ESMAP

Energy Sector Management Assistance Program

Briefing Note 006/10

Energy Intensive Sectors of the Indian Economy

Path to Low Carbon Development

LOW CARBON GROWTH COUNTRY STUDIES PROGRAM

MITIGATING CLIMATE CHANGE THROUGH DEVELOPMENT

CARBON FINANCE ASSIST

LOW CARBON GROWTH COUNTRY STUDIES PROGRAM

TABLE OF CONTENTS

Energy Intensive Sectors of the Indian Economy

PATH TO LOW CARBON DEVELOPMENT

India is at an important juncture in its development. During the five years prior to the recent global economic and financial crisis, its gross domestic product (GDP) grew more than nine percent annually, with high rates of investment and savings and a strong increase in exports. This rapid economic growth has generated substantial potential for public and private investments in infrastructure development. The Government of India is aiming to double its per capita GDP over 10 years (as outlined in India's 11th Five Year Plan for 2007–12[1]). In order to sustain such dramatic and rapid income growth for a country as populous as India, transformative changes will be required to address the current energy deficit and constraints, and keep up with significant growth in energy demand across all sectors of the economy.

Although on a per capita basis India has a relatively low carbon footprint (Figures 1 and 2), CO_2 emissions are set to grow rapidly due to projected rapid economic growth. Compared to other large economies, India has a unique development challenge. It is committed to lifting millions out of poverty within a generation and to provide lifeline electricity to about 400 million people who currently do not have access, addressing chronic energy shortages within the context of limited availability of low-cost, lower carbon energy resources.

The scale of projected growth of energy demand raises questions about increasing CO_2 emissions, which have global implications. India's CO_2 emissions from fossil fuel use were less than five percent of the world total in 2007 (IEA 2009) but this is likely to increase with economic development. India relies heavily on coal for its commercial energy supply (53 percent of installed generation capacity), has limited other domestic energy resources, and is increasingly dependent on imported fossil fuels.

India's future growth in CO_2 emissions from the energy sector will depend on the extent to which the growth in energy use is offset by:

- **Further reductions in the energy intensity of GDP** by meeting growth and development goals with proportionally less energy use and associated CO_2 emissions

[1] The years mentioned in the text are India's fiscal years, which run from April to March.

- **Further reductions in the CO_2 intensity of the energy supply** through greater increases, where possible, in the share of energy from lower carbon or even carbon-neutral energy resources

This overview highlights the main findings of *Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development*, a study specifically requested by the Government of India to help identify low carbon growth opportunities for India and contribute to global climate change mitigation (Box 1).

BOX 1.

Getting Started

Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development is the product of a collaborative effort between the World Bank and the Government of India, under the overall leadership of the Planning Commission and the Ministry of Power, and with the financial assistance of the Department for International Development (DFID) and the Energy Sector Management Assistance Program (ESMAP).

The study was requested by the Government of India to develop the analytical capacity for identifying low carbon growth opportunities up to the end of the 15th Five Year Plan (March 2032) in major sectors of the economy; and to facilitate informed decision making by improving the knowledge base and raising national and international awareness of India's efforts to address global climate change.

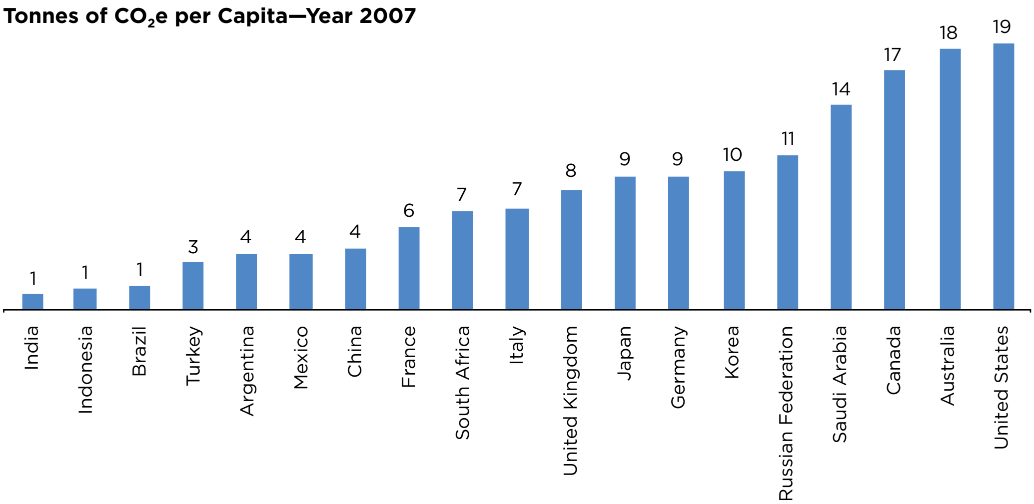
The study uses an innovative engineering-based, bottom-up model to examine CO_2 emissions from energy use during 2007 to 2031. It focuses on sectors and areas that are expected to contribute significantly to India's future growth in CO_2 emissions:

- Power generation, transmission, and distribution
- Electricity consumption by households
- Nonresidential buildings
- Energy consumption in six energy intensive industries
- Fuel use in road transport

The report presents India's potential "carbon futures". It does not 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.

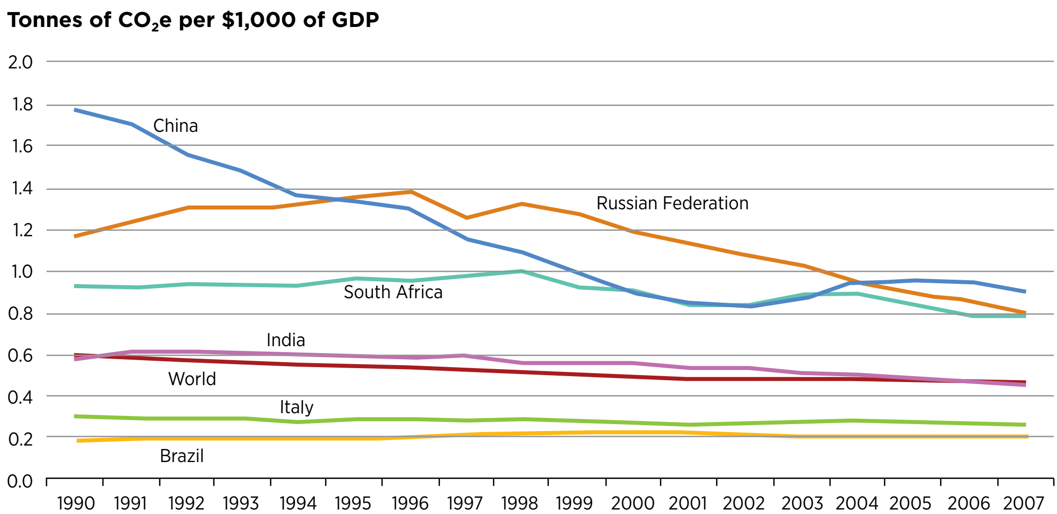
The report received significant support from ministries and agencies of the Government of India, including the Planning Commission, the Ministry of Environment and Forests, the Ministry of Power, the Central Electricity Authority, and the Bureau of Energy Efficiency. The World Bank team was initially led by Kseniya Lvovsky and in the subsequent phase by Kwawu Mensan Gaba and Charles Cormier as co-leaders of the task team. The team included John Allen Rogers, who led the efforts on modeling; and Masami Koijima and Michael Toman, who were active peer reviewers during the preparation phase of the study. Technical background reports were produced by a team of consultants from the Lawrence Berkeley National Laboratory led by Jayant Sathaye and from Segment Y Automotive Intelligence Pvt. Ltd. led by Paul Blokland.

Figure 1: India's Per Capita CO_2 Emissions Compared to Other G-20 Economies



Source: IEA 2009, World Bank 2009, and Author's calculations.

Figure 2: CO_2 Intensity of India Compared with Select G-20 Economies



Sources: IEA 2009, World Bank 2009, and Author's calculations.

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

EVALUATING DEVELOPMENT PATHWAYS

Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development describes potential emission trajectories to 2031. It uses an innovative bottom-up, engineering-style model (Box 2) to examine CO_2 emissions for different scenarios or potential "carbon futures" for India. The report explores how total emissions might evolve under different assumptions about energy supply and demand drivers, in different sectors of the economy.

The analysis focuses on power generation and supply (including grid- and captive-generation, and transmission and distribution); electricity consumption by households; nonresidential buildings; energy consumption in six energy-intensive industries (iron and steel, aluminum, cement, fertilizer, refining, and pulp and paper); and fuel use in road transport—all of which are estimated to contribute significantly to India's future CO_2 emissions. These 5 sectors covered 75 percent of GHG emissions from energy use in India in 2007 (IEA 2009), the base year for the study.

The bottom-up model is used to analyze future demand 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. It does not 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.

Whilst multiple scenarios were investigated, the report's findings are based on three scenarios and their sensitivity analyses. Table 1 shows a summary of these scenarios.

Scenario 1 | **"Five Year Plans" Scenario,** assumes full implementation of the Five Year Plans and other projections and plans by the Government of India.

Scenario 2 | **"Delayed Implementation" Scenario,** more closely follows historical performance in implementation of the Five Year Plans.

Scenario 3 | **"All-Out Stretch" Scenario,** adds to Scenario 1 steps to increase energy efficiency and low-carbon energy sources.

PRINCIPAL FINDINGS

All scenarios and their sensitivity analyses show that emissions of CO_2 equivalent (CO_2e) from the sectors studied, increase 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.

Additionally, if efforts in the non-energy sectors, like agriculture and forestry (which the Bank study did not examine), are also sustained, trends indicate that

Table 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% slippage in new capacity addition for higher efficiency coal, hydropower, wind, and biomass	Additional 20 GW of solar and 20 GW of imported hydropower
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% slippage in new capacity addition for higher efficiency coal, hydropower, 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.

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; and reforestation.

Power Generation, Transmission, and Distribution

Three major findings emerged 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 (Figure 3).

The share of total power generation derived from coal increases from 73 percent in 2007 to 78 percent in Scenario 1. 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 power at affordable prices; problems associated with the implementation of planned investment programs; and the abundance of (global and domestic) coal and its relatively low prices.

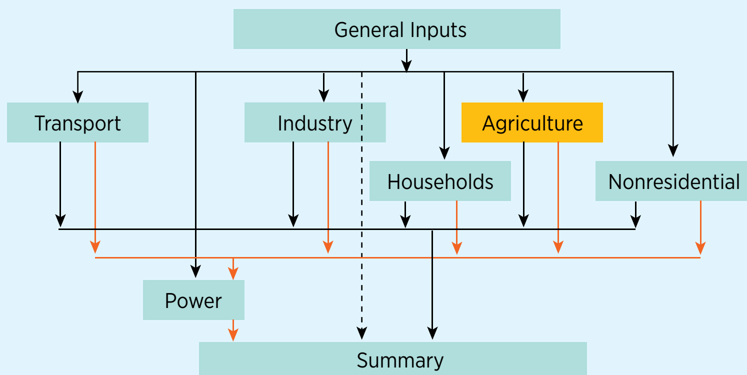
Should the Five Year Plans Scenario experience significant delays in implementation, as observed in the last three Five Year Plans (April 1991 to March 2006), the share of total power generated from coal increases to 84 percent (Sce-

BOX 2.

India's Low Carbon Development Model

The Government of India worked with the study team to build a Low Carbon Development (LCD) model, which was used as a consensus-building and planning tool to analyze key sectors of the economy and assess the impact of policy choices on GHG emission levels. It is a user-friendly, low-cost, bottom-up, engineering-style model that uses Microsoft Excel and Visual Basic to transparently share assumptions and data, and model energy supply and demand and emissions over 26 years.

Low Carbon Development Model Structure



Source: Authors.

The model currently evaluates five sectors in the economy:

Supply

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

Demand (covering energy consumed by end user)

- Residential electricity use
- Nonresidential buildings
- Six energy-intensive industries with significant potential for future expansion —iron and steel, further separated into large integrated steel plants and small-scale plants; aluminum; cement; fertilizer; refining; and pulp and paper
- Road transport, comprising two-wheeler vehicles to heavy-duty trucks and buses

nario 2). Only in Scenario 3 does the share of coal decline slightly to 71 percent.

The amount of CO_2 emitted per kWh varies markedly from scenario to scenario (Figure 4). Compared to 2007, CO_2 emissions per kWh of grid electricity in 2031 are about 19 percent lower under Scenario 3: All-Out Stretch Scenario, almost 13 percent lower under Scenario 1: 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

These together account 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 nonavailability of data, but its relative share is expected to decline as the Indian economy continues to modernize and grow.

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. 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. 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 by captive power is included and covers generators with a minimal unit size of 1 MW using mainly diesel as fuel, except in industry where other fuels may be used. Fuel consumed by smaller generators in households, shops, and others is not considered.

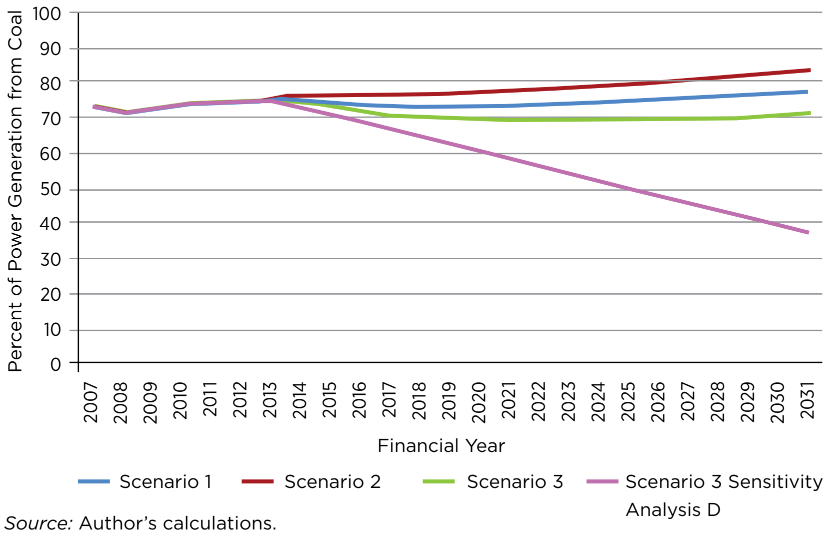
Projections for future ownership of vehicles and electric appliances by households are based on assumed GDP and population growth rates, household size, distribution of household income (using expenditures as a proxy), and urbanization. Vehicle fuel use and electricity are projected based on the vehicle 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, population growth, and associated energy consumption of the technology for each application.

Adapted from "Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development," World Bank, May 2011.

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.

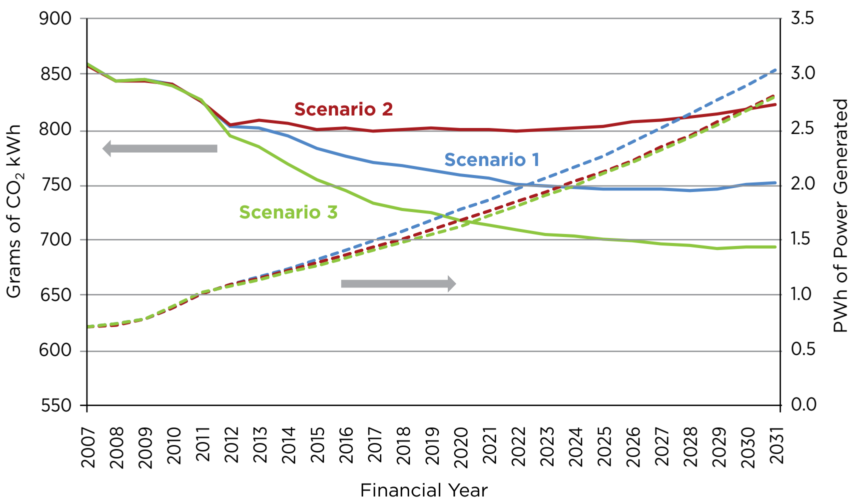
Second, the model finds reducing technical transmission and distribution losses remains one of the most cost-effective means of improving power sector performance while simultaneously reducing CO_2 emissions and providing the cobenefits of energy security and reduction of local air pollution.

Figure 3: Share of Coal in Grid Power Generation



Source: Author's calculations.

Figure 4: CO_2 Emissions from Grid Electricity Generation

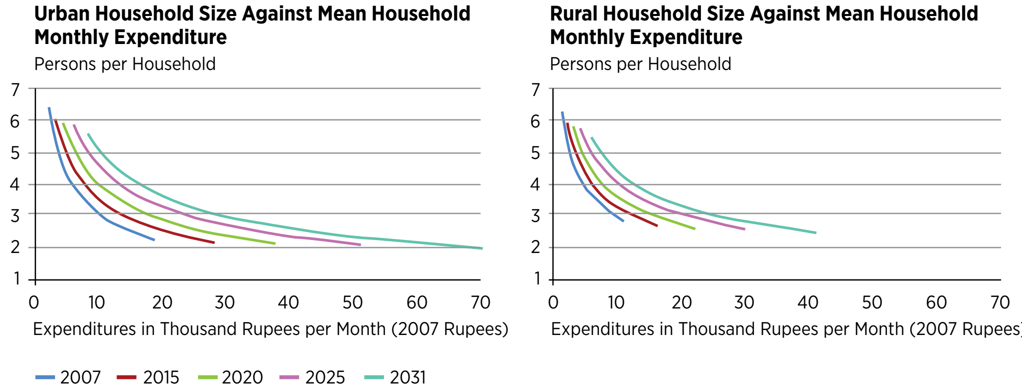


Source: Author's calculations.

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 the same amount of grid electricity as in Scenario 1 is supplied to end-users, there is a reduction of 568 million tonnes in CO_2 emissions (equivalent to the total emissions of the power sector in 2005) and of 94 billion rupees (equivalent to US$ 2.1 billion in 2007) in investment in new plants and renovation of existing plants between 2007 and 2031.

Third, results show that Scenario 2 lowers capital expenditures for grid electricity by about 14 percent on the basis of 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 im-

Figure 5: Household Size Distribution, Urban (left) and Rural (right), against Mean Household Expenditure



Sources: National Statistical Surveys and Author's calculations.
Note: Study projects household size and expenditure as a proxy for household income.

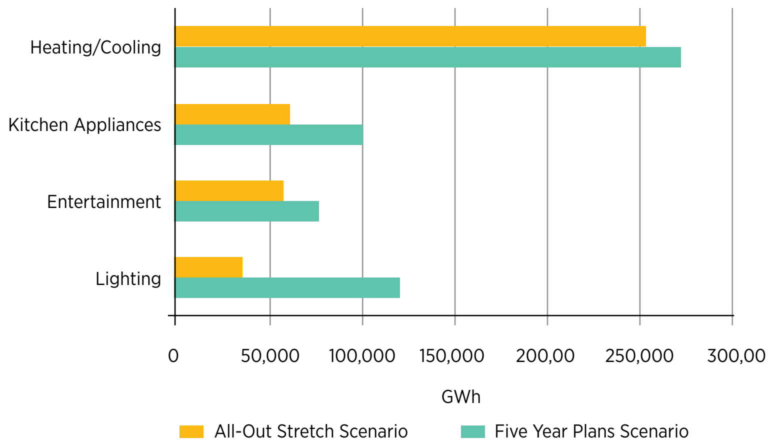
posing higher costs to society as a whole: over the medium term, a portion of investment in the power sector is shifted from the grid system to privately owned, smaller scale power generators (over 1MW) throughout the economy running mainly on diesel.

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.

Household Use of Electricity

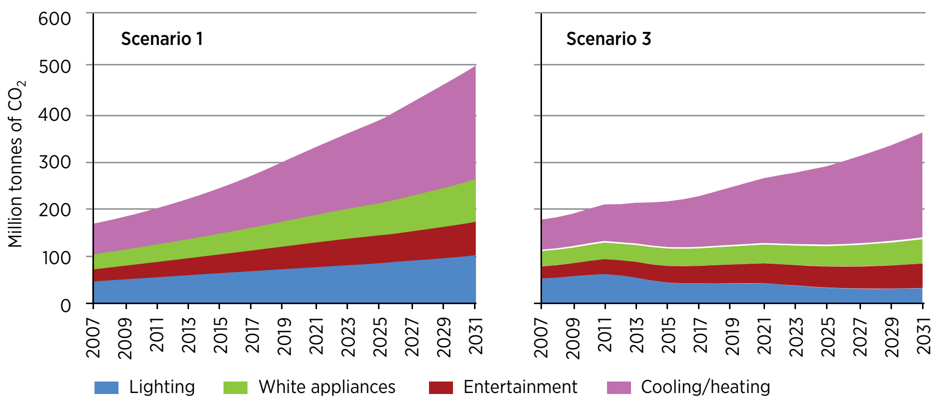
Household electricity consumption is growing significantly, accounting for approximately 21 percent of the total electricity demand in 2007. Lighting accounts for approximately 30 percent of total residential electricity use in 2007, followed by fans, refrigerators, electric water heaters, and televisions. Increasing population and urbanization (urbanization rate is projected to rise from 29 percent in 2006 to 33 percent in 2026), decreasing household size, and rising household income and expenditure, are expected to drive greater ownership and use of electrical appliances (Figure 5). 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 will 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 of the

Figure 6: Total Household Electricity Consumption in 2031



Source: Author's calculations.

Figure 7: CO_2 Emissions from Household Electricity Consumption

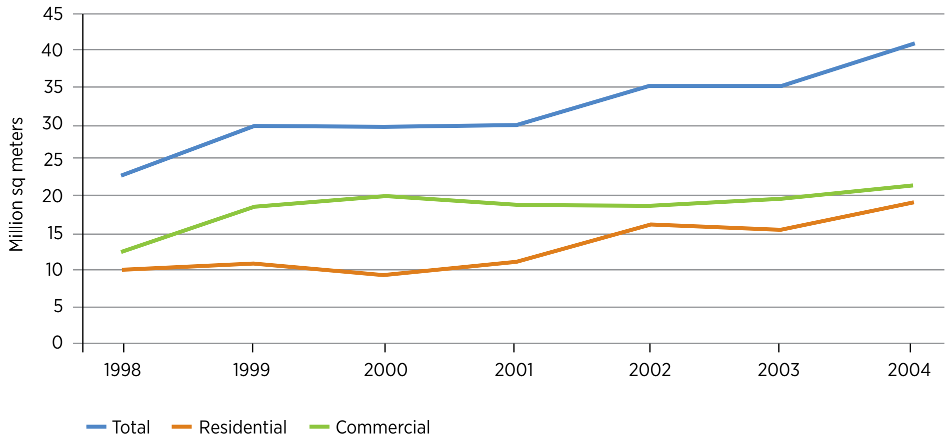


Source: Author's calculations.

European Union (EU) 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 modeling confirms that adopting energy efficiency standards for household appliances significantly reduces electricity demand. The amount of electricity used for space-cooling and water-heating is slightly more than one third of total electricity consumed, but rises to nearly half by 2031 in Scenario 1 (Five Year Plans) as household incomes gradually increase. In Scenario 3 (All-Out Stretch) 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 (Figures 6 and 7).

Figure 8: Historical Trends in New Construction



Source: Sathaye, et al, 2010.

Nonresidential Buildings

India has historically seen a near consistent 5 percent rise in annual energy consumption in the nonresidential 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 5 years.

New construction has typically higher energy usage (per square meter) than existing buildings and the trend shows a consistent annual growth rate of about 10 percent (Figure 8). 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 care 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.

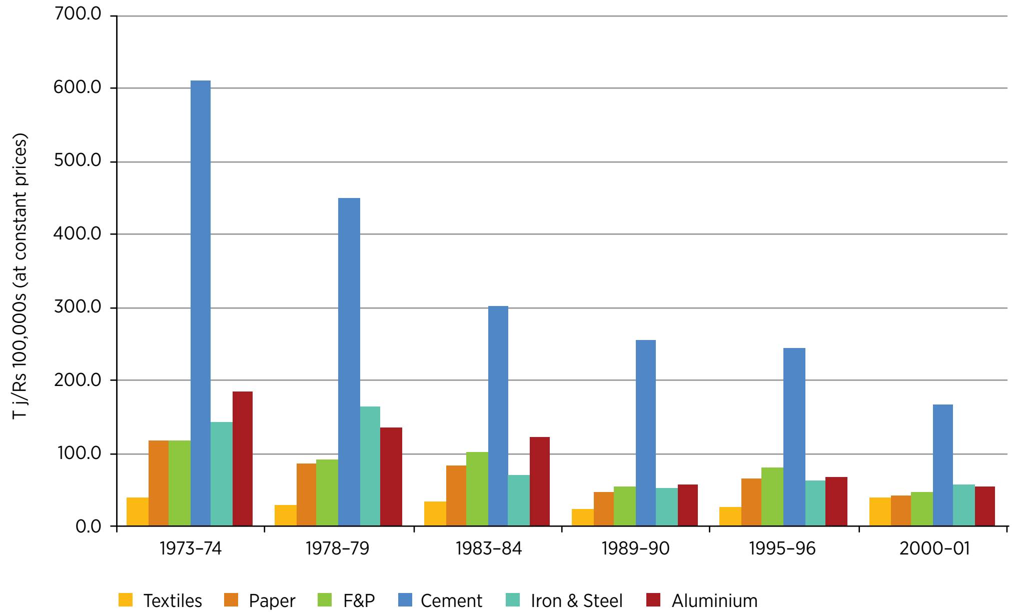
The analysis assessed the trend in the consumption of electricity, diesel used for additional power generation and use of liquefied petroleum gas (LPG; mainly for heating water and cooking in restaurants) for six categories of buildings, two of which—hospitals and offices—were separated further into public and private use. 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, which indicates financially viable opportunities for intervention.

Industry

Thirty five percent of the final energy consumption in India is attributed to the industrial sector; with the energy intensive industries—iron and steel, aluminum, cement, fertilizer, refining, and pulp and paper—accounting for 66 percent of the energy consumed in the sector in 2005 (Figure 9). The light industries—food processing, textiles, wood products, printing and publishing, and metal processing—account for the rest.

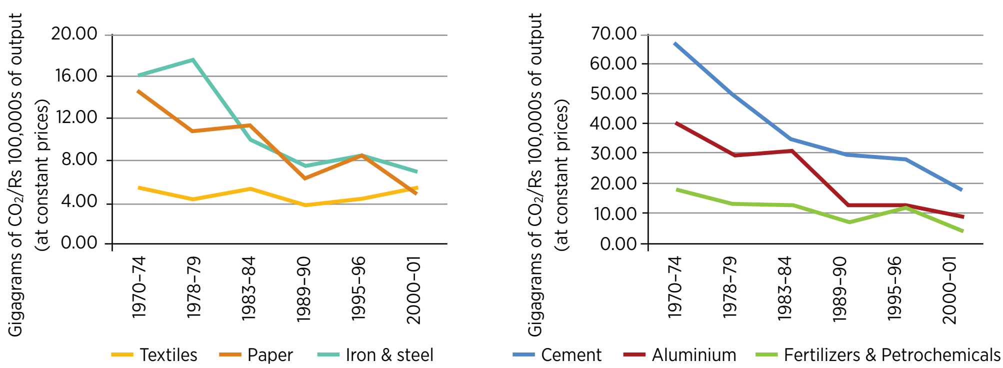
Industry has recorded greater energy efficiency improvements since the late 1980s than any other sector in India (Roy 2007). All the principal industries have shown declining emissions intensity in recent decades (Figure 10). Between 1970 and 2001, the aluminum, cement, and fertilizer industries achieved the largest reduction in emissions intensity (right graph). Textiles, paper, and iron

Figure 9: 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 10: Emission Intensity of Industries



Sources: Dasgupta and Roy 2000, 2001; Dasgupta 2005

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 continues, and textiles, where the intensity increases. 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.

India's nearly 3 million small and medium enterprises (SMEs) constitute more than 80 percent of the total number of industrial enterprises and approximately 60 percent of the country's GDP (Indian Institute of Foreign Trade estimate). 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. With the introduction of the Energy Conservation Act in 2001 and the promotion of various energy efficiency improvement schemes by the Bureau of Energy Efficiency, there appears to be significant, potentially exploitable, energy and emission-saving opportunities in Indian industries, if barriers to energy efficiency improvements in India can be overcome.

Road Transport

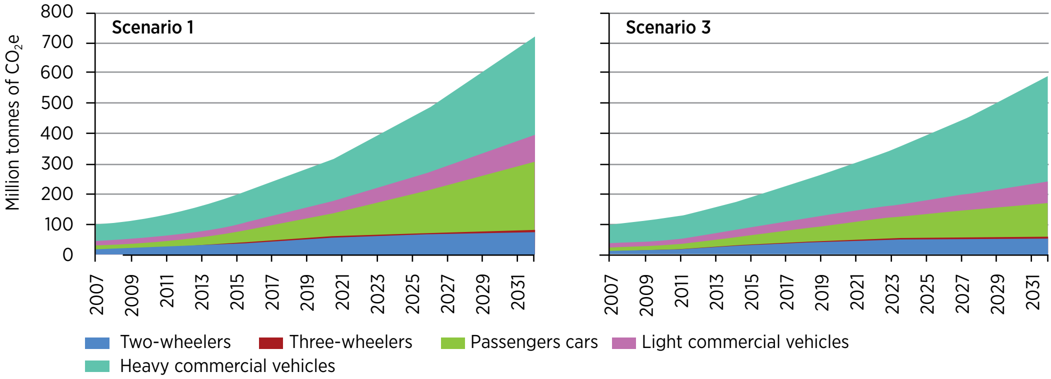
Emissions from the transportation sector are the fastest growing in India, with road transportation being the major contributor. This is due particularly to increasing urbanization; in 2004, about 8 percent of total emissions were attributed to transportation and road transport accounted for 90 percent of this 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 the urban population increases and cities get more connected, the current growing trend of vehicle ownership rate of about 5 to 15 percent is expected to increase.

The analysis calculates that CO_2e emissions from the sector will increase by a factor of 6.6 in Scenario 1 (Five Year Plans) and 5.4 in Scenario 3 (All-Out Stretch) between 2007 and 2031 (Figure 11). Emissions from road transport are 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 (Figure 12). In Scenario 3, where tighter CO_2 emission standards for passenger 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. By 2013, emissions from heavy-duty commercial vehicles in Scenario 3 will exceed those in Scenario 1 because of greater use of buses for public transport.

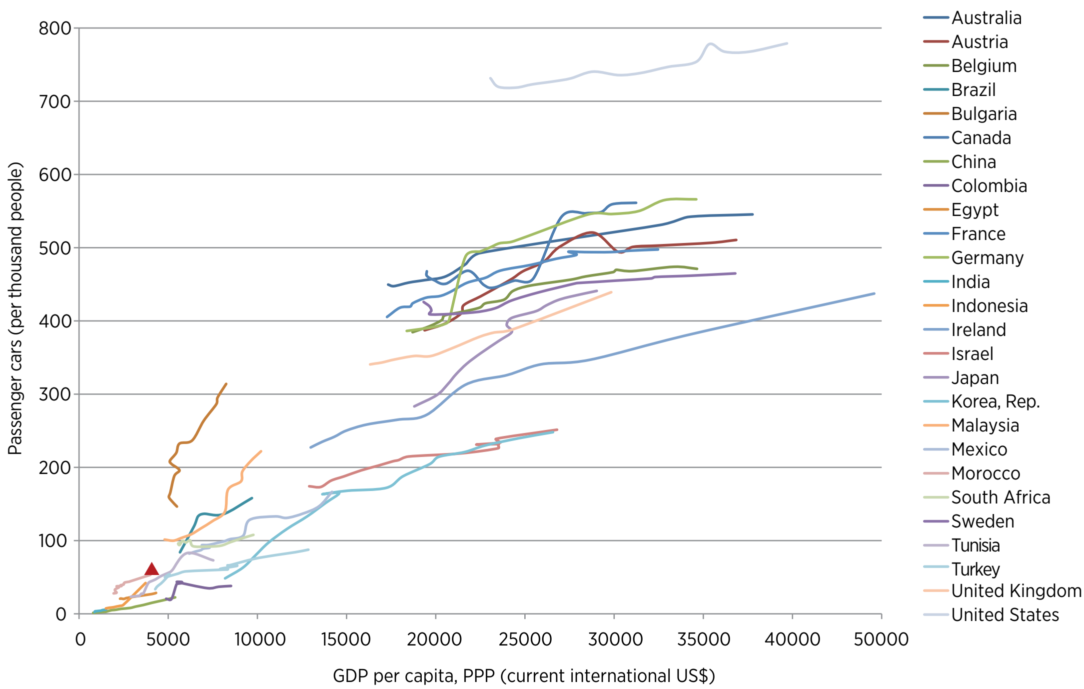
Shifting passengers from private to public transport reduces congestion and, where the shift is from cars to buses, CO_2e emissions (Figure 13). Shifting passengers from motorcycles to buses, aids local air quality but does little to reduce overall CO_2e emissions. This is because emissions per kilometer 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, to levels recorded in recent periods, could increase the rate of return in each case.

Figure 11: CO_2e Emissions from Road Transport



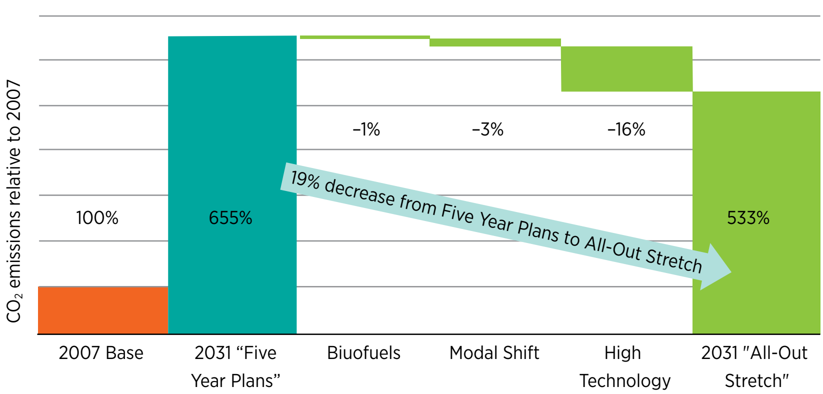
Source: Author's calculations.

Figure 12: 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 13: CO_2e Emissions from Road Transport



Source: Author's calculations.

BOX 3.

Key Assumptions in Scenario 1: Five Year Plans

As with all other scenarios, GDP is assumed to grow at an average rate of 7.6% 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% in the 11th Plan, 50% in the 12th Plan, 70% in the 13th Plan, and 90% 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.
- Technical transmission and distribution losses are reduced from 29% in 2005 to 15% 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. 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% increase in hydropower capacity in the 11th Plan (from 35 GW to 51 GW) and another 59% increase in the 12th Plan (from 51 GW to 81 GW). By 2031, the installed hydropower capacity in the model is 139 GW.
- Besides large-scale hydropower, the Five Year Plans envisage increasing renewable energy, including wind power, biomass, and small hydropower, to 10% of installed capacity by April 2012 (from the current share of 8%). According to current plans, India would have harnessed 88% of its available potential for wind and 43% of small hydropower potential by 2021.
- Nuclear energy is doubled in the 11th Plan and the installed capacity of nuclear plants is more than tripled by 2031 from 3,900 MW in 2006 to 13,000 MW. This represents 2.9% of the total grid installed capacity in 2006 and 2.1% in 2031.

BOX 4.

Key Assumptions in Scenarios 2 and 3

Scenario 2: Delayed Implementation of supply measures 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 loss reduction 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% of the rates assumed in Scenario 1.

Scenario 3: All-Out Stretch Scenario includes, relative to Scenario 1, 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 hydropower and an additional 20 GW on top of the solar target 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 subsectors, the scenario considers about 340 GHG emission-reducing measures that have been adopted commercially since 2006 in the country and have a real rate of return of 10% 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% 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 passenger cars and 10 years for light-duty commercial vehicles, and additional CO_2 savings from modal shifts.
- Sensitivity Analysis C looks at the impact of accelerating by 5—instead of 10—years the transmission and distribution loss reduction program. Sensitivity Analysis D considers the scale of transformative measures needed in additional carbon-neutral electricity capacity to enable stabilization of total CO_2 emissions from power generation by 2025.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POSSIBLE TRAJECTORIES OF GHG EMISSIONS

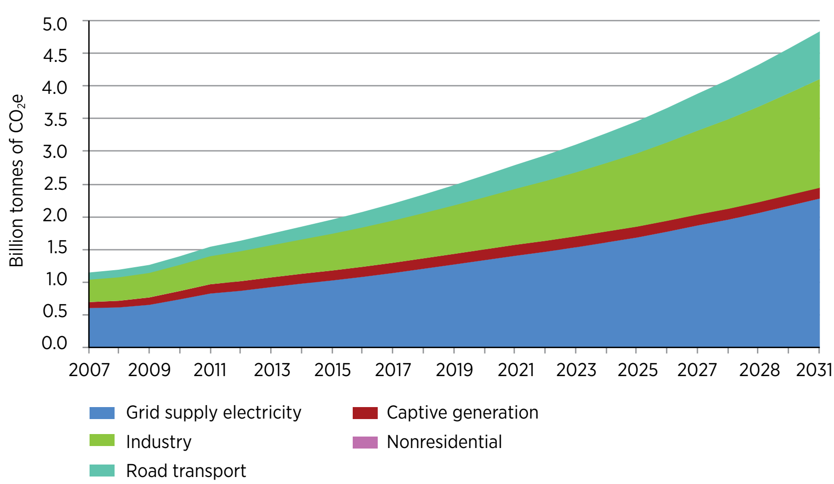
Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development describes the possible trajectories of GHG emissions out to 2031, under different assumptions for three scenarios (Table 1, Boxes 3 and 4).

Scenario 1 | Five Year Plans: CO_2e emissions increase from 1.1 to 4.5 billion tonnes in 2031. 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 14). LPG use in nonresidential buildings accounts for only a small share of the overall increase.

Scenario 2 | Delayed Implementation: CO_2e emissions increase from 1.1 to 4.7 billion tonnes in 2031 (Figure 15). Among the various sectors, grid electricity supply accounts for 49 percent of the increase, followed by industry at 27 percent. Road transport results in a 16 percent increase and captive power contributes about 8 percent to compensate for the decline in grid supply.

Scenario 3 | All-Out Stretch CO_2e emissions increase from 1.1 billion tonnes in 2007 to 3.7 billion tonnes by 2031. Among the various sectors, grid electricity supply accounts for 53 percent of the increase, followed by 26 percent for industry, 16 percent for road transport, and 5 percent for captive power (Figure 16). Total emissions in Scenario 3 are lower than in the previous two scenarios (Figure 17).

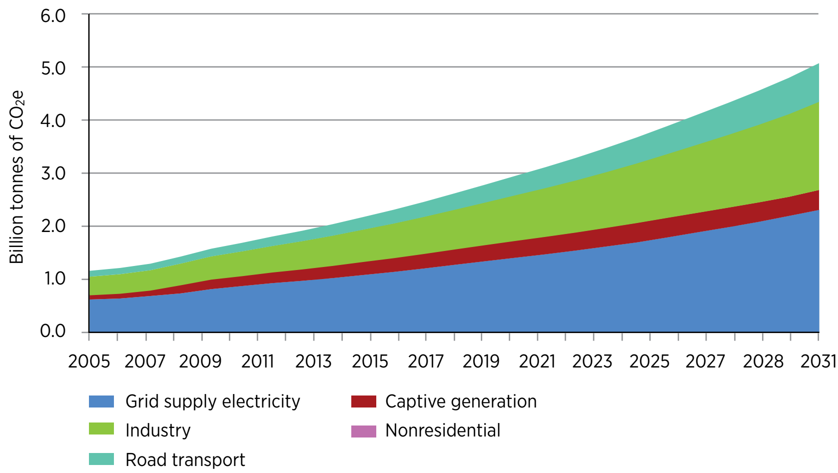
Figure 14: Total CO_2 Emissions in Scenario 1: Five Year Plans (in billion tonnes)



Source: Author's calculations.

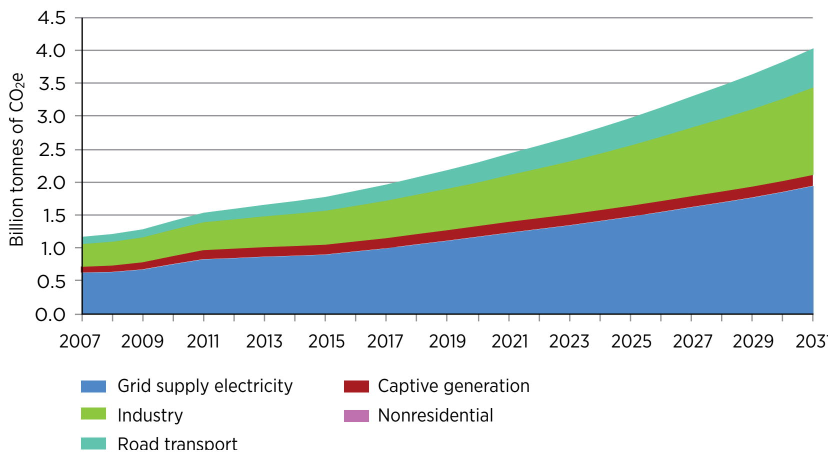
Notes: Electricity supply—grid and captive—covers electricity used across the entire economy, including those areas not covered by this study. Industry covers process-related emissions and direct use of fossil fuels in the six subsectors. Nonresidential covers direct use of fossil fuels. Road transport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

Figure 15: Total CO_2 Emissions in Scenario 2: Delayed Implementation (in billion tonnes)



Source: Author's calculations.

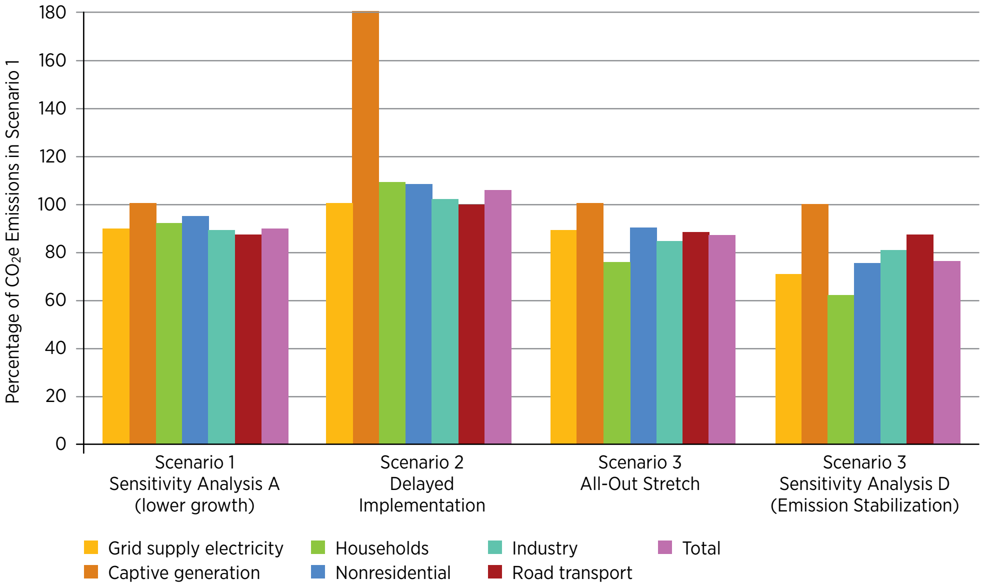
Figure 16: Total CO_2 Emissions in Scenario 3: All-Out Stretch (in billion tonnes)



Source: Author's calculations.

Emission stabilization: The study also asked what additional capacity of carbon-neutral generation would be needed to stabilize CO_2 emissions in the power sector by 2025. Replacing 130 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 energy—achieved 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 3.2 billion tonnes, which is 2.7 times the 2007 level. It is important to point out that these calculations do not consider the feasibility or cost of such massive additional introduction of carbon-neutral generation.

Figure 17: Comparison of Cumulative Emissions in 2007–2031 Relative to Scenario 1



Source: Author's calculations.

SUMMARY AND IMPLICATIONS

Expansion needs for power generation over 2007–31 are vast, with increases estimated 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 *Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development*, electricity consumption of Indian households will remain relatively frugal, with even the wealthiest 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 2006 per capita world production, despite a significant increase in outputs to support India's growth.

Although all major sectors of the energy system 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. Specifically:

- *Achieving Targets:* A crucial first step towards lower carbon development over the long term, as well as improved energy sector performance in the near 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, 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.
- *Low Carbon Energy Sources:* 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. More stringent energy efficiency standards for appliances and buildings would also be needed. The likelihood of success also depends on establishing a comprehensive monitoring and evaluation system at the national level to detect any systemic slippages during program implementation and ensure that early corrective measures are taken.
- *Transport:* 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. At the same time, to lower long-term GHG emissions and meet tight local emission standards, it would be critical that new vehicles entering service have high fuel economy—regardless of any future developments of low-cost, low-carbon, and environmentally sound biofuels.
- *Costs:* 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 (Box 5). The speed of the hypothesized carbon-neutral capacity investments in the 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.
- *Energy Efficiency:* 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 upfront costs. A well-known industry example of the former 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.

Options that Dramatically Reduce GHG Growth 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.

Another option is adoption of newly emerging carbon-neutral energy sources—beyond wind and hydropower, 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 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

BOX 5.

For the Power Sector, What will it Cost?

The costs of achieving a lower carbon path in India 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.

Large upfront costs (Table A) remains the single greatest barrier to adopting efficiency enhancement measures and renewable energy. 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. Table B provides 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.

Capital expenditures for grid electricity in Scenario 1 are about 16% higher than in Scenario 2 (Table B). As expected, the implementation of Scenario 3 incurs the highest upfront costs, 23% 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% or higher.

Table A: 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)
Hydropower	Large storage	[b]	1,325	—	0
Hydropower	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: CEA (2007a, b), Mott and McDonald (2007), and Author's calculations.
a. Costs provided in rupees in 2007 and converted to US$ 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

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

Scenario Description	Billions of 2007 Rupees NPV (2007)	Billions of 2007 Rupees TOTAL	Difference from Scenario 2 NPV (2007)	Difference from Scenario 2 TOTAL
Scenario 1				
Life extension & efficiency improvement	570	1,400	90	180
New capacity	8,000	24,000	1,100	4,400
Total	8,600	25,000	1,200	4,200
% difference			16	20
Scenario 2				
Life extension & 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% slippage				
Life extension & 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 & 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: Author's calculations.

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

Notes:

1) NPV computed using a discount rate of 10%. Rupees are in 2007 rupees. Total is the sum of annual investments without discounting. All numbers in the table are rounded off. As a result, differences do not exactly match the differences between the numbers in the table.
2) 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.
3) The table presents the cost figures in two ways:
   a. Investments discounted at 10% to compute the net present value in 2007
   b. Total investments without discounting

sources for only five years (IEA 2008).

Given the limited outcome of the Copenhagen 2009 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, which increases for emission stabilization, the carbon finance costs would be staggering, unless the carbon-neutral technologies were fairly cost competitive.

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 *Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development* 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 hand, they should be pursued as a top priority.

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ACRONYMS AND UNITS

CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DFID	Department for International Development (UK)
EU	European Union
F&P	Fertilizers and petrochemicals
g	Grams
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt hour
IEA	International Energy Agency
kWh	Kilowatt hour
LCD	Low carbon development
LPG	Liquefied petroleum gas
mbd	Million barrels per day of oil
mcfd	Million cubic feet per day
Mm^3	Million cubic meters
Mt	Million tonnes
MW	Megawatts
NPV	Net present value
PJ	Petajoule
R	Rupee
SME	Small- and medium-size enterprises
t	Tonne
Tj	Terajoule
TWh	Terawatt hour
US$	United States dollar

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Energy Sector Management
Assistance Program
The World Bank
1818 H Street, NW
Washington, DC 20433 USA
email: esmap@worldbank.org
web: www.esmap.org

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Carbon Finance-Assist Program
World Bank Institute
1818 H Street, NW
Washington, DC 20433 USA
email: cfassist@worldbank.org
web: www.cfassist.org

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Department for International Development
1 Palace Street, London SW1E 5HE
email: enquiry@dfid.gov.uk
web: www.dfid.gov.uk