India: Options for Low-Carbon Development

Synopsis of a Study by the World Bank for Government of India

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Energy-Intensive Sectors of the Indian Economy: Synopsis

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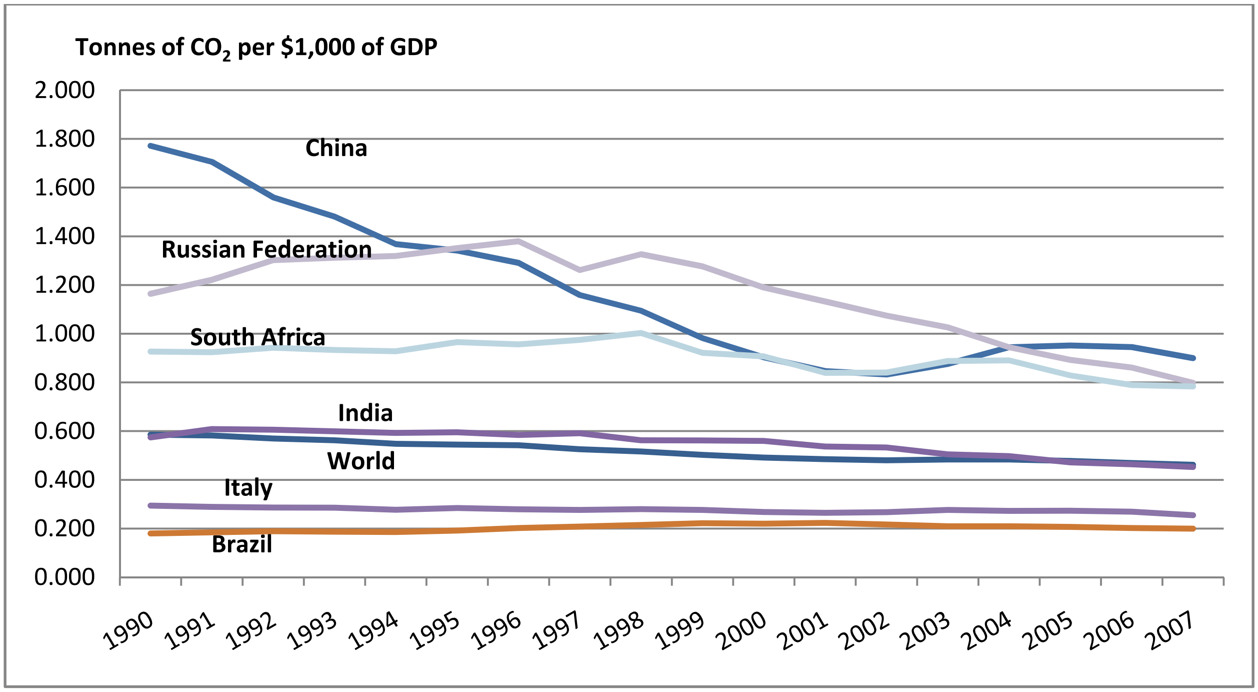
I. Introduction: India's Current Carbon Footprint and Challenges for Future Development

1. 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 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. The objective of this synopsis is to give an account of the modeling results projecting fuel use in energy-intensive sectors and associated carbon dioxide (CO_2) emissions between 2007 and 2032.
2. The Indian economy currently has a relatively low carbon footprint. Though India is ranked among the top 10 emitters due to the size of its economy and population, the per capita CO_2 emissions from fuel combustion, at 1.2 tonnes in 2007, was a fraction of the global average of 4.4 tonnes. In the same year, India's CO_2 emission intensity per unit of gross domestic product (GDP), valued at purchasing power parity (PPP), was at the world average (see Figure 1). While globally, emissions intensity declined every year between 1990 and 2006 (except in 2003 and 2004), in many developed and developing countries, the decline in emissions intensity during the 1990s has been followed by an increase in the current decade. A recent study identifies India as one of the 20 countries in which CO_2 emission intensity declined successively over two subperiods (1994–1996 to 1999–2001 and 1999–2001 to 2004–2006), with larger declines in the second subperiod (Kojima and Bacon 2009).
3. India's relatively low carbon footprint can be attributed to several factors. The large number of people who still lack access to electricity and modern commercial fuels, and the low energy consumption of the poor, contribute to low per capita emissions. There are roughly 400 million people who still lack access to electricity, and 456 million in 2005 were still living at $1.25 a day (U.S. dollars at PPP).
4. Another factor is change in the composition of GDP with economic modernization since 1990. Both the industry and service sectors have increased their share of GDP at the expense of agriculture, and service more so 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. More importantly, the service and industry sectors have reduced their respective energy intensities significantly, with services as a whole registering a greater reduction. 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.

Figure 1: CO_2 Emissions per Unit of GDP



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

Note: GDP is valued at purchasing power parity in 2005 U.S. dollars.

5. In the years ahead, India faces several challenges. Electricity supply is both inadequate and unreliable: in financial year (FY) 2007 (April 2007 to March 2008), which was considered as the base year of the study, the overall electrical energy deficit was about 10 percent and peak shortages exceeded 17 percent. More than two thirds of all Indian households relied on traditional use of biomass as the main source of cooking fuel and one third of households on kerosene for lighting in 2004/5 (NSSO 2007). 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 of India's poverty reduction objective.

6. India is at a unique juncture in its development. Prior to the recent global economic and financial crisis, its GDP grew at more than 9 percent per year over the period 2003–2007, with high rates of investment and savings and strong export growth. This rapid economic growth generated substantial potential for public and private investments in development. As outlined in India's 11th Five Year Plan (2007–2012), the government of India is aiming to double per capita GDP over 10 years. Such dramatic and rapid income growth for a country as populous as India would require a significant transformation and have a significant effect on India's energy sector.

7. This collaborative study by the World Bank and the government of India deals with CO_2 emissions from the combustion of fossil fuels in India beginning in 2007 through the 15th Five Year Plan, ending in FY2031. It focuses in particular on power generation, energy consumption in six energy-intensive industries and 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.

8. 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: India's CO_2 emissions from fuel use in 2007 were less than 5 percent of the world total, according to the International Energy Agency (IEA 2009), but its share of the global emissions is likely to increase with economic development. India currently relies heavily on coal for its commercial energy demand (53 percent of installed capacity), but it lacks sufficient domestic energy resources, and is increasingly dependent on imports of fossil fuels to meet demand. With an expectation of a substantial increase in energy use, 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 anticipated; and (b) 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.

9. The findings reported in this synopsis present India's potential "carbon futures"—how total emissions might evolve out to FY2031 under different broad assumptions about energy supply and demand drivers. 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 mitigation. Nor does it provide a comprehensive cost-benefit analysis of alternative measures to limit the growth of CO_2 emissions. Instead, the study looks at the potential evolution of total emissions from several sectors of the economy to see how these vary with assumptions made in different scenarios.

II. Analytical Approach

10. To compare different carbon futures for India, the study team developed an engineering-based bottom-up model to project future demand for energy in sectors of important consumption and expected growth, to consider different options for the electricity supply mix to meet those demands, and to calculate resultant CO_2 emissions under different scenarios. Although a small fraction of the total emissions computed, the model also includes process-related non-CO_2 greenhouse gas emissions in industry and from vehicle tailpipes.

11. The model includes the following sectors of the economy:

Supply

- Electricity generation, both grid and captive, covering the entire economy (basing demand to be met by supply for the sectors not covered in the study on assumptions about GDP growth and income elasticities)

Demand (covering energy consumed by end users)

- Several energy-intensive industries with significant potential for future expansion: (a) iron and steel, further separated into large integrated steel plants and small-scale plants; (b) aluminum; (c) cement; (d) fertilizer; (e) refining; and (f) 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 five sectors under study 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 greenhouse gas 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.

12. Although the model focuses primarily on electricity production and use, it also includes 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 for lack of data, diesel use for irrigation and powering agricultural equipment is also not studied. 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 megawatt (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.

13. 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.

14. 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.

15. As noted, the objective of the study is to explore potential carbon futures under different assumptions that are gathered together into various scenarios. We consider three scenarios and four sensitivity analyses.

16. **Scenario 1: A “Five Year Plans” scenario.** This scenario is based on projections of expansion of electricity generation capacity in the 11th (2007–2012) and 12th (2012–2017) Five Year Plans; the Integrated Energy Policy, which outlines projections until the 15th Five Year Plan (2027–2032); papers by the 11th Plan Working Group and the Central Electricity Authority; and programs by the Ministry of New and Renewable Energy. The scenario includes planned investments to expand capacity, increase reliability, and strengthen energy efficiency, but takes into account slippages in investments and actual GDP growth rates to date. GDP is assumed to grow at an average rate of 7.6 percent between 2009 and 2031. A sensitivity analysis (“A”) on scenario 1 explores the implications of reducing the GDP growth rate by an average of 1 percentage point to 6.6 percent between 2009 and 2031.

17. Scenario 1 reflects ambitious investments in lower-carbon energy capacity currently planned by India. Technical transmission and distribution losses are reduced from 29 percent in 2005 to 15 percent in 2025, significant amounts of older thermal capacity are retired or renovated, and the share of supercritical coal plants is increased from 20 percent in the 11th Plan to 90 percent in later years. Hydropower increases fivefold, approaching the technical limit of what is possible. Other renewable energy sources—including wind power (the onshore capacity of which is taken to the technical limit of what is likely to be achievable), biomass, and small hydro—increase considerably as well, and nuclear capacity more than quadruples.

18. In scenario 1, industrial CO_2 intensity (tonnes of CO_2 per tonne of product) improves as newer more efficient production capacity is added to attend the growing demand. Between 2007 and 2020 an improvement of over 15 percent is achieved by the integrated steel producers; around 13 percent for small iron and steel plants, aluminium, cement and fertilizer; 7 percent for pulp and paper and less than one for refining. Per-household electricity consumption in scenario 1 increases over this period as rising household income promotes greater appliance use. As a result household CO_2 intensity from electricity rises 15 percent from 1.1 to 1.3 tonnes of CO_2 per electrified household over the 2007 to 2020 period despite appliances becoming more efficient.

19. In non-residential buildings, the changes in scenario 1 over the 2007 to 2020 period are complex since new buildings have higher specific energy consumption per square meter than pre-existing buildings; energy consumption in pre-existing buildings increases and both are offset with improvements in appliance efficiency. Overall, average non-residential CO_2 intensity (tonnes of CO_2 per square meter of floorspace) decreases over the 2007 to 2020 period by 5 percent, ranging from an increase of 13 percent for hospitals to a reduction of 19 percent for schools. In transport, over the 2007 to 2020 period car ownership—including the Nano and other low cost cars—grows over six times from 5.7 to 36.3 million cars whilst motorcycle ownership grows 3.8 times from the higher base of 40 to 151 million units. Since the average CO_2 emissions per passenger-kilometer by car are approximately three times those by motorcycle, as a result, vehicle fuel consumption and CO_2 emissions increase over time.

20. **Scenario 2: A "delayed implementation of supply measures" scenario.** This scenario assumes that, relative to scenario 1, there are slippages in several supply-side initiatives:

- A delay of five years in the transmission and distribution loss reduction program
- Hydropower capacity limited to 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, as indicated in paragraph 12. A sensitivity analysis ("B") on scenario 2 explores the implications of a more aggressive build of clean-technology power plants with hydropower capacity being built to 80 percent of what is technically achievable and wind, solar, biomass-based plants, and supercritical coal-fired power plants built at 80 percent of the planned rate.

21. **Scenario 3: An "all-out stretch" scenario.** Relative to scenario 1, this scenario includes reducing energy demand through energy efficiency improvement in industry, nonresidential buildings, and household use of electricity. For the six industrial subsectors, the scenario models an average adoption rate in manufacturing facilities by 2020 of 80 percent of 340

greenhouse gas 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).[1] 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 greenhouse gases. Compared to scenario 1, CO_2 equivalent (CO_2e) emissions per tonne of product (such as steel and cement) are reduced by almost 20 percent on average by 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.

22. For road transport, the all-out stretch scenario assumes more stringent fuel economy standards for light vehicles, matching European Union 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), and additional CO_2 savings from modal shifts. On the supply side, the scenario adds 20 gigawatts (GW) of imported hydro and 20 GW from solar 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. There are two sensitivity analyses on the all-out stretch scenario. One ("C") looks at the impact of accelerating by five years the transmission and distribution loss reduction program whilst the other ("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.

23. **Table 1** provides a brief summary of the scenarios and their sensitivity analyses.

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[1] The rate of return for any efficiency enhancement measures is affected, amongst other factors, by energy prices. This study assumes \$0.99 per liter of gasoline, \$0.72 per liter of diesel, \$0.0791 per kilowatt-hour of grid electricity, \$53 per tonne of imported coal (cost, insurance, and freight), \$11 per tonne of domestic coal at the mine mouth (rising to about \$20 at the power plant gate), \$18 per tonne of lignite, and \$11 per million British thermal units of natural gas, all expressed in 2007 U.S. dollars.

Table 1: Scenario Descriptions

Assumption categories	**Scenario 1** Five Year Plans	**Scenario 2** Delayed implementation	**Scenario 3** All-out stretch
Average annual GDP growth in FY2009-2031	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 build of cleaner coal, large hydro (larger than 10 MW), small 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 lower GDP growth (6.6%)	B. As scenario 2 but with 20 percent slippage in build of cleaner coal, large hydro (larger than 10 MW), small 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: World Bank staff.

III. Findings

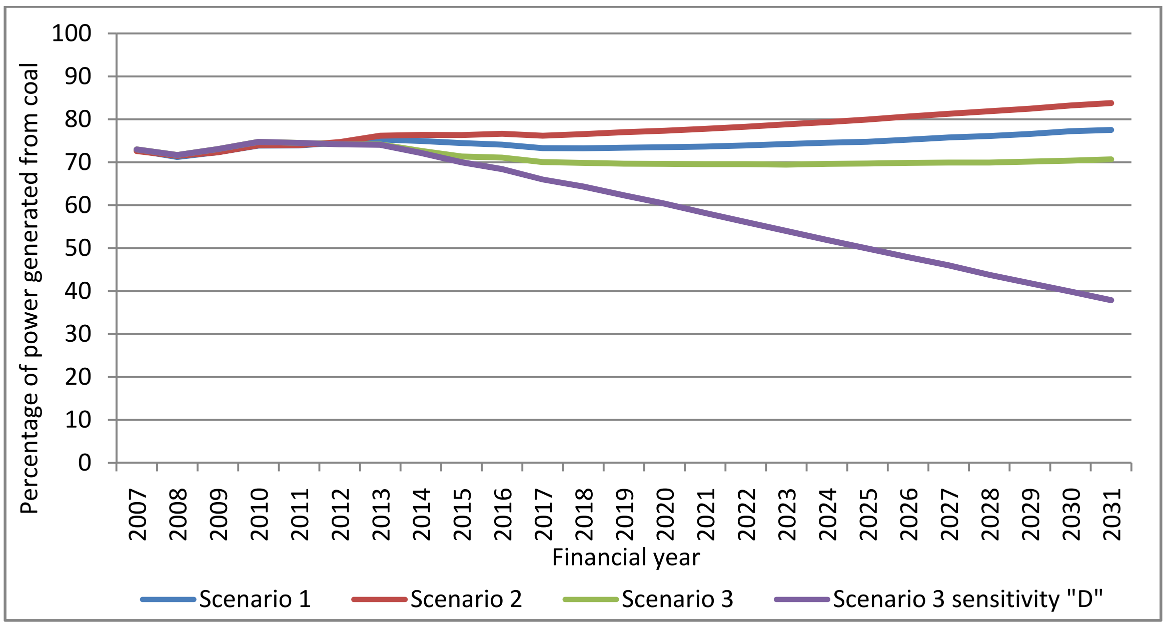
24. All scenarios and their sensitivity analyses reported here show CO_2e emissions from the sectors studied increasing from 1.1 to between 2.8 and 4.7 billion tonnes of CO_2e between FY2007 and 2031. The results specific to each of the five sectors are discussed first, followed by trends in the growth of CO_2e emissions and the impact of the timing of the implementation of various emission-reducing measures on cumulative emissions. Based on estimates, CO_2 intensity of the five sectors studied improves by 28 percent in scenario 1 between FY2007 and 20031, and by as much as 41 percent in scenario 3, although it shows an improvement of only 25 percent in scenario 2.

Electricity Generation

25. The model estimates that coal-fired generation plants are likely to continue to dominate energy 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 FY2007 to 78 percent in 2031 in scenario 1, and declines only slightly to 71 percent even in scenario 3 (Figure 2). This is a consequence of the lack of significant alternative natural resources in India, lack of availability of clean 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 the 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.

Figure 2: Share of Coal in Grid Power Generation



Source: World Bank staff calculations.

26. These results rely on a set of assumptions on the CO_2 emission characteristics of energy from various sources. Table 2 shows CO_2 emissions per kilowatt-hour (kWh) of electricity generated by different types of power plants examined in this study and associated construction costs. 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 used in the model were derived from the Central Electricity Authority's database for 2007/8 (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.

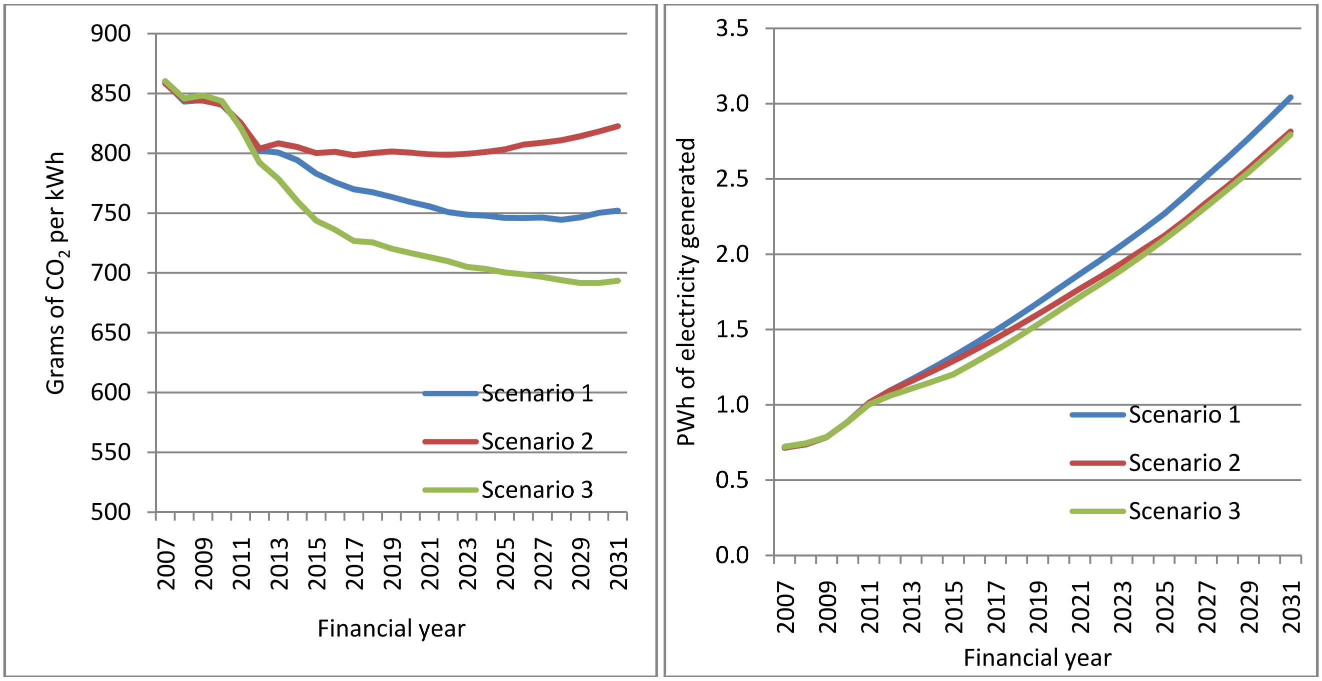
Table 2: Costs and Emission Characteristics of New Power Plants

Type	Subtype	Capacity (MW)	CO_2 emissions (g/kWh)	Investment in plant & equipment (US$/kW)[a]
Hydro	Large storage	[b]	0	1,325
Hydro	Run of river	[b]	0	1,104
Nuclear	Heavy water reactor	220	0	1,435
Coal	Subcritical (domestic coal)	500	980	883
Coal	Subcritical (domestic coal)	250	1,000	930
Coal	Low supercritical[c] (domestic coal)	660	949	945
Coal	High supercritical[c] (domestic coal)	800	919	969
Coal	Ultra supercritical (domestic coal)	1,000	874	1,041
Coal	Subcritical (imported coal)	500	957	844
Coal	Subcritical (imported coal)	250	977	890
Coal	Low supercritical (imported coal)	660	928	910
Coal	High supercritical (imported coal)	800	898	942
Coal	Ultra supercritical (imported coal)	1,000	854	984
Natural gas	Open cycle	250	492	662
Wind	Not applicable	100	0	993
Solar	Concentrated solar power with storage	15	0	6,071

Sources: Central Electricity Authority and other Indian sources.
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.

27. In terms of total grid electricity generated, scenarios 2 and 3 are comparable, whereas scenario 1 is above the other two. However, the amount of CO_2 emitted per kWh varies markedly from scenario to scenario (Figure 3). 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 technical transmission and distribution losses remain high five years longer than in scenario 1 and 10 years longer than in scenario 3, and in which the rates of construction of new supercritical power plants and renewable power generation are half the rates 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 (see Figure 2).

Figure 3: CO_2 Emissions from Grid Electricity Generation



Source: World Bank staff calculations.
kWh = kilowatt-hour, PWh = petawatt-hours = 10^{12} kilowatt-hours.

28. 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. **Table 3** shows the impact of advancing or delaying by five years the implementation of the transmission and distribution loss reduction program assumed in scenario 1 on CO_2 emissions and total investment 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.[2]

Table 3: 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: World Bank staff 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.

[2] Scenario 2 is different from the five-year delay case in Table 3 because scenario 2 does not assume that the same amount of grid electricity is supplied. Instead, the shortfall is compensated by greater captive generation.

29. 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.

30. Table 4 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 FY2007 and 2031. 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

Table 4: 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 & 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 & efficiency improvement	480	1,600	–90	180
New capacity	6,900	19,000	–1,100	–4,400
Total	7,400	21,000	–1,200	–4,200
% difference			–14	–17
Scenario 2 sensitivity "B" -- 20 percent slippage				
Life extension & efficiency improvement	480	1,600	–90	200
New capacity	7,400	21,000	–600	–2,800
Total	7,900	22,500	–700	–2,600
% difference			–8	–10
Scenario 3				
Life extension & efficiency improvement	600	1,300	30	–110
New capacity	8,500	27,500	500	3.700
Total	9,100	29,000	540	3,600
% difference			6	14

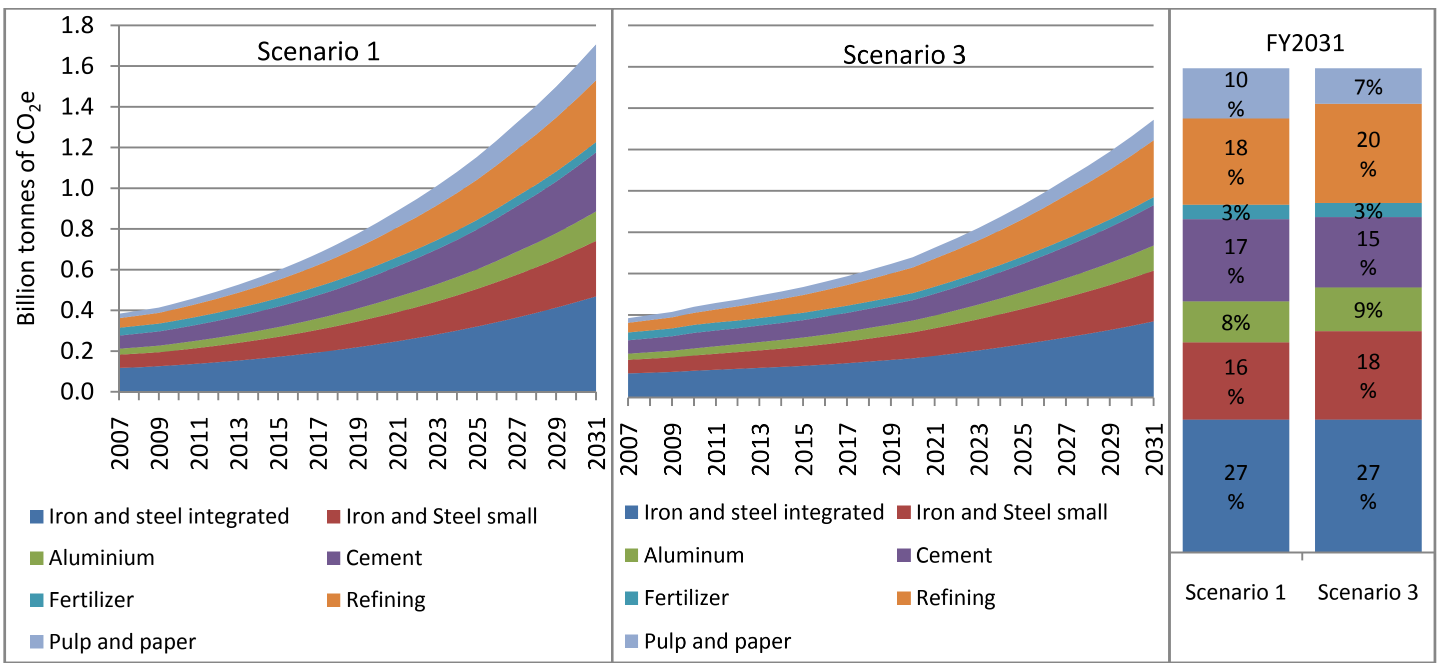
Source: World Bank staff calculations.
NPV = net present value; life extension & efficiency improvement includes technical transmission and distribution loss reduction measures.
Notes: NPV computed using a discount rate of 10 percent. Rupees are in 2007 rupees. Total is the sum of annual investments 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.

The table shows that delayed implementation, captured in scenario 2, lowers capital expenditures for grid electricity by about 14 percent. In this scenario, captive generation covers the unmet electricity demand caused 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 the sensitivity analysis "B" where delayed implementation affects only 20 percent of clean technology introduction capital expenditures for grid electricity by about 8 percent. In contrast, scenario 3 incurs higher up-front costs, as expected. 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.

Energy-Intensive Industries

31. 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 4. Among the six industries considered in this study, iron and steel dominates, accounting for nearly half of 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 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.

Figure 4: CO_2e Emissions from Six Industries



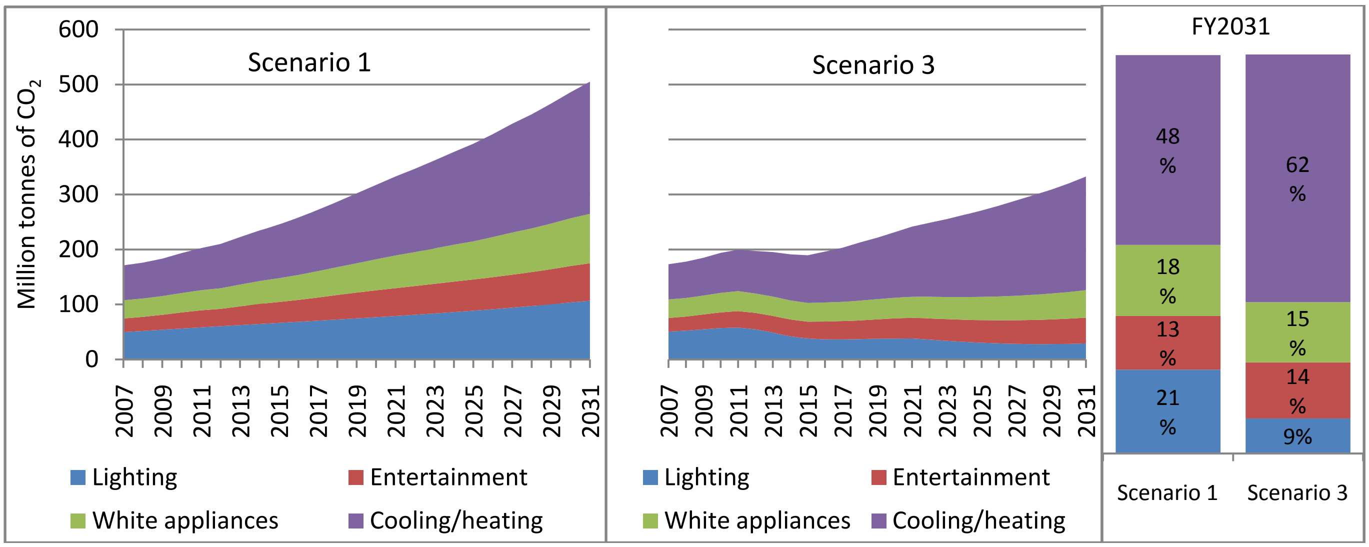
Source: World Bank staff calculations.
Note: "Iron and steel integrated" are large integrated steel plants, "iron and steel small" are small steel plants.

Household Use of Electricity

32. To estimate future consumption of electricity by households, patterns for ownership of 14 appliances were examined. Taking ownership data from the National Sample Surveys and censuses, the number of each appliance was estimated for each future year based on household income and the number of households in each income category. Assumptions were made about broad subcategories within each category of appliance as a function of size and technology, the number of hours each appliance is used, and the amount of electricity consumed per hour. Electricity consumption calculated for 2005 using this methodology

broadly matched electricity supplied to residential consumers. The results 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 FY2031 in scenario 1. 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 is achieved for lighting: in FY2031, the total amount consumed is 70 percent lower in scenario 3 than in scenario 1. Data were not available to estimate the incremental costs of tightening emission standards. Figure 5 shows CO_2 emissions calculated from power used for operating household appliances.

Figure 5: CO_2 Emissions from Household Electricity Consumption



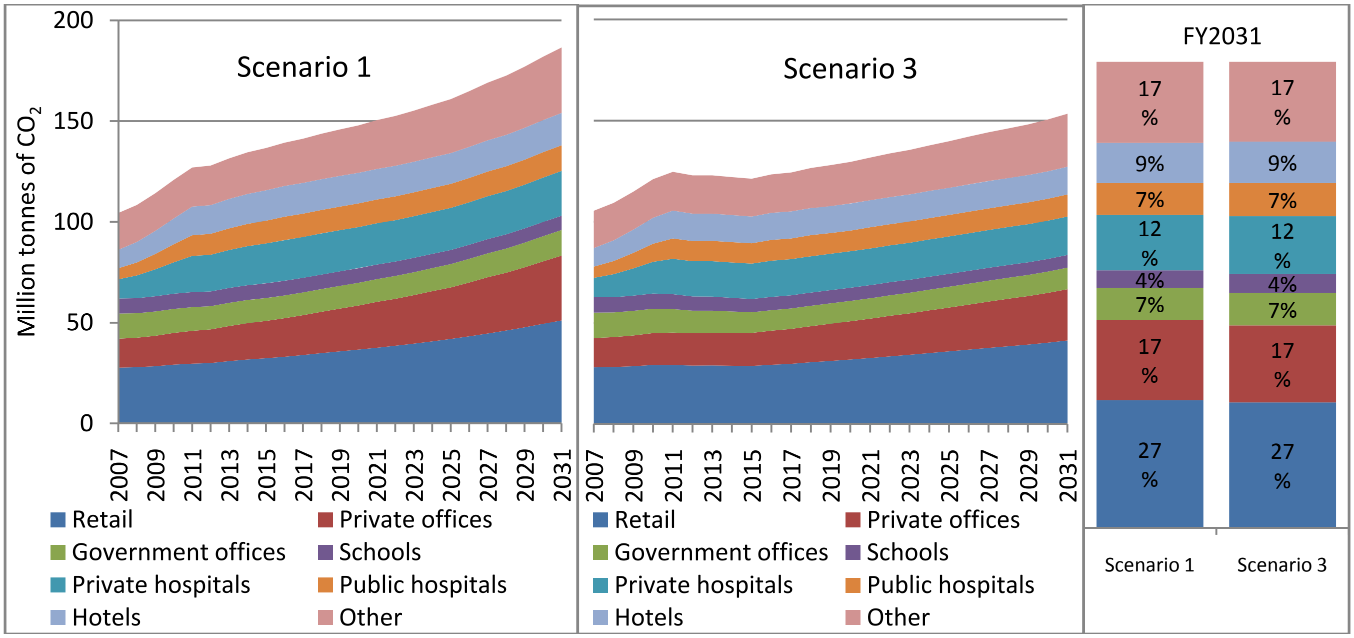
Source: World Bank staff calculations.
Notes: Entertainment covers television sets, computers, radios, CD players, DVDs, and VCRs. White appliances cover refrigerators, washing machines, ovens, microwave ovens, and toasters. Cooling covers fans, air coolers, and air-conditioning units. Heating is for electric water heaters.

Nonresidential Buildings

33. 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 both scenarios 1 and 3, retail stores have the highest share of electricity consumption. The largest reductions in electricity use in scenario 3 are achieved in retail and private offices. All measures for tightening energy efficiency standards to achieve these reductions are estimated to have real rates of return of 10 percent or higher.

34. The evolution of CO_2 emissions from electricity use and combustion of diesel for on-site power generation and of liquefied petroleum gas is shown in Figure 6. The difference between scenarios 1 and 3 is due solely to the higher energy efficiency of electric appliances in the latter.

Figure 6: CO_2 Emissions from Nonresidential Buildings



Source: World Bank staff calculations.

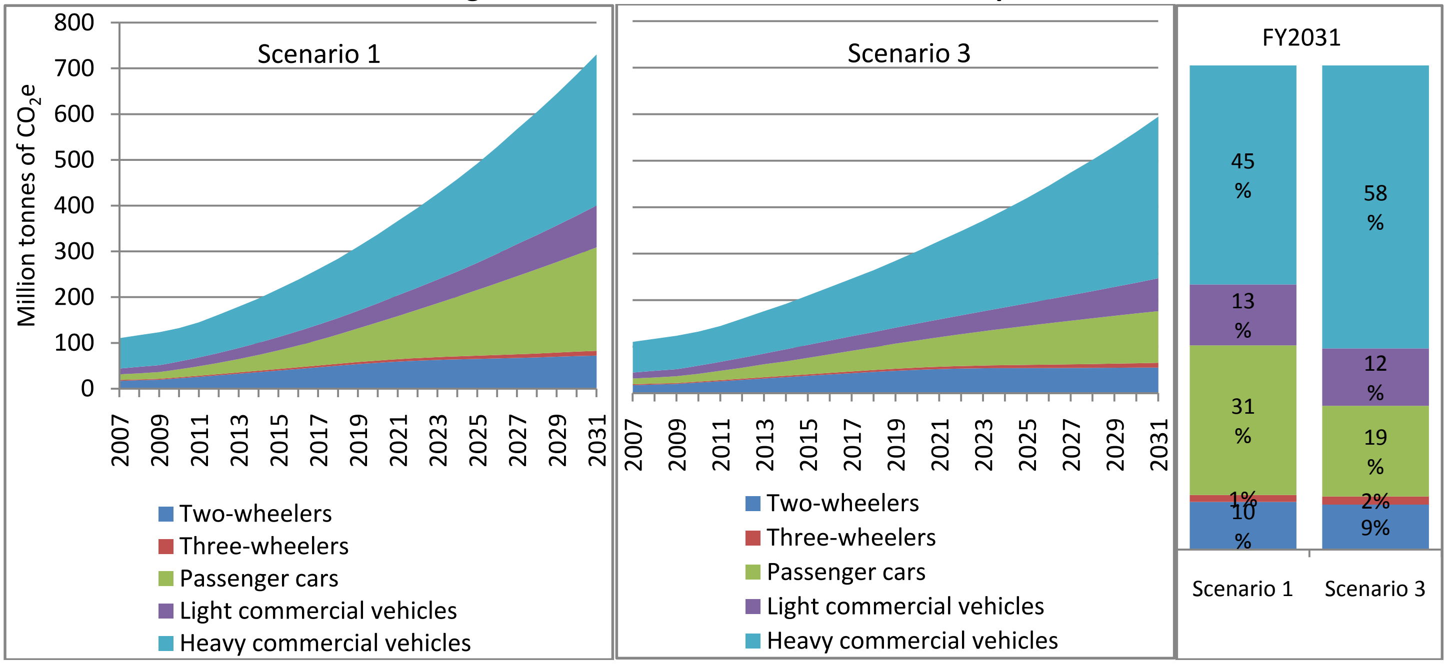
Road Transport

35. 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. By 2013, emissions from heavy-duty commercial vehicles in scenario 3 exceed those from scenario 1 because of much greater use of buses for public transport (Figure 7).

36. 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.

37. 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.

Figure 7: CO_2e Emissions from Road Transport

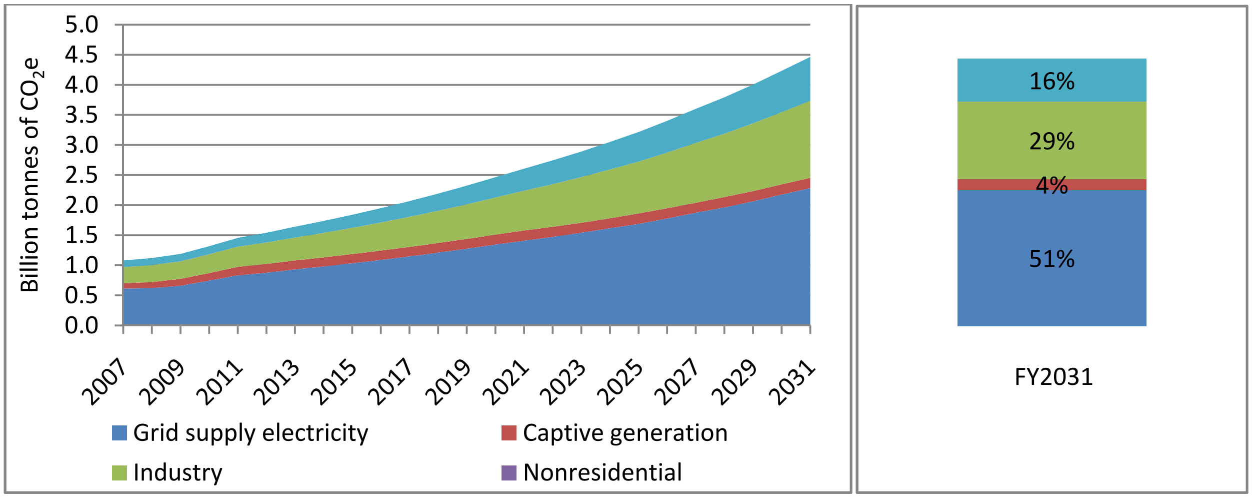


Source: World Bank staff calculations.
Note: Sport utility vehicles are included in light commercial vehicles.

Total CO_2 Emissions

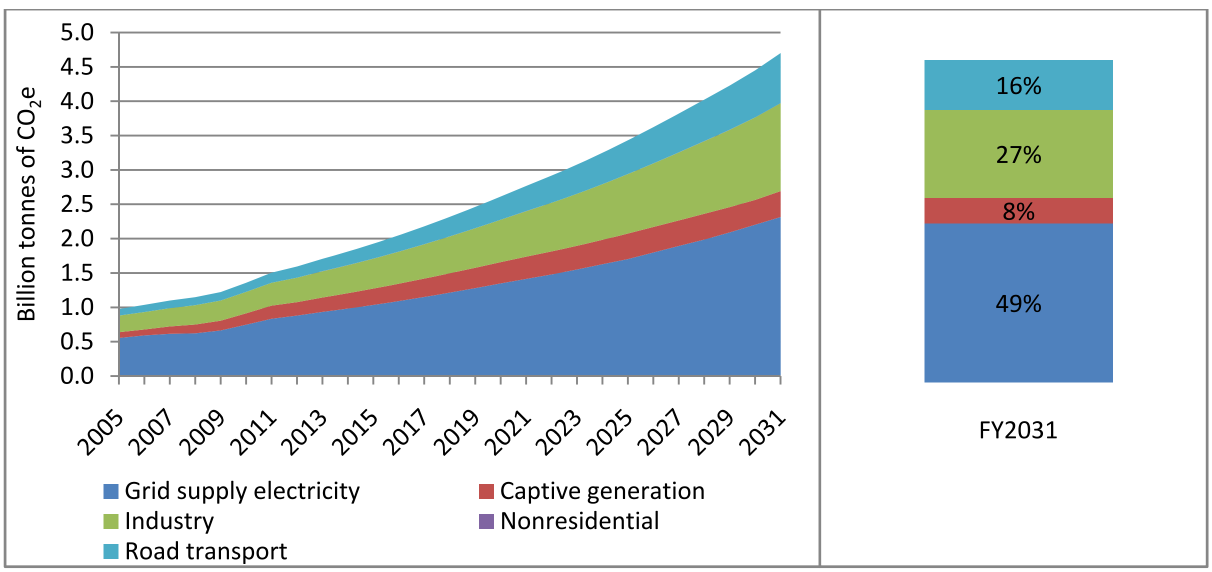
38. For the three main scenarios, shown in Figure 8-Figure10, CO_2e emissions for the five sectors covered by the study will increase from the 2007 level of 1.1 billion tonnes to 4.5 billion tonnes in scenario 1, 4.7 billion tonnes in scenario 2, and 3.7 billion tonnes in scenario 3.

Figure 8: Emission Profile for Scenario 1, Five Year Plans



Source: World Bank staff calculations. See Notes [3]

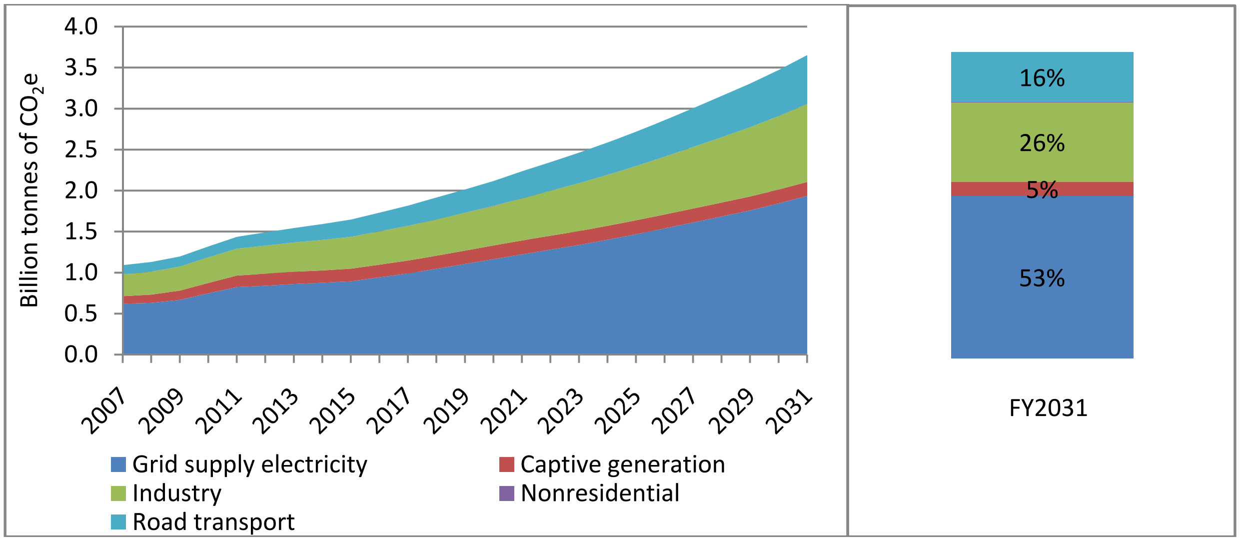
Figure 9: Emission Profile for Scenario 2, Delayed Implementation of Supply Measures



Source: World Bank staff calculations.
Notes: See notes for Figure 8.

[3] *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 that their total contribution is not visible in the figures.

Figure 10: Emission Profile for Scenario 3, All-Out Stretch Scenario



Source: World Bank staff calculations.
Notes: See notes for Figure 8.

39. The sector shares for emissions do not vary much across the scenarios. The largest share of CO_2e emissions continues to come from the power sector, which is estimated at 54 percent (captive generation and grid supply) in FY2031 in scenario 1, 57 percent in scenario 2, and 58 percent in scenario 3. However, the largest increase in CO_2e emissions occurs in the transport sector, which is expected to increase by a factor of 6.6 in scenario 1 and 5.4 in scenario 3.

40. The potential for reducing annual emissions by implementing all the demand-side and supply-side measures in scenario 3 is estimated at 815 million tonnes CO_2 relative to scenario 1 by FY2031, as shown in Table 5. While the largest volume of emission reduction is from the power sector, the highest percentage of reduction is from industry.

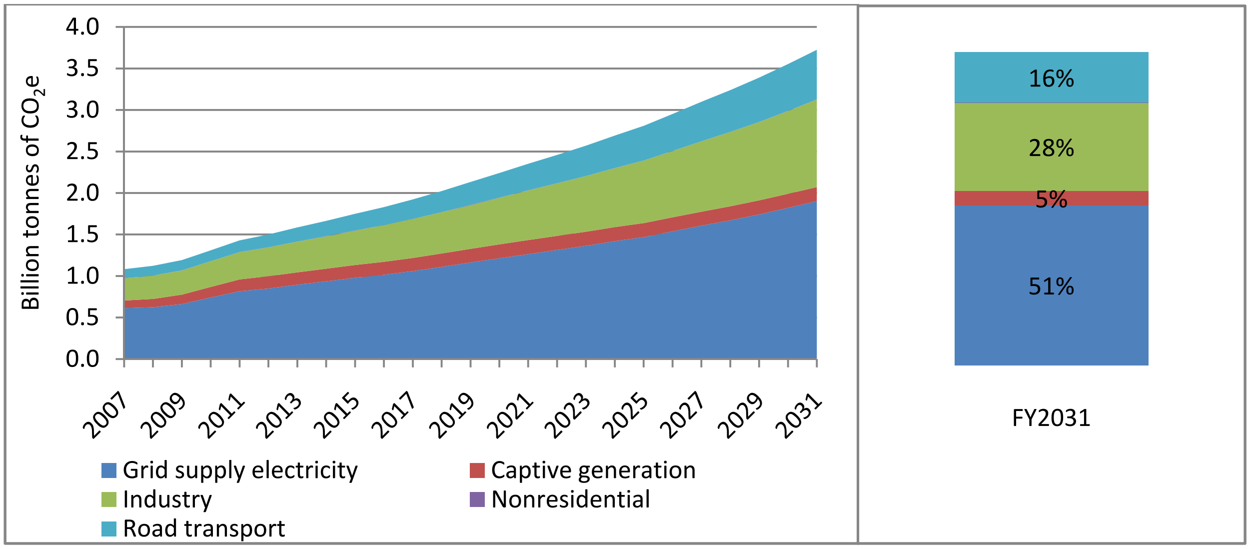
Table 5: Emission Reduction Potential in FY2031, Million Tonnes of CO_2e

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	595	135	19
Total	4,468	3,653	815	18

Source: World Bank staff calculations.
Notes: See notes for Figure 8.

41. The sensitivity analysis "A" on scenario 1, taking lower GDP growth, reduces both demand and CO_2e emissions. In FY2031, GDP in the sensitivity case is 19 percent lower than in scenario 1, and CO_2e emissions are 16 percent lower, reflecting a GDP elasticity of CO_2e emissions smaller than unity (Figure 11).

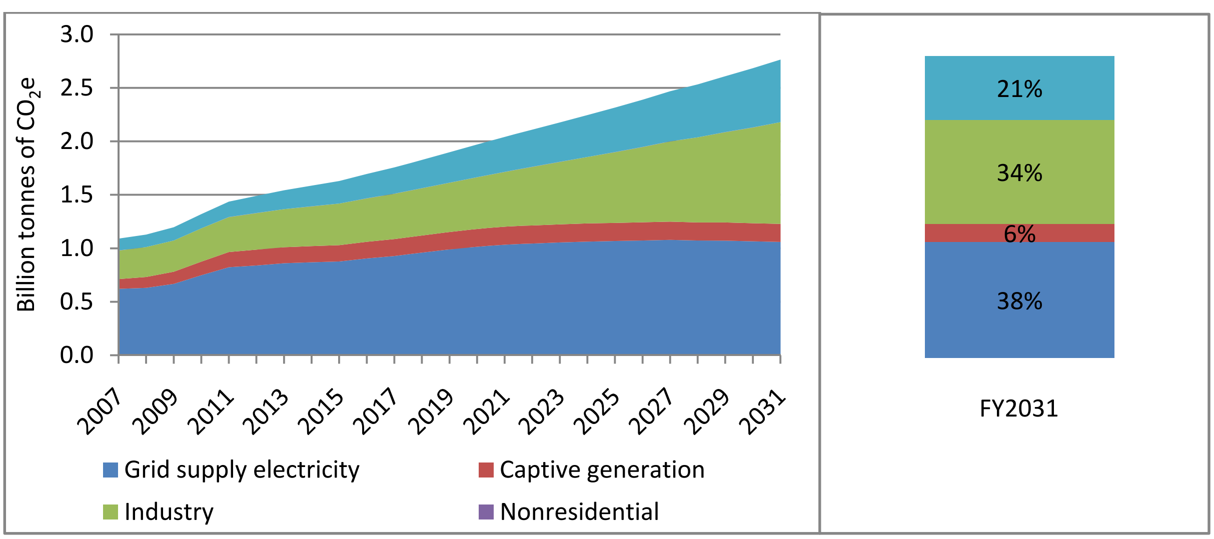
Figure 11: Emission Profile for Lower GDP Growth Sensitivity Analysis



Source: World Bank staff.
Notes: See notes for Figure 8.

42. 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 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 12). By FY2031, 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 (Figure 12). 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.

Figure 12: Sensitivity Analysis "D" for Scenario 3, Emission Stabilization in Power Sector



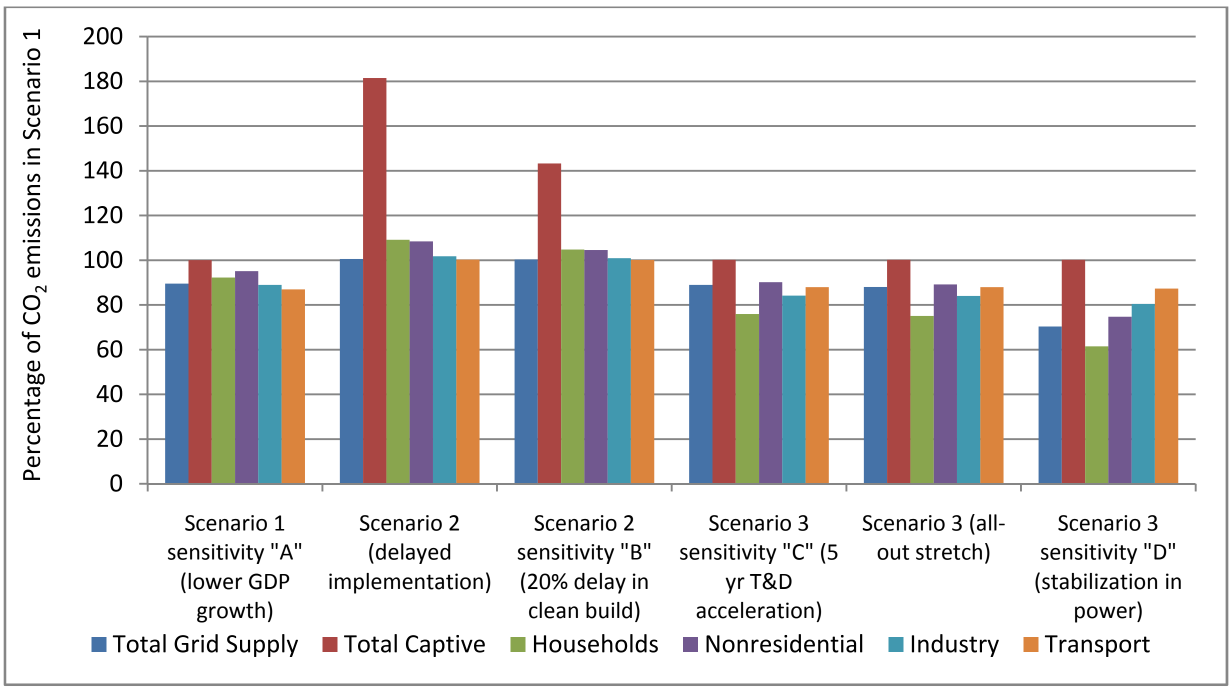
Source: World Bank staff calculations.
Notes: See notes for Figure 8.

Role of Timing of Implementation

43. Because one important difference between the scenarios is the pace of implementation of emission-reducing measures, their effects cannot be deduced from comparison of emissions in the terminal year alone. For example, while the completion of the transmission and distribution loss reduction steps is varied between 2015 and 2030, technical transmission and distribution losses are reduced to 15 percent in all scenarios by FY2031. 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. **Error! Reference source not found.** Figure 13 presents the results of such a comparison, based on the emissions in scenario 1 set equal to 100 for each sector. For the non-power sectors, the figure includes all energy consumption, including CO_2 emissions from power consumed in the sector and traced back to the generation sector.

44. The results show that CO_2 emissions from captive power generation are nearly doubled in scenario 2, as a result of the 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. The sector with the largest difference between scenarios 1 and 3 is residential, where most appliances consuming energy are subject to tighter minimal efficiency standards beginning in the 2010s.

Figure 13: Comparison of Cumulative Emissions in FY2007–2031 Relative to Scenario 1



Source: World Bank staff calculations.
Notes: See notes for Figure 8. For households, nonresidential, and industry, CO_2 emissions from power consumption are included and traced back to grid power generation.

IV. Conclusions and Implications

45. 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 continued industrial modernization and other means.

46. According to this study, moreover, the electricity consumption patterns of Indian households will remain relatively frugal, with even the richest third of urban households in FY2031 consuming only about one third of the average current electricity consumption in the European Union. For steel, primary aluminum, fertilizers, refined petroleum products, and paper, per capita consumption in India even in 2030 is forecast to be no higher than per capita world production in 2006, despite a significant increase in outputs to support India's growth.

47. Although all major sectors of the energy system can contribute to a 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 improves the allocation of financial, technical, institutional, and skills-based resources, achievement rates may continue the roughly 50 percent success rate experienced for the addition of new generation capacity in the past three Five Year Plans (1991–2006). In that case, one could anticipate even faster emission growth over time compared to scenario 2 (delayed implementation), in which the total installed capacity in FY2031 is "only" 13 percent lower than in scenario 1 in which all Five Year Plan targets for generation are fully implemented.

48. The achievement of the targets contained in the 11th and subsequent Five Year Plans in the power sector requires the coordination of institutions across all levels of government—federal, state, and municipal—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 *and* higher costs. Accelerated adoption of renewable energy, which would reduce reliance on thermal power generation and improve the diversification of the energy mix, requires a streamlined regulatory framework; in the case of large hydropower, it requires a concerted effort to improve the 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 cleaner energy sources beyond existing ambitious plans would require significant structural changes, including access to new energy sources and technologies, improved delivery mechanisms, and widened access to a skilled workforce. Strengthened energy efficiency standards for appliances and buildings would also 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.

49. It is widely agreed that growth in greenhouse gas 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 time frame 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 cities. Most transport infrastructures (including urban roads, rail, and highways) have long operational lives, and the way that new infrastructure is implemented 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 road congestion, health impacts from local air pollution, and greenhouse gas 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 would need to be done 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 nonmotorized travel in order to cover this growth in demand and slow down the apparently inevitable growth in motorized transport. At the same time, for lowering long-term greenhouse gas emissions, it would be critical that new vehicles entering service have high fuel economy and meet tight local emission standards.

50. Ultimately the scope of this study does not allow making conclusive statements about the costs of achieving different future carbon trajectories. The foregoing sections show that, on the supply side, particularly in grid electricity, there are capital cost increases in the order of 15 percent to achieve the "stretch" results. These outlays, however, are only part of the total cost of achieving such ambitious greenhouse gas reductions. The speed of the hypothesized carbon-neutral capacity investments in the sensitivity analysis "D" for scenario 3 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.

51. Against these costs are possibilities 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 up-front 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 energy efficiency improvement and capacity expansion give positive rates of return and the former 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 arise because banks tend to have a portfolio of risks and do not focus only on the mean return. 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.

52. It will be necessary for decision makers in India to carefully consider the costs and benefits they will obtain from different cleaner-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 congestion, which would also 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 greenhouse gas emissions.

53. Aside from the possibilities discussed to this point, what are the options for truly dramatic reductions in greenhouse gas growth, even as energy use expands? One possibility is to enhance regional trade in cleaner energy sources**.** Given the limited availability of clean domestic energy resources in India compared to its needs, international cooperation to facilitate access by India to natural gas and hydropower imports would change the energy options available to the country. Increased energy trade would require both a long-term commitment to purchase the energy to be generated and sustained efforts to develop the resources at the regional level. It would also require strong counterparty assurances of supply reliability to mitigate concerns in India over energy security.

54. The other 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 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 (Holloway et al. 2008). At this stage of technological know-how, then, the choices would come down to a significant further advance in cost-effective solar (for example, concentrated solar power over large areas of India's deserts with the right radiation conditions), or a hugely ambitious further expansion in nuclear power -either of which would have to be roughly cost-competitive with coal in order to be no-regrets investments. In the case of concentrated solar power, there would be inevitable trade-offs with competing demand for water resources, which are increasingly stressed in India, as well as a lack of land availability. Cooling water availability will also present a challenge for nuclear capacity addition. One alternative would be co-financing of additional costs for these (and other higher-cost carbon-neutral resources) through sales of CO_2 reduction credits or other carbon finance mechanisms, although there remains uncertainty as to whether nuclear energy would be eligible for such financing. But given the large amounts of carbon-neutral investment

needed in the all-out stretch scenario and even more so for emission stabilization, unless the carbon-neutral technologies were fairly cost-competitive the carbon finance costs would be staggering.

55. 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.

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