Indian industries.

The cement industry has recorded by far the most impressive energy intensity reduction, as shown in Figure 2.5. In 1973, iron and steel was the largest consumer of coal (38.5 percent) of the six industries covered in this study, followed by cement (27.8 percent) and textiles (16.8 percent). In 1983, the cement industry exceeded the iron and steel industry in coal consumption. In 2000, the cement and iron and steel industries each consumed 30 percent of industrial coal use.

All the principal industries have shown a declining emissions intensity in recent decades (Figure 2.6). Between 1970 and 2001, the aluminum, cement, and fertilizer industries achieved the largest reduction in emissions intensity (right graph). Textiles, paper, and iron and steel reduced emissions intensity less (left graph). Since 1989, however, the emissions intensity declined only marginally for all industries, except for cement where the significant decline continued, and textiles, where the intensity increased.

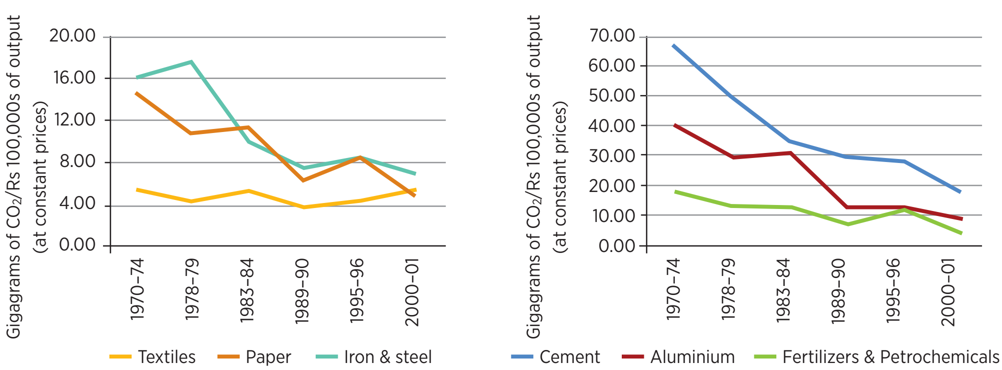
The six energy-intensive sub-sectors modeled in this study are described in detail in Annex 3. In all three scenarios, the model assumes that new plants that are added adopt best energy-efficiency

Figure 2.5 | Energy Intensity of the Six Energy-Intensive Industries from 1973 to 2001



Source: Sathaye, et al., 2010.
Notes: F&P = Fertilizer and petrochemical industries. Energy intensity valued at 1995 prices.

Figure 2.6 | Emission Intensity of Industries



Sources: Dasgupta and Roy 2000, 2001; Dasgupta 2005.

practice appropriate for India at that point in time. More specifically, the model assumes that energy efficiency increases every year by 0.5 percent beginning in 2011 in all newly purchased and installed equipment and plants.

ROAD TRANSPORT SECTOR

Road transport is a significant consumer of energy in the urban environment as well as the major mode of transport for intercity movement, with 65 percent share in freight and 90 percent in pas-

senger. It consumes almost exclusively petroleum products and can be expected to exhibit large growth in energy requirements and GHG emissions over the coming years as rising household income and urbanization promote private vehicle ownership and use.

Although India is relatively less urbanized than many countries, its urban population has increased by over 100 million since 2001. Cities are increasingly becoming the engine of the national economy, accounting for about 60 percent of India's GDP.

Emissions from the transportation sector are the fastest growing of any sector. India's GHG emissions from transport rose from approximately 80 million tonnes per year in 1994 to approximately 119 million tonnes per year in 2000. In 2004, the transportation sector in India contributed about 8 percent of the country's energy-based GHG emissions. About 90 percent of these were from road transport, compared to a global average of 72 percent. It is important to note that roads carry approximately 65 percent of the total freight and 90 percent of passenger traffic across the country. As India grows and becomes further interconnected, GHG emissions are likely to acceler-

ate if the current trend of emission growth continues. Vehicle population in the country is also growing, with rates of 5–15 percent per year, depending on the class of vehicle.

The transport sector faces a number of challenges. It has mixed ownership and management, with the public and private sectors participating in both development and operation of transport services. Until a few years ago, the provision of transport infrastructure for all modes was the exclusive responsibility of the public sector. In cases where the public sector is responsible for provision and maintenance of infrastructure and the private sector for operations, the two sectors at times work at cross-purposes. To maximize their earning and profits, freight operators tend to overload vehicles beyond the upper axle-load limit, thereby damaging the road pavement.

On the other hand, the government does not provide appropriate infrastructure to carry high axle-load traffic, enabling minimization of costs. Inadequate funds are allocated for road maintenance, resulting in poor road surfaces and a consequent increase in the operating costs of road vehicles. Data collected on road conditions in several states for a World Bank-funded project show that 30–40 percent of state roads are in poor to bad condition, increasing fuel consumption by 8 to 12 percent compared to well-maintained roads. In addition, better roads allow higher highway cruising speeds and larger trucks. Based on authors' calculations, the combined impact of these improvements can reduce GHG emissions per tonne of road-freight exceeding 25 percent. Given the amount of vehicle and freight traffic, large fuel savings could be achieved countrywide if roads were properly maintained, and freight vehicles properly loaded.

Further, India is also facing infrastructure capacity constraints in all subsectors of the freight transport system. The high-density traffic corridors connecting the metro cities are facing congestion in both the rail and road subsectors. All measures that could alleviate the congestion in the short to medium term in the rail and road subsectors have long gestation periods, high transaction costs, serious operational weaknesses, and capacity constraints related to the introduction of new technologies in rolling stock and signaling systems, use of information technology to optimize utilization of existing capacities, and better infrastructure capable of serving higher unit loads. In the longer term, it is clear that India will have to invest in capacity additions to alleviate congestion and improve service delivery in a diverse economy. Such investments could include high-speed roads capable of taking higher axle loads; larger, more fuel-efficient, and less polluting vehicles; heavier rail and longer freight trains; and faster freight wagons to reduce the speed difference between passenger and freight trains.

Due to the accelerated rate of urbanization, the provision of urban infrastructure services has lagged far behind the growing demand. Urban infrastructure bottlenecks are increasingly becoming a critical constraint on further urban economic growth. Other factors exacerbating the situation include: (a) insufficient funding for transport infrastructure investments and maintenance, linked to insufficient attention to cost recovery and user charges; (b) imposition of social service obligations on the public sector transport operators (particularly Indian Railways and publicly operated bus companies) without compensation, but also without accountability for performance; and (c) rapid motorization (increasing personal transport).

There are significant technological developments in the manufacturing of passenger vehicles in India that will influence GHG emission growth. Despite the delay in the start of the full production of its Nano, Tata Motors is set up to manufacture 250,000 units annually, against annual new passenger car sales of about 1.3 million in 2008. All other manufacturers are also preparing to launch low-cost cars, although none are planning to match the price of Nano. Making cars more affordable will clearly accelerate the growth of car ownership.

The National Urban Transport Policy offers some guidelines and financial and fiscal incentives to the states and cities for designing their urban transport strategies. It promotes transit-oriented development of new towns and the creation of comprehensive mobility plans in existing cities with the objective of reducing overall transport demand and integrating land use and transport planning. It encourages state governments to set up a dedicated urban transport fund with proceeds from earmarked state and local taxes, and traffic demand management measures such as parking charges, to cover the urban transport investment requirements.

The policy stresses the need to establish modern urban bus services in all cities (most cities currently do not have these) and has produced standardized urban bus specifications to promote quality services. The central government is also providing substantial financial assistance for metro rail projects and bus rapid transit systems, and envisages setting up unified metropolitan transport authorities in all cities with a population of 1 million or more to facilitate coordinated planning and implementation of urban transport programs and projects.

However, there are many institutional barriers to be overcome to catalyze environmentally sustainable urban development and transport development programs at the metropolitan area, city, or municipal levels. According to recent work by the European Commission (European Commission 2007), a combination of technical and nontechnical measures will be required to explicitly limit GHG emissions from road transport. In India, achieving this will be considerably more complicated and any delay in initiating a major structural change in urban design and transport management locks in more GHG emissions for decades.

The modeling of road transport in this study examines consumption of gasoline, diesel, compressed natural gas, and bioethanol used by motor vehicles of all sizes. Private vehicle ownership is modeled in exactly the same way as household appliances, using urban and rural centiles. Because data to model the number of two-wheelers, but not passengers, per household were available, each car-owning household is assumed to have only one, thereby giving a lower bound on car ownership. The model takes into account penetration of low-cost passenger cars in the market. To offset the inability to model the number of cars owned by households, which lowers car ownership across the economy, the model does not assume that the sales of low-cost cars reduce the sales in other car segments.

GENERAL ENERGY EFFICIENCY IMPROVEMENT

Despite the financial attractiveness of energy efficiency investments and several efforts to build the Indian technical capacity to deliver energy efficiency solutions, there has been limited adoption of efficient technologies and replication of best practices. As in many countries, the risk-adjusted profitability is higher for capacity expansion than for energy efficiency measures, and in a rapidly growing economy, there is a tendency for greater investments in capacity expansion. In addition there are numerous barriers and market failures for energy efficiency investments in India, similar to those typically seen in projects globally, as well as India-specific constraints such as access to finance, which is particularly acute but not limited to small- and medium-size enterprises (SMEs). SMEs constitute more than 80 percent of the total number of industrial enterprises in the country, accounting for 45 percent to industrial production, 17 percent of GDP, and 40 percent of India's exports. Indian companies typically face constraints in accessing adequate and timely financing for energy efficiency on competitive terms, particularly longer-tenure loans, but also, in the context of the 2008–2009 financial crisis, working capital loans. In some cases, pricing policies contribute to significant distortions and inefficiencies—such as free power to consumers in the agricultural sector, leading to unsustainable use of natural resources.

Other well-documented barriers to the adoption of energy efficiency and demand-side management schemes in India include: (a) high up-front transaction costs; (b) lack of incentives to utilities who perceive demand-side management as a loss of market base; (c) lack of corporate leadership on energy efficiency and focus on increased outputs, commercial competitiveness, quality, and profitability; (d) lack of intermediation capacity and incentives; (e) the absence of a reliable measurement and verification regime; and (f) lack of trained personnel to integrate the technology, financial, and commercial aspects.

Although there is lack of data to track past performance, several studies point out that actual implementation of targeted government programs aimed at energy efficiency and demand-side management has been sluggish. The 8th Five Year Plan ear-marked Rs 1,000 crore (US$200 million) for targeted programs in energy efficiency with potential savings of 5 GW of installed power generation capacity and 6 million tonnes of petroleum products. As a result of objectives set out in the 9th Five Year Plan, the Energy Conservation Act was enacted and the Bureau of Energy Efficiency (BEE) was established. The 10th Five Year Plan targeted energy savings of 85 million kWh—about 13 percent of the estimated demand of 719,000 million kWh—by the end of the 10th Plan. There were no specific funds allocated to meet the energy-saving targets. Under the various initiatives undertaken by the BEE—the Bachat Lamp Yojana (BLY), the Standards and Labeling Scheme for household appliances, the agricultural and municipal demand-side management, and the Energy Efficiency in SMEs—savings equivalent to 2,600 MW of generation capacity has been targeted (BEE, 2009).

III. Scenario 1: Five Year Plans

Scenario 1, alternatively called Five Year Plans scenario, is based on projections of expansion of electricity generation capacity in the 11th (April 2007–March 2012) and 12th (April 2012–March 2017) Five Year Plans, the Integrated Energy Policy which outlines projections until the 15th Five Year Plan (April 2027–March 2032), papers by the 11th Plan Working Group and the CEA, programs led by the Ministry of New and Renewable Energy such as Jawaharlal Nehru National Solar Mission, and model projections on growth in industry, nonresidential buildings and transport. The scenario includes planned investments to expand capacity, increase reliability, and strengthen energy efficiency.

KEY ASSUMPTIONS

As with all other scenarios, GDP is assumed to grow at an average rate of 7.6 percent between 2009 and 2031. Beyond the 12th Five Year Plan, the model assumes an elasticity of demand for electricity with respect to income falling from 0.78 in 2017 to 0.67 in 2023 and constant thereafter.

More specific assumptions include the following:

- In thermal generation, the share of supercritical coal-fired plants will increase to 20 percent in the 11th Plan, 50 percent in the 12th Plan, 70 percent in the 13th Plan, and 90 percent thereafter. For the existing coal-fired plants, the strategy is to rehabilitate or retire 5 GW of the lowest-performing plants within the 11th Plan, and 10 GW in the 12th Plan. In addition, the Government of India plans to renovate and modernize about 27 GW of coal-fired power plants by 2017, which will improve energy efficiency (World Bank, 2009c).
- Technical transmission and distribution losses are reduced from 29 percent in 2005 to 15 percent in 2025 in accordance with existing plans.
- Captive demand grows from 78,000 GWh in 2006 to 131,000 GWh in 2011 and then remains constant thereafter (MoP, 2007). This is subtracted from the total demand to arrive at the demand met by the grid. Transmission and distribution losses are added to the grid-based demand and shortages/spinning reserves considered to calculate the gross electricity supply needed for the grid.

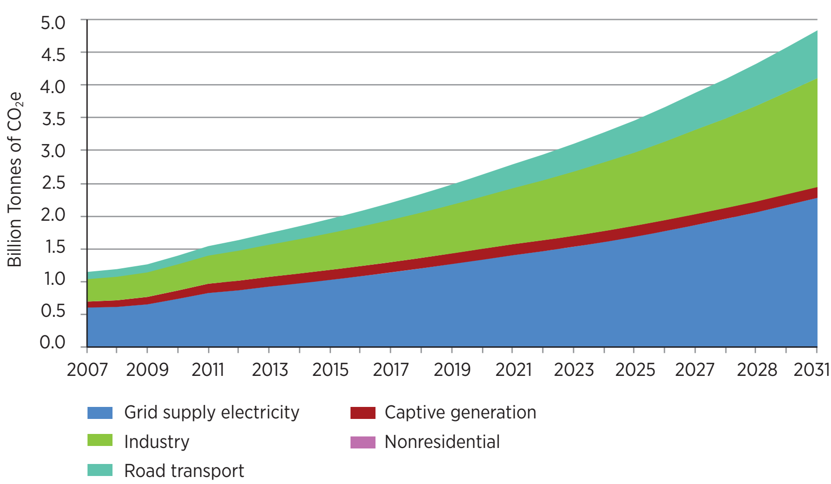
- In the case of hydropower, the Government of India has an ambitious plan to realize the full potential (150 GW) by 2031, which is a fivefold increase in installed hydropower capacity within the next two decades. The Government also has interim targets of a 50 percent increase in hydropower capacity in the 11th Plan (from 35 GW to 51 GW) and another 59 percent increase in the 12th Plan (from 51 GW to 81 GW).
- Besides large-scale hydropower, the Five Year Plans envisage increasing renewable energy, including wind power, biomass, and small hydro, to 10 percent of installed capacity by April 2012 (from the current share of 8 percent). According to current plans, India would have harnessed 88 percent of its available potential for wind and 43 percent of small hydro potential by 2021.

KEY FINDINGS

Overall, the model predicts that, in the five sectors, CO_2-equivalent (CO_2e) emissions will increase from 1.1 to 4.9 billion tonnes in 2031, despite significant investments to develop domestic renewable energy sources such as hydropower, wind and biomass as well as improvements in efficiency as envisaged in the Integrated Energy Policy and the 11th Five Year Plan. Among the various sectors, grid electricity supply accounts for 51 percent of the emissions increase, followed by 20 percent for industry, 16 percent for road transport, and 4 percent for captive power generation (Figure 3.1). Nonresidential buildings account only a small share of the overall increase according to the model.

As per the model, India's installed power generation capacity will need to increase fivefold from 145 GW to about 720 GW by 2031. The emission increase from the power sector dominates since model projections show that coal-fired generation plants (59 percent of installed capacity by 2031 as shown in Figure 3.2) are likely to continue to be the mainstay of energy supply to the grid, despite considerable efforts to increase the share of renewable and other lower-carbon energy in the power generation mix. By 2031, the share of coal-fired plants will likely increase from 55 percent

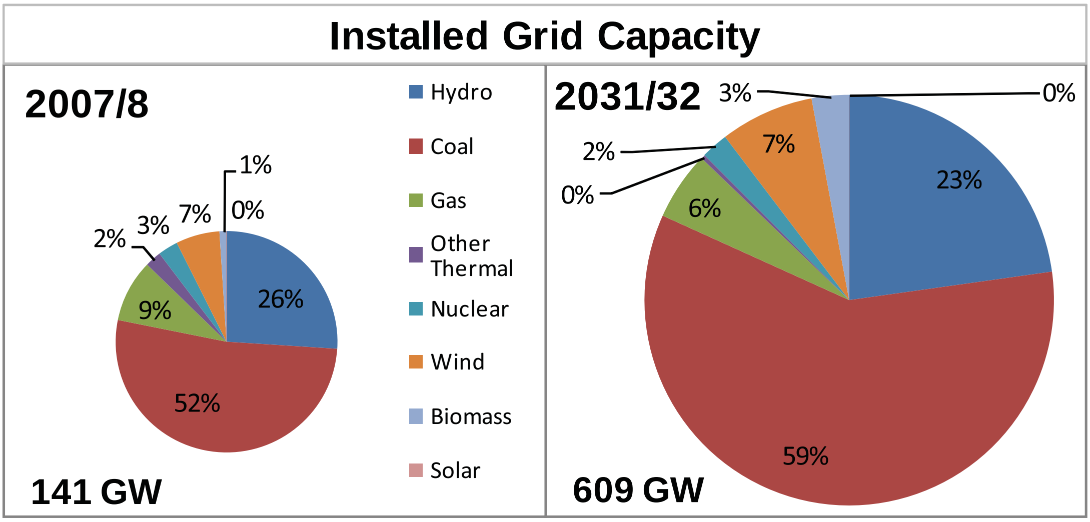
Figure 3.1 | Total CO_2 Emissions in Scenario 1 (billion tonnes)



Source: Authors' calculations.

Notes: Electricity supply—grid and captive—covers electricity used across the entire economy, including those areas not covered by this study. Industry covers process-related emissions and direct use of fossil fuels in the six subsectors. Nonresidential covers direct use of fossil fuels. Road transport covers gasoline, diesel, compressed natural gas, and bioethanol used by motor vehicles of all sizes. Nonresidential buildings contribute so little from using diesel and liquefied petroleum gas (LPG) that their total contribution is not visible in the figures.

Figure 3.2 | Share of Coal-Based Generation Capacity in 2031 in Scenario 1

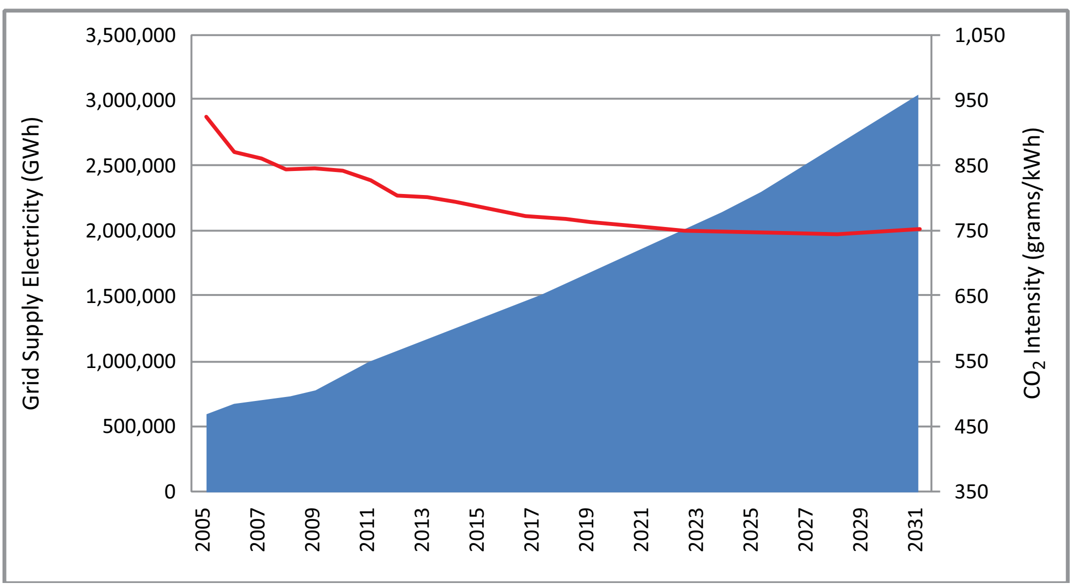


Source: Authors' calculations. 2007/8 plot is based on the CEA CO_2 Baseline Database for the Indian Power Sector updated with data from CEA website (November 5, 2009) on commissioned plants and those under construction.

to 65 percent in the generation capacity (MW), but the carbon intensity of the sector will likely decrease (Figure 3.3). This is simply a consequence of the lack of natural resources in India, lack of availability of lower-carbon technologies such as solar at affordable prices, implementation issues, and the abundance of (global and domestic) coal and its relative cost advantage.

Among the various efficiency improvement options, the reduction of technical transmission and distribution losses clearly appears as a measure that can both reduce GHG emissions and provide significant co-benefits in terms of energy security and the reduction of local air pollution. If one considers a transmission and distribution loss reduction from the current estimated level

Figure 3.3 | Evolution of Grid Electricity Supply and Associated CO_2 Intensity



Source: Authors' calculations.

of 29.3 percent to 15.05 percent in 2025 as planned, then the energy supplied through the grid decreases by a total of 16 percent of supplied power over the 25-year period.

In Scenario 1, the tonnes of CO_2 per tonne of product in industry fall as newer, more efficient production capacity is added to meet the growing demand. Between 2007 and 2031, the integrated steel producers reduce their emissions intensity by more than 19 percent, small iron and steel plants and fertilizer manufacturers about 17 percent, aluminium and cement manufacturers about 12 percent, pulp and paper 8 percent, and refining less than 1 percent.

In nonresidential buildings, the changes in scenario 1 from 2007 to 2031 are complex since new buildings have higher specific energy consumption per square meter than pre-existing buildings. Energy consumption in pre-existing buildings also increases as more appliances and equipment are added. These are offset by improvements in appliance efficiency. Overall, the average CO_2 intensity (tonnes of CO_2 per square meter of floor space) of nonresidential buildings decreases from 2007 to 2031 by 7 percent, ranging from an increase of 11 percent for hospitals to a reduction of 25 percent for schools.

The tonnes CO_2 emitted per household from electricity consumption rises 50 percent from 1.1 to 1.7 from 2007 to 2031 despite appliances becoming more efficient, because more households gain access to electricity and rising income spurs greater appliance ownership and use. The rise in electricity consumption is concentrated particularly in low-income households. Between 2007 and 2031, the share of electricity use by the bottom third of the population increase from 13 percent to 19 percent in urban areas and from 11 percent to 23 percent in rural areas. During the same period, the top third of the population will record a decreasing relative share, from 61 percent to 49 percent for urban and from 64 percent to 43 percent for rural. However, electricity consumption in India will still remain far below that in the European Union or North America. For example, electricity consumption of the top third of the Indian population in 2031 is expected to be only one third of the EU-15 average electricity consumption of 2004.

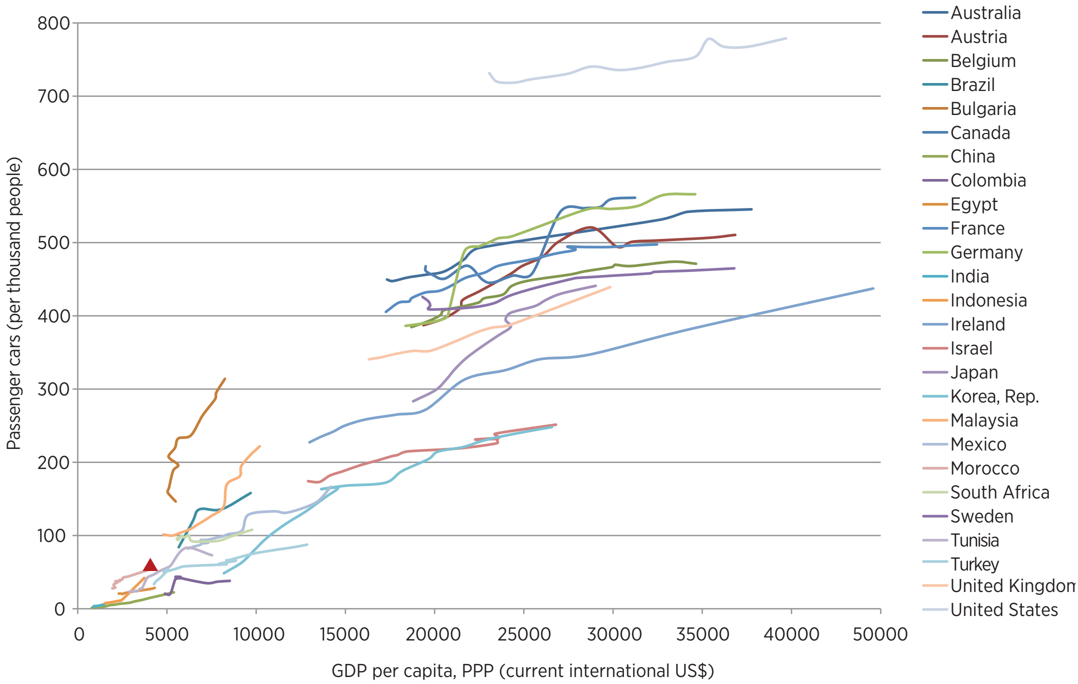
The share of lighting in the total residential electricity use will decline from 30 percent to 21 percent by 2031 due to the increased use of other appliances. By that year, heating and cooling appliances are estimated to consume 270 terawatt-hours (TWh) a year, or 48 percent of total residential electricity. Of this, the largest consumption is for operating fans (36 percent), followed by electric water heaters (26 percent), air coolers (20 percent), and air conditioning (18 percent).

Kitchen appliances are estimated to consume 102 TWh in 2031, or 18 percent of the total. Of the 102 TWh, 82 percent will be for refrigerators, followed by 6 percent for washing machines, 5 percent each for electric ovens and toasters, and 3 percent for microwave ovens. Entertainment appliances as expected to consume another 77 TWh, or 13 percent of the total. Out of 77 TWh, television sets account for 78 percent, compact disc (CD) and MP3 players 13 percent, radios 6 percent, digital video disc (DVD) and video cassette recorders (VCRs) 2 percent, and computers 1 percent.

In road transport, car ownership grows from 5.7 million in 2006 to 41.4 million in 2020 and to 113 million in 2031. Motorcycle ownership grows 40 million in 2006 to 164 million in 2020 and to 287 million in 2031. Nano and other low-cost cars are included; their inclusion increased the number of cars at the expense of two-wheelers. Since the average CO_2 emissions per passenger-kilometer by car are approximately three times those by motorcycle, vehicle fuel consumption and CO_2 emissions increase over time. Rapid growth of vehicle purchase notwithstanding, car ownership in 2031 will continue to be lower than the average of about 350 for every 1000 persons in the countries belonging to the Organisation of Economic Co-operation and Development (Figure 3.4).

The sensitivity analysis *A* on scenario 1, taking lower GDP growth, reduces both demand and CO_2e emissions. In 2031, GDP in the sensitivity case is 19 percent lower than in scenario 1, and CO_2e emissions are 14 percent lower, reflecting a GDP elasticity of CO_2e emissions smaller than unity. Among the various sectors, grid electricity supply accounts for 47 percent of the total emissions, followed by 34 percent for industry, 15 percent for road transport, and 4 percent for captive power generation (Figure 3.5). Nonresidential buildings account only a small share of the overall increase according to the model.

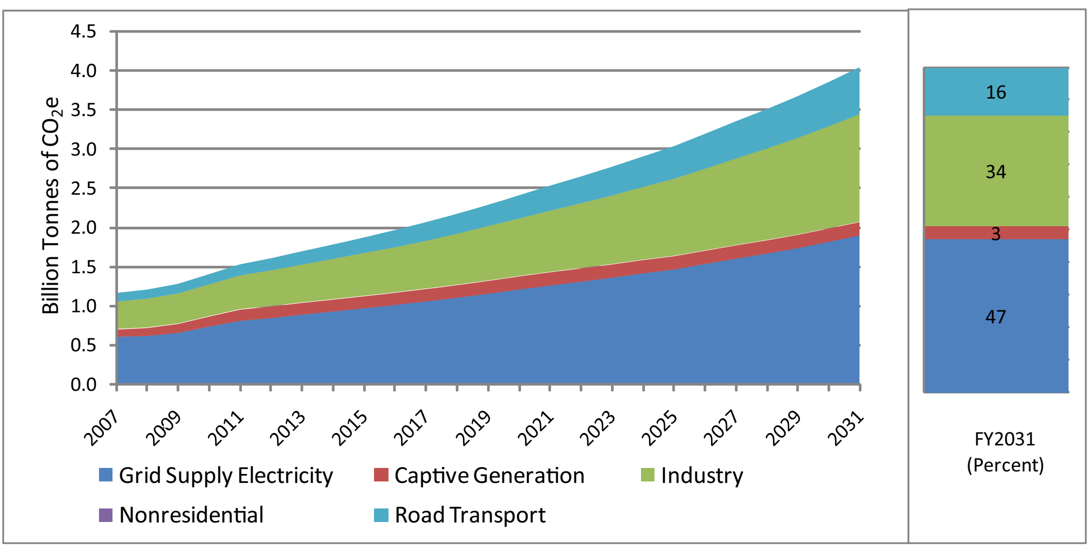
Figure 3.4 | Car Ownership per Thousand People (in relation to GDP per capita) 1990-2008



Source: Author's calculations (for India) and data from OECD/IEA (2007).

Note: ▲ India is estimated to have 86 cars per 1000 people and a GDP/capita of US$3700 in 2031/2. US passenger cars include other 2 axle and 4 tire vehicles. *Sources:* EarthTrends (http://earthtrends.wri.org), World Bank Database, US National Transportation Statistics.

Figure 3.5 | Emission Profile for Lower GDP Growth Sensitivity Analysis



Source: Authors.

Notes: See notes for Figure 3.1.

IV. Scenario 2: Delayed Implementation of Supply Measures

Meeting all targets of Five Year Plans, as assumed in scenario 1, might require a paradigm shift in how power sector operations are conducted and monitored, projects are implemented (existing assets maintained and modernized, and new assets added), and sector development is planned. Scenario 2 is based on the achievement rates of the past three Five Year Plans and builds into its assumptions delayed implementation of electricity supply measures.

KEY ASSUMPTIONS

Scenario 2 assumes that, relative to scenario 1, there will be delays with respect to the following measures:

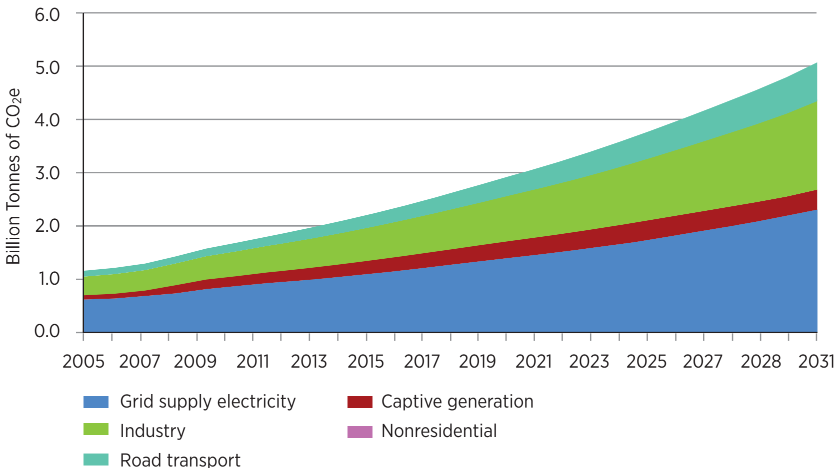
- A delay of five years in the transmission and distribution reduction loss program
- Hydropower capacity added at half the rate, reaching by 2031 half of what is technically achievable
- Supercritical coal-fired power plants built at half the planned rate
- Wind, solar, and biomass-based plants built at half the planned rate.

Unmet demand would be satisfied by additional captive power generation. Sensitivity analysis *B* on scenario 2 explores the implications of new capacity addition for the technologies mentioned above at 80 percent of the rates assumed in scenario 1.

KEY FINDINGS

In scenario 2, CO_2e emissions increase from 1.1 to 5.1 billion tonnes in 2031, as shown in Figure 4.1. Among the various sectors, grid electricity supply now accounts for 43 percent of the increase, followed by industry which accounts for 33 percent. Road transport results in a 16 percent increase and captive power contributes about 8 percent to compensate for the decline in grid-supply. Non-residential buildings account for only a small share of the overall increase.

Figure 4.1 | Total CO_2 Emissions in Scenario 2 (billion tonnes)

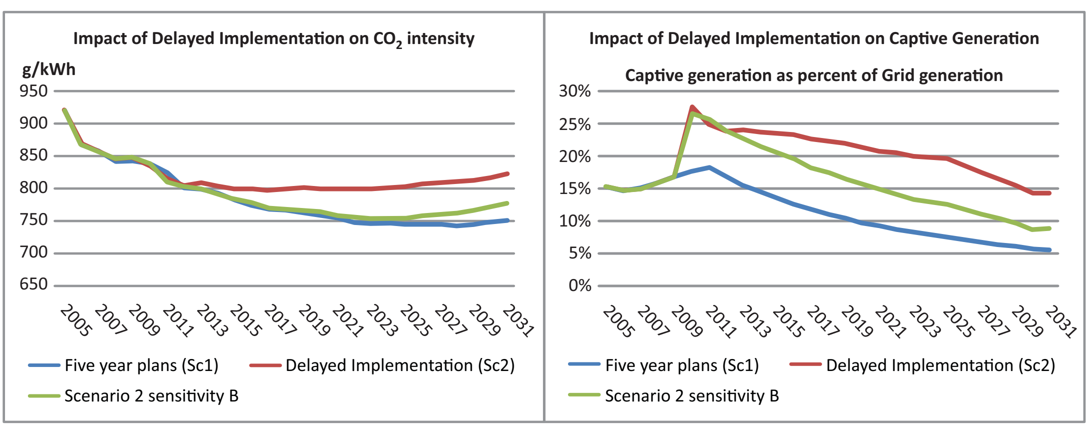


Source: Author's calculations.

Scenario 2 shows the impact of slowing the addition of new capacity for higher-efficiency coal, hydro power larger than 10 MW, small hydro, wind, and biomass, together with a five-year delay in meeting the transmission and distribution loss reduction targets. Sensitivity analysis *B* limits the slippage in new capacity addition to 20 percent. As can be seen in Figure 4.2, the carbon intensity of the grid electricity supply rises as a result. By 2031, captive power generation is expected to supply 14.4 percent of electricity (compared to 5.5 percent in scenario 1) and the carbon intensity of the grid increases to 820 g CO_2/kWh (9 percent higher than the 750 g CO_2/kWh in scenario 1). In sensitivity case B, by 2031, captive generation supplies 9 percent of electricity and the carbon intensity of the grid increases to 780 g CO_2/kWh.

Table 4.1 shows that delayed implementation lowers capital expenditures for grid electricity by about 15 percent. Captive generation covers the unmet electricity demand created by delayed implementation, giving a temporary relief to the public sector but incurring higher costs to the society as a whole. Over the medium term, a portion of investment in the power sector is shifted

Figure 4.2 | Impact of Delayed Implementation in Scenario 2 on CO_2 Intensity and Captive Power Generation



Source: World Bank staff calculations.

Table 4.1 | Investment Costs for Life Extension, Efficiency Improvement, and New Capacity in Grid-Supplied Electricity

	BILLIONS OF 2007 RUPEES		DIFFERENCE FROM SCENARIO 1	
SCENARIO DESCRIPTION	NPV (2007)	TOTAL	NPV (2007)	TOTAL
Scenario 1				
Life extension and efficiency improvement	570	1,400	0	0
New capacity	8,000	24,000	0	0
Total	8,600	25,000	0	0
Scenario 2				
Life extension and efficiency improvement	480	1,600	–90	200
New capacity	6,900	19,000	–1,100	–4,400
Total	7,400	21,000	–1,200	–4,200
% difference	—	—	–14	–17
Sensitivity analysis *B*				
Life extension and efficiency improvement	490	1,700	–80	240
New capacity	7,800	22,000	–200	–1,800
Total	8,300	24,000	–300	–1,600
% difference	—	—	–4	–6

Source: Authors' calculations.

Notes: NPV computed using a discount rate of 10 percent. Rupees are in 2007 rupees. Total is the sum of annual investments without discounting. All numbers in the table are rounded off. Differences do not exactly match the differences between the numbers in the table as a result.

from the grid system to privately-owned, smaller-scale power generators throughout the economy running mainly on diesel. In sensitivity analysis *B*, less slippage raises capital expenditures for grid electricity, and the overall capital expenditure level is only about 5 percent lower than in scenario 1.

The direct expenditure on rehabilitation and modernization and new plant and equipment for grid-supply over the 23-year period in the model shows a decrease of 17 percent in scenario 2 when compared to scenario 1 and a decrease of 6 percent in sensitivity analysis *B* when compared to scenario 1. However, greater expense and investments are borne by the private sector through higher captive generation, and will entail higher overall costs to the economy.

V. Scenario 3: "All-Out Stretch" Scenario

It is often suggested that if the technology and resources become available, then India will be able to undertake many more actions on the demand side to further lower its low-carbon path than envisaged in the 11th Five Year Plan and the Integrated Energy Policy.

KEY ASSUMPTIONS

Relative to scenario 1, the "all-out stretch" scenario includes measures to further add low-GHG generation technology, improve energy efficiency in the supply chain, and further reduce energy demand through energy efficiency improvement in industry, nonresidential buildings, and household use of electricity:

- On the supply side, the scenario adds an additional 20 GW of imported hydro and an additional 20 GW on top of the targets for solar energy announced in the 2008 National Action Plan on Climate Change, accelerates the reduction of transmission and distribution losses by five years, and provides additional funding for 13 GW of lowest-efficiency coal plants to renovate them ahead of schedule for life extension and to bring their efficiency levels up to those of new plants.
- For the six industrial sub-sectors, the scenario considers about 340 GHG-emission-reducing measures that have been adopted commercially since 2006 in the country and that have a real rate of return of 10 percent or higher (not including the transaction costs that are often incurred with energy efficiency measures). They comprise energy efficiency improvement measures for all forms of energy—electricity, coal, oil, and natural gas—as well as a few processes unrelated to energy use releasing GHGs. The average percent of all plants adopting these measures (that apply to them) increases in a straight line from 2011 to reach a stable 80 percent in 2020.
- For appliance use by households and in nonresidential buildings, the scenario considers mandatory minimum efficiency standards of Indian three-star ratings, evolving over time to international standards (such as U.S. Tier 1) with a time lag, which varies from appliance to appliance. Where Indian standards do not yet exist, mandatory minimum standards are made to match international standards, again with a time lag for most appliances.

- For road transport, scenario 3 assumes more stringent fuel economy standards for light vehicles, matching EU CO_2 emissions standards with a time lag of 8 years for cars and 10 years for light commercial vehicles, and additional CO_2 savings from modal shifts.
- Sensitivity analysis *C* looks at the impact of accelerating by five—instead of ten—years the transmission and distribution loss reduction program. Sensitivity analysis *D* considers what scale of transformative measures would be needed in additional carbon-neutral electricity capacity to enable total CO_2 emissions from power generation to stabilize by 2025.

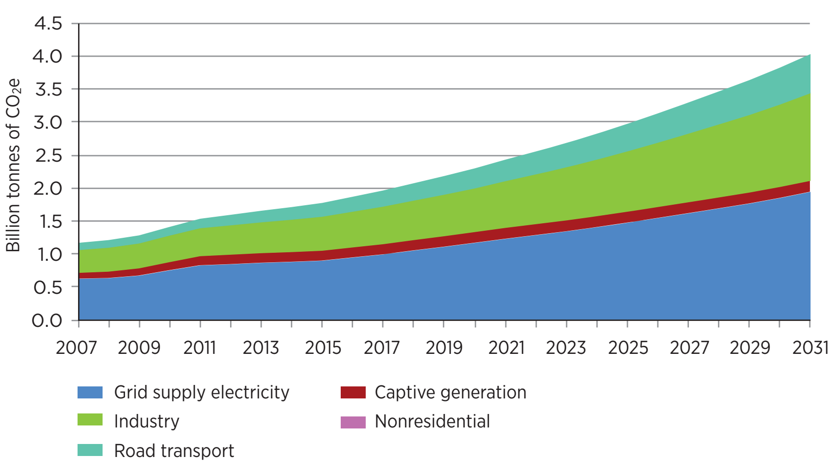
KEY FINDINGS

The model findings suggest that CO_2e emissions for the sectors covered by the study will increase from the 2007 level of 1.1 billion tonnes to 4.0 billion tonnes in scenario 3 which is lower than in the previous two scenarios. Among the various sectors, grid electricity supply in this scenario accounts for 46 percent of the increase, followed by 35 percent for industry, 17 percent for road transport, and 3 percent for captive power (Figure 5.1). Nonresidential buildings once again account only a small share of the overall increase.

Under the "all-out stretch" scenario, although the capacity requirements for grid supply will decline in 2031 from 609 GW (in scenario 1) to 586 GW, coal-fired plants will still dominate the energy mix in India with a relative share of 51 percent (Figure 5.2). As mentioned before, this is a consequence of the lack of natural resources in India, lack of availability of lower-carbon technologies such as solar at affordable prices, implementation issues, and the abundance of (global and domestic) coal and its relative cost advantage. The carbon intensity of the sector will fall over the period to the lowest level of the three scenarios (Figure 5.3).

Table 5.1 shows the impact on CO_2 emissions and capital investments of advancing or delaying by five years the implementation of the transmission and distribution loss reduction program assumed in scenario 1 over a 25-year period, assuming that the same amount of grid electricity as in scenario 1 will be supplied to end-users in all cases. In the case involving a delay of five years, additional plant capacity is needed to compensate for the larger technical losses, increasing the total investment requirement. This is in contrast to scenario 2, which does not assume that the same

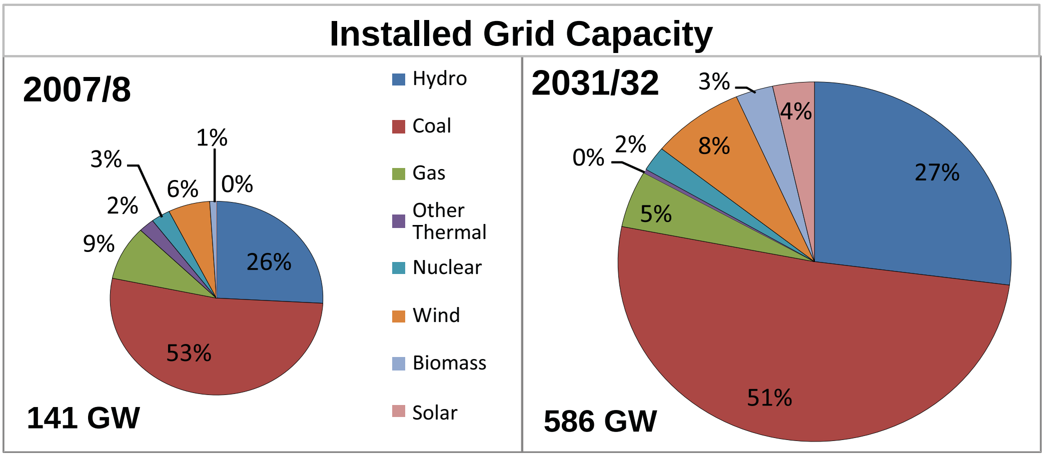
Figure 5.1 | Total CO_2 Emissions in Scenario 3 (billion tonnes)



Source: Author's calculations.

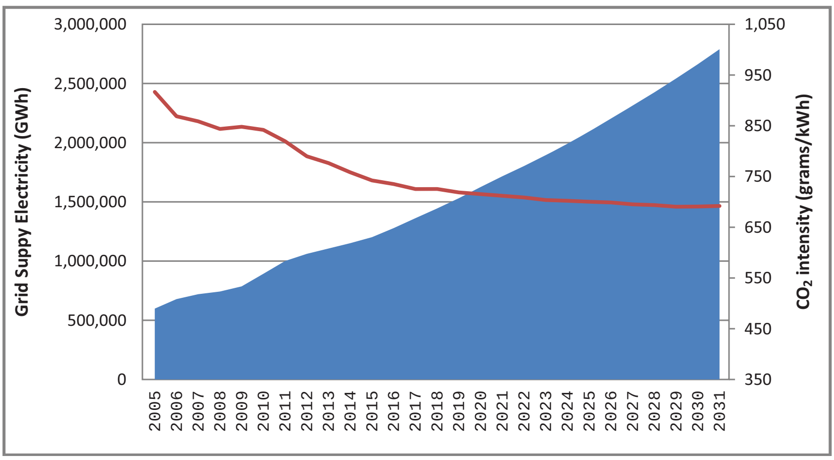
See notes for Figure 3.1.

Figure 5.2 | Share of Coal-Based Generation Capacity in 2031 (Scenario 3)



Sources: Authors' calculations. 2007/8 plot is based on the CEA CO2 Baseline Database for the Indian Power Sector updated with data from CEA website (November 5, 2009) on commissioned plants and those under construction.

Figure 5.3 | Evolution of the Grid Electricity Supply and Associated CO_2 Intensity



Source: Authors' calculations.

Table 5.1 | Impact of Pace of Transmission and Distribution Loss Reduction Program

TRANSMISSION AND DISTRIBUTION LOSS REDUCTION IMPLEMENTATION	CHANGE IN CO_2 EMISSIONS IN 2007–2031 (MILLION TONNES)	CHANGE IN INVESTMENT IN 2007–2031[a] (BILLION 2007 RUPEES)
Accelerated by 10 years	–568	–94
Accelerated by 5 years	–248	–6
Delayed by 5 years	1,392	227

Source: Authors' calculations.

Note: The years are financial years.

a. The total investment covers all investments needed to supply the same amount of electricity to consumers as in scenario 1 and includes life extension, efficiency improvement, and new plant construction.

Table 5.2 | Emission Reduction Potential in 2031, Million Tonnes of CO_2e

SOURCE	SCENARIO 1	SCENARIO 3	DECREASE	% DECREASE
Grid supply electricity	2,287	1,937	350	15
Captive generation	169	170	0	0
Industry	1,281	950	330	26
Nonresidential	1	1	0	0
Road transport	730	594	136	19
Total	4,468	3,653	815	18

Source: Authors' calculations.

amount of grid electricity is supplied and in which the supply shortfall is compensated by greater captive generation.

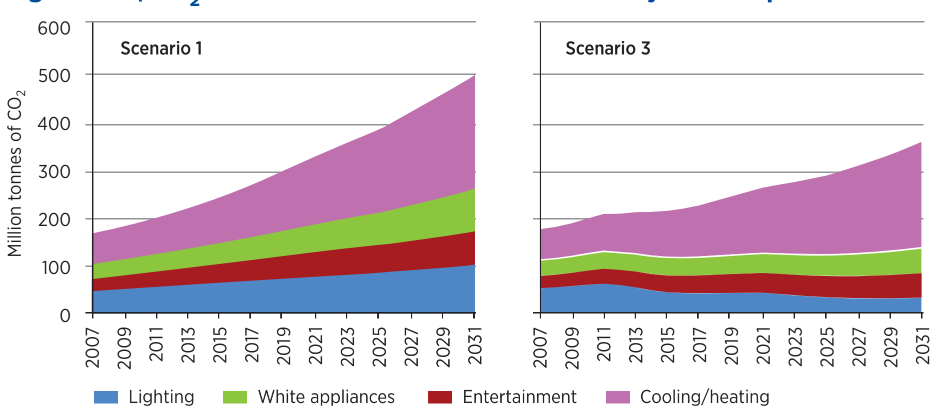
The potential reduction in annual emissions by 2031 following full implementation of all demand-side and supply-side measures in scenario 3 is estimated to be 815 million tonnes of CO_2 relative to scenario 1, as shown in Table 5.2. While the largest volume of emission reduction is from the power sector, the highest percentage of reduction is from industry.

On the demand side, as a result of tighter mandatory energy efficiency standards for household appliances, the largest reduction in electricity consumption is achieved for lighting: in 2031, the total amount consumed is 70 percent lower in scenario 3 than in scenario 1. While the share of electricity consumed for space-cooling and water-heating exceeds 60 percent by 2031 (compared to 43 percent in scenario 1), the total amount of electricity consumed is decreased by almost a third (Figure 5.4). Data were not available to estimate the incremental costs of tightening efficiency standards.

One interesting finding regarding appliances is that for some, such as television sets, gains in energy efficiency from mandatory standards are easily offset by the shift to less energy-efficient technology and larger capacity—for example, from cathode ray tubes to liquid crystal displays and to plasma and larger screen sizes. Nevertheless, the impact of introducing higher-efficiency standards for new appliances may be considerable. Figure 5.5 shows the difference in the total household power consumption in 2031 due to the efficiency measures modeled in scenario 3. For household appliances, scenario 3 gives of 29 percent compared to scenario 1.

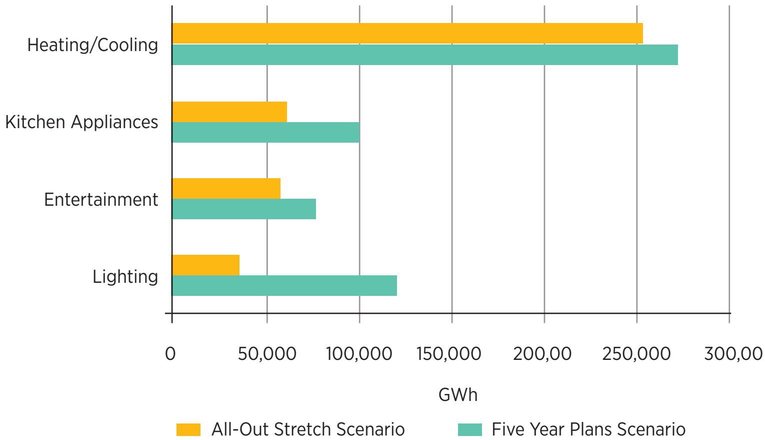
It can be seen that, by 2031, the difference in household electricity consumption amounts to 163,000 GWh per year, equivalent to the total output of approximately forty 500MW power sta-

Figure 5.4 | CO_2 Emissions from Household Electricity Consumption



Source: Authors' calculations.

Figure 5.5 | Total Household Electricity Consumption in 2031



Source: Authors' calculations.

tions. However, the rebound effect has not been included. Although the context is different, one study in rural India found the combined direct and indirect rebound effect for lighting to be 100 percent—which means there were no net energy savings, although the lighting program brought considerable welfare benefits to the villagers (Roy 2000).

On the industry side, the combined effect of adopting 340 process improvement measuress in 80 percent of plants by 2020 and exogenous 0.5 percent-per-year efficiency improvement from 2011 onward in newly purchased and installed plants and equipment is a 17 percent decline in total emissions by 2031 relative to scenario 1 (Table 5.3).

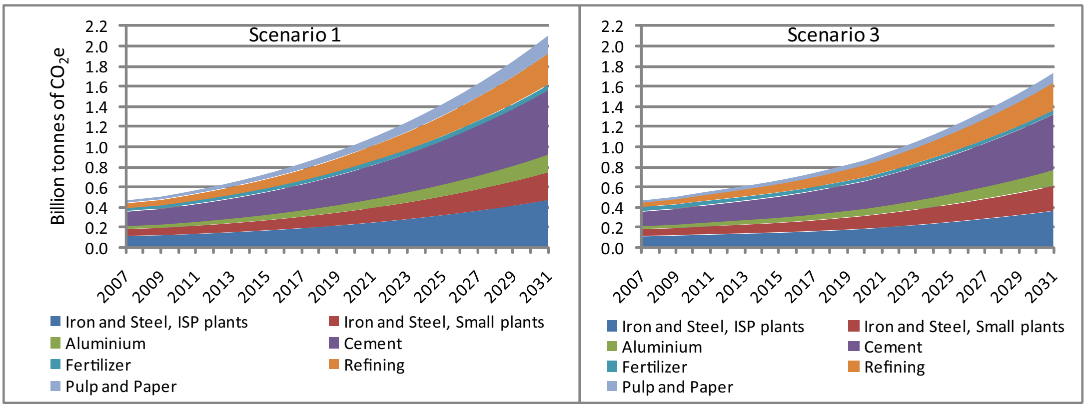
CO_2e emissions from electricity use (both grid-supplied and captive), from direct combustion of fossil fuel, and from processes unrelated to energy use are plotted in Figure 5.6. Among the six industries considered in this study, iron and steel and cement dominate, accounting for nearly 70 percent total CO_2e emissions in 2007. CO_2e emissions from integrated and small plants are broadly proportional to their total production. This finding, which may seem surprising at first—small plants cannot take advantage of economies of scale and tend to be less efficient—is due to the fact

Table 5.3 | 2031 CO_2e Emissions from the Selected Six Industries in Scenarios 1 and 3

2031/32 CO_2e Emissions (millions of tonnes)			Iron and Steel, ISP plants	Iron and Steel, Small plants	Aluminium	Cement	Fertilizer	Refining	Pulp and Paper	Total
Scenario 1 (Five year plans)										
	without grid supply electricity	t (E+06)	469	273	180	643	51	304	177	2,096
	from grid supply electricity	t (E+06)	121	72	7	57	9	0	42	307
	Total	t (E+06)	590	344	186	700	59	304	219	2,403
Scenario 3 (All-out stretch)										
	without grid supply electricity	t (E+06)	369	245	156	549	39	275	99	1,732
	from grid supply electricity	t (E+06)	112	67	6	53	7	0	28	273
	Total	t (E+06)	482	312	162	601	47	275	127	2,005
Saving without grid supply electricity		t (E+06)	100	27	24	95	12	29	79	364
Saving including grid supply electricity		t (E+06)	108	32	24	99	13	29	93	398

Source: Authors' calculations.

Figure 5.6 | CO_2e Emissions from Six Industries, Five Year Plans



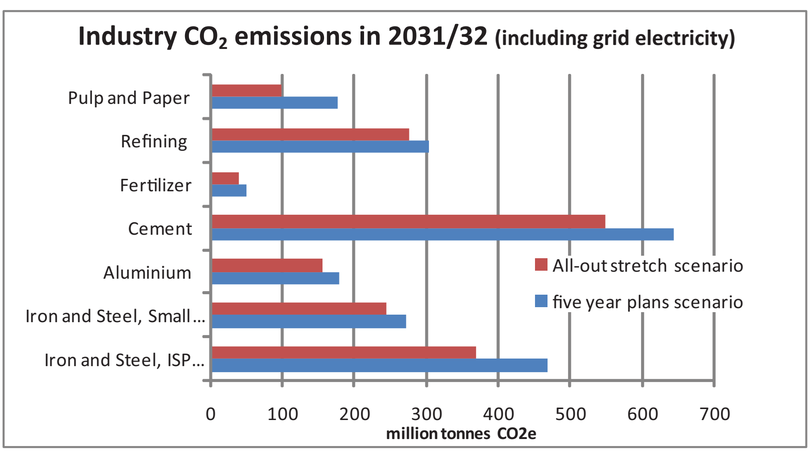
Source: Authors' calculations.

that many small plants use scrap, a process that is much less energy intensive than other processes, whereas none of the large integrated plants do. For example, in 2007, a quarter of steel manufactured by small-scale plants was made from scrap.

As shown in Figure 5.7, the largest savings-potential in energy-intensive industries compared to business-as-usual is demonstrated by large integrated steel plants and the cement industry (more than 95 million tonnes each of CO_2e per year in 2031), followed by pulp and paper (79 million tonnes CO_2e per year in 2031). Small iron and steel producers, aluminum, and refining each can potentially reduce annual CO_2e emissions by about 25 million tonnes, while the fertilizer industry can save 11 million tonnes CO_2e per year.

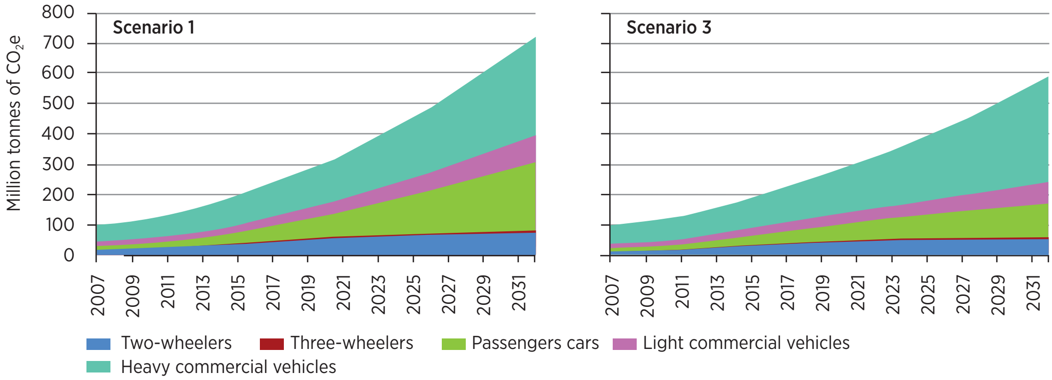
In the transport sector, scenario 3 assumes more stringent fuel economy standards for light vehicles, matching EU CO_2 emission standards with a time lag of eight years for cars and 10 years for light commercial vehicles (there are not yet CO_2 emission standards for heavy vehicles), along with sustainable urban and transport planning policies that encourage the conditions for development of mass transit systems result in a 19 percent reduction of emissions (Figure 5.8).

Figure 5.7 | CO_2e Emissions from Six Industries, All-Out Stretch



Source: Authors' calculations

Figure 5.8 | CO_2e Emissions from Road Transport



Source: Authors' calculations.

There will be greater reductions in local air pollutants as the vehicle fleet moves towards current EU emissions standards (EURO 5 for light-duty vehicles and EURO V for heavy-duty) by 2015, which will have large benefits for human health in India's urban centers.

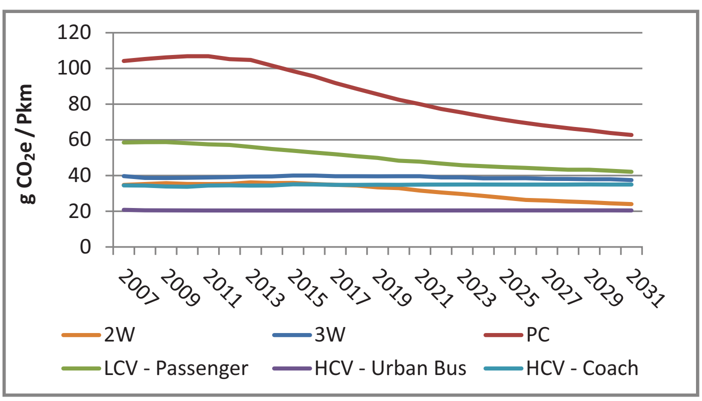
While the car ownership will remain at the same level of 86 per 1000 people as in scenario 1 in 2031, the CO_2 intensity of road transport—for both passenger vehicles (Figure 5.9) and freight transport (Figure 5.10)—falls.

A comparison of total CO_2 emissions from road transport in 2031 between scenarios 1 and 3 is given in Figure 5.11. Compared to 2007, the emission levels are several-fold higher. The difference between the two scenarios exceeds the total CO_2 emissions in 2007, largely due to more aggressive adoption of technologies that increase fuel economy in scenario 3.

For nonresidential buildings, consumption of electricity, diesel used for additional power generation, and use of liquefied petroleum gas (mainly for heating water and also for cooking in restaurants) was estimated. Six categories of buildings, two of which are separated further into public and private, are considered in this study. Meeting tighter energy efficiency standards for electric appliances lowers consumption by about 10 percent in scenario 3. The largest reductions in electricity use in scenario 3 are achieved in retail and private offices (Figure 5.12).

The study also examined what additional capacity of carbon-neutral generation would need to be added to stabilize CO_2 emissions in the power sector by 2025 with no further growth. Replacing

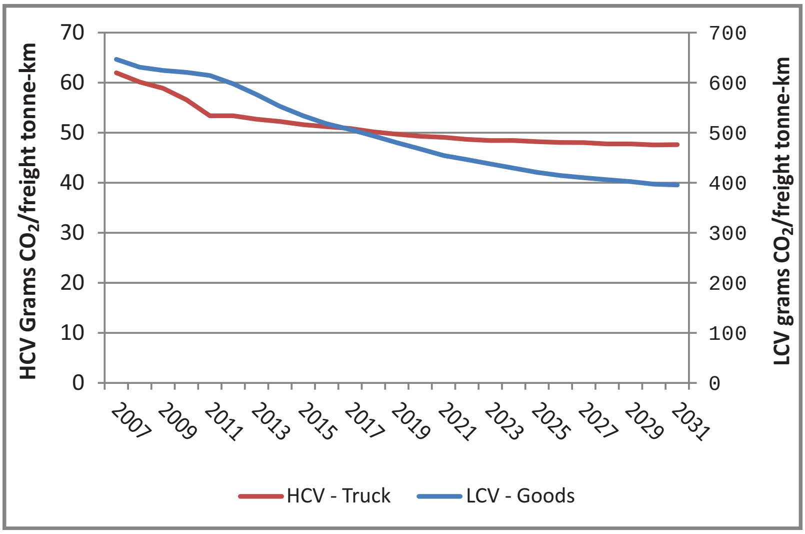
Figure 5.9 | CO_2 Emissions/Passenger-Kilometer



2W = two wheelers
3W = three-wheelers
PC = passenger cars
LCV = light commercial vehicles
HCV = heavy commercial vehicles

Source: Authors' calculations.

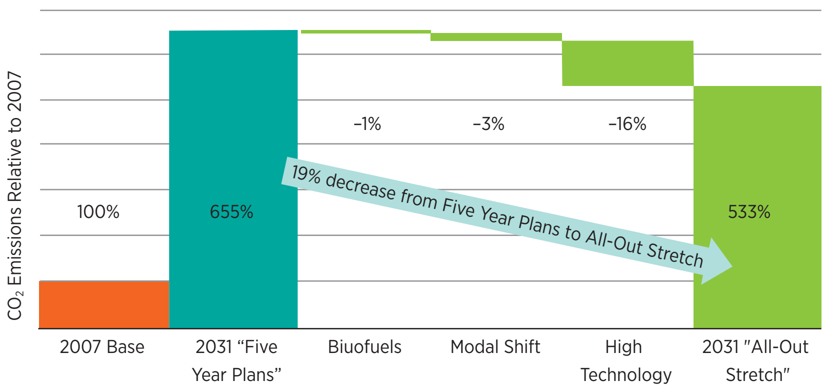
Figure 5.10 | CO_2 Emissions/Freight Tonne-Kilometer



LCV = light commercial vehicles
HCV = heavy commercial vehicles

Source: Authors' calculations.

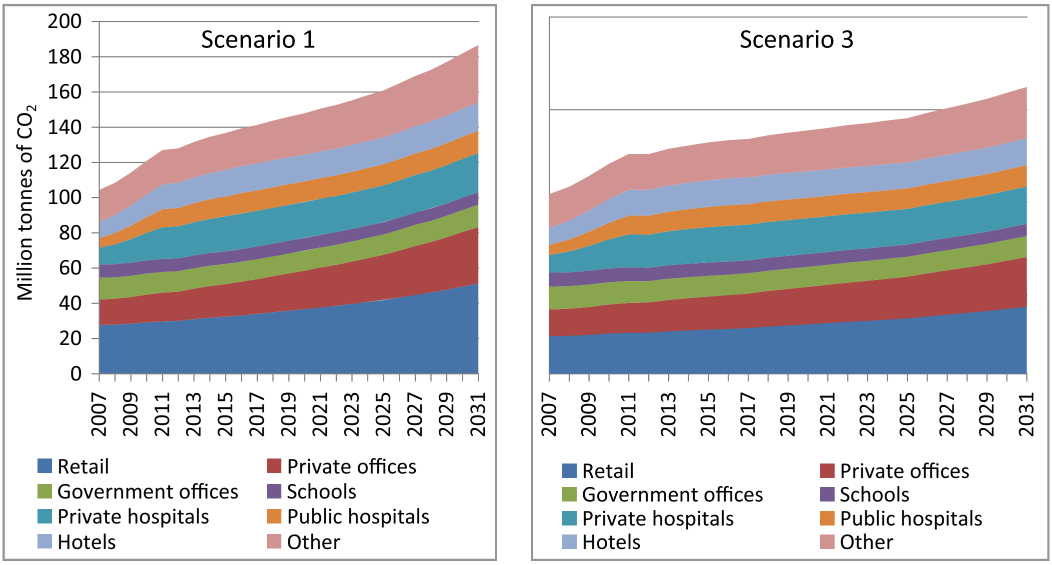
Figure 5.11 | CO_2e Emissions from Road Transport



Source: Authors' calculations.

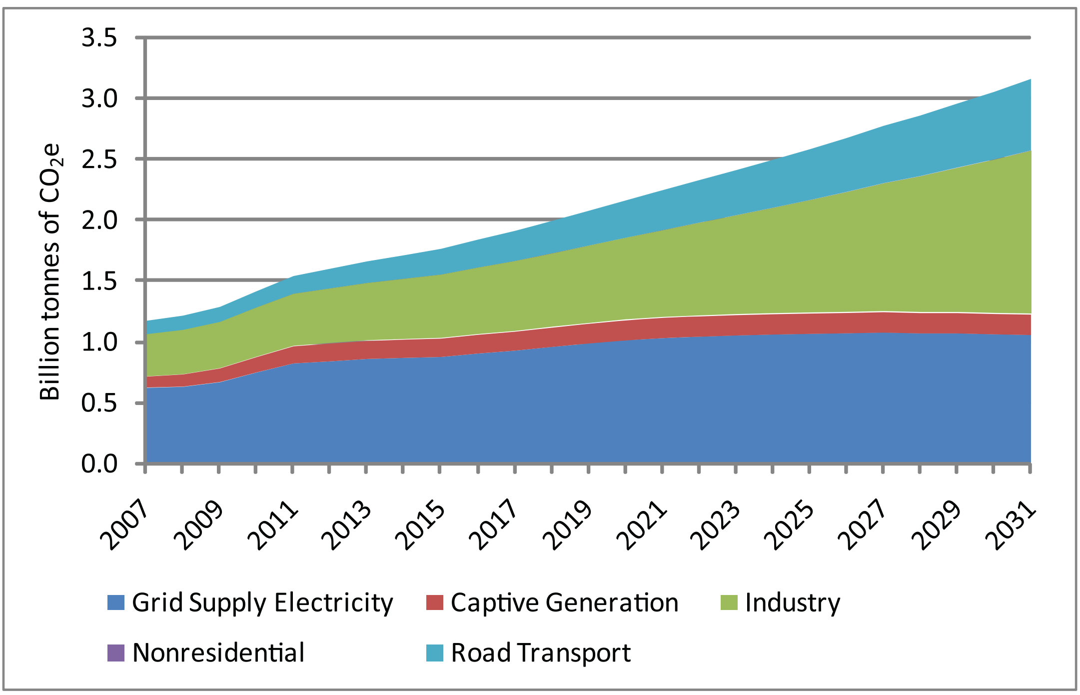
130 GW of coal-based and 2 GW of gas-based power generation with carbon-neutral generation capacity beyond scenario 3—for example, importing more hydropower from neighboring countries and adding more nuclear—was found to achieve this stabilization target (Figure 5.13). By 2031, these measures nearly halve CO_2 emissions relative to scenario 1 in the power sector and reduce the overall CO_2e emissions to 3.2 billion tonnes, which is 2.7 times the 2007 level. Among the various sectors, grid electricity supply accounts for only 22 percent of the increase, industry for 50 percent, road transport for 24 percent, and captive power for 4 percent. It is important to point out that these calculations say nothing about the technical feasibility or the cost of such massive additional introduction of carbon-neutral generation.

Figure 5.12 | CO_2 Emissions from Nonresidential Buildings



Source: Authors' calculations.

Figure 5.13 | Sensitivity Analyses for Scenario 3 – Emissions Stabilization in Power Sector



Source: Authors' calculations.

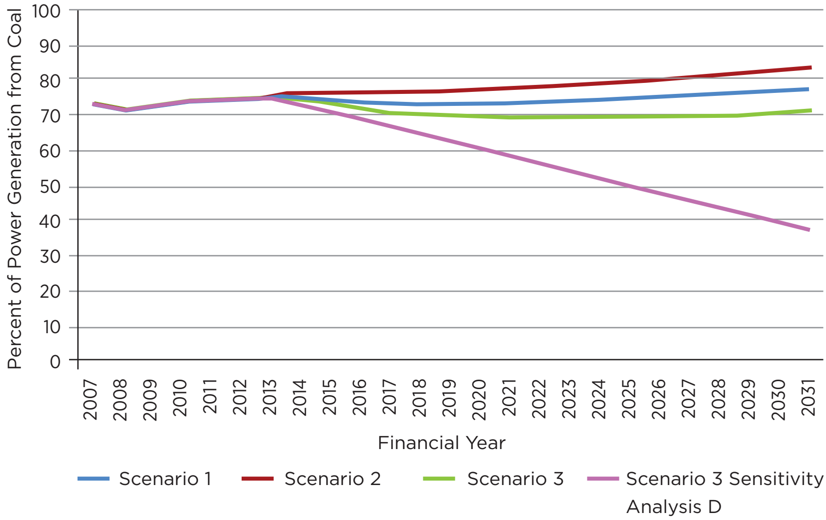
VI. Comparison of Scenarios

The model estimates that coal-fired generation plants are likely to continue to dominate electricity supply to the grid despite best efforts to increase the share of less carbon-intensive sources of power. The share of total power generated derived from coal increases from 73 percent in 2007 to 78 percent in 2031 in scenario 1, and declines only slightly to 71 percent even in scenario 3 (Figure 6.1). As mentioned earlier, this is a consequence of the lack of significant alternative natural resources in India, lack of availability of lower-carbon technologies such as solar at affordable prices, problems associated with the implementation of planned investment programs, and the abundance of (global and domestic) coal and its relative cost advantage. The highest share of coal in power generation is found in scenario 2, in which the introduction of renewable energy is slowed down at half the rate of scenario 1 and the share of grid-supplied power generated from coal increases to 84 percent in the terminal year. Only in sensitivity analysis *D* for scenario 3, in which even more carbon-neutral generation is introduced to replace generation from fossil fuels so that emissions from grid power supply are stabilized by 2025, is the share of coal power generation essentially halved, reaching 38 percent by the end of the study period.

For total grid electricity generated, scenarios 2 and 3 are comparable, whereas scenario 1 is above the other two (Figure 6.2). However, the amount of CO_2 emitted per kWh varies markedly from scenario to scenario. By the terminal year, CO_2 emissions per kWh are almost 20 percent higher in scenario 2 and 8 percent higher in scenario 1 than in scenario 3. By far the most carbon-intensive is scenario 2, in which transmission and distribution technical losses remain high five years longer than in scenario 1 and 10 years compared to scenario 3, and in which the rates of construction of new super-critical power plants as well as renewable power generation are at half the rate in scenario 1. In scenario 1, CO_2 emissions per kWh begin to rise in the last few years of the modeling period as a result of the rising share of coal-based power generation.

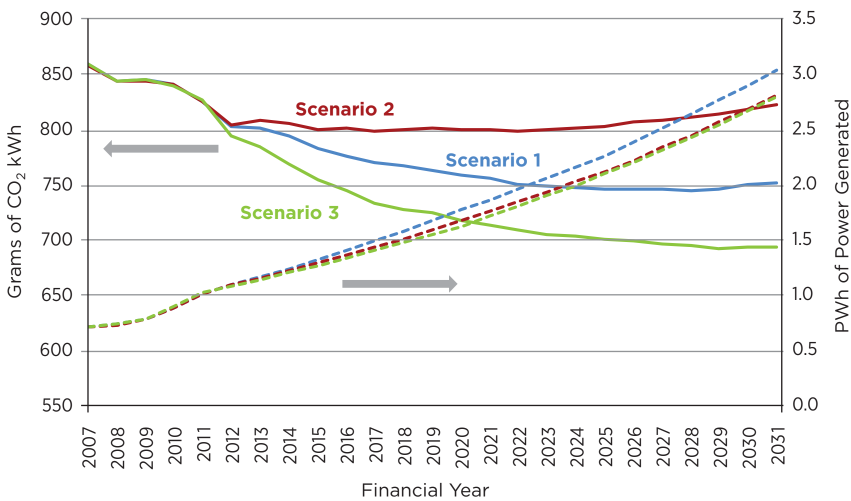
Because one important difference between the scenarios is the pace of implementation of emissions-reducing measures, their effects cannot be deduced from comparison of emissions in the terminal year alone. For example, while the completion of the program to reduce transmission and distribution losses is varied between 2020 and 2030, technical transmission and distribu-

Figure 6.1 | Share of Coal in Grid Power Generation



Source: Authors' calculations.

Figure 6.2 | CO_2 Emissions from Grid Electricity Generation



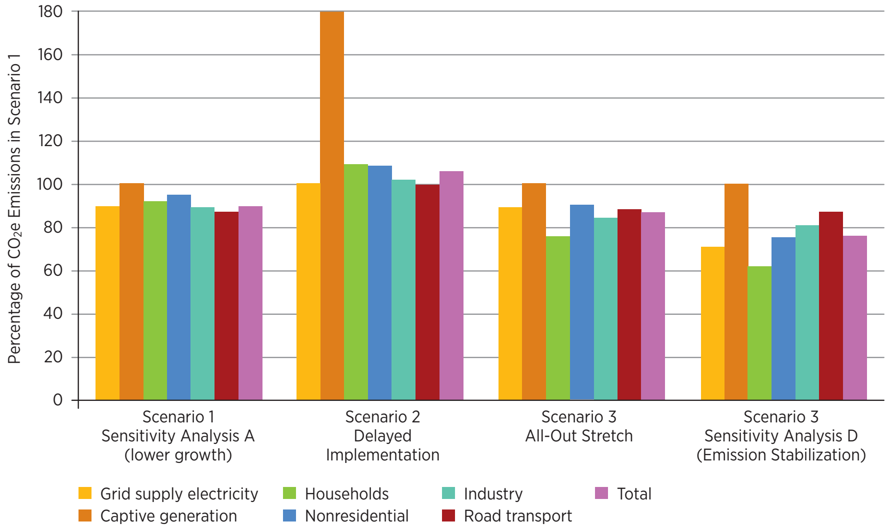
Source: Authors' calculations.

PWh = petawatt-hours

tion losses are reduced to 15 percent in all scenarios by 2031. What the differences do affect is the trajectory of CO_2 injection into the atmosphere.

One way of assessing the effects is to compare cumulative emissions over the study period. Figure 6.3 presents the results of such a comparison, based on the emissions in scenario 1 set equal to 100 for each sector. The results show that CO_2 emissions from captive power generation is nearly doubled in scenario 2, as a result of much higher capacity needed to compensate for lower power output from the grid system. Scenario 3 reduces demand and power generation efficiency as well as carbon intensity. Household consumption of electricity had the largest difference between scenarios 1 and 3, which became even larger in sensitivity analysis *D*.

Figure 6.3 | Comparison of Cumulative Emissions in 2007–2031 Relative to Scenario 1



Source: World Bank staff calculations.

IMPLEMENTATION COSTS OF THE DIFFERENT SCENARIOS

The costs of achieving a lower-carbon path are determined by two factors: (a) the investment and operating costs of the low-carbon programs, and (b) the transaction costs linked to the implementation of the low-carbon programs. While it was difficult to estimate the transaction costs because of limited data availability, the study used CEA data to determine order-of-magnitude estimates of total investments. It is expected that the following costs will be updated on a regular basis by the government to have a more accurate estimate of the costs of achieving a lower carbon development path.

One of the greatest barriers to adopting efficiency enhancement measures and renewable energy is the large up-front cost of doing so. While the incremental investment costs may be recovered in later years by lower operating costs, resulting in net positive rates of return, the need to raise greater financing up front remains a problem in many situations (World Bank 2008c).

Using the same approach as in Table 4.1, Table 6.1provides order-of-magnitude estimates of total investments in life extension, efficiency improvement, and new plants and equipment for grid electricity in the three scenarios between 2007 and 2031. Scenario 2 is taken as the baseline for the incremental cost calculations because this scenario more closely follows the historical performance in meeting the government's generation capacity addition targets. Investments are estimated each year in 2007 rupees. The table presents the cost figures in two ways:

- Investments discounted at 10 percent to compute the net present value in 2007
- Total investments without discounting

The table shows that the capital expenditures for grid electricity in scenario 1 are about 16 percent higher than in scenario 2. This additional expenditure will have to be borne by the public sector. As expected, the implementation of scenario 3 incurs the highest up-front costs, 23 percent higher than in scenario 2. However, with the exception of solar power, all investment projects for adding new generation capacity have a real rate of return of 10 percent or higher.

Table 6.1 | Investment Costs for Life Extension, Efficiency Improvement, and New Capacity in Grid-Supplied Electricity

SCENARIO DESCRIPTION	BILLIONS OF 2007 RUPEES		DIFFERENCE FROM SCENARIO 2	
	NPV (2007)	TOTAL	NPV (2007)	TOTAL
Scenario 1				
Life extension and efficiency improvement	570	1,400	90	180
New capacity	8,000	24,000	1100	4,400
Total	8,600	25,000	1200	4,200
% difference	—	—	16	20
Scenario 2				
Life extension and efficiency improvement	480	1,600	0	0
New capacity	6,900	19,000	0	0
Total	7,400	21,000	0	0
Scenario 2 sensitivity "B" — 20 percent slippage				
Life extension and efficiency improvement	490	1,700	10	100
New capacity	7,800	22,000	900	3,000
Total	8,300	24,000	900	3,000
% difference	—	—	12	14
Scenario 3				
Life extension and efficiency improvement	600	1,300	120	–300
New capacity	8,500	27,500	1,600	8,500
Total	9,100	29,000	1,700	8,000
% difference	—	—	23	38

Source: Authors' calculations.

NPV = net present value; life extension & efficiency improvement includes technical transmission and distribution loss reduction measures.

Notes: NPV computed using a discount rate of 10 percent. Rupees are in 2007 rupees. Total is the sum of annual investments without discounting. All numbers in the table are rounded off. Differences do not exactly match the differences between the numbers in the table as a result.

VII. Challenges in Achieving the Low Carbon Path

Energy is emerging as a significant constraint on growth across all sectors. At a sustained annual GDP growth rate of 7.6 percent to 2031, electricity and transportation fuel supply in India will need to quintuple. India's ability to secure a reliable supply of energy resources at affordable prices will be one of the most important factors in shaping its future energy consumption. India lacks sufficient energy resources and is increasingly dependent on oil imports to meet energy demand. In addition to pursuing domestic oil and gas exploration and production projects, India is also stepping up its natural gas imports, particularly through imports of liquefied natural gas.

For the sectors covered by the study, expansion needs are large and the country's objective of achieving universal access and strengthening the reliability of electricity services will have a large impact on GHG emission growth over the study period.

Although all major sectors that are consumers of energy can contribute to lower-carbon development, the pursuit of such a development path would require comprehensive and large-scale changes in sector investment, performance, and governance, particularly in the power sector. A crucial first step towards lower-carbon development over the longer term, as well as improved energy sector performance in the nearer term, would be for India to substantially improve upon its past performance in achieving its targets.

Unless India allocates financial, technical, institutional, and skills-based resources more efficiently, capacity addition may continue at half the planned rate as in the past three Five Year Plans (1991–2006). In that case, one could anticipate even faster emissions growth compared to scenario 2 (delayed implementation), in which the total installed capacity in fiscal 2031 is "only" 13 percent lower than in scenario 1 in which all Five Year Plan targets for generation are fully met.

Meeting the targets contained in the 11th and subsequent Five Year Plans in the power sector requires coordination of institutions across all levels of government—including the federal, state, and municipal governments—and an enhanced performance of the relevant institutions. If grid electricity continues to fall short of demand, then captive generation relying on diesel could expand, resulting in higher CO_2 emissions per kWh in later years and higher costs for the economy.

Accelerated uptake of renewable energy, which would reduce reliance on thermal power generation and enhance the diversification of the energy mix, requires a streamlined regulatory framework; in the case of large hydropower, it requires a concerted effort to improve capacity to systemically implement existing policies on land acquisition and restoration and rehabilitation of project-affected peoples. The development of solar power, nuclear power, and other lower-carbon energy sources beyond existing ambitious plans would require significant structural changes, including access to new energy sources and technologies, better delivery mechanisms, and widened access to a skilled workforce. Strengthened energy-efficiency standards for appliances and buildings also would be needed. As has been observed in many other reports, these are institutional as much as technological challenges. The likelihood of success also depends on putting in place a monitoring and evaluation system to detect any systemic slippages during program implementation and to ensure that early corrective measures are taken.

It is widely agreed that growth in GHG emissions is particularly difficult to mitigate in the transportation sector in those countries that currently have low private-vehicle ownership rates coupled with exploding urban populations and rapid economic growth. Over the timeframe of this study, India's urban population is expected to double, placing substantial stress on existing—often insufficient—transport infrastructure both for long-distance freight and the movement of people within the cities. Most transport infrastructure (including urban roads, rail, and highways) have long operational lives and the way new infrastructure is established today to satisfy these growing needs will lock India into development pathways that may be difficult to change at a future date. Rising time-loss from on-road congestion, health impacts from local air pollution, and GHG emissions can be addressed only over the long term by difficult but fundamental changes that transform land use and transit policies. Over the near term, much work is needed to provide extensive and better mass-transit in cities, to invest in the shift of freight transport from road to rail, and to improve facilities for non-motorized travel in order to cover this growth in demand and slow down the apparently inevitable growth in motorized transport. Whilst, it is critical that new vehicles entering service have high fuel economy to lower the growth in long-term GHG emissions, at the same time, tighter local emissions standards are needed to alleviate worsening air pollution

The scope of this study does not allow making conclusive statements about the costs of achieving different future carbon trajectories. Compared to the current situation, the foregoing sections show that, on the supply side, particularly in grid electricity, there are capital cost increases on the order of 20–25 percent to achieve the "stretch" results. These outlays, however, are only part of the total cost of achieving such ambitious GHG reductions. The speed of the hypothesized carbon-neutral capacity investments is estimated to increase costs considerably—more than 25 percent on top of the 20–25 percent increase mentioned above—and infrastructure and other investments for substantially reducing transport sector emissions would be very large.

There are possibilities in many sectors for significant improvements in energy efficiency in many sectors, with low or potentially negligible costs. However, those opportunities depend on accomplishing various policy and institutional changes noted above, which constitutes a challenge. Other barriers include competition for limited funds from projects with higher risk-adjusted rates of return and constraints on financing availability for covering upfront costs. A well-known example of the former in industry is the much higher rate of return that can potentially be achieved by expanding production capacity rather than improving energy efficiency, even if both give positive rates of return and energy efficiency has the added benefits of potentially lowering illnesses and premature death from reduced local air pollution. Amplifying the tendency to choose production capacity expansion over energy efficiency improvement is the drive to expand a firm's market share.

Financing limitations further arise because banks do not focus only on the mean return; they are also concerned about and take steps to manage the risks of their portfolios. Quite a few low-

carbon technologies have high perceived-risks, and these perceptions can be reinforced by bad experience. For example, compact fluorescent lamps burning out in a few hundred hours instead of lasting the designed 10,000 hours, despite the much higher purchase price, would deter significant market penetration in lighting. To the extent that the much shorter actual life is a result of inferior manufacturing, this points to the critical importance of setting and enforcing performance standards, and taking poorly performing products off the market before consumers lose confidence. But closely associated with the performance of lower-energy-intensity electric appliances and equipment is the quality of electricity delivered—frequent and large voltage fluctuations could easily damage appliances designed for more stable power, returning the discussion back to that on the performance of grid electricity supply.

Aside from the possibilities discussed to this point, what are the options for truly dramatic reductions in GHG growth, even as energy use expands? One option is to promote international cooperation and regional trade in lower-carbon energy sources to allow India, under appropriate conditions, to have access to natural gas in neighboring countries. However, the geopolitical environment in the region is not yet conducive for such option. Another option is adoption of emerging new carbon-neutral energy sources—beyond wind and hydro, which are already assumed to be maximally exploited in our scenario analysis—that are acceptably safe and relatively affordable. Much attention has been given internationally to the possibility of carbon capture and storage for use with fossil fuels. Unfortunately, aside from the fact that large-scale carbon capture and storage is still pre-commercial, India's geology does not seem particularly hospitable. Current estimates indicate that India's oil and gas fields plus coal fields have less than 5 billion tonnes of CO_2 storage capacity. This could store national emissions from large point sources for only five years (IEA 2008).

Given the limited outcome of the Copenhagen negotiations, the financing of additional costs for the higher-cost carbon-neutral resources through sales of CO_2 reduction credits or other carbon finance mechanisms has become uncertain. But given the large amounts of carbon-neutral investment needed in scenario 3 and even more so for emission stabilization, unless the carbon-neutral technologies were fairly cost-competitive the carbon finance costs would be staggering.

It will be necessary for decision-makers in India to carefully consider the costs and benefits they will obtain from different lower-carbon energy options. For example, greatly expanded renewable capacity will require predictable and stable feed-in tariffs to attract investments until such time as the technologies become fully cost-competitive. Such price subsidies run counter to the general prescription for economically-efficient energy pricing and compete with other priorities for scarce resources, including expanding the availability of modern energy services for the poor. The technology cost-gaps would be lessened should India decide to impose a relatively comprehensive system of energy price adjustments to reflect carbon content and local environmental impacts, as well as policy instruments to encourage reduced traffic congestions that also would increase energy efficiency in transport in most cases. But such an ambitious policy has not yet been achieved by any country, developed or developing. In the meantime, India will benefit from looking at particular institutional and pricing reforms that provide maximum development and environmental benefits while also contributing to slowing GHG emissions growth.

Ultimately, India needs to decide what steps it will take to meet the continuing energy and economic development needs of its people, taking into account the costs of risks and various options. India also shares with the rest of the world an interest in limiting disruptive and costly climate change. The findings in this study underscore the challenge of meeting energy access, energy cost, and global environmental objectives within the menu of technological options currently available. Where there are synergies between cost-effective efficiency improvement and demand management on the one hand and reduction of carbon intensity on the other, they should be pursued as a top priority.

Annex 1 | Scope and Methodology

This section outlines the overall approach and assumptions used for computing marginal abatement costs and switching prices of carbon. Separate sector-specific methodology papers describe scenarios, data sources, and calculation and forecasting methodologies in more detail. The assumptions used are summarized in Annex 2.

SCENARIO BUILDING

Scenarios are constructed in the bottom-up model to compute CO_2e emissions, investments, and operating and maintenance costs annually to the terminal year. Where reasonable estimates can be made, associated transaction costs (for adopting more energy-efficient measures, for example) will have been included. Exogenous constraints in each scenario limit the annual adoption of specified technologies; vintaging is used to forecast the replacement of existing assets with new technologies (including retrofitting). In the residential sector, affordability of appliance and vehicle ownership is taken into account by dividing households into 100 quintiles of ascending household expenditure in urban and rural areas and calculating each separately.

COSTS

All costs are expressed in constant rupees. Economic analysis in the strict sense, in which all direct and indirect taxes and subsidies are excluded, is considered beyond the scope of this study because of the difficulties in tracing all taxes. To a limited degree and to the extent feasible, subsidies and differential taxes are accounted for.

TREATMENT OF TERMINAL YEAR AND RESIDUAL VALUE

For those assets that come on stream towards the end of the study period a residual value equivalent to the fraction of the initial cost (where the fraction is that of the years remaining) is assigned. The study will, however, estimate the rate of decline in residual use values using nonlinear assumptions where asset-specific information to support those assumptions is available. For existing plants and equipment, residual values are not assigned except where premature scrappage occurs. The specifics of where these cases arise and how they are handled are explained in the methodology document for each sector.

IMPLEMENTATION COSTS

There are many interventions that are not implemented to the extent that would be suggested based on equipment purchase and operating costs alone because there are other transaction costs associated with implementation, which can be significant. To the extent possible, this study incorporated these additional transaction costs.

Annex 2 | Sources of Data and Assumptions

Table A2.1 | Sources of Data

Population	"Report of the Technical Group on Population Projections Constituted by the National Commission on Population." Office of the Registrar General & Census Commissioner, India. May 2006, revised December 2006.
GDP	GDP projections in *Global Development Finance 2009*. June 2009. http://go.worldbank.org/JMGYIA32M0
Appliance ownership	Ownership of appliances reported in: (*i*) National Sample Survey Round 61 (fan, air-conditioner, cooler, refrigerator, radio, television), (*ii*) National Sample Survey Round 58 (washing machine, CD player tape recorder, DVD/VCR), (*iii*) the survey conducted by the National Council of Applied Economic Research in 2004 (computer), and (*iv*) a survey of 600 households conducted by DSCL (lighting).
Car ownership	Car sales data to 2007/8, data from the 61st round of the National Sample Survey conducted in July 2004–June 2005.
Power generation	Updated with Clean Development Mechanism (CDM) database ver3 (2006) and CDM database for 2007 published on 25 September 2008. Updated with data from CEA Web site (dated 5 November 2009) on commissioned plants and those under construction.
Power consumption	For appliances, historic data from 2008. For efficiency standards, 2008 standards for new sales and U.S. and EU standards through to 2010 applied with a time lag.

Table A2.2 | General Assumptions

GDP	GDP growth used is the government of India target of 8 percent between 2010 and 2021, falling to 7.5 percent in 2022–2026 and 7 percent in 2027–2031. With the unfolding global financial crisis, the anticipated reduced GDP growth rates are 6.2 percent in 2009/10, growing to 8 percent in 2012/13 and falling to 7.5 percent in 2015–2018, 7 percent in 2018–2020, 6.5 percent in 2021–2024, and 6 percent to 2031.
Population and urbanization	Population and urbanization projections from the Census of India to March 2026. This study extends the series to 2031.
Household size	The Census of India reports 193 million "normal" households. This study adopts the United Nations methodology in projecting household size to 2031. Projections are based on past trends of the ratio of the number of households to population 15–64 years of age.
Percentage discount rate, *r*	10 percent representing the "global average" opportunity cost of capital.
Marginal abatement cost	Calculated for comparison of pairs of equivalent activities. Duration and temporal production profiles matched for the primary outputs. If two different life years, the shorter-life item is replaced until the end of life of the longer-life item. If the shorter-life item has any life remaining, a residual value is assigned. Greenhouse gas emissions undiscounted, costs discounted using a midyear assumption. The first year in discounting is the year of the production of the primary output.
Residual value	A fraction of the capital cost equivalent to the fraction of the remaining years. Residual values are assigned to all plants and items of equipment that come on stream during the study period with remaining life in the terminal year (2031), or to the remaining life of the shorter-life equipment in the last replacement period in comparison of pairs for marginal abatement cost calculations.
Scenario building	Vintaging and exogenous constraints are applied.

Table A2.3 | Power Sector

Long-Run Demand Income Elasticity for Electricity	**Period**	**Percentage**
	2006–2011	1.00
	2012–2016	0.90
	2017–2021	0.85
	2022–2026	0.80
	2027–2031	0.75
Captive generation	73,639.7 GWh in 2005/6, 78,000 GWh in 2006/7, growing to 131,000 GWh in 2011/12 and constant thereafter.	
Installed capacity at the end of 15th Plan	Large hydro: 139,000 MW Thermal: 479,000 MW Renewable: 100,000 MW Nuclear: 13,000 MW	
Transmission and distribution losses (technical)	Business as usual: 29.03 percent in 2005/6 linearly reducing to 15.05 percent in 2025/26 and constant thereafter. Alternative scenario: Slower improvement in loss reduction, taking an additional five years to reach 15.05 percent.	
Load-duration curve	Maintains the 2005 national system-wide load-duration curve values constant at 79.2 percent.	
Supply shortage/spinning reserves	Total energy shortage of 9.8 percent of supplied demand in 2005/6 is eliminated by 2009/10 and a 5 percent spinning reserve is achieved in 2011/12 and maintained thereafter.	

(continued)

Table A2.3 | Power Sector *(continued)*

Hydro	Increased to 128,000 MW installed capacity (plus small hydro included in renewable) by 2033, in line with the Working Group Report and Integrated Energy Policy proposals.
Nuclear	Gradual increase from 3,900 in 2006 to 13,000 MW by 2031.
Thermal – coal fired: supercritical	50 percent of new plants in 12th Plan and 70 percent of new plants in 13th Plan in line with the Working Group Report, and 90 percent of new plants thereafter, as proposed.
Thermal – coal fired: ultra-super-critical	None considered in this round of calculations during this period.
Carbon capture and storage, circulating fluidized bed and integrated gasification combined cycle technologies	Were not considered in this round of calculations, in line with the Working Group Report.
Plant renovation and end of life	**Type** / **Planned life (years)** / **Extension (years)** / **End of life (years)** Hydro / 50 / 35 / 85 Nuclear / 40 / – / 40 Thermal / 25 / 15 / 40

Table A2.4 | Household Electricity

Electrification rate	This study uses data from the 61st round of the National Statistical Survey to compute the percentage of electrified households in 2004/5. The rate of electrification in both rural and urban locations is closely related to monthly per capita expenditure and projected by centile.
Appliance ownership and source of data	61st round of National Statistical Survey: Fan, air conditioner, cooler, refrigerator, radio, television. 58th round of National Statistical Survey: Washing machine, CD player, tape recorder, DVD, VCR. National Council of Applied Economic Research: Computer. DSCL Ltd. household survey: Lighting, electric water heater, oven, toaster, microwave, booster pump.
Appliance life	The average age of retirement for all appliances is assumed to be 15 years except: (a) lighting, where the assumed mean useful operational life is 1,250 hours of operation for incandescent light bulbs, 10,000 hours for fluorescent tubes, or 5,000 hours for compact fluorescent light bulbs; and (b) computer, where the assumed mean useful operational life is 5 years.
Appliance historical parc configuration	In 2005 an average age of the historical parc configuration of each appliance is assumed to be 4 years in all cases except for computers (2 years) and lighting (0.5 years for incandescent light bulbs, 3.7 years for fluorescent tubes, 1.8 years for compact fluorescent light bulbs).
Mean power consumed by each appliance (in-use and stand-by)	Historical parc unit power consumed by each appliance determined from retail-level sales data in India. Future unit power consumptions from India and other country manufacturers' data and efficiency standards. Scenarios were run applying different future efficiency standards.
Appliance usage	Television 4 hr/day, washing machine 7 loads/week, air conditioner 575 hr/yr, cooler 1,440 hr/yr, fan 2,520 hr/yr, fridge continuous, electric oven and toaster 15 mins/day, microwave 6 mins/day, computer 2.2 hr/day, DVD/VCR 156 hr/yr, radio 2,190 hr/yr, CD 1,460 hr/yr, electric water heater 140 days/yr (60L/day 50 deg C), lighting usage factor for each lighting unit of 2.5 hr/day.

Table A2.5 | Nonresidential Electricity

Retail and office floor area	Commercial space growth over 1998–2004 using historical data from the Construction Industry Development Council demonstrated an elasticity of 0.39 against GDP growth. This was maintained over the modeling period. Existing office floor space is divided into private and government and 80 percent of new construction is assumed to be private. Existing floor space (in 2005) is assumed to be replaced at a 1 percent per year rate.
Hotel floor area	Recent trends in the number of hotel rooms were provided by The Federation of Hotel and Restaurant Association, and forecast by them to 2016. 0.93 hotel beds per 1,000 population in 2001 increases to 2.1 hotel beds per 1,000 population in 2016 and stabilizes at this figure. Floor area increases proportionally. Existing floor space (in 2005) is assumed to be replaced at a 1 percent per year rate.
Hospital floor area	The floor area in the health sector (hospitals and clinics) is expected to grow gradually as the level of health services improves with economic development. The number of beds per capita is taken as a proxy for health services overall. Ministry of Health data forecast an increase in the number of beds from 0.88 beds per 1,000 population in 2001 to 1.96 beds per 1,000 population in 2015, stabilizing at 2 thereafter. 48 percent of new construction is assumed to be private. Existing floor space (in 2005) is assumed to be replaced at a 1 percent per year rate.
School floor area	Education floor area is assumed to scale according to education levels – number of students enrolled in primary, secondary, and post-secondary education. The primary gross enrollment ratio of 116 in 2004 is assumed to remain stable. The secondary gross enrollment ratio of 54 in 2004 is assumed to increase at historical rates to 80 by 2021 and remain stabile thereafter. Post-secondary education with a gross enrollment ratio of 19 in 2004 is expected to increase at historical rates to 68 by 2031. UNESCO age group population statistical forecasts (at a constant floor area per student) determine projected floor space. Existing floor space (in 2005) is assumed to be replaced at a 1 percent per year rate.
Other nonresidential floor area	The floor area is expected to grow from historical levels given by economic census data (2005) at the average growth rate of retail and offices. Existing floor space (in 2005) is assumed to be replaced at a 1 percent per year rate.
Energy end use fractions by type of usage	Equipment penetration and hours of operation derived from energy audits commissioned by Bureau of Energy Efficiency, estimates based on the USAID ECO-III study (2009) for hospitals, benchmarking studies on APEC countries, literature reviews, and building-level data collected by Lawrence Berkeley National Laboratory from architectural firms based in India. Air conditioning space cooling and lighting directly modeled. Other electrical use derived from samples and aggregate numbers.
Energy end use intensity by type of usage	As above, in order to ensure consistency with current sector electricity consumption, total electricity demand of each building type is calibrated to government statistics. In this estimate grid electricity is added to diesel electricity generation. All commercial sector diesel consumption is assumed to be used for backup electricity generation, with an efficiency of 25 percent.

Energy end use fractions by type of usage (continued):

End use fractions	Lighting (%)	Cooling (%)	Fans (%)	Other (%)
Retail	40.0	45.0	—	15.0
Offices	30.0	40.0	10.0	20.0
Schools	45.0	5.0	45.0	5.0
Hospitals	25.0	40.0	10.0	25.0
Hotels	25.0	55.0	—	20.0
Other	37.5	31.0	17.7	13.7

(continued)

Table A2.5 | Nonresidential Electricity *(continued)*

kWh/m²	Construction: Existing	Construction: New
Retail	198	268
Offices (private)	172	189
Offices (gov't)	150	165
Schools	56	56
Hospitals (private)	228	408
Hospitals (gov't)	120	215
Hotels	267	280
Other	97	123

Appliance historical parc technology mix

Lighting and cooling technology mix by type of usage derived from samples

	Incandescents (%)	Compact fluorescent light bulbs (%)	Fluorescent lamps (%)
Retail	20.0		80.0
Offices (private)	20.0		80.0
Offices (gov't)	20.0		80.0
Schools	5.0	20.0	75.0
Hospitals (private)	20.0	20.0	60.0
Hospitals (gov't)	20.0	20.0	60.0
Hotels	60.0	20.0	20.0
Other	17.9	9.7	72.4

	CUAC air-cooled (%)	WRAC + splits (%)	Multisplits + cassette (%)	Air-cooled chiller (%)	Water-cooled chiller (%)	None (%)
Retail	2.0	6.0		30.0	50.0	12.0
Offices (private)	8.6	5.2	5.0	6.3	6.3	68.6
Offices (gov't)	8.6	5.2	5.0	6.3	6.3	68.6
Schools		5.0				95.0
Hospitals (private)	5.0	34.0		20.0	20.0	21.0
Hospitals (gov't)	5.0	34.0		20.0	20.0	21.0
Hotels	5.0	10.0		20.0	50.0	15.0
Other	3.0	8.0	0.9	14.0	22.7	51.3

Note: CUAC = commercial unitary air conditioner; WRAC = window room air conditioner.

Mean power consumed by each appliance (in-use and stand-by)

Historical parc unit power consumed by each lighting and cooling appliance determined from historical data in India. Future unit power consumption improvements from India and other country manufacturers' data and efficiency standards. Scenarios were run applying different future efficiency standards.

Table A2.6 | Road Transport

<table>
<tr><td>Vehicle types modeled</td><td>2W (two-wheelers): mopeds, scooters, motorcycles
3W (three-wheelers): all three-wheelers
PC (passenger cars): mini; small; lower medium, medium, and upper medium; large and luxury; sport utility vehicles
LCV (light-commercial vehicles), passenger: Asian utility vehicles and multipurpose utility vehicles
LCV, goods: minivan/truck, pickup, van
HCV (heavy commercial vehicles): urban bus, coach, and truck, each by gross vehicle weight group</td></tr>
<tr><td>Vehicle population</td><td>Total vehicle population grows from an estimated 65 million in 2008 to 442 million in 2031. Of these, 285 million are two-wheelers and 113 million are passenger cars (including SUVs).</td></tr>
<tr><td>Private vehicle ownership</td><td>Motorized two-wheelers grow from an estimated 48 per 1,000 people in 2008 to 217 in 2031. Of these, 53 percent are expected to be electric. Private car ownership grows from 6 cars per 1,000 people in 2008 to 86 in 2031.</td></tr>
<tr><td>Vehicle emission standards</td><td>Includes the adoption of tighter vehicle technical standards with Euro 4 entering the market in 2010 and Euro 5 in 2015. Euro 6 is not currently included.</td></tr>
<tr><td>Vehicle efficiency standards</td><td>Business-as-usual case: No efficiency improvement except for changes to the sales mix by subtype of vehicle. Two-wheelers become mainly electric.
Alternative case, cars (excluding SUVs): Sales-weighted average CO_2 emissions drop from estimated 190 g/km in 2008 to 155 g/km in 2015. Further reductions are applied to reach 128 g/km in 2020. Additional reductions post-2020 achieve sales-weighted average CO_2 emissions of 100 g/km by the end of the following decade (2030).
Alternative case, light-duty vehicles (including SUVs): An estimated 231 g/km in 2008 improves at half the rate of cars to achieve 175 g/km in 2022, and 160 g/km in 2028. These figures are the targets for the European Union in 2012 and 2015 respectively.</td></tr>
<tr><td>Biofuels</td><td>All scenarios consider that from 2009 to 2012, petrol will have a 5 percent blend share by volume of ethanol (up from a current assumed average of 2 percent) and that this will increase to 10 percent thereafter. No biodiesel blend share is considered.</td></tr>
<tr><td>Vehicle capacity and loading</td><td>Capacity of light-duty minivans, minitrucks, and pickups is considered to be 0.6 tonnes per vehicle. The load capacity of vans is taken as 1 tonne per vehicle. Capacity of heavy-duty goods vehicles is taken as difference between (chassis plus average body) and GVW. Capacity of heavy-duty passenger vehicles taken as urban: standing capacity at 6 pers/m^2, long distance: seated capacity, both with average body style. Average 365/24 loading considered at 50 percent capacity.</td></tr>
<tr><td>Percentage vehicle-kilometers traveled under different urban, rural, and highway road speed conditions</td><td>
<table>
<tr><th>India:</th><th colspan="3">Average (km/hour)</th><th colspan="3">Mileage share (%)</th></tr>
<tr><th>Vehicle type</th><th>Urban</th><th>Rural</th><th>Highway</th><th>Urban</th><th>Rural</th><th>Highway</th></tr>
<tr><td>Car: Mini</td><td>18</td><td>45</td><td>80</td><td>90</td><td>9</td><td>1</td></tr>
<tr><td>Car: Small and above</td><td>18</td><td>55</td><td>90</td><td>70</td><td>20</td><td>10</td></tr>
<tr><td>MUVs</td><td>18</td><td>55</td><td>90</td><td>40</td><td>50</td><td>10</td></tr>
<tr><td>LDVs</td><td>18</td><td>40</td><td>60</td><td>50</td><td>45</td><td>5</td></tr>
<tr><td>HDV: Trucks</td><td>16</td><td>35</td><td>45</td><td>10</td><td>20</td><td>70</td></tr>
<tr><td>HDV: U-bus</td><td>13</td><td>30</td><td>45</td><td>90</td><td>5</td><td>5</td></tr>
<tr><td>HDV: Coach</td><td>16</td><td>40</td><td>60</td><td>10</td><td>50</td><td>40</td></tr>
<tr><td>Two-wheeler</td><td>20</td><td>40</td><td>60</td><td>50</td><td>48</td><td>2</td></tr>
<tr><td>Three-wheeler</td><td>18</td><td>20</td><td>n/a</td><td>80</td><td>20</td><td>0</td></tr>
</table>
</td></tr>
<tr><td>Ambient temperature</td><td>Vehicle-population-weighted average taken to be similar to Mumbai.</td></tr>
</table>

Table A2.7 | Industry

Activity growth (Domestic demand)	Iron and steel:	54.6 tonnes per US$1 million GDP		
	Aluminum:	1.39 tonnes per US$1 million GDP		
	Cement:	171.3 tonnes per US$1 million GDP		
	Fertilizer:	annual growth given by (7*10^6*LN(I0) - 3*10^7)/(7*10^6*LN(I-1) - 3*10^7) where I is the per capita income in US$		
	Refinery:	191.1 tonnes per US$1 million GDP		
	Pulp and paper:	9.07 tonnes per US$1 million GDP		
Iron and steel Technology and energy consumption (2007)	By type of producer:			
	Integrated steel producers 64 percent			
			Production mix	**Energy (gigajoules/tonne)**
	Blast furnace–oxygen-blown converter		75.9%	32.0
	Direct reduced iron: natural gas electric arc furnace		17.7%	19.0
	Direct reduced iron: coal electric arc furnace		6.4%	21.4
	New plants 15 percent baseline improvement			
	Small-scale steel producers 36 percent			
			Production mix	**Energy (gigajoules/tonne)**
	Blast furnace–oxygen-blown converter		5.0%	35.9
	Direct reduced iron: coal electric arc furnace		95.0%	31.2
	Scrap		2 million tonnes	3.5
	New plants 20 percent baseline improvement			
Aluminum Technology and energy consumption (2007)	Ratio alumina/aluminum: 2.00			
	Scrap: 0.4 million tonnes per year growing at 10 percent per year			
			Production mix	**Energy (kWh/tonne)**
	Prebaked		89.4%	14,415.7
	Vertical stud Soderberg		10.6%	17,892.3
	New plants			14,167.0
				(gigajoules/tonne)
	Alumina			14.9
	New plants			13.2
	Secondary production			5.6
	New plants			4.0
Cement Technology and energy consumption (2007)		**Production mix**	**Clinker ratio**	**Energy (gigajoules/tonne)**
	Ordinary Portland cement	39.4%	0.950	3.33
	Portland pozzolana cement	52.2%	0.900	3.33
	Portland blast furnace slag cement	8.4%	0.345	3.33
	New plants	—	—	3.03

(continued)

Table A2.7 | Industry *(continued)*

			Production mix	Energy (gigajoules/tonne)
Fertilizer Technology and energy consumption (2007)	Natural gas		66.0%	35.54
	Naphtha		30.0%	41.23
	Fuel oil		4.0%	49.06
	CO_2 emissions in ammonia production: Current plants 2.9 tCO_2 per tonne product, new plants 2.0 tCO_2 per tonne product.			
Refinery Technology and energy consumption (2007)	Energy intensity current plants: 3.9 gigajoules per tonne.			
Pulp and paper Technology and energy consumption (2007)			**Production mix**	**Energy (gigajoules/tonne**
	Integrated mills	Wood based	30.0%	60.03
	Small plants	Agro based	32.0%	32.38
		Waste paper pulping	38.0%	24.13
Efficiency improvements	Marginal abatement cost curves were developed for each industry. The curves included a total of 334 specific process improvements and were developed with carbon-saving measures derived from Indian case studies, CDM projects, and United States carbon-saving measures for each industry sector converted to the Indian situation. A high-efficiency scenario was constructed applying these process improvements in only 80 percent of plants over the 2011 to 2021 time frame, including an exogenous 0.5 percent per year efficiency improvement from 2011 onward in newly purchased and installed plant and equipment.			

Annex 3 | Description of Industrial Sector

IRON AND STEEL

India is the seventh largest steel-producing country in the world. However, the per capita consumption in 2005 was only about a quarter of the global average, and 8 times lower than that of the United States and 10 times lower than Germany (International Iron and Steel Institute 2007). Production has grown rapidly, mostly driven by domestic demand, and is expected to continue to grow fast to meet the country's needs for development. Industrialization drives an increase in demand for materials for construction of basic infrastructure, such as railways, buildings, and power networks. Domestic steel demand is also driven by the rising automobile industry.

Iron and steel is the largest consumer of energy in the industrial sector in India, with a share of 28 percent of total energy use in industry (de la Rue du Can et al., 2008). The sector is highly concentrated, with nine companies producing 64 percent of total crude steel and the remaining 36 percent produced by small-scale industries.

Production of iron and steel consists in several steps, amongst which the most energy-intensive are iron production, steel production, and finished product preparation. There are three main routes that can be followed: production of iron through blast furnaces followed by steel production in oxygen-blown converters; production of sponge iron through direct reduction, followed by production of steel in electric furnaces; and direct production of steel from scrap metal in electric furnaces. The last is by far the least energy intensive, as it avoids the production of iron.

In India, the steel industry is slowly diverting itself from the blast furnace–oxygen-blown converter route to the direct reduction–electric furnace route. Production of sponge iron has grown very rapidly over the last 16 years, increasing by a factor of 28. This results from the installation of three large natural gas-based direct reduction–electric furnace plants and the mushrooming growth, after 2002, of small coal-based sponge iron plants (JPC 2005). Other energy-efficient measures implemented by steel industries include use of tar in blast furnaces; carbon monoxide firing in vertical shaft kilns; adoption of multislit burner; installation of variable frequency drives; installation of vapor absorption systems; use of high-efficiency motors, pumps, and blowers; improved insulation of furnaces; and replacing electric heaters with fuel-fired heaters.

The recent growth in the small coal-based sponge iron industry has been favored by the growth in domestic steel demand. Specific energy consumption in small units is high due to lack of economies of scale, intermittent operation with 40–60 percent utilization of installed capacity, and the very low engineering base and use of obsolete technology.

ALUMINUM

The aluminum sector consumed about 7 percent of total energy used in the industry sector in India in 2005 (de la Rue du Can et al., 2008). India's share of world aluminum capacity is about 3 percent. Indian reserves of bauxite, the key raw material in aluminum production, are abundant, with deposits of about 3 billion tonnes or 5 percent of world deposits. The Indian aluminum sector is highly concentrated, with only three large producers: Hindalco, Sterlite Industries, and the National Aluminum Company (Nalco).

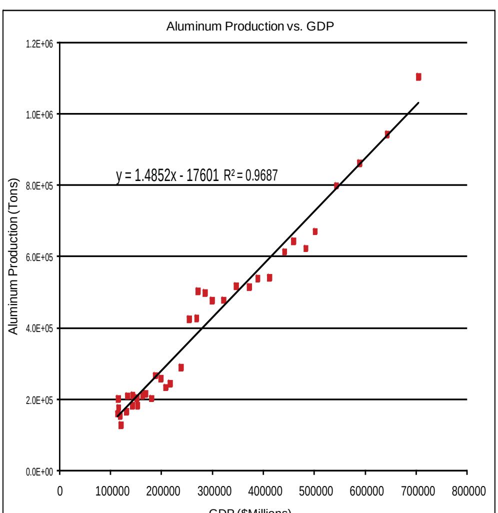
The sector is also composed of secondary producers that process aluminum into rollers and extruders and either purchase from domestic producers or import the primary metal (billets and blooms). It is estimated that secondary producers produce about 600,000 tonnes of fabricated product (Metalworld 2008). The main end users of aluminum are the electrical, automobile, packaging, and construction sectors.

Over the past few decades, aluminum consumption in India has grown steadily. As Figure A3.1 shows, this increase scales almost precisely with GDP. Aluminum consumption has increased by 1.39 tonnes per US$1 million of GDP.

The production of aluminum is a very energy-intensive process, requiring a large quantity of electricity. Energy cost represents on average 40 percent of total production cost. The main energy steps for primary aluminum production consist first in refining bauxite into alumina, then reducing alumina to aluminum by means of electrolysis, and finally rolling slab ingots into flat sheets.

CO_2 emissions from fuel combustion arise mostly in the refining process of alumina. Most of the steam and heat required is based on coal consumption. During the production of aluminum, the bulk of the energy required is electric power supplied mostly by captive power plants, which

Figure A3.1 | Per Capita Aluminum Production versus GDP



Source: Sathaye, et al., 2010.

need to provide continuous current. In India, captive power plants use coal to generate the required electricity, resulting in considerable indirect CO_2 emissions.

Reduction of CO_2 emissions is possible during different stages of aluminum production. The most energy-intensive step, electrolysis, compares positively with world best standards. The Lawrence Berkeley National Laboratory estimates that Indian smelters use on average only 8 percent more than world best practice. Over the last five to seven years, most Indian smelters have implemented energy efficiency measures that have reduced their energy intensity. Moreover, with a doubling of the production capacity in seven years, modern and efficient technology has been installed.

However, potential for improved energy efficiency remains, especially in the first phase of aluminum production, namely alumina production, and in the production of electricity through captive power in all Indian smelters.

CEMENT

The cement industry is one of the most energy intensive sectors, as well as being a high-efficiency achiever. The cement industry in India comprises 132 large cement plants with a production capacity of 167 million tonnes per year and more than 365 mini cement plants with an estimated capacity of 11 million tonnes per year. India is the second largest manufacturer of cement after China, accounting for about 6 percent of the world's production. Despite the industry's rapid growth, per capita cement consumption in India still remains one of the lowest in the world (about 165 kilograms).

With rapid expansion, the cement industry has also made strides in upgrading its production methods and assimilating state-of-the-art technologies. Modern Indian cement plants are comparable with the best in the world. Upgrading by converting wet process plants to semidry and full dry processes has resulted in considerable economies in fuel and power consumption. Wet process capacity, which accounted for 97 percent in 1950, had been brought down to 3 percent in 2007, and 96 percent of the production capacity has modern, efficient, and environment-friendly dry process technology. The remaining 1 percent is based on the semidry process.

At present the Indian cement industry produces 13 different varieties of cement employing three different process types. The basic difference among the different varieties of cement lies in the percentage of clinker used. Production of clinker is responsible for the process emissions and most of the energy-related emissions. The use of blended cement, in which clinker is replaced by alternative materials such as blast furnace slag and fly ash from coal-fired power stations, results in lower CO_2 emissions (IPCC 2007).

According to the Bureau of Energy Efficiency (BEE) (2003), the new-generation cement plants in India have excellent energy efficiency norms comparable to the most efficient plants in the world. The Bureau has developed specific energy consumption norms and benchmark tools that allow companies to assess their performance in term of energy efficiency. However, there is scope for further improvement in several areas.

FERTILIZER

India is currently the second largest producer of nitrogenous fertilizer in the world, after China (USGS 2009). Production has grown at an average rate of 6 percent annually since 1981. Presently, there are 65 large-sized fertilizer plants in India. Of these, 32 units produce urea, 20 produce diammonium phosphate and complex fertilizers, and 13 produce ammonium sulfate, calcium ammonium nitrate, and other types of fertilizers. On a production volume basis, Indian nitrogenous fertilizers are mostly composed of urea (88 percent); the remaining share consists of the complex fertilizer di-ammonium phosphate (10 percent) and different types of ammonium fertilizers (2 percent).

Despite the rapid growth of the fertilizer industry, per capita nitrogenous fertilizer consumption in India remains low compared to the global average. Per capita consumption is around 15 kilograms in India; about 2.4 times lower than the global average. The production of ammonia (NH3) represents the most energy-intensive step in the production of nitrogenous fertilizer.

In India, average energy use per tonne of ammonia has decreased considerably over the years. A recent study by the Fertilizer Association of India estimates that the weighted average energy consumption of all ammonia and urea plants in 2007/8 was reduced by about 30 percent from the level of 1987/88 (Nand and Manish 2008). Various technology improvements have also contributed to energy intensity reduction. Among the most significant upgrades are the recovery of hydrogen with the installation of purge gas recovery units, the switch to better metallurgy for reformer tubes, and cogeneration and other types of heat integration improvements (Nand and Manish 2008).

The production of ammonia is also significant industrial source of CO_2 emissions, which are released during the combustion of fuel and during the chemical reaction to produce ammonia. None of the carbon from the fuel is stored in the final products produced; as a result all the carbon from fuel used as feedstock is emitted. On average, Indian nitrogen fertilizer energy intensity remains relatively higher than international levels. Indian fertilizer industry reliance on non-natural-gas-based plants partly explains its higher energy intensity, as more fuel is required to produce the same output as natural gas-based plants.

REFINING

Production of petroleum products in India has doubled in eight years, from 68 million tonnes in 1998 to 145 million tonnes in 2006. There is a total of 18 refineries (with 17 in the public sector). India currently has a low overall cracking to distillation ratio because it uses light crude oil, some of which is produced domestically, though it is expected that Indian refineries will continue to expand their ability to process less expensive heavy, higher-sulfur grades of crude oil in the future.

As with steel, cement, and aluminum, the growth in production of refinery products is found to scale roughly with GDP, at a rate of 191 tonnes of refinery products per US$1 million of GDP. In 2005/6 the aggregate refinery fuel use and losses represented 9 percent of total crude inputs, which is significantly higher than in developed countries, where it is close to 4 percent (International Energy Agency 2008). In the 10 years following 1995/96 refinery throughput rose 180 percent, while energy consumption rose nearly 220 percent, leading to a 40 percent increase in energy consumption per unit of crude processed. This increase in unit consumption was due in part to the installation of more energy-intensive processing units, such as diesel hydro-desulfurizers after 1997 to improve the quality of Indian transport fuels.

CO_2 emissions from refineries originate from two main sources: fuel combustion and industrial processes. Industrial process emissions occur from production processes where CO_2 is a by-product of chemical reactions in the production of hydrogen. Hydrogen is used by oil refineries to meet limits on sulfur content in refined fuels and to convert heavy petroleum products into lighter products. Feedstocks used to produce hydrogen include natural gas, liquefied petroleum gas, naphtha, and refinery fuel gas. Experiences of various oil companies have shown that most energy saving investment requirements are relatively modest.

PULP AND PAPER

The Indian pulp and paper industry is the sixth largest energy user in the Indian industrial sector, accounting for 3 percent of industrial energy use in 2004. It is a highly fragmented industry with over 650 productive units, of which only 27 are large integrated mills, representing 25 percent of total capacity. Paper mill capacities range from 1,000 to 200,000 tonnes per year, with an average of 11,500 5 tonnes per year (Jain, Singh, and Kulkarni 2005), compared to 300,000 tonnes per year in Europe and North America. Thus, even large Indian mills are of only small to medium size by current international trends. The country is almost self-sufficient in manufacture of most varieties of paper and paperboard, with a total production of 5.9 million tonnes in 2005/6. Production increased at an annual rate of 6 percent over the period 1995–2005. Import is confined only to certain specialty papers, such as lightweight coated varieties of paper.

Similarly to steel, cement, and aluminum, paper production is found to scale roughly with GDP, at a rate of 9.1 tonnes of paper per US$1 million GDP, and pulp and paper production is expected to grow over 6 times 2008/9 values by 2031, reaching 35 million tonnes.

The amount of energy used depends on the nature of the feedstock and the desired quality of the product. In India, about 38 percent of total paper production is based on wastepaper, 32 percent on bagasse and agriculture residues, and the remaining 30 percent on wood (TERI 2007). The size of plant is correlated with the nature of the feedstock used. Large plants use wood, plants of a medium size generally use agro-waste, and small plants use predominantly wastepaper. Wood-based production is, however, gradually declining because of raw material availability constraints. Under the existing forest policy, the paper industry cannot use wood from any of the national forest reserves. The share of wastepaper (secondary fiber), which is less energy intensive, has increased considerably over the last 10 years. The quantity of domestic recovered paper more than doubled in the period 1995–2005 and imports of recovered paper increased by 24 percent annually over the same period (FAO 2007).

The paper industry in India is very energy intensive. About 75–85 percent of the energy requirement in pulp and paper production is used as process heat and 15–25 percent for electrical power. Coal and electricity are the two major sources of energy in Indian paper industries. Other fuels, such as fuel oil, are also used to fire boilers, and diesel oil is used for small backup power generators. Steam is primarily used in digesters and pulp-making equipment, while electricity is mainly used in the paper-making process. Pulp making is one of the most energy-consuming processes in the paper and paperboard supply chain.

The pulp and paper industry in India is a mix of old and new plants with a diversified technology absorption pattern, resulting in wide variation in specific energy consumption levels. The different varieties and grades of paper being manufactured demand different process technologies, affecting the energy requirements of the plants. A comprehensive study was undertaken by the Central Pulp and Paper Research Institute (CPPRI 2005a) for the Bureau of Energy Efficiency to fully document how energy is used in the pulp and paper industry in India.

According to the CPPRI study, compared to best practices, there is a large scope for energy efficiency improvements in the paper industry. The study also developed norms for various categories of mills, taking into account factors such as raw material, varieties and grades of pulp and paper produced, age of the plants, technology status, and the capacity of major equipment and machinery. The classification into wood-, agro-, and recycled fiber-based mills was further disaggregated into subgroups to account for the differences in quality of paper produced.

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Dwarka
द्वारका

The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank that assists low- and middle-income countries to increase know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth.

For more information on the Low Carbon Growth Country Studies Program or about ESMAP's climate change work, please visit us at www.esmap.org or write to us at:

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