CO_2 MITIGATION POTENTIAL OF GRID-SUPPLIED THERMAL POWER GENERATION EXPANSION IN INDIA*:*

Preliminary Assessment of Current Plans and Additional Opportunities

Background Paper

India: Strategies for Low Carbon Growth

June 2008
The World Bank

CONTENTS

Acknowledgements ..………………………………………………………………… i
Acronyms and Abbreviations ……………………………………………………… ii
Executive Summary ……………………………………………………………………… iii
Introduction 1
1. Currently Installed Capacity and Forecast to 2011–12 1
1.1 Hydro 2
1.2 Non-conventional Energy Sources 3
1.3 Nuclear 3
1.4 Thermal 3
2. Long-term Development to 2031–32 4
3. Specific Options that could Reduce the Carbon-intensity of Power Generation 6
3.1 Summary of Options 6
3.2 Options Affecting Existing Plants 7
3.2.1 Retirement of Units with Lowest Availability 7
3.2.2 Retirement or Renovation of Coal-Fired Units with Highest Heat Rates 8
3.2.3 R&M alternatives 9
3.2.4 Impact of an enhanced rehabilitation and maintenance on gas fired units 11
3.2.5. Overall Efficiency Improvement of an Additional 0.5 percent in all Currently Existing Thermal Units 12
3.3 Options Affecting New Plants 12
3.3.1. Incorporation of Supercritical Technology in New Plants 12
3.3.2 Non-conventional Energy Sources 14
Benefit Accruing from Non-conventional Energy Sources 15
3.3.3 Reduction of Technical Losses in Power Distribution 15
*3.3.4 Active Promotion of More Grid-connected Captive Units during 11th and 12th Plans*16
Appendix A: Preliminary Results 17
Appendix B: Principal Assumptions 18
References 20
Bibliography 20

Table 1: Nameplate Capacity Installed at the end of the 10th Plan 1
Table 2 : Proposed Nameplate Capacity Addition and Retirement in the 11th Plan 2
Table 3: Summary of CO_2 Emissions Reductions from Evaluated Options 6
Table 4: Summary of CO_2 Reductions from Evaluated Options Affecting New Plants 7
Table 5: Thermal units with Lowest Availability 7
Table 6: Subcritical Coal-fired Plants Ordered by Efficiency 8
Table 7: Subcritical Coal-fired 210–250MW Plants Ordered by Efficiency 9
Table 8: Proposed Enhanced R&M Options 10
Table 9: Gas-fired Plants Ordered by Efficiency 11
Table 10: Supercritical Introduction Scenario 13
Table 11: Alternative Accelerated Introduction Scenario 13
Table 12: Principal Assumptions 18
Table 13: Detailed Assumptions 19

Figure 1: Electricity Generation and CO_2 Intensity 6
Figure 2: Impact of an Enhanced Rehabilitation and Maintenance Program on CO_2 Emissions. 10

Acknowledgements

This report was produced as a background paper for the study, *India: Strategies for Low Carbon Growth*. The team that has worked on this paper comprises the following World Bank staff and consultants: R. K. Jain, Masami Kojima, Kseniya Lvovsky, Amelia J. Moy, Mudit Narain, John Rogers, Suphachol Suphachasalai and E. Stratos Tavoulareas. Valuable comments were received from John Besant-Jones, Rohit Khanna and Gary Stuggins. The team would like to thank the Central Electricity Authority for their assistance with data collection and continuing support. Kseniya Lvovsky is the former Task Team Leader for the Study, Kwawu M. Gaba the current Task Team Leader, Charles J. Cormier the current co-Task Team Leader, Karin E. Kemper and Salman Zaheer are responsible Sector Managers, and Isabel M. Guerrero is the Country Director.

Acronyms and Abbreviations

CEA	Central Electricity Authority
CO_2	Carbon dioxide
GDP	Gross domestic product
Gt	Gigatons or billion metric tons
GWh	Gigawatt-hour
IEP	Integrated Energy Policy
kWh	Kilowatt-hour
MNRE	Ministry of New and Renewable Energy Sources
MPa	Megapascal
MoP	Ministry of Power
MW	Megawatt
NEP	National Electricity Policy
O&M	Operation and maintenance
R&M	Renovation and maintenance
Rs	Indian rupees

Executive Summary

While the Indian power sector has made significant progress over the last few decades in generation, transmission, and distribution of electricity, the country's rapidly growing economy still experiences severe power supply shortages, and about half of the rural population lacks access to electricity.

The demand for electricity will inevitably continue to rise further with the projected growth of the economy. According to the Planning Commission's "Integrated Energy Policy: Report of the Expert Committee", gross domestic product growth rates of 8 to 9 percent have been projected during the 11th plan (2007−2012[1]). With 9 percent growth and an income elasticity of 1.0, the "Report on Seventeenth Electric Power Survey of India" and the "National Electricity Plan," both by the Central Electricity Authority, estimated that the total requirement of grid-supplied electricity generation would amount to 1,008,000 gigawatt hours (GWh) per year by fiscal 2011–12 not including grid-connected wind, solar and small hydro. When the latter electricity sources are added, the total electricity generation would amount to 1,038,000 GWh per year.

This paper looks at the short and long term development of electricity generation that is needed to support this high economic growth rate together with increasing rural electrification, and identifies and assesses the carbon dioxide mitigation impact of several measures that help meet this demand while reducing the carbon intensity of power generation at the same time.

The paper looks specifically at measures contained in the 11th plan and assesses their impact on emissions up to 2031–32. The measures assessed are taken from various government plans and documents. In addition, the paper assesses the impact on carbon dioxide (CO_2) emissions of some optional enhancements to these measures that can further reduce CO_2 emissions and improve other aspects of plant operations.

Overall, the paper shows that the power generation expansion plans as approved in the 11th plan already include a number of measures that lower CO_2 emissions from existing plants and avoid emissions from the increased capacity that is installed. In addition to these published measures, the paper suggests opportunities to achieve a larger CO_2 emissions reduction by further improving the efficiency and operation of thermal plants.

The next phase of the study will refine this assessment, evaluate a larger number of options, and complement CO_2 impact estimates with cost estimates of alternative measures, policy implications, and local benefits.

[1] The 11th plan covers five fiscal years, from fiscal 2007–08 (April to March) to 2011–12.

Introduction

At the macro-economy scale, India is a low-intensity producer of CO_2 emissions. Its per-capita CO_2 emissions are among the lowest in the world with about 1 metric ton per person compared with 4.5 for the world average and 20 for the United States. In absolute terms, reflecting India's status as the second most populous country in the world and one of the world's largest economies with spectacular recent growth, its CO_2 emissions are significant and rising. Currently at around 1.1 billion metric tons, CO_2 emissions are projected—according to the "Integrated Energy Policy: Report of the Expert Committee" issued by the Planning Commission in 2006 (referred to as the IEP hereafter)—to reach a range of 3.9 to 5.5 billion metric tons by fiscal 2031–32. Of these, more than half of India's total energy-related CO_2 emissions are expected to come from power generation (Planning Commission 2006).

India needs high growth in electricity generation. Even reaching a grid supply of 3,662,000 GWh by 2031-32 as planned in the IEP, India's annual per-capita electricity will still be around 2,500 kWh, just over the world average in 2003. At the same time, as the world moves towards an awareness of the need to stabilize the ambient concentration of CO_2 at a level that would prevent dangerous changes to the climate, India has exhibited concrete plans that will substantially reduce these when compared to what could be expected under a business-as-usual scenario.

India's program of power sector development also has substantial co-benefits in development, poverty reduction, energy security, cost of energy, and local emissions which by themselves can justify most of the actions proposed. This present paper, however, will focus exclusively on the abatement potential for CO_2 emissions.

This paper covers:

- The power generation expansion plan approved in the government's 11th plan
- Long-term development of power generation
- A discussion of specific options that could further reduce the carbon-intensity of power generation.

1. Currently Installed Capacity and Forecast to 2011–12

During the 10th plan (2001–07), India added 27,283 megawatts (MW) of grid connected generation capacity to reach the installed capacity shown in Table 1.

Table 1: Nameplate Capacity Installed at the end of the 10th Plan

	Nameplate Capacity (MW)
Hydro	34,654
Thermal	86,015
Nuclear	3,900
Renewable	7,760
Total	132,329

Source: CEA 2007.
Note: Data as of 31 March 2007

Additional capacity of up to 95,886 MW is planned to be commissioned before the end of the 11th plan (Table 2). This includes 13,500 MW of renewable energy (where wind and hydro smaller than 25 MW are the major sources) and the retirement of 5,000 MW of thermal power plants during this period. Added to the above, the "Report of the Working Group on Power for the Eleventh Plan (2007–12)" (MoP 2007, referred to as the Working Group Report hereafter), shows captive power generation increasing from 78,000 GWh at the end of the 10th Plan (2006–07) to 131,000 GWh at the end of the 11th Plan (2011–12) to give an expected combined (captive plus grid) supply of 741,000 GWh in 2006–07 and 3,793,000 GWh in 2031–32.

Table 2 : Proposed Nameplate Capacity Addition and Retirement in the 11th Plan

All data in MW	Carry-over (slippage) from 10th plan to be commissioned during the 11th plan	11th plan additions (2007 to 2012)	Units to be retired in 11th plan	Nameplate Capacity at end of 11th plan
Hydro	968	15,585		51,207
Thermal	8,520	50,124	(5,000)	139,659
Supercritical	*660*	*7,994*		*8,060*
Subcritical	*4560*	*46,024*	*(5,000)*	*131,599*
Nuclear	220	3,160		7,280
Sub-total	9,708	68,869	(5,000)	198,146
Renewable	3,809	13,500		25,069
Total	13,517	82,369	(5,000)	223,215

Source: CEA 2007

Table 2 shows that generating technologies that may be considered CO_2 neutral to leading order (hydro, renewable, and nuclear)[2] will comprise approximately 37 percent of India's installed nameplate capacity by the end of the 11th planning period although, at 23 percent of grid supply, their contribution to electricity generation is considerably lower. The data on slippage from the 10th plan is taken from "All India Electricity Statistics, General Review 2007" (CEA 2007d).

1.1 Hydro

Considerable efforts have been made to augment electricity generation from hydro power; installed hydro capacity will increase by 48 percent during the 11th plan period. Since the timeframe for a hydro project from its inception to commissioning is normally longer than 5 years, additional capacity within this timeframe would be difficult to achieve.

In recognition of the need to develop hydro projects over a longer timeframe, the government of India has an aggressive plan to add 30,000 MW during the 12th plan (2012–2017), with the feasibility of exploiting the entire domestic hydro potential of around 150,000 MW by 2031–32. A realistic baseline scenario considered by the World Bank contemplates that a total of 20,000 MW could be installed by 2016–17, 131,000 MW by 2031–32, and that India could achieve its maximum hydro potential in the following years.

[2] Considered on an operation basis for the purpose of this paper and ignoring other full-life-cycle GHG emissions.

1.2 Non-conventional Energy Sources

As proposed by the Ministry of New and Renewable Energy for the 11th plan in its annual report for fiscal 2006–07, the total installed capacity of renewable energies is expected to grow to more then three-times its present capacity by the end of fiscal 2011–12. The addition comprises 10,000 MW from wind, 1,400 MW from small hydro, and 2,100 MW from biomass (MNRE 2007).

During 12th and 13th plans (2012–2022), the following additional capacities are targeted:

- Wind 22,500 MW
- Small hydro 3,140 MW
- Biomass 4,363 MW

1.3 Nuclear

For nuclear generation, the installed capacity is planned to nearly double by the end of the 11th plan (Working Group Report). The addition of nuclear during the 12th and 13th plans (2012–2022) is projected to reach a capacity of around 11,000 MW.

1.4 Thermal

All remaining grid-supplied electricity requirements will be generated from coal, oil, and gas. Thermal generation has always been the main source of India's electricity generation and constitutes approximately 63 percent of the total installed capacity by the end of the 11th plan. Of this, approximately 85 percent of capacity is based on coal (including lignite), comprising predominantly pulverized coal-fired subcritical plants. Coal is expected to remain the backbone of the Indian power sector for years to come.

Table 2 shows that the 58,644 MW additions to total thermal generation, targeted during the next 5 years, include 8,060 MW of supercritical units. The Ministry of Power's Working Group on Power has proposed that the thermal capacity commissioned during the 12th plan be predominantly supercritical (MoP 2007). Because about 40,000 MW of capacity addition in the 12th plan is expected to be thermal units, this implies that around 28,000 MW of supercritical plants could possibly be operational by 2017. As with hydro, the lead times required for new plants would make it difficult to increase the installation of supercritical units during the 11th plan. Apart from gains in power supply and reduction in variable costs, this planned more towards supercritical technology would also make the Indian power sector less carbon-intensive.

The Ministry of Power's Central Electricity Authority (CEA) recognizes that the system expansion in previous 5-year plans has fallen far short of the targets that were set, but believes that it is in a better position to meet its goals in the current (11th) and future plans, since orders have already been placed for many of the important investments. However, the impacts of possible slippage rates will be considered in a later stage of this study to evaluate the outcome, should these targets not be met.

2. Long-term Development to 2031–32

A preliminary long-term development scenario (whose principal results are shown in appendix A based on the assumptions detailed in Table 12 and Table 13 in appendix B) has been modeled to evaluate the relative order of magnitude of the mitigation interventions examined in this document. It generally follows the CEA's aggressive expansion plan coupled with demand projections that relate to the government's high growth scenario for the economy. The calculations presented in this study are not intended to be representative of any likely specific growth path or be consistent with other studies.

For this forecast, GDP has been considered to grow at an average annual rate of 8.0 percent until 2022 and 7.4 percent thereafter, combined with an aggressive improvement in energy efficiency of all sectors. Whilst the econometric multi-variate analysis presented in the "Report on Seventeenth Electric Power Survey of India" (CEA 2007c) shows a historic 30-year GDP elasticity of electricity demand of 1.27, this forecast considers that considerable further improvements in energy efficiency will reduce the elasticity within the modeling period from 1.0 during the 11th plan (2007–12) to 0.80 by fiscal 2020–21. The combination of these two factors model a high demand forecast with an average annual increase in electricity demand of 8.3 percent in the 11th plan and dropping to 5.9 percent from the 14th plan onwards. This gives an annual demand growth rate of 6.7 percent between 2007–08 and 2031–32.

Whilst several industrial sectors are already improving their energy efficiency to achieve and maintain their international competitive position, other sectors such as households may find it challenging to reduce energy intensity because increasing income will result in new or expanded uses of energy as households acquire new electrical appliances and use them longer hours.

Data collection has been initiated with the intention of developing a bottom-up model of feasible demand-side interventions to improve energy efficiency in the different sectors and demonstrate the feasibility of reaching these. Demand-side measures are often shown to be the most economic way to improve energy efficiency and reduce CO_2 emissions, and these will be examined in a later phase of this study.

The initial grid supply condition in the model shows a shortfall at the end of the 10th Plan (2006–07) of 8.8 percent. The forecast assumes that all the system expansion and generation, transmission and distribution improvements contemplated in the 11th plan occur on time and that, as stated by the Working Group Report captive power generation increases from 78,000 GWh in 2006–07 to 131,000 GWh in 2011–12. Since one important goal of the 11th plan is to achieve a spinning reserve of 5 percent on an average annual energy basis by 2011–12, captive power generation is held constant in the model after this date with the rest of electricity being supplied by the grid.

Under these scenarios, the expected combined sum of power supplied to the grid and captive power generated by users increases at an average annual rate of 6.5 percent from 740,000 GWh in 2006–07 to 3,793,000 GWh in 2031–32 as shown in Figure 1.

This forecast assumes that great strides are made, as proposed in the "Working Group Report", in the use of grid-connected renewable energy (other than hydro) with wind and biomass providing 4.5 percent of power generation in 2011–12 and rising to 15.1 percent by 2031–32. Total grid-connected nameplate capacity over the same timeframe grows at an average annual rate of 6.6 percent from 132 GW in 2006–07 to 695 GW in 2031–32.

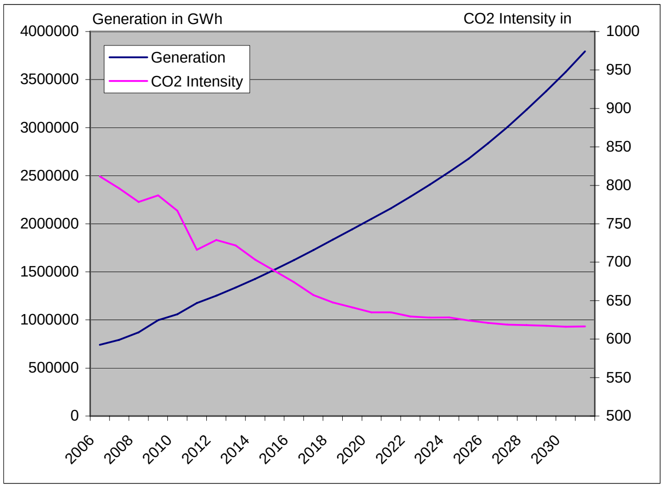
It is difficult to exaggerate the benefits to the power sector of finally achieving a spinning reserve and ending the perennial supply shortage. Where a serious power shortage exists, there is intense pressure to keep all plants operating, whatever their efficiency or cost, at the expense of essential maintenance activities, adequate plant scheduling, and dispatch optimization. Having this reserve will allow many improvements in day-to-day operation that can result in an overall efficiency gain for the entire system.

Under this preliminary long-term growth scenario, whilst thermal supplies 79 percent of the electrical energy generated in 2006–07, this percentage drops to 72 percent in 2031–32 as hydro, and then wind and biomass, increase. Even without this growth in renewable, by extensively adopting supercritical technology in new coal-fired plants and detailed attention to rehabilitation, maintenance, and operational practices on existing plants to decrease their heat rates, the carbon intensity of thermal grid-supplied power may improve over this timeframe from an overall average of 1,022 grams of CO_2 per kilowatt-hour (g CO_2/kWh) in 2006–07 to 854g CO_2/kWh in 2031–32, representing an improvement of more than 16 percent.

This preliminary long-term growth scenario is used to evaluate several discrete supply-side interventions for both existing and future plants. These will be used in later stages of this study to develop marginal CO_2 abatement curves and evaluate the cost and policy implications of distinct options that can reduce the carbon intensity of power generation. Further options of supply-side interventions will be included as additional data become available, and will be combined with the demand-side abatement options identified in each of the sectors that consume electricity.

The carbon intensity of total grid supply (including hydro, renewable, and nuclear) decreases by almost 24 percent between 2006–07 and 2031–32 from 812 to 616g CO_2/kWh as shown in Figure 1. The total CO_2 emissions from grid-supply generation increases from 538 million metric tons in 2006–07 to almost four times this value (2,258 million metric tons) by 2031–32. This represents an average annual increase of 5.7 percent.

Figure 1: Electricity Generation and CO_2 Intensity



Source: World Bank calculations.

This scenario includes the incorporation of supercritical technology (at steam conditions of 20MPa/538°C/538°C) in new plants, but not the lower heat rates discussed in section 3.3 of this report (see Table 10 and Table 11). The two sets of options, if adopted, could reduce cumulative CO_2 emissions between now and the end of the 15th plan (fiscal 2031–32) by 667 and 1,044 million metric tons, respectively.

3. Specific Options that could Reduce the Carbon-intensity of Power Generation

3.1 Summary of Options

Table 3 describes several options for existing plants that can lower CO_2 emissions, and the potential size of the emissions reduction in each case.

Table 3: Summary of CO_2 Emissions Reductions from Evaluated Options Affecting Existing Plants

Item	Measures evaluated	Expected reduction per year (million metric tons of CO_2 avoided)	Expected impact in each 5 year plan after implementation (million metric tons of CO_2 avoided)
3.2.1	Retirement of existing units with lowest availability	0.3	2
3.2.2 & 3.2.3	Retirement or renovation of existing coal-fired units with highest heat rates (includes enhanced R&M alternatives)	22.9 to 45.9	230
3.2.4	Enhanced rehabilitation and maintenance on existing gas fired units	4.2	21
3.2.5	Overall efficiency improvement of an additional 0.5% in all existing thermal units	10	50
Sum of the above			303

Source: World Bank calculations

For new plants, yet to be constructed, a summary of the CO_2 emissions reductions that could be achieved by selected options is shown in Table 4.

Table 4: Summary of CO_2 Reductions from Evaluated Options Affecting New Plants

Item	Measures evaluated	Expected impact between 2007–08 and 2031–32 (million metric tons of CO_2 avoided)
3.3.1	Incorporation of supercritical technology (at the baseline temperature and pressure conditions (20MPa/538°C/538°C) shown in Table 10) in new plants vs. subcritical technology	1,437
3.3.1	Incorporation of supercritical technology in new plants with improved temperature and pressure (see Table 10) vs. item 1 above	667
3.3.1	Incorporation of supercritical technology in new plants with higher temperature and pressure (see Table 11) vs. item 1 above (667 above + 377)	1,044
3.3.2	Incorporation of non-conventional energy sources (wind and biomass) for up to 15% of energy generated	4,893
3.3.3	Reduction of technical losses in power distribution by 14 percentage points	6,478
Sum of the above		13,852

Source: World Bank calculations

3.2 Options Affecting Existing Plants

3.2.1 Retirement of Units with Lowest Availability

According to the "CO_2 Baseline Database for the Indian Power Sector. Version 2.0" (CEA 2007a, referred to as the CO_2 Database hereafter), and updated with specific unit information from the CEA, 112 thermal units with a combined capacity of 6,484 MW operated at less than 20 percent of their installed capacity in fiscal 2004–05 and 2005–06 (see Table 5). The total power generated by these 112 units in 2004–05 was 2,010 GWh, which is the equivalent of one 300 MW unit operating at an average load of 77 percent.

Table 5: Thermal units with Lowest Availability

	Utilization of:	
	Less than 5% capacity	Less than 20% capacity
Number of units	88	112
Fuel	Capacity in MW	
Coal – subcritical	2,347	3,077
Diesel	313	513
Gas	1,117	1,650
Naphtha	860	1,034
Oil	210	210
Total MW	4,847	6,484

Source: World Bank calculations using the CO_2 Database. Note: Data from 2004–05.

In 2004–05 these 112 units emitted 2.27 million metric tons of CO_2. If they were replaced by one subcritical coal-fired thermal unit operating at the top efficiencies of similar units installed in India in that same year, CO_2 emissions would have fallen by 363,000 metric tons to 1.89 million. The savings would be equivalent to 16 percent of the emissions in 2004–05.

During the 11th plan, the CEA plans to retire 5,000 MW of their lowest performing thermal units (MoP 2007). Assuming the units to be retired are selected from these 112 units, and given their low contribution to electricity generation, the benefits of retiring these units could outweigh the costs. Their retirement may result in an annual CO_2 emissions reduction of more than 300,000 metric tons and free up brownfield sites for the installation of new units.

3.2.2 Retirement or Renovation of Coal-Fired Units with Highest Heat Rates

Upon elimination of all the 112 thermal units cited above, the CO_2 Database contains 316 coal-fired subcritical units. These units were classified into quintiles in order of increasing emissions expressed in g CO_2/kWh. Each quintile contains the same number of units (63 on average) and not the same total installed capacity. The most efficient plants are in the top quintile, the least efficient in the bottom quintile. The results are shown in Table 6.

Table 6: Subcritical Coal-fired Plants Ordered by Efficiency

Quintile	Number of units	Capacity (MW)	Energy Generated (GWh)	Average CO_2 emissions (g CO_2/kWh)	Average Efficiency (%)
1	64	22,581	154,990	990	33.2
2	63	12,710	94,602	1,044	31.5
3	63	9,763	68,270	1,140	28.9
4	63	9,200	49,333	1,279	25.7
5	63	6,330	28,052	1,572	21.0
Total	316	60,584	395,247		

Source: World Bank calculations using the CO_2 Database. *Note*: Data from 2004–05.

It can be seen in Table 6 that, in 2004, the top quintile had an average net heat rate efficiency of 33.2 percent and CO_2 emissions of 990 g/kWh whilst the lowest efficiency quintile exhibited an average net heat rate efficiency of 21.0 percent and CO_2 emissions of 1,572 g/kWh. The bottom quintile had CO_2 emissions which were 59 percent higher than the top quintile.

During the 12th plan, the CEA proposes to retire or recondition 10,000 MW in addition to the 5,000 MW contemplated for the 11th plan. These actions, together with a mixture of enhanced maintenance and improved operating procedures, should aim to achieve as much of this improvement as possible with a gradual phase-in over the following 10 years. Given the above observations, serious consideration may be given to retiring or increasing the efficiency of at least 15,000 MW of the bottom two quintiles, rather than the 10,000 MW currently contemplated.

In 2004–05, among those supplying the grid, 63 units with a combined capacity of 3,707 MW had no reheat. These would be leading candidates for scrappage.

3.2.3 R&M Alternatives

Twenty nine, or almost half of the units in the lowest quintile of Table 6, had reheat. If these and the other units in the bottom four quintiles could be improved to match the performance of the top quintile, annual CO_2 emissions would fall by 46 million metric tons to 391 million metric tons, resulting in a reduction of 10.5 percent.

However, the backbone of the grid supply that would most benefit from a concentrated effort to improve maintenance and rehabilitation are the 210–250 MW subcritical coal-fired plants. The CO_2 Database contains 139 units as shown in Table 7 (as of 2004–05). As before, the units were sub-divided into quintiles containing 27–28 plants each in order of increasing CO_2 emissions in g/kWh.

The top 5 percent of units in the 210–250 MW range, numbering 7, had an annual average efficiency of 34.2 percent. The average efficiency of the plants in the bottom four quintiles was lower by between 2.5 and 10.1 percentage points (or lower by up to 30 percent).

The top 5 percent of units in the 210–250 MW range also had an annual average utilization rate of 95.4 percent. The bottom four quintiles had utilization rates (compared to this figure) that were lower by between 9.5 and 23.6 percentage points (or up to 25 percent lower).

Table 7: Subcritical Coal-fired 210–250MW Plants Ordered by Efficiency

Quintile	Number of units	Capacity (MW)	Energy Generated (GWh)	Utilization % of Installed Capacity	Average CO_2 emissions (g CO_2/kWh)	Average Efficiency (%)
1	27	5,830	45,642	89.4	994	33.1
2	28	6,160	46,339	85.9	1,038	31.7
3	28	5,880	43,205	83.9	1,062	31.0
4	28	5,880	40,734	79.1	1,158	28.4
5	28	5,960	29,779	71.8	1,371	24.1
Total	139	29,710	205,699			

Source: World Bank calculations using the CO_2 Database.
Note: Data from 2004–05.

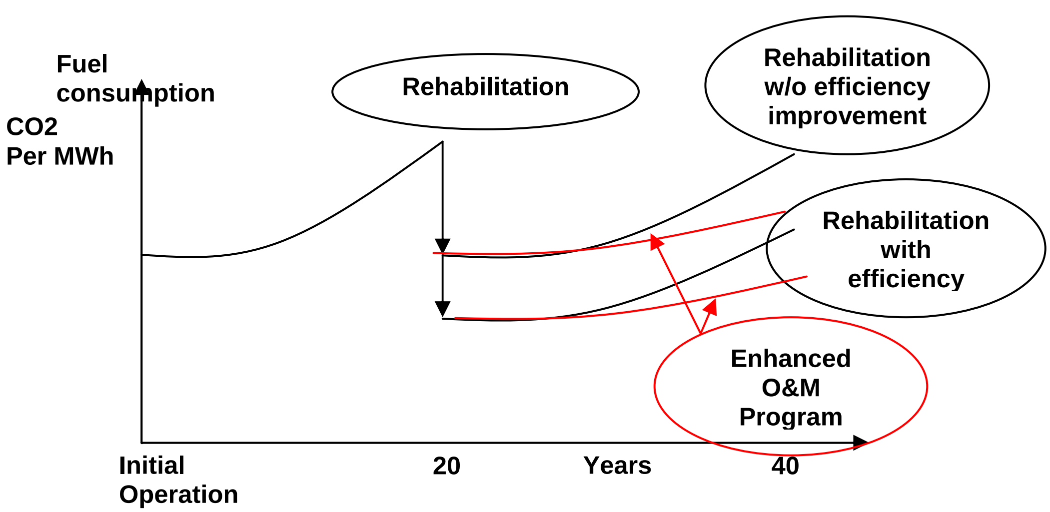
The renovation and maintenance (R&M) alternatives that could be applied to these units after typically about 25 years of operation include those shown in Table 8. Units that have an efficiency that has not degraded excessively may be subjected to a standard R&M program whilst others, such as those shown in quintiles 4 and 5 that exhibit substantial efficiency degradation, would benefit from an extended R&M program that not only regains capacity but can also recoups the lost efficiency (shown as "rehabilitation with efficiency improvement" in Figure 2). In both cases, there is an option of conducting an enhanced version of the program, where for relatively little additional investment the improved operation can be maintained for at least 10 years longer. The impact that these programs could have is shown graphically in Figure 2.

Table 8: Proposed Enhanced R&M Options

	Standard R&M	Extended R&M
Applicability	Applicable to units that have maintained their original efficiency but lost capacity	Applicable to units that exhibit a substantial loss in efficiency and in capacity
Additional work includes		New air heater New steam turbine blades for at least the critical high temperature stages Reduction of boiler air-in leakage and combustion system optimization Rehabilitation of condenser and feedwater systems focusing on efficiency improvements
Output (MW)	Regain lost capacity	Regain lost capacity
Efficiency	Regain 60% of lost efficiency	Regain or exceed original design efficiency
Equiv Availability	Back to design	Back to design
Life expectancy	15 years	15 years
Investment	Rs 1.0 crores/MW (US$240/kW)	Rs 1.8 crores/MW (US$430/kW)
Additional Investment in enhanced program to maintain improved operation for at least 10 years	Rs 0.2 crores/MW (US$50/kW)	Rs 0.2 crores/MW (US$50/kW)
Additional operation and maintenance (O&M) costs with enhanced program	Higher annual maintenance costs	Higher annual maintenance costs

Source: World Bank calculations.

Figure 2: Impact of an Enhanced Rehabilitation and Maintenance Program on CO_2 Emissions



Source: World Bank.

If the bottom four quintiles could be improved to match the performance of the most efficient quintile, the electricity generated by these 139 units would increase by 13.1 percent from 206,000 to 233,000 GWh and, at the same time, the CO_2 emissions intensity would decline 10 percent from 1,105 to 994 g/kWh.

In this preliminary long-term growth scenario, an important assumption is that new plants may be continually operated at internationally proven heat rates. New subcritical units installed from the 12th plan onwards (principally 500MW) have been considered at average annual net heat rate efficiencies of 35.3 percent, which is more than 2 percentage points higher than that historically maintained by the top quintile of 250 MW units shown in Table 7, and also above the current average annual net heat rate efficiency of 500 MW plants (which was 33.3 percent in 2004–05). The lower end of the range quoted from international experience, however, is more applicable to India given the quality of available coal and other factors.

3.2.4 Impact of an enhanced rehabilitation and maintenance on gas fired units

Table 9 shows the 131 gas-fired units in the CO_2 Database ordered by CO_2 emissions. Quintiles are defined as in the foregoing paragraphs.

Table 9: Gas-fired Plants Ordered by Efficiency

Quintile	Number of units	Capacity (MW)	Energy Generated (GWh)	Average CO_2 emissions (g CO_2/kWh)	Average Efficiency (%)
1	27	3,131	20,098	404	45.6
2	26	2,564	16,621	463	39.4
3	26	2,216	13,883	482	38.0
4	26	1,103	6,734	548	33.5
5	26	738	2,886	804	23.3
Total	131	9,752	60,222		

Source: World Bank calculations using the CO_2 Database.
Note: Data from 2004–05.

The gas-fired units in the top quintile (those with the lowest heat rates) had an average net heat rate efficiency of 45.6 percent and CO_2 emissions of 404g/kWh in 2004–05, whilst the lowest quintile exhibited an average net heat rate efficiency of 23.3 percent and CO_2 emissions of 804 g/kWh. It is worth noting that the CO_2 emission levels of the gas-fired plants in the top quintile are only 41 percent of the emissions of the coal plants in the top quintile, clearly demonstrating the carbon intensity benefits of switching from coal to natural gas.

Following the same logic as above, in 2004–05 these 131 units emitted 28.5 million metric tons of CO_2 in 2004–05. If the bottom four quintiles could be improved to match the performance of the top quintile, the CO_2 emissions would fall by 4.2 million metric tons (14.7 percent) to 24.3 million metric tons. Since the electricity generated in several gas-fired plants has been limited by the availability of gas, improved availability is not considered in this paper.

These calculations suggest that it could be beneficial to further improve the efficiency of at least 26 units that are operating at about half their expected efficiency.

3.2.5. Overall Efficiency Improvement of an Additional 0.5 percent in all Currently Existing Thermal Units

In 2004–05 the total operating thermal units emitted 504.8 million metric tons of CO_2. If it were possible to increase the efficiency of each existing unit by 0.5 percentage points by improving the units operation and maintenance, the total CO_2 emissions would fall by 10 million metric tons (2.0 percent) to 495 million metric tons. The CEA has initiated a "Partnership in Excellence" program with these goals in mind and the attainment of a spinning reserve during the 11th plan could give the power sector the breathing space needed to achieve this goal.

3.3 Options Affecting New Plants

3.3.1. Incorporation of Supercritical Technology in New Plants

In the 12th plan the majority of the new units are proposed to be supercritical. The 11th plan includes only eleven 660 MW and one 800 MW supercritical units. Of these, five 660MW units are in an advanced stage of construction whilst the other units are planned for commissioning during the 11th plan.

According to the CEA,[3] the time currently required between project concept and order placement for new plants is about 12 months and the time required between order placement and commissioning is:

- 800 MW 54 months
- 500 MW 39 months
- 250 MW 30 months.

From the above, it follows that it would be virtually impossible, at this stage, to increase the number of supercritical units for commissioning during the 11th plan. The 12th plan contains an aggressive proposal for adoption of supercritical technology: 50 percent of new plants commissioned during this five-year period are to be supercritical.

In this study, supercritical technology is adopted to the end of the 15th plan at the rate stated by the Ministry of Power (adoption schedule shown in Appendix B) and the study examined the impact on the carbon intensity of thermal grid-supplied power of using the temperature and pressure conditions proposed for the 12th plan (20MPa/538ºC/538ºC) to the end of the 15th plan

The incorporation of supercritical technology from the 12th plan onwards reduces the overall carbon intensity of thermal grid-supplied power by more than 16.3 percent between 2007–08 and 2031–32 when compared to equivalent subcritical units. With the growth assumptions included in the preliminary model, this adoption of supercritical units at the baseline temperature and pressure conditions generates a cumulative abatement of 1,437 million metric tons of CO_2 between 2007–08 and 2031–32, or 4.5 percent of the total CO_2 emissions from grid power.

However, greater abatement can be achieved if the CEA acts upon its proposal to continually improve temperature and pressure conditions in the supercritical technology that they introduce

[3] personal communication with V.S. Verma, Member Planning, CEA,

in each subsequent plan. Whilst it would be easier to go for a "cookie-cutter" approach by not improving technology from one plan to the next, and whilst this would reduce engineering design and lead time, it is possible to gain additional efficiency (and lower CO_2 emissions) by learning from, and improving on, the technology applied in each successive plan, as shown below.

The supercritical introduction scenario shown in Table 10 improves upon the baseline case discussed above. The carbon intensity falls by 20.7 percent (in contrast to 16.3 percent in the baseline case), the heat rate decreases by 3.75 percent, and the capital costs increase by up to 6 percent for the new units constructed over the coming 25 years.

Table 10: Supercritical Introduction Scenario

5-year Plan	Steam conditions (MPa/°C/°C)	Heat rate decrease (%)	Increased capital costs (%)
Baseline technology	~20MPa/538°C/538°C	Base	Base
11th and 12th	24.7MPa/538°C/565°C	0.8	2
13th	24.7MPa/565°C/565°C	1.75	4
14th	24.7MPa/565°C/593°C	2.50	5
15th	24.7MPa/593°C/593°C	3.75	6

Source: World Bank calculations.

The preliminary calculations for the above scenario estimate an additional CO_2 emissions reduction of 667 million metric tons (cumulative) between 2007–08 and 2031–32, or approximately 2.1 percent of the total grid supply CO_2 emissions, compared with supercritical units at the baseline temperature and pressure condition throughout the entire projection period.

Table 11 shows a plausible accelerated introduction of increasingly advanced supercritical technology where a heat rate decrease of up to 4.50 percent and a carbon intensity decrease of 22.4 percent could be achieved in the new units constructed over the same time period, at the expense of a capital cost increase of up to 10 percent.

Table 11: Alternative Accelerated Introduction Scenario

5-year Plan	Steam conditions (MPa/°C/ °C)	Heat rate decrease (%)	Increased capital costs (%)
Baseline technology	~20MPa/538°C/538°C	Base	Base
11th	24.7MPa/538°C/565°C	0.8	2
12th	24.7MPa/565°C/565°C	1.75	4
13th	24.7MPa/593°C/593°C	3.75	6
14th	27MPa/593°C/610°C	4.00	8
15th	27MPa/610°C/625°C	4.50	10

Source: World Bank calculations.

This more aggressive introduction of improved supercritical units in Table 11 reduces cumulative CO_2 emissions by 1,044 million metric tons between 2007–08 and 2031–32, corresponding to 3.3 percent of the total CO_2 emissions from grid electricity, compared to operating supercritical units at the baseline temperature and pressure conditions.

3.3.2 Non-conventional Energy Sources

Whilst the Working Group Report does not take into account the generation of electricity from non-conventional energy sources for planning purposes, the preliminary long-term growth scenario in this paper includes growth in renewable energy (principally wind and biomass) to meet a target of sourcing 15 percent of grid power from renewable energy by 2031–32. This is in addition to hydro (including small hydro plants with a capacity of less than 25 MW), which by 2031–32 accounts for almost 10 percent of the grid-supplied electricity demand. The forecast includes an installed nameplate capacity of 104,000 MW of renewable energy, 57 percent of the estimated medium-term potential cited in the Working Group Report.

Biomass

Whilst it could be feasible to have 5–15 percent of the heat input provided by biomass in either existing or new boilers, this preliminary long-term scenario increases the use of biomass to generate 3.7 percent of annual grid-supplied energy by 2031–32. Biomass may include sawdust, wood wastes, municipal solid wastes and other waste fuels. This is currently included in the forecast scenario as part of renewable energy.

However, there is an argument that it could be beneficial to consider burning a low percentage of biomass in some existing strategically-located coal-fired units, but further studies are required. If 5 percent of the heat input for a specific boiler (existing 110–250 MW units could be appropriate for this purpose) were provided from biomass, this would mean 5 percent less coal for the same power generation and a maximum reduction in CO_2 emissions proportional to the biomass input. If there are no changes in land use and biomass is not specifically cultivated for this purpose, the CO_2 emissions reduction could be larger: for example, collecting and transporting biomass might consume less energy than what it takes to transport the coal that biomass replaced to the same power plant. If biomass were cultivated specifically for this purpose, however, it would be necessary to take into account the full GHG impact of cultivation including emissions from tillage and fertilizer manufacture and use.

There should be no change in the performance of these plants except for the CO_2 reduction. The cost for boiler conversion to accommodate co-firing would be of the order of Rs 0.4 crore per MW (US$100/kW) and there should be no substantial impacts on O&M costs although the possibility of increased corrosion is a consideration that could need further study.

Analysis of biomass co-firing would require further information from India on the amount of biomass that could reasonably be expected to be available and that could be co-fired, sustainability of supply, and the average cost of biomass per unit of energy delivered to the plant.

Wind

Additional non-conventional generation is included in this preliminary long-term scenario supplying 11.5 percent of grid electricity by 2031–32, thus meeting the expressed goal of 15 percent grid-interactive renewable power by this year. Whilst this is currently included as wind in the bottom-up model set up for this study, further work is required to include a mix of photovoltaic and other solar (such as heating condensate and feed water for coal-fired generation) in this total. While these additions may only marginally affect CO_2 emissions, they could have a substantial impact on costs.

Benefit Accruing from Non-conventional Energy Sources

The effect of adding generation from non-conventional energy sources is significant. Should the wind, biomass, and small hydro (less than 25MW) plants that are included in this model during the 11th and subsequent plans not be built, the energy demand could be satisfied by additional supercritical coal-fired technology at the baseline temperature and pressure conditions.

Under this scenario, preliminary calculations show that thermal units in 2031-32 would supply 88% of the electricity to the grid instead of 72% and the overall CO_2 intensity in that year would increase from 616g/kWh to 758g/kWh; an increase of 23%. Building the wind, biomass, and small (<25MW capacity) hydro plants that are included in this model during the 11th and subsequent plans generates an accumulated abatement of 5,224 million metric tons of CO_2 over the period from 2007–08 to 2031–32.

If the small hydro is built but without the wind and biomass components, preliminary calculations show an accumulated abatement from 2007–08 to 2031–32 of 4,893 million metric tons of CO_2, when compared with the CO_2 emissions that would have resulted from generating the same amount of electricity using supercritical coal-fired technology at the baseline temperature and pressure conditions.

3.3.3 Reduction of Technical Losses in Power Distribution

The Ministry of Power in the 10th plan emphasized the need to reduce the large aggregate technical and commercial losses in the power distribution sector. Together with transmission losses, the government estimated that up to 29 percent of the power supplied to the grid was not reaching the final consumer in 2005–06. This loss lowers the energy efficiency and increases CO_2 emissions from the power generation sector.

Investment and reforms have been made but there is a pressing need for continuing efforts in the 11th and subsequent plans. In 2001, the Government of India introduced the accelerated power development and reforms program (APDP), with the objective of initiating a financial turnaround in the performance of the state-owned power sector. One of the expected benefits from the program was the reduction of aggregate technical and commercial losses from about 60 percent to around 15 percent in five years, in the first instance targeting the urban areas and high density/consumption areas.

This preliminary long-term scenario includes an assessment of the impact on CO_2 emissions of lowering technical losses to 15 percent by 2025–26. This 14 percentage point improvement in transmission and distribution efficiency could result in an abatement of 6,478 million metric tons of CO_2 between 2007–08 and 2031–32 when compared with the CO_2 emissions that would have occurred in generating the same amount of electricity using supercritical coal-fired technology at the baseline temperature and pressure conditions.

3.3.4 Active Promotion of More Grid-connected Captive Units during 11th and 12th Plans

Giving increased incentives to companies over the coming decade to install efficient grid-connected captive units and supply the grid as peakers for even only one hour a day could offer measurable advantages in low carbon growth. The incentives could take the form of priority fuel assignments and/or fiscal benefits:

- The additional electricity supplied by these privately-financed units could allow India to cover their true end-user demand shortfall at an earlier date.
- The increase in peak supply could take pressure off the grid for peak expansion, particularly for those sectors with the highest growth in electricity demand.
- Having greater peak supply would allow more flexibility in an improved merit-based low-carbon dispatch.

The Working Group Report considers a potential of 5,500 MW of captive that could be fed into the grid in this manner and the study team suggests that this figure could increase substantially with adequate incentives.

Appendix A: Preliminary Results

Power sector results

Constant Rupees of year: *2007*	*Units*	*2006-07*	*2011-12*	*2016-17*	*2021-22*	*2026-27*	*2031-32*
Maximum Plated Capacity							
Total Hydro	MW	34,654	51,204	71,130	92,700	112,433	130,953
Total Thermal	MW	86,003	139,624	176,388	237,928	321,277	445,017
Total Nuclear	MW	3,900	7,060	8,660	10,660	12,660	14,660
Total Renew	MW	7,760	25,070	45,501	70,843	85,893	103,943
Total Maximum Plated Capacity	MW	132,317	222,958	301,680	412,131	532,263	694,572
Generation							
Total Hydro	GWh	90,584	134,281	184,215	240,361	294,239	344,911
Total Thermal	GWh	525,984	804,851	1,101,075	1,438,208	1,911,966	2,643,612
Total Nuclear	GWh	31,043	57,012	70,140	86,544	102,990	119,459
Total Renew	GWh	14,867	47,003	135,388	266,323	397,195	554,313
Total Generation	GWh	662,478	1,043,148	1,490,817	2,031,436	2,706,388	3,662,295
Unit Fossil Energy Consumption							
Total Hydro	MJ/kWh	0.00	0.08	0.13	0.17	0.19	0.22
Total Thermal	MJ/kWh	11.01	10.01	9.93	9.75	9.57	9.40
Total Nuclear	MJ/kWh	0.00	0.00	0.00	0.00	0.00	0.00
Total Renew	MJ/kWh	0.00	0.00	0.00	0.00	0.00	0.00
Total Unit Fossil Energy Consumption	MJ/kWh	8.75	7.73	7.35	6.93	6.78	6.81
Total Fossil Energy Consumption							
Total Hydro	PJ	0	11	24	40	57	75
Total Thermal	PJ	5,793	8,053	10,938	14,029	18,302	24,848
Total Nuclear	PJ	0	0	0	0	0	0
Total Renew	PJ	0	0	0	0	0	0
Total Total Fossil Energy Consumption	PJ	5,794	8,064	10,962	14,069	18,359	24,923
Unit Variable CO2e Emissions per GWh							
Total Hydro	g/kWh	0.00	0.12	0.11	0.10	0.09	0.09
Total Thermal	g/kWh	1,022.25	928.38	912.76	896.60	879.43	853.94
Total Nuclear	g/kWh	0.00	0.00	0.00	0.00	0.00	0.00
Total Renew	g/kWh	0.00	0.00	0.00	0.00	0.00	0.00
Total Unit Variable CO2e Emissions per GWh	g/kWh	811.63	716.32	674.15	634.78	621.30	616.42
Total Variable CO2e Emissions							
Total Hydro	Gg	0	17	21	23	27	32
Total Thermal	Gg	537,688	747,210	1,005,013	1,289,493	1,681,448	2,257,476
Total Nuclear	Gg	0	0	0	0	0	0
Total Renew	Gg	0	0	0	0	0	0
Total Total Variable CO2e Emissions	Gg	537,688	747,227	1,005,034	1,289,516	1,681,475	2,257,508
Investment Cash Flow in New							
Total Hydro	Rupees (E+09)	228.78	247.64	227.70	213.57	212.00	212.00
Total Thermal	Rupees (E+09)	334.10	367.37	692.17	1,082.98	1,665.26	2,221.47
Total Nuclear	Rupees (E+09)	44.14	16.90	26.00	26.00	26.00	26.00
Total Renew	Rupees (E+09)	181.93	206.76	218.90	161.84	146.28	182.30
Total Investment Cash Flow in New	Rupees (E+09)	788.95	838.68	1,164.76	1,484.39	2,049.54	2,641.77
Investment Cash Flow in Renovation							
Total Hydro	Rupees (E+09)	3.32	13.04	6.54	11.31	5.49	6.13
Total Thermal	Rupees (E+09)	1.86	3.43	3.36	1.90	2.62	27.50
Total Nuclear	Rupees (E+09)	0.00	0.00	0.00	0.00	0.00	0.00
Total Renew	Rupees (E+09)	0.00	0.00	0.00	0.00	63.75	61.17
Total Investment Cash Flow in Renovation	Rupees (E+09)	5.17	16.47	9.89	13.21	71.86	94.80
Investment in New							
Amounts in Year of Operation							
Total Hydro	Rupees (E+09)	128.39	558.12	227.70	227.70	212.00	212.00
Total Thermal	Rupees (E+09)	45.31	721.03	611.17	822.07	1,404.14	1,943.67
Total Nuclear	Rupees (E+09)	0.00	0.00	26.00	26.00	26.00	26.00
Total Renew	Rupees (E+09)	344.64	328.65	223.40	239.70	143.00	174.00
Total Investment in New	Rupees (E+09)	518.33	1,607.79	1,088.27	1,315.47	1,785.14	2,355.67
Investment in Renovation							
Amounts in Year of Operation							
Total Hydro	Rupees (E+09)	4.58	15.87	5.30	10.98	3.37	3.80
Total Thermal	Rupees (E+09)	1.47	3.61	2.87	1.76	2.39	18.80
Total Nuclear	Rupees (E+09)	0.00	0.00	0.00	0.00	0.00	0.00
Total Renew	Rupees (E+09)	0.00	0.00	0.00	0.00	86.35	82.16
Total Investment in Renovation	Rupees (E+09)	6.06	19.47	8.17	12.74	92.10	104.76

Source: World Bank calculations.

Appendix B: Principal Assumptions

A preliminary set of calculations were performed to evaluate the relative order of magnitude of the mitigation interventions mentioned in this paper. It does not pretend to be representative of any likely specific growth path, or be consistent with other studies. Further scoping work will be conducted prior to presenting modeling details and future projections.

Principal implicit assumptions in this long-term growth scenario are shown in Table 12 with further detail in Table 13.

Table 12: Principal Assumptions

Item	Concept	Assumption
1	Annual GDP growth rate	An average of 8.0% from 2007 to 2020 as requested by the Planning Commission ; and 7.4% thereafter similar to the World Energy Outlook 2007 (International Energy Agency 2007) high growth scenario.
2	Demand elasticity for electricity	An average of 1.0 for the 11th plan, 0.89 for the 12th plan, and decreasing to 0.80 by 2020 and stable thereafter. This is based on the Working Group Report.
3	Growth in captive generation	10.9% per year during the 11th plan as proposed by the "Working Group Report"; and 0% annual growth thereafter so that all the required capacity expansion is included in the model since India will have a spinning reserve of 5% from 2011–12
4	Price elasticity for electricity	No change in demand due to pricing effects because no significant price increases in real terms are envisaged
5	Transmission and distribution losses	Gradual reduction from 29.3% in 2006–07 to 15.05% in 2025–26 and constant thereafter as proposed by the Working Group Report.
6	Supply shortage	Energy supply meets average annual energy demand in 2009–10 with 5% spinning reserve from 2011–12 based on an annual energy basis as proposed by the Working Group Report.
7	Load demand curve	As in the Ministry of Power referenced documents, the historic 2004–05 all-India load demand curve is used for all years. Wind is directly assigned. Hydro is dispatched at an average of 30% energy factor and all other plants are dispatched on a merit-based low variable cost basis.
8	Hydro	Increased to 128,000 MW installed capacity (plus small hydro included in renewable) by 2033 in line with the Working Group Report and IEP proposals
9	Nuclear	Gradual increase to from 3900 in 2006–07 to 14,660 MW by 2031–32 as proposed by the Working Group Report.
10	Thermal – coal fired: supercritical	50% of new plants in 12th plan and 70% of new plants in 13th plan in line with the "Working Group Report", and 90% of new plants thereafter as proposed
11	Thermal – coal fired: ultra-supercritical	None considered in this round of calculations during this period
12	Carbon capture and storage, CFB and IGCC	Were not considered in this round of calculations in line with the Working Group Report.

Source: World Bank calculations.

Table 13: Detailed Assumptions

		2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
GDP Annual Growth Rate	%	9.7%	9.0%	8.4%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	7.9%	7.9%	7.9%	7.9%
Long Run Income Elacticity	%	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.85	0.85	0.85
Long Run Price Elacticity	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Price Change in Constant Rupees	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Growth in Captive Demand	%	5.9%	10.9%	10.9%	10.9%	10.9%	10.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
T & D Technical Losses	%	29.3%	26.9%	25.7%	24.4%	23.2%	22.0%	21.4%	20.8%	20.2%	19.6%	19.0%	18.6%	18.1%
Supply Shortage	%	-8.8%	-7.6%	-4.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Safety Factor reserve for forecast errors	%	0.0%	0.0%	0.0%	1.5%	1.3%	3.0%	3.0%	3.0%	3.0%	3.0%	3.5%	3.5%	3.5%
Percentage satisfied by lowering frequency	%	-3.0%	-3.0%	-3.0%	-1.0%	-1.0%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
Spinning tertiary reserve	%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Total Spinning Reserve	%	-11.8%	-10.6%	-7.5%	0.5%	0.3%	5.0%	5.0%	5.0%	5.0%	5.0%	5.5%	5.5%	5.5%
Additional reserve Capacity	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plants built by the model: Plated Capacity														
Hydro built per year	MW	0	0	0	0	0	0	0	4,000	4,000	4,000	4,000	4,000	4,000
Wind built per year	MW	0	0	0	0	0	0	0	1,100	1,200	1,400	1,900	1,700	1,800
Biomass built per year	MW	0	0	0	0	0	0	0	280	300	340	480	440	460
Solar built per year	MW	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear built per year	MW	0	0	0	0	0	0	0	400	400	400	400	400	400
Coal SubCritical	MW	0	0	0	0	0	0	0	2,000	5,000	5,000	5,500	3,500	3,500
Coal Supercritical	MW	0	0	0	0	0	0	0	1,600	4,800	4,800	5,600	8,000	8,800
Coal Ultracritical	MW	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal with Carbon Capture	MW	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	MW	0	0	0	0	0	0	0	0	500	500	500	500	500
Total	MW	0	0	0	0	0	0	0	9,380	16,200	16,440	18,380	18,540	19,460

		2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32
GDP Annual Growth Rate	%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
Long Run Income Elacticity	%	0.85	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Long Run Price Elacticity	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Price Change in Constant Rupees	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Growth in Captive Demand	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
T & D Technical Losses	%	17.7%	17.2%	16.8%	16.4%	15.9%	15.5%	15.1%	15.1%	15.1%	15.1%	15.1%	15.1%	15.1%
Supply Shortage	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Saftey Factor reserve for forecast errors	%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Percentage satisfied by lowering frequency	%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
Spinning tertiary reserve	%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Total Spinning Reserve	%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
Additional reserve Capacity	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plants built by the model: Plated Capacity														
Hydro built per year	MW	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Wind built per year	MW	1,900	1,900	2,200	2,300	2,300	2,400	2,400	2,600	2,600	2,700	2,800	3,200	3,200
Biomass built per year	MW	480	480	550	600	600	600	600	650	650	700	700	750	750
Solar built per year	MW	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear built per year	MW	400	400	400	400	400	400	400	400	400	400	400	400	400
Coal SubCritical	MW	3,500	3,500	4,000	1,500	1,500	2,000	2,000	2,000	2,500	2,500	2,500	3,000	3,000
Coal Supercritical	MW	8,000	8,000	9,600	13,600	15,200	16,000	16,800	19,200	20,800	22,400	24,000	26,400	26,400
Coal Ultracritical	MW	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal with Carbon Capture	MW	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	MW	500	500	500	1,000	1,000	1,000	1,000	1,000	1,000	1,500	1,500	1,500	1,500
Total	MW	18,780	18,780	21,250	23,400	25,000	26,400	27,200	29,850	31,950	34,200	35,900	39,250	39,250

Source: World Bank calculations.

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