Relative Environment Economics of Natural Gas and Other Fossil Fuels for Power Generation and Policy Options for India

Prepared for

Petroleum Federation of India

Project Report No. 2007ER04

The Energy and Resources Institute

March 2008

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T E R I. 2007
Relative Environment Economics of Natural Gas and Other Fossil Fuels for Power Generation and Policy Options for India
New Delhi: The Energy and Resources Institute.
[Project Report No. 2007ER04]

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List of Acronyms

APM	Administered pricing mechanism
BAU	Business as usual
CCTs	Clean coal technologies
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CO_2	Carbon dioxide
CRF	Capital recovery factor
ECX	European Climate Exchange
EIA	Energy Information Administration
EPS	Electrical Power Survey
FOB	Free on Board
GHGs	Greenhouse Gases
GW	Giga watt
GWP	Global warming potential
HBJ	Hazira Bijaipur Jagdishpur
ICI	Indonesian coal price index
IEP	Integrated energy policy
IPCC	Intergovernmental Panel on Climate Change
KG	Krishna Godavari
LNG	Liquefied natural gas
LSHS	Low Sulphur Heavy Stock
MMSCMD	Million Standard Cubic Meter per day
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MW	Megawatt
NATCOM	National Communication
NELP	New exploration licensing policy
O&M	Operating and maintenance
OTC	Over the Counter
PLF	Plant load factor
PLR	Prime lending rate
SEBs	State Electricity Board
SED	Stowing excise duty
UNFCCC	United Nations Framework Convention on Climate Change
WACC	Weighted average cost of capital
WPI	Wholesale price index

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Executive summary

ES.1 Relevance of study

The Indian power sector faces substantial shortages. In FY 2006-07, the all-India energy and peak shortages in the country were 9.9% and 13.5% respectively. The situation is expected to worsen, as the electricity demand is likely to almost double[1] in 2021-22 as compared to present level. To bridge the existing demand supply gap and to take care of the growing demand, India needs to invest heavily in the requisite power generation capacity. Coal, at present, dominates the total installed capacity in the country (54%), with natural gas being a distant third (10%). Such a dominance of coal is expected to continue based on the present policy. For instance, of the total capacity addition of 68, 869 MW planned during the Eleventh Five Year Plan period, 70% is presently estimated to be coal and lignite based and hydro (23%), natural gas (3%), nuclear (5%) accounting for the rest.

As per estimates, domestic coal reserves are insufficient to support the planned coal based power generation capacity and hence the need for increasing imports. In fact, the import dependence has doubled during last 5 years. However, with the recent upsurge in the international coal prices, there are questions being raised on the availability of imported coal at reasonable prices. Therefore, it is imperative for the country to explore other options for adding the huge power generation capacity.

Considering the present limitations in increasing nuclear power generation capacity and renewable power to a sizeable extent, option of natural gas based power generation needs serious consideration. Notwithstanding decline in APM gas availability, there is an expected increase in the supply of natural gas, primarily from the recent gas finds in the Krishna Godavari (KG) Basin. Attempts are also being made to increase imports of Liquefied Natural Gas (LNG) in the country.

Another crucial aspect for diversifying India's power generation basket is the need to move towards a cleaner source of energy. According to the Fourth Assessment Report (2007) of the Intergovernmental Panel on Climate Change (IPCC) it is "unequivocal" that Earth's climate is warming. The main cause of this increasing threat to global environment is increasing concentration of greenhouse gases (GHGs). Carbon dioxide (CO_2) is the most abundant anthropogenic (human-caused)

[1] 1.76 times the existing level of electricity demand in 2006-07

GHG in the atmosphere. In view of recent increase in atmospheric concentration of CO_2 at a rate of about 0.5 percent per year, and that anthropogenic emissions of CO_2 result primarily from the extraction and combustion of fossil fuels for energy, there is an urgent need to not only decrease use of carbon emitting fuels like coal but also to encourage use of cleaner fuels like natural gas. Natural Gas is considered a more environmentally benign fuel as it emits 60% lesser CO_2 than that emitted by coal. The power sector needs to appreciate that future lies in a low-carbon economy and promotion of natural gas/LNG is important not only from energy security point of view but also from environmental point of view.

The report attempts to examine the prospects of natural gas (domestic and LNG) as a fuel for power generation vis-à-vis coal (domestic and imported). Increasing the use of natural gas for power sector has been impeded by the relatively higher financial cost of natural gas vis-à-vis coal. This problem has been compounded by the poor financial health of State Electricity Boards (SEBs). However, the problem of increase in anthropogenic emissions of CO_2 now warrants consideration of new dimensions. The report not only focuses on the relative financial costs of different fuels for power generation but also attempts to internalise the carbon abatement costs to evaluate the long term economic impact of different fuel options.

ES.2 Methodology and assumptions

The report focuses on four fuel options for the Indian power sector that are expected to meet a substantial chunk of power demand- domestic coal, imported coal, domestic natural gas, and, LNG.

Figure ES.1 summarizes the methodology adopted for the study. It is noteworthy to mention here that while estimating the cost of abatement, emissions during mining/production and during combustion of fuel at the power plant have been considered.

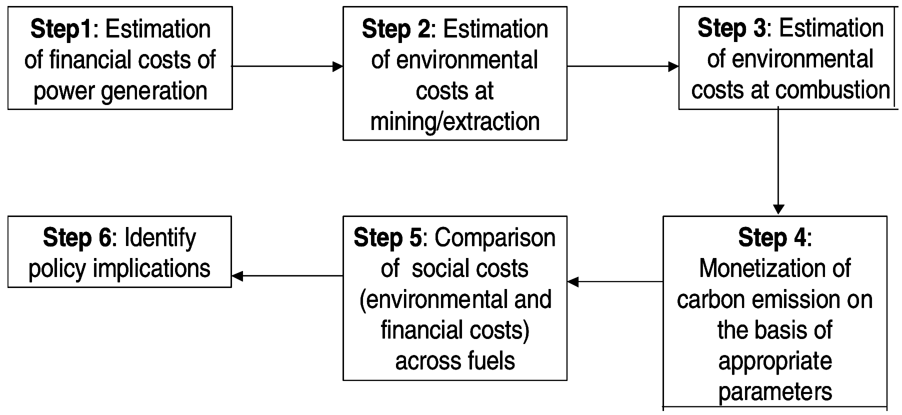

Figure ES.1 Methodology of the study

ES.2.1 Assumptions

ES.2.1.1 Locations of power plants and fuel-linkages

Given that Indian electricity sector is divided into 5 regions viz. North, South, East, West and North East, specific locations have been identified to cover all these regions. Further, depending on domestic availability and import options for different fuels, fuel-linkages at each location are identified. These locations have also been identified so as to appreciate the relative economics of fuels and other non- financial factors. These locations are – pithead, high demand centres, coastal locations and hinterlands.

ES.2.1.2 Fuel prices (Base case)

The price of domestic coal consumed in India varies according to its grade. For computing the prices for domestic coal at various locations, a simple average of prices, as given by the Ministry of Coal, for E & F coal grades[2] has been taken in the analysis. On the other hand, in case of imported coal, the Free on Board (fob) price of coal imported from Indonesia[3] i.e. USD 56.66/tonne[4] has been taken in Base Case. Price of domestic gas is taken as USD 4.2/MMBtu[5] (Rs.6710/tcm) in the base case while the price of LNG is considered to be USD 7.11 MMBtu[6].

ES.2.1.3 General power plant characteristics

[2] E & F grade of coal is mostly used in Indian power stations
[3] In India, 70% of coal is being imported from Indonesia and rest from Australia and South Africa, hence base case considers fob price of Indonesian coal.
[4] Indonesian Coal Price Index (ICI), Grade 2 coal considered. Prices as on 31 August 2007. Details available at http://www.coalindoenergy.com, accessed on 5th November 2007
[5] Price inclusive of royalty
[6] www.blommberg.com, last accessed on 18th October 2007

Table ES.1 indicates the norms used for different technological options for determining per unit cost of generation.

Table ES.1 Inputs and assumptions considered in the study

Element	Units	Coal based power plant (Domestic/ Imported)	Gas based CCGT (Domestic/LNG)
Heat rate^	kcal/kWh	2450	1850
Efficiency^	%	35	46
Capital cost *	Rs. Million/MW	40	32
PLF^	%	80	80
Auxiliary consumption^	(%)	9	3
Life of plant *	Years	30	20
Discount factor (WACC)**	%	13.30	13.30
Cost of debt ^^	%	13.00	13.00
Cost of equity^	%	14.00	14.00
Fixed operating cost (% of capital cost)^	(%)	2.50	1.50

SOURCES ^ Based on the Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations, 2004 available at http://cercind.gov.in/28032004/finalregulations_terms&condition.pdf accessed during July 2007

^^ Current PLR ranges from 12.75% to 13.25%. The average of the same has been taken. Source: http://www.rbi.org.in/home.aspx accessed on 17th July 2007.

* Based on discussion with Sector Experts

** Based on debt-equity ratio of 70:30 as per CERC norms

ES.2.1.4 General assumptions related to estimation of abatement costs

To compute per unit CO_2 abatement cost for each fuel in step 2 & 3, i.e. at mining and combustion stage, specific assumptions are made regarding emission factors, conversion rate, etc as under (table ES.2).

Table ES.2 General assumptions related to estimation of abatement costs

Particulars	Units	Domestic coal	Imported coal	Domestic gas	LNG
Methane emission factor during and post mining	m^3CH_4/t	2.00			
Conversion rate - volume of CH_4 to mass of CH_4	$Gg/10^6m^3$	0.67			
Specific coal consumption	kg/kWh	0.65			
Global warming potential	CO_2 equivalent methane	23.00			
Specific gas consumption	scm/kWh			0.185	
1 cubic meter of gas	Btu			35300.00	
Emission factor during combustion	tC/TJ	26.13	25.80	15.30	15.30
Conversion used during combustion	TJ/kcal	$419 * 10^{(-11)}$	$419 * 10^{(-11)}$	$419 * 10^{(-11)}$	$419 * 10^{(-11)}$
Carbon oxidization factor^	1.00	1.00	1.00	1.00	1.00
Conversion factor for converting C into CO_2	44/12	3.67	3.67	3.67	3.67

SOURCE Literature related to global warming and GHG emissions

^ During the combustion of a fuel a small fraction of the carbon is not oxidised. This fraction is usually small (99-100% of carbon is oxidised) and so 100% oxidization of carbon is assumed.

ES.3 Key findings of the study

ES.3.1 Financial cost results

Figure ES.2 depicts the base case financial cost estimations.

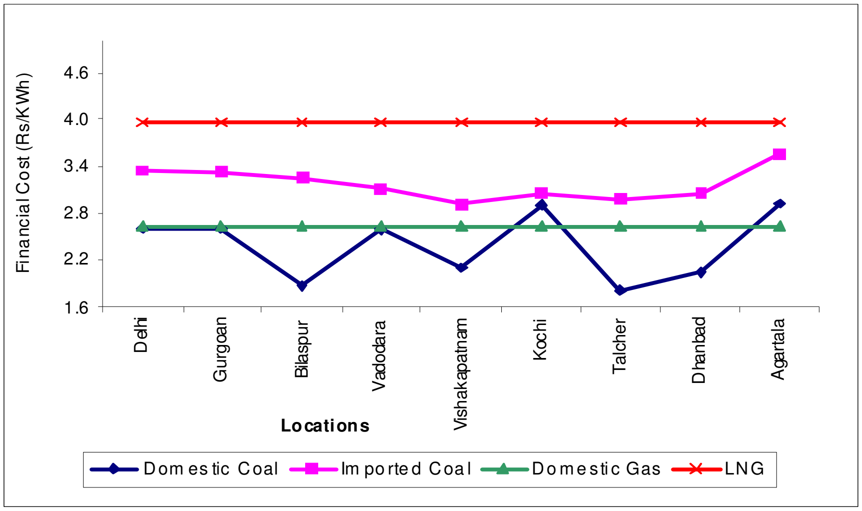

Figure ES.2 Financial cost of generation (Base Case)
SOURCE TERI's estimates

Following key conclusions emerge from the above analysis:

- **Financial cost of power generation based on domestic coal has a definite advantage over that based on natural gas.**
- A key determinant of relative financial costs of power generation is the share of freight charges in the total fuel cost and the basis adopted for freight charges. Consequently, cost of **domestic coal based power generation at pithead is much lower than that at non-pithead locations .**
- **Imported coal, though having a higher calorific value is not as competitive as domestic coal due to its higher cost.**
- **Per unit cost of power generation using domestic natural gas/LNG is constant irrespective of location of the plant.** This is because gas transmission charges, at present, are levied on postage stamp basis, implying uniform charge irrespective of the distance. **This makes financial cost of domestic natural gas based power generation competitive at locations where domestic coal needs to be sourced from a long distance.** Thus, if the transportation tariff methodology changes from postage based to distance linked then the financial economics may undergo a change.

- **As the price of LNG increases it loses its competitive edge over imported coal.** In the Base Case, price of LNG is taken as USD7.11/MMBtu, which is reflective of the international spot market prices. At this price, cost of power generation is Rs 3.98/kWh, which is not competitive to that by imported coal. However, given the continuous hardening of the coal markets, LNG can become competitive vis-à-vis imported coal .
- **Further, in case LNG is taken at pooled prices, it becomes a competitive option on financial cost basis itself.**

ES.3.1.1 Financial scenario analysis-key results

Further, certain variables were varied to understand their impact on per unit financial cost of each fuel. The variables varied included, cost of debt (or rate of interest on debt) and fuel prices of natural gas, imported coal and LNG. Figure ES.3 to ES.6 summarises the changes in per unit financial cost of power generation with changes in above-mentioned variables.

In figure ES.3 the cost of debt has been decreased from 13.30% to 8% to reflect the capability of promoters to be able to source debt at a lower rate of interest.

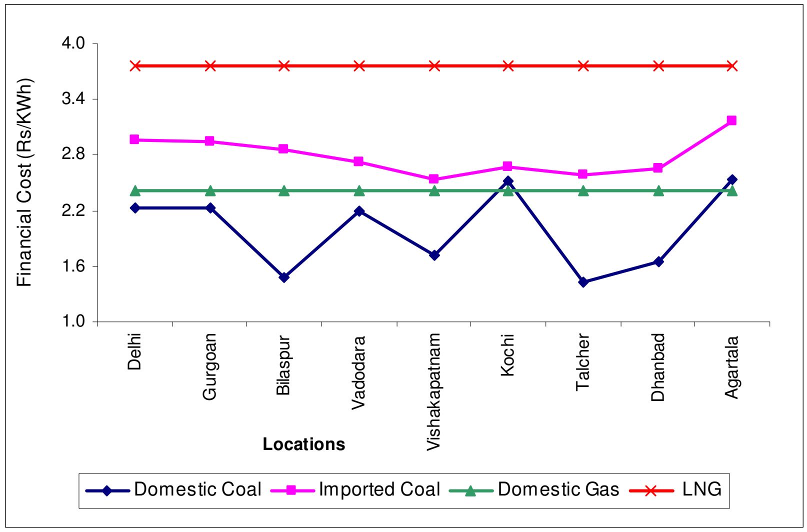

Figure ES.3 Financial cost of generation taking cost of debt as 8%
SOURCE TERI's estimates

In the base case the price of imported coal is taken at USD 56.66/ tonne. However, to understand the sensitivity of financial cost of generation with higher coal prices (as is the current trend in international coal markets), under the alternate scenario the imported coal price is considered to be USD 90/tonne (Figure ES.4).

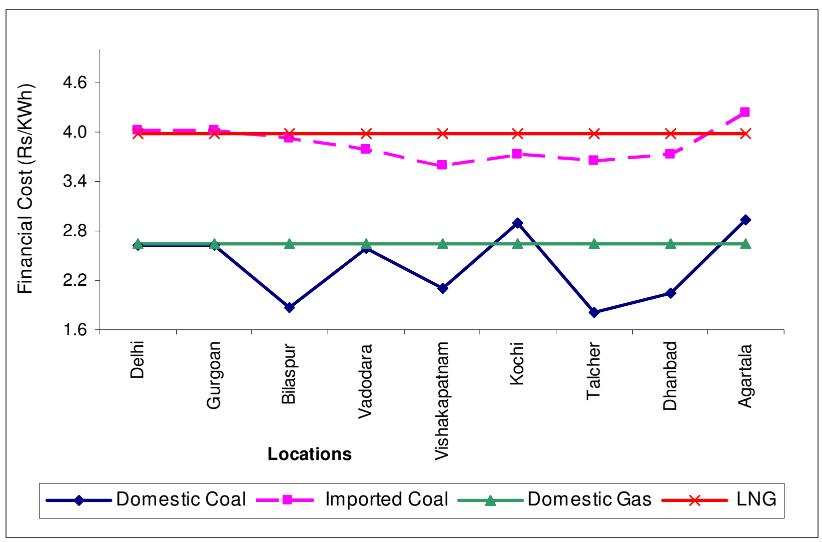

Figure ES.4 Financial cost of generation taking Imported Coal at fob price USD 90/tonne
SOURCE TERI's estimates

At present most of the gas being used in the power sector is APM (Administered Pricing Mechanism) gas. Natural gas under this mechanism is available at a subsidised price of USD 2.4/MMBtu (figure ES. 5). While under the base case the domestic natural gas price is taken as USD4.2/MMBtu, the price approved by the Government of India for the Reliance D6 block.

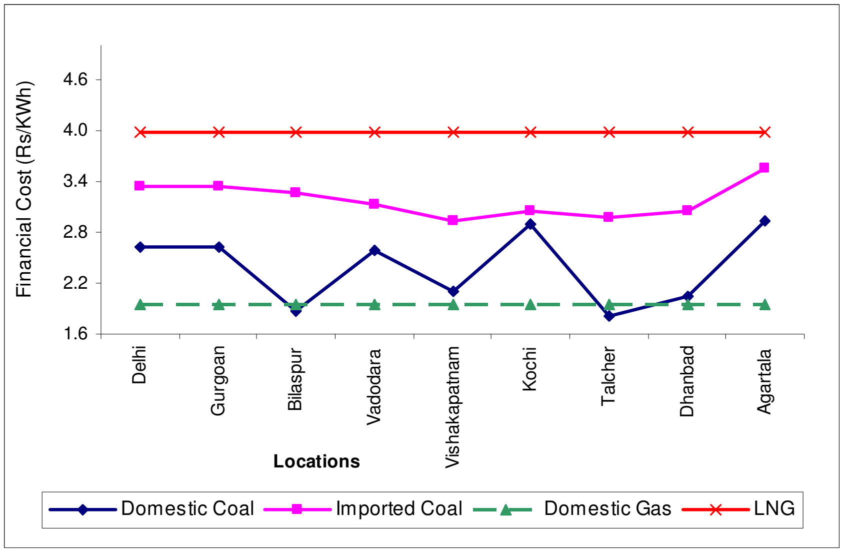

Figure ES.5 Financial cost of generation taking Domestic gas at APM price USD 2.4/MMBtu (Rs 3200/tcm)
SOURCE TERI's estimates

Under the base case for LNG, price is taken to be USD 7.11/MMBtu, however recently the GoI has instructed pooling of prices of LNG being imported by Petronet LNG Limited at Dahej. The pooled price of LNG is around USD 4.33/MMBtu. The same has been considered in the alternate scenario (Figure ES.6).

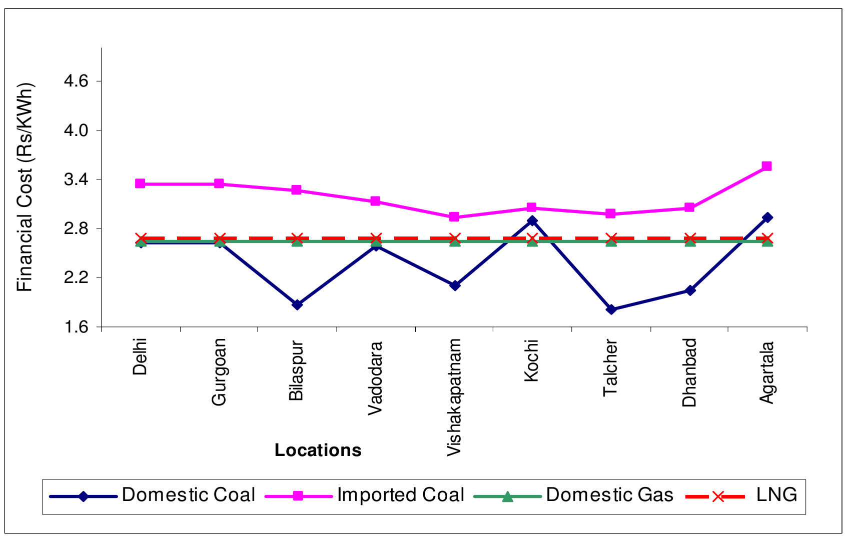

Figure ES.6 Financial cost of generation taking LNG at pooled price USD 4.33/MMBtu
SOURCE TERI's estimates

The key findings from the financial cost scenarios are:

- **If the cost of debt decreases and consequently the discount factor is lowered, domestic coal becomes clearly a preferable option vis-à-vis all other fuels excepting for imported coal at coastal locations**
- **If imported coal is priced at USD 90/tonne as against USD 56.66/tonne LNG becomes competitive vis-à-vis imported coal at demand centres.**
- **If domestic gas is priced at existing APM price i.e. Rs 3200/tcm, it becomes the preferable option at most locations excepting pitheads where it is still more economical to use domestic coal.**
- **If LNG is available at the currently pooled price, LNG becomes preferable to imported coal at all locations and is at par with market priced domestic gas.**
- Domestic coal and domestic gas will always be preferable to other fuels for power generation. However due to problem in their availability**, there arises a need for choice between imported gas (LNG) and imported coal which will depend very significantly on the way prices for these fuels move in the international market.**

ES.3.2 Economic cost analysis and results

To arrive at the economic costs, the per unit CO_2 abatement costs for each fuel is computed and added to the per unit financial cost of power generation. CO_2 abatement cost for each fuel is computed at both mining and combustion points. Table ES.3 summarises the CO_2 abatement costs for each fuel.

Table ES.3 CO_2 abatement costs per unit of electricity (in kWh)

Particulars	Unit	Domestic coal based plant	Imported coal based plant	Domestic natural gas based plant	LNG based plant
Total Emissions					
Mining/extraction	tCO_2/kWh	$20.10 * 10^{(-6)}$	N.A.	$3.00 * 10^{(-6)}$	N.A.
Combustion of fuels	tCO_2/kWh	$983 * 10^{(-6)}$	$970 * 10^{(-6)}$	$435 * 10^{(-6)}$	$435 * 10^{(-6)}$
Total Emissions	tCO_2/kWh	$1003.00 * 10^{(-6)}$	$970 * 10^{(-6)}$	$438 * 10^{(-6)}$	$435 * 10^{(-6)}$
Cost of Emissions					
Price of CER	Euro/tCO_2	23.46	23.46	23.46	23.46
Price of CER	Rs/tCO_2	1329.70	1329.70	1329.70	1329.70
Mining/Extraction	Rs/ kWh	0.027	NA	0.005	NA
Combustion of fuels	Rs/ kWh	1.305	1.29	0.578	0.578
Cost of Abatement	Rs/ kWh	1.332	1.29	0.583	0.578

SOURCE TERI's estimates

When economic costs are considered, i.e. after inclusion of abatement costs of CO_2 emissions, gas based generation improves its competitiveness vis-à-vis coal based power. This is primarily because of higher abatement cost for coal based power generation units. Inclusion of CO_2 abatement costs increases economic cost of power generation on an average by 57% and 41% in case of domestic coal and imported coal respectively, while the increase in economic cost of power generation using environmentally friendly fuels like domestic natural gas and LNG, is relatively lower percentage i.e. 22% and 15% respectively. Figure ES.7 summarises the base case for economic cost of generation for each fuel.

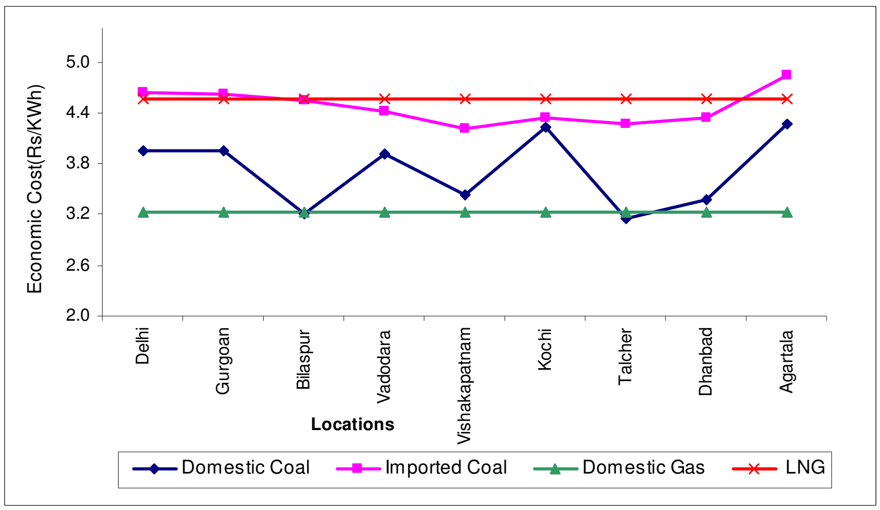

Figure ES.7 Economic cost of generation (Base Case)
SOURCE TERI's estimates

The following points emerge from the base case analysis after inclusion of abatement costs:

- **Cost of power generation increases with inclusion of CO_2 abatement costs**. The cost increases by a greater percentage in case of coal as compared to natural gas. Abatement costs form on an average 36.2% and 18.3% of economic cost in case of domestic coal and domestic natural gas, respectively.
- Pithead coal based power generation is one of the cheapest options considered. **At locations other than pithead, domestic natural gas turns out to be most favourable.**
- **Although even after incorporating the abatement costs pithead coal based power generation is competitive to natural gas based generation, its competitiveness has decreased substantially compared to financial costs**.

- **LNG becomes competitive vis-à-vis imported coal taking into consideration the abatement costs** [7]. Abatement costs form on an average 29% of economic cost in case of imported coal and 12.6% in case of LNG.
- **LNG though has a higher per unit economic cost of generation; it becomes competitive at interior locations where imported coal needs to be transported over a long distance** . This is primarily on account of high incidence of domestic freight in the total fuel cost.

ES.3.2.1 Economic costs scenario analysis-key results

Power generation is significantly impacted by price of fuels. Therefore, to account for wide variations/volatility and likely range of the prices of fuels, different price scenarios have been considered to view their impact on per unit economic cost of generation. Scenarios developed include:

- Imported coal at fob price USD 90/tonne
- Domestic natural gas at APM price Rs 3200/tcm (USD 2.4/MMBtu)
- LNG at pooled price USD 4.33/MMBtu

Figure ES.8 to ES.10 summarises the changes in per unit economic cost of generation in case of different scenarios.

[7] Economic cost is inclusive of CO_2 abatement cost.

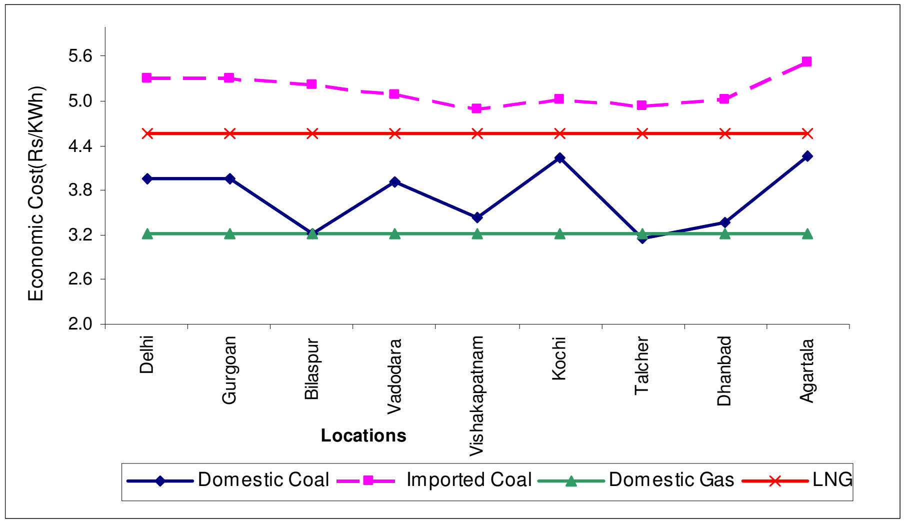

Figure ES.8 Economic cost of generation taking Imported Coal at fob price USD 90/tonne

SOURCE TERI's estimates

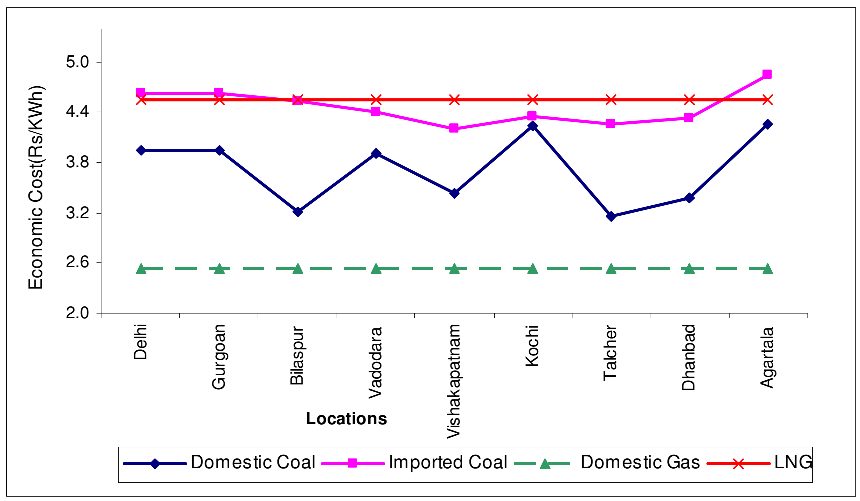

Figure ES.9 Economic cost of generation taking domestic gas at APM price USD 2.4/MMBtu (Rs 3200/tcm)

SOURCE TERI's estimates

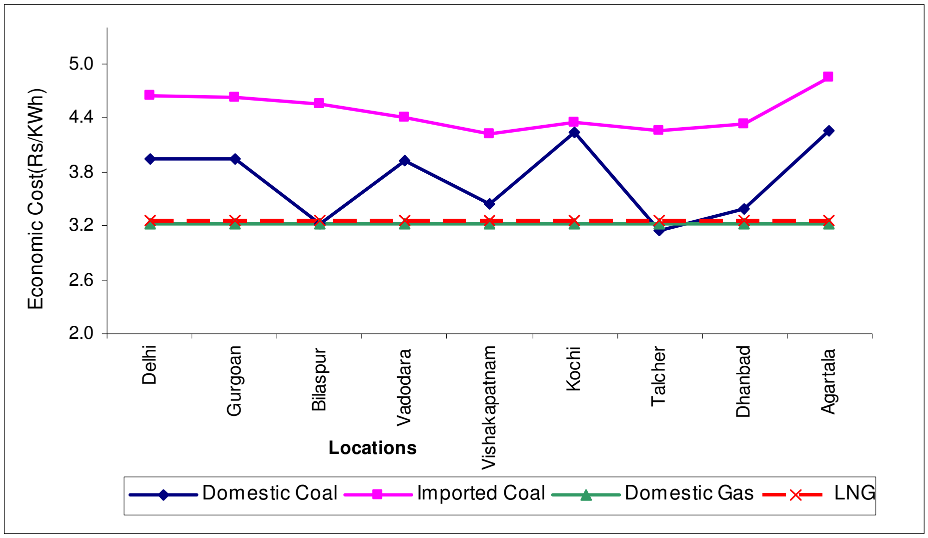

Figure ES.10 Economic cost of generation taking LNG at pooled price
SOURCE TERI's estimates

The key results after undertaking such an exercise are presented below:

- **Power generation based on domestic coal no longer remains the cheapest option after inclusion of abatement costs except at pitheads**. On the other hand, market priced natural gas becomes the most favourable option for power generation at all locations excepting pitheads.
- **At pithead, domestic coal based power generation continues to be the cheapest.**
- **LNG no longer remains the costliest fuel for power generation at USD 7.11/MMBtu.** It becomes favourable at demand centres and at interior locations. At all other locations it competes with the imported coal based generation as inclusion of abatement cost increases the economic cost of imported coal based power generation by 41%.
- **In the alternate scenario where LNG is considered at the pooled price, it becomes *favourable* to domestic coal at all locations, excepting pitheads** and competes with domestic natural gas at all locations. Under this situation, imported coal at USD56.66/tonne becomes the costliest fuel for power generation.

ES.4 Recommendations and value proposition by study

They key recommendations that emerge from the study are as follows:

- In the long-term to meet the power requirements, India needs to diversify its energy resources and focus not only coal but also on natural gas. Use of these fuels for power generation is dependent on their relative financial costs.
  - Coal based power generation at pithead turns out to be the cheapest and hence should be continued to utilize domestic coal resources.
  - At demand centres and interior locations in the country, domestic natural gas based power generation turns out to be favourable compared to that based on coal. Thus, natural gas based power generation should be encouraged at these locations.
- With the resource constraint of domestic coal and domestic natural gas; the prospect of steep increase in imported coal prices and the need to diversify power mix to ensure energy security, LNG requires serious consideration in the Indian long term planning for power generation. Hence, efforts need to be made, on an urgent basis, to ensure long- term availability of the fuel and strike long- term LNG deals.
- A policy push also needs to be given to promote LNG similar to that given to imported coal. For instance, similar to Ultra Mega Power Projects (UMPPs) planned on imported coal; UMPPs based on LNG can also be planned.
- Considering the importance of mitigating CO_2 emissions arising from power generation, it is recommended that cost of abatement of CO_2 be internalised for the purpose of evaluating economics of generating power based on different fuels at the locations under consideration.
- There are close linkages between energy and environment and this need to be reflected in the policy. Comprehensive energy and environment-linked policy would lead to not only economic benefits but also reduce pollution and CO_2 emissions. Such a holistic approach has become even more relevant today than ever before because of the increasing concerns about GHG emissions and the consequent implications for climate change.

To achieve the above necessitates collective action from all concerned stakeholders relating to power generation to make India a low carbon economy. However, the first step towards achieving this is a requisite policy framework to create an enabling environment for power and oil and gas industry to further this agenda. Box ES.1 summarises value proposition for each stakeholder namely policy makers, oil & gas sector and power sector so as to ensure that the above recommendations are implemented.

Box ES.1 Recommendations and value proposition of the study

Policymakers

- Tax distortions on cleaner fuels (natural gas) need to be corrected urgently. Cleaner fuel should attract lower taxes as compared to other fuels. One such intervention could be to give natural gas the declared goods status.
- Similar to UMPPs based on imported coal, a policy needs to be devised for promoting LNG based UMPPs
- To enhance energy security of the country strong policy push is required to ensure diversification of the fuel mix for power generation. Although dependence on domestic fuels is expected to continue with domestic coal dominating the fuel mix; for all incremental fuel requirements LNG should be promoted vis-à-vis imported coal.
- Considering the adverse impact of GHG emissions and the need for low carbon economy, abatement cost for CO_2 emissions should be considered while evaluating relative economics of fuels for power generation.
- Forms of energy and environment are closely related. Therefore, while formulating any energy policy environmental implications should be duly accounted for

Oil and gas Industry

- Recognizing natural gas a cleaner fuel and the need to limit CO_2 emissions the oil and gas industry need to make concerted efforts with the concerned authorities to have a suitable policy framework promoting natural gas for power generation.
- Requisite infrastructure, LNG terminals, transmission and distribution pipelines for natural gas need to be developed on an urgent basis by the industry.
- Tie up supplies for LNG based on demand estimates including power generation

Power Industry

- Domestic Coal being most favorable at pithead locations, its usage at these locations should be continued.
- Besides GHG emissions, coal based generation also has adverse local health impacts attached. This discourages its use in big cities having high population and large power demand. Hence, in such cities usage of cleaner fuels such as natural gas should be promoted.

CHAPTER 1 Introduction

1.1 Background

Electricity is an essential component of energy mix for ensuring economic development. However, at present Indian power sector is unable to meet the growing power demand. In FY 2006-07, the all-India energy and peak shortages in the country were 9.9% and 13.5% respectively.[8] As per the 17th Electrical Power Survey (EPS) of the Central Electricity Authority (CEA), the electricity demand is likely to increase by 39.7% in 2011-12 as compared to 2006-07, by another 43.7% in 2016-17 as compared to 2011-12 and by yet another 37.5% in 2021-22 as compared to 2016-017. The above projections are made assuming that the government is able to meet its objective of 100% village electrification and to provide power to all by 2012. In order to bridge the existing as well as potential gap between energy supply and demand, India needs to invest heavily in power and other related infrastructure. The challenge to add the requisite power generation capacity is enormous and tying up fuel supplies need to be analysed, keeping in view both the financial and economic costs.

At present, coal based power generation capacity dominates the total installed capacity in the country (Figure 1.1), followed by hydro. Natural gas is a distant third accounting for only 10% of the total.

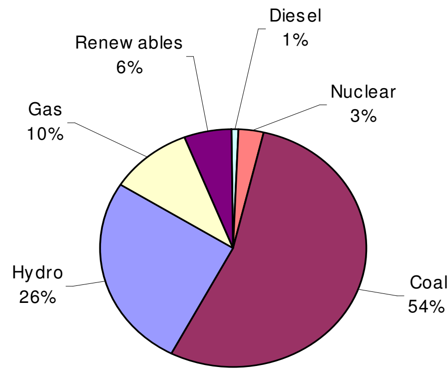

Figure 1.1 Fuel wise installed capacity (as on 31st March 2007)
SOURCE Central Electricity Authority of India, www.cea.nic.in

Such dominance of coal is expected to continue in the future. The Report of the Working Group on Power for Eleventh Plan estimates a total capacity addition of 68, 869 MW during the plan period, of which seventy percent is presently estimated to

[8] Central Electricity Authority, www.cea.nic.in, last accessed on 15th August 2007

be coal and lignite based. This high dependence on only one fuel for meeting the huge demand requirements has both security and environment implications. To meet these set targets, India would be required to increase its imports of coal. India has already become the fastest growing coal importer after China and its coal import dependence has almost doubled from FY 2000-01 to FY 2006-07. It is imperative that the country explores all possibilities to achieve a reasonable level of diversification of fuel for power generation. There is already considerable focus on power generation from fuels other than the ones dominating the present scene. For instance, the Integrated Energy Policy[9] stresses the need of introducing fuels other than coal and projects that by 2031-32 natural gas based power generation would have a share of around 16% in the total power generation.[10] On the other hand, in the next five years, the Working Group Report expects only 3% of the planned additional capacity to be based on natural gas. The reason quoted by the Report for such low share of natural gas is its availability and pricing. This is highlighted by the fact that as the availability of the subsidized natural gas (priced as per Administered Pricing Mechanism (APM)) is declining however; the power sector finds itself unable to pay the prevailing market price of natural gas.

At present, the Indian power sector is the largest consumer of natural gas. Around 38% of total natural gas supply is consumed by the power sector; the next largest consumer being fertilizer sector accounting for about 25% of the consumption.[11] Further, the supply of natural gas is expected to increase in the coming years, primarily from the recent gas finds in the Krishna Godavari (KG) Basin (off the eastern coast of India), which represents one of the largest finds in the world in recent years (it has reportedly the potential of delivering 80 MMSCMD). In addition, a number of LNG terminals, to store and market imported liquefied gas, are also being planned in various locations. A definite advantage natural gas has over coal is its relative fuel efficiency and that it is comparatively environmentally benign. In addition, setting up a gas-based power plant requires a smaller gestation period and capital investment as compared to that based on coal. The financial health of the power sector has, however, been a matter of grave concern, particularly for new capacity addition, irrespective of the fuel options. The strategies for improving the financial health of SEBs are outside the purview of this study.

[9] Integrated Energy Policy, Report of Expert Committee, Planning Commission; August 2006
[10] This is based on the forced gas usage scenario. Source: Integrated Energy Policy; Planning Commission; pp 22
[11] Basic Statistics on Indian Petroleum and Natural Gas (2005-06); MoPNG Economic Division

Nonetheless, a proper fuel mix has to take into account short and long-term financial costs as well as the environmental costs associated with the fuels.

1.1.1 Environmental impact of global warming

According to the Fourth Assessment Report (2007) of the Intergovernmental Panel on Climate Change (IPCC) it is "unequivocal" that Earth's climate is warming. The main cause of this increasing threat to global environment is increasing concentration of greenhouse gases (GHGs) in the environment. Carbon dioxide (CO_2) is the most abundant anthropogenic (human-caused) GHG in the atmosphere. In recent years, atmospheric concentration of carbon dioxide has been rising at a rate of about 0.5 percent per year[12], and because anthropogenic emissions of carbon dioxide result primarily from the extraction and combustion of fossil fuels for energy, there is an urgent need to not only decrease use of carbon emitting fuels like coal but also to encourage use of cleaner fuels like natural gas.

Natural Gas is considered a more environmentally benign fuel as it emits 60% lesser carbon dioxide than that emitted by coal.[13] Figure 1.2 shows world carbon dioxide emissions (in billion metric tons) from energy sector by various fuel types. As can be seen, natural gas emits the least carbon emissions while coal is expected to emit the maximum amount of carbon emissions by 2030, the possibility of promoting usage of cleaner fuels such as natural gas in the various consuming sectors needs to be explored in this context.

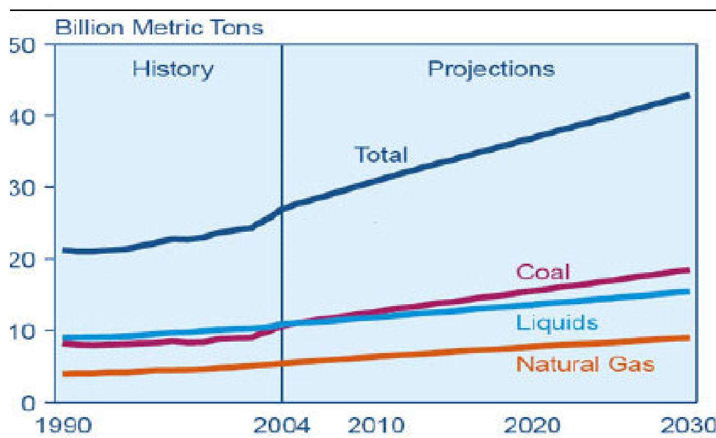

Figure 1.2 World Carbon Dioxide emissions from energy sector by fuel type
SOURCE Energy Information Administration (EIA), International Energy Annual 2004 (May-July 2006), www.eia.doe.gov/eia (For History); EIA, System for the analysis of Global Energy Markets (2007) (For Projections).

[12] International Energy Outlook 2007, **Energy related carbon dioxide emissions,** Energy Information Administration, http://www.eia.doe.gov/oiaf/ieo/emissions.html
[13] Sudha Mahalingam.2006

A similar argument is valid for the power sector, where, as mentioned earlier; a substantial part of generation is coal based.

1.2 Objective of the study

The objective of the study is to examine the prospects of natural gas as a fuel for power generation vis-à-vis coal.[14] Increasing the use of natural gas for the power sector has been impeded by the relatively higher financial cost of natural gas vis-à-vis coal. This problem has been compounded by the poor financial health of State Electricity Boards (SEBs). However, the problems of climate change brought out now warrant consideration of new dimensions. The present study, not only focuses on the relative financial costs of different fuels for power generation but also attempts to internalize the carbon abatement costs for shifting to a cleaner fuel to evaluate the long term economic impact of different fuel options. While the relatively higher financial costs for natural gas has so far been rightly pointed out as a reason for preference for coal, the consequences of climate change clearly indicate urgent need for looking into the cost implications from the point of view of sustainability and long-term costs to the earth. The analysis also spells out the policy alternatives for all relevant stakeholders.

1.3 Value proposition of the study

This Study is one of its kinds that not only attempts to internalize certain environmental impacts of power generation while comparing the fuel resources but also provides a way forward to a number of stakeholders.

1.3.1 Policymakers

i. At present, policy regarding fuel choice for power sector is based primarily on the financial costs associated with the respective fuels. This study provides a framework to the policy makers so that they can also consider certain environmental costs in making relevant policies.

1.3.2 Oil and gas industry

i. Depending upon the relative attractiveness of natural gas for power generation (financial and environmental), business models can be prepared
ii. Based on greater emphasis on natural gas future sourcing options can also be planned

[14] Liquid fuels such as LSHS, naphtha have not been considered in the study because:

1. Prices of these fuels are much higher as compared to both coal and natural gas
2. Power plants based on these fuels are commissioned primarily to meet peak demands only, whereas coal as well as natural gas is used to set up base load plants.

1.3.3 Power industry

i. Clear direction can be given to the industry in terms of both financial and economic costs
ii. The power sector can project itself as a less polluting industry by using a more environmentally benign fuel

1.4 Structure of the report

This report is organised in six chapters:

Chapter 2 details out the comparative financial cost analysis for different fuel sources of power generation in India. Chapter 3 presents various scenarios to bring forth impact of select parameters on the financial cost of power generation. Chapter 4 outlines the methodology adopted to estimate economic cost of power generation by internalising carbon abatement costs. Chapter 5 presents various scenarios that bring forward impact of change in select parameters on the economic cost of power generation. Chapter 6 provides the recommendations and value proposition for the relevant stakeholders.

CHAPTER 2 Financial cost estimation

This chapter focuses on financial costs for power generation in India associated with each fuel considered under the analysis. This chapter details out the approach adopted, inputs and assumptions considered for financial analysis.

2.1 Methodology

2.1.1 Locations chosen for computing cost of generation

Given that Indian electricity sector is divided into 5 regions viz. North, South, East, West and North East, specific locations have been identified to cover all these regions in India. Table 2.1 and map 2.1 mentions the various power plant locations and the respective sources. For all these locations, domestic availability and import options for different fuels have been taken into account.

Cost of power generation has been calculated at all these locations, for following fuels[15]:

i. Domestic coal
ii. Imported coal
iii. Domestic natural gas
iv. Liquefied Natural Gas (LNG)

For coal based power plants the nearest fuel source has been identified and the distances have been calculated from the respective fuel sources.

[15] See footnote 14 for clarifications

Map 2.1 Locations of power plants and sources assumed

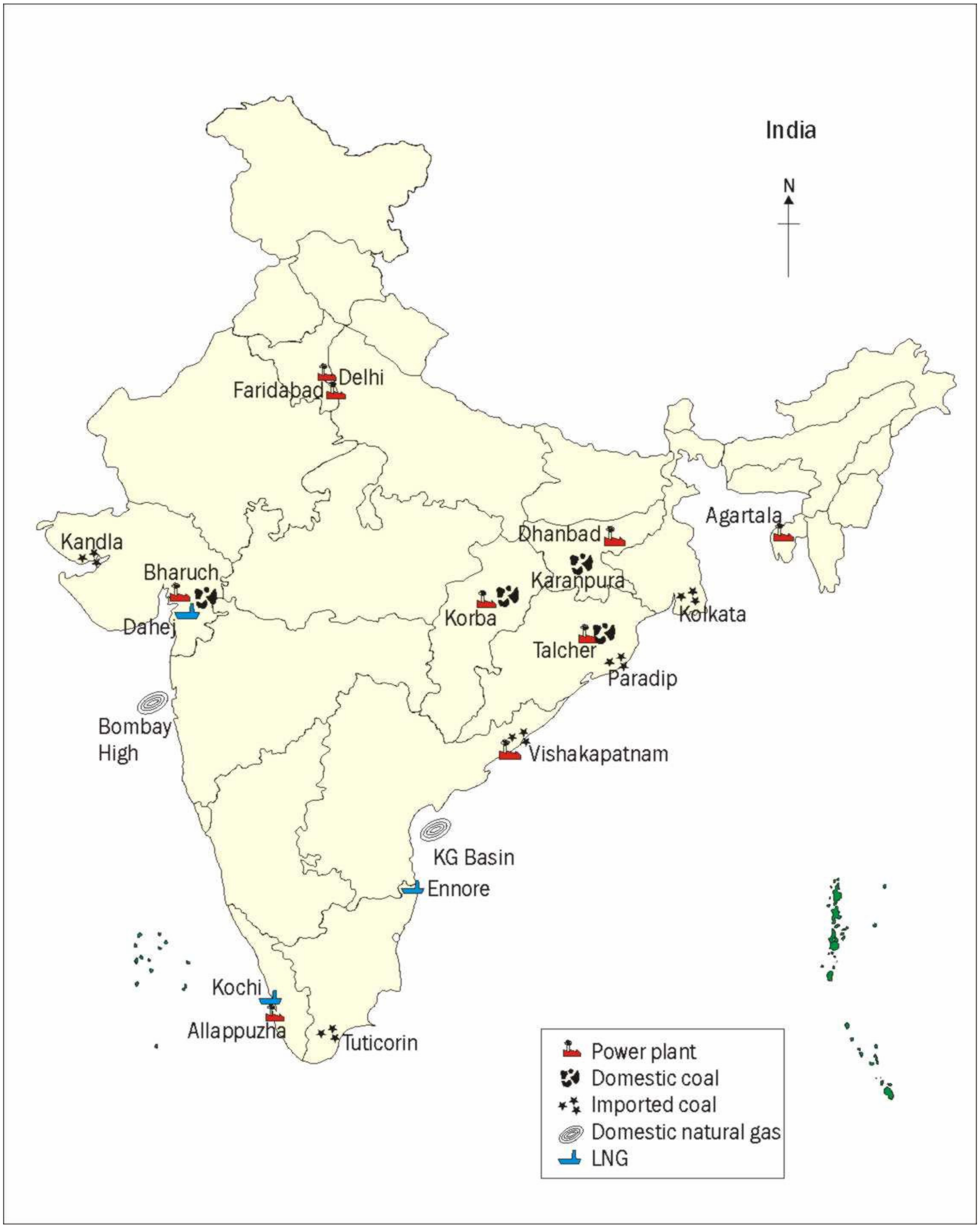

Table 2.1 Locations of power plants and sources assumed

Region	Power Plant Location	Source of Fuel: Domestic coal	Imported coal	Domestic natural gas	LNG
North	Delhi	Central Coal field, Karanpura, Jharkhand	Kandla port	Western Offshore fields	Dahej terminal
	Faridabad (Gurgoan)	Central Coal field, Karanpura, Jharkhand	Kandla port	Western Offshore fields	Dahej terminal
West	Korba (Bilaspur)	Pithead power plant	Kolkata port	K G basin	May not be viable to source LNG*
	Bharuch (Vadodra)	Western Coal field	Kandla port	Western Offshore fields	Dahej terminal
South	Vishakapatnam	Talcher Coal field, Orissa	Vishakapatnam port	K G basin	Kochi terminal
	Allappuzha (Kochi)	Talcher Coal field, Orissa	Tuticorin port	K G basin	Kochi terminal
East	Orissa (Talcher)	Pithead power plant	Paradip port	K G Basin Gas	Kochi Terminal
	Dhanbad	Central Coal field, Karanpura, Jharkhand	Kolkata port	K G basin	May not be viable to source LNG*
North East	Agartala	ECL Raniganj, Barddhaman District	Kolkata port		May not be viable to source LNG*

SOURCE: Discussion with experts

Note: Places mentioned in parentheses represent places closest to the chosen location from where distance was available.

* Though it is not viable to source LNG at these locations due to non-existence of requisite infrastructure, for analysis purposes, it is assumed that LNG is sourced through the proposed Ennore Terminal.

2.1.2 Approach

In order to understand feasibility of power generation fuels in terms of financial cost, a base case scenario based on a number of parameters has been arrived at. The financial cost of generation consists of three parts, namely:

- Fixed cost per unit
- Operating and maintenance (O&M) cost per unit
- Fuel cost per unit

The steps followed in estimating each of the above components are given below:

2.1.2.1 Fixed cost per unit

For estimating the fixed cost per unit, following elements have been considered:

a. *Capital cost & life of plant* –The capital cost per megawatt (MW) and the life of plant has been considered. These have been estimated based on discussion with sector experts.

b. *Plant Load Factor (PLF) and auxiliary consumption*– The Central Electricity Regulatory Commission (CERC) (Terms and Conditions of Tariff) Regulations, 2004 gives operating norms for all the thermal power stations operating in the country. Thus, in our analysis we have taken normative PLF of 80% for all thermal plants (both coal and gas based). Further, normative auxiliary consumption of 9% in case of coal-based generation and 3% in case of gas-based generation have been taken. These parameters have been used to estimate the gross generation and net generation (energy sent out) of the plant.

c. *Determination of levelized capital cost:* In order to estimate the levelized capital cost the present value of the capital cost was annualised based on the life of plant and a suitable discount rate.
d. *Determination of the discount rate:* The discount rate has been arrived at based on the Weighted Average Cost of Capital (WACC). For arriving at the WACC, the debt equity ratio has been assumed to be 70:30[16]. The rate of interest for the debt is assumed to be the current prime lending rate (PLR) i.e. 13%[17]. Return on equity is assumed to be 14%, as suggested in the CERC norms.
e. *Capital Recovery Factor (CRF):* Power generation project involves substantial up-front capital commitments. Thus, for computing fixed cost of a project over its whole life there is a need to provide for a discount factor which would convert this one time investment into costs distributed equally over the life of the project. For this purpose CRF is computed. It is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time. CRF is used to compute the per unit annutized capital cost of power generation.

2.1.2.2 O&M cost per unit

O&M cost has been considered as a fixed percentage of capital cost based on the norms provided under the CERC (Terms and Conditions of Tariff) Regulations, 2004. These have further been escalated at the rate of 5.29% per annum and subsequently levelized over the life of the plant. The escalation factor has been determined based on the average of the Wholesale Price Index (WPI) for last three years.[18]

[16] CERC Norms
[17] Current PLR ranges from 12.75% to 13.25%. The average of the same has been taken. Source: http://www.rbi.org.in/home.aspx accessed on 17th July 2007.
[18] Average has been taken of WPI for the years 2004-05, 2005-06 and 2006-07 Source: https://reservebank.org.in/cdbmsi/servlet/login/ accessed on 17th July 2007

2.1.2.3 Fuel prices

Landed prices for various fuels have been arrived at after taking into consideration transportation charges, taxes and other intermediate costs incurred. Tables 2.2 to 2.5 summarize the price build-ups used for various fuels. All these figures have been arrived at based on the information as available in December 2007.

Table 2.2 Price build-up of Domestic Coal

Cost component	Units
Pit head price	Rs/ tonne
Royalty	Rs/ tonne
Stowing Excise Duty (SED)	Rs/ tonne
Surface transportation charge[19]	Rs/ tonne
Sizing Charges	Rs/ tonne
Sub total (A)	Rs/ tonne
Sales Tax @ 3%	%
Sales Tax (B)	Rs/ tonne
Price inclusive of sales tax (A+B)	Rs/ tonne
Freight charges	Rs/ mt/ km
Delivered price	Rs/ tonne

SOURCE TERI's estimates

Table 2.3 Price build-up of Imported Coal

Cost component	Units
FOB price (A)	USD/ tonne
Ocean Freight and Insurance (B)	USD/ tonne
CIF price (A+B)	USD/ tonne
Exchange rate	Rs/ USD
CIF price (C)	Rs/ tonne
Landing Charges (including wharfage)	Rs/ tonne
Import Duty @ 5%	%
Import Duty (D)	Rs/ tonne
Sales Tax @ 3%	%
Sales Tax (E)	Rs/ tonne
Landed Cost (C+D+E)	Rs/ tonne
Transportation charges	Rs/ mt/ km
Delivered price	Rs/ tonne

SOURCE TERI's estimates

Table 2.4 Price build-up of domestic natural gas

Cost Component	Units
Consumer price at well head/ land fall point (A)	Rs/ tcm
Royalty	%
Royalty (B)	Rs/ tcm
Price inclusive of Royalty (A+B)	Rs/ tcm

[19] Charges levied for transporting coal from the mine to the nearest means of transport (usually railways)

Cost Component	Units
Transmission	Rs/ tcm
Sub total (C)	Rs/ tcm
Sales Tax	%
Sales Tax (D)	Rs/ tcm
Delivered Price (C+D)	Rs/ tcm
Exchange Rate	Rs/ USD
Delivered price of Natural Gas	USD/ MMBtu

SOURCE TERI's estimates
Note: tcm = thousand cubic meter
MMBtu = million British thermal units

Table 2.5 Price build-up of LNG

Cost Component	Units
LNG fob price	USD/ MMBtu
Shipping charges + sea insurance	USD/ MMBtu
CIF price (A)	USD/ MMBtu
Landing Charges (including wharfage)	Rs/ MMBtu
Customs Duty @ 5%	%
Customs Duty (B)	USD/ MMBtu
Regasification charge (C)	USD/ MMBtu
Transmission charge (D)	Rs/ tcm
Sales Tax	%
Sales Tax (E)	Rs/ tcm
Delivered Price (A+B+C+D+E)	Rs/ tcm

SOURCE TERI's estimates

All these price build-ups have been prepared by TERI based on discussions with sector experts.

2.1.2.4 Transportation charges

An important component that impacts the cost of power generation is the freight charge incurred in transporting the fuels within the country. In case of coal, railway freight charges have been taken, which is distance specific in nature.[20] In case of natural gas the freight is assumed to be the freight levied on the Hazira Bijaipur Jagdishpur (HBJ) pipeline, which is on postage stamp basis. The transportation charge for gas along the HBJ pipeline is USD 0.757/ MMBtu (Rs 1150/tcm), linked to the calorific value of 8500 kcal/scm.[21]

2.1.2.5 Fuel cost per unit

This has been estimated by taking into consideration the cost of primary and secondary fuels required for power generation. Landed prices of the primary fuels have been calculated to arrive at the fuel cost per unit cost. Data for the secondary fuel has been taken from available published sources.

[20] Source: Indian Railways
[21] http://www.gailonline.com/gailnewsite/businesses/gastransmissioncosintroduction.html accessed on 13th August 2007

2.1.2.6 Total financial cost per unit

The total cost of generation is therefore arrived at by summing up per unit capital, O&M and fuel costs.

2.1.3 Inputs and assumptions

This section spells out the inputs and assumption used for estimating the financial cost of power generation through various fuel options. It highlights the norms used and the fuel prices considered.

2.1.3.1 Norms

Table 2.6 indicates the norms used for different technological options.

Table 2.6 Inputs and assumptions considered in the study

Element	Unit	Coal based power plant (Domestic)	Coal based power plant (Imported)	Domestic Natural Gas CCGT	LNG CCGT Plant
Heat rate^	kcal/kWh	2450	2450	1850	1850
Efficiency^	%	35	35	46	46
Capital cost *	Rs. Million/MW	40	40	32	32
PLF^	%	80	80	80	80
Auxiliary consumption^	(%)	9	9	3	3
Life of plant *	Years	30	30	20	20
Fixed operating cost (% of capital cost)^	(%)	2.50	2.50	1.50	1.50
Discount Rate (WACC)~	(%)	13.30	13.30	13.30	13.30

SOURCES: ^ Based on the Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations, 2004 available at http://cercind.gov.in/28032004/finalregulations_terms&condition.pdf accessed during July 2007
* Based on discussion with Sector Experts
~ Based on Debt-equity ratio of 70:30 as per CERC norms.

2.1.3.2 Prices and calorific values

The price of domestic coal consumed in India varies according to the grade of coal, with each grade having different calorific value. The Coal Directory of India for FY 2005-06 gives the average gross calorific value for coal used in power generation in India for FY 2004-05 as 3755 kcal/kg. For computing the prices for domestic coal at various locations, a simple average of prices as given by the Ministry of Coal for E & F coal grades (which are mostly used in Indian power stations) has been taken. On the other hand, the calorific value of imported coal is much higher compared to domestic coal. In India, coal is imported from Indonesia, Australia and South Africa, with more than 70% of coal being imported from Indonesia. Thus, in the base case scenario, calorific value of imported coal is assumed to be same as calorific value of Indonesian coal i.e. 5800 kcal/kg.[22] Free on

[22] Indonesian Coal Price Index (ICI), Grade 2 coal considered. Details available at http://www.coalindoenergy.com, accessed on 5th November 2007

Board (fob) price of coal imported from Indonesia, as on 31st August 2007, was USD 56.66/tonne[23] and same has been assumed in Base Case.

In case of natural gas (domestic and LNG), calorific value is considered to be 10000 kcal/scm.[24] In the Base Case, price of domestic gas is assumed to be USD 4.2/MMBtu[25] (Rs 6710/tcm). This price is the government approved price of Reliance Industries for its gas find in KG Basin. The price of LNG in the Base Case is assumed to be USD 7.11 MMBtu[26] (fob price), which is reflective of prevailing spot market prices. Tables 2.7 to 2.9 indicate the fuel price considered for the analysis.

Table 2.7 Prices and calorific values of fuels

	Calorific value		Price	
Fuel	**Unit**	**Value**	**Unit**	**Value**
Coal				
Pithead-Korba	kcal/ kg	3755^	Rs/ tonne	720.23"
Pithead-Talcher	kcal/ kg	3755^	Rs/ tonne	633.71"
Domestic non pit head*	kcal/ kg	3755^	Rs/ tonne	See table 2.8
Imported*	kcal/ kg	5800~	Rs/ tonne	See table 2.9
Natural gas				
Domestic	kcal/tcm	10000#	USD/MMBtu	5.68**
LNG	kcal/tcm	10000#	USD/MMBtu	10.09***
Fuel Oil[27]	kcal/ kg	10400#	Rs/ litre	16542.06****

SOURCES:
* Assumptions regarding prices and calorific values for domestic non-pithead and imported coal are given in table 2.8 and 2.9
^ Average Gross Calorific value for coal used in power generation in India for FY 2004-05: source: Coal Directory of India
~ Indonesian Coal Price Index (ICI), Grade 2 coal considered. Details available at http://www.coalindoenergy.com, accessed on 5th November 2007
" Average price for E & F grades of coal, http://www.coalindia.nic.in/pricing.htm
As per GAIL, http://www.gailonline.com/customerzone/power.htm
** Based on price build-up prepared by TERI - base price at USD 4.2/ MMBtu (Rs 6710/tcm)
*** Based on price build-up prepared by TERI, taking USD7.11/MMBtu as the base price
**** http://www.infraline.com/oilprices/fuelprices.asp (Mumbai refinery)

Table 2.8 Prices and Calorific Values of Domestic Coal (Non- Pit head)

	Calorific value^		Price"	
Location	**Unit**	**Value**	**Unit**	**Value**
Delhi	kcal/ kg	3755	Rs/ tonne	1741.80
Faridabad (Gurgoan)	kcal/ kg	3755	Rs/ tonne	1741.80

[23] Indonesian Coal Price Index (ICI), Grade 2 coal considered. Prices as on 31 August 2007. Details available at http://www.coalindoenergy.com, accessed on 5th November 2007
[24] As per GAIL, http://www.gailonline.com/customerzone/power.htm
[25] Price inclusive of royalty
[26] www.blommberg.com, last accessed on 18th October 2007
[27] Fuel oil is used as a secondary fuel for coal based power generation

Bharuch (Vadodara)	kcal/ kg	3755	Rs/ tonne	1703.73
Vishakapatnam	kcal/ kg	3755	Rs/ tonne	1026.01
Allappuzha (Kochi)	kcal/ kg	3755	Rs/ tonne	2143.61
Dhanbad	kcal/ kg	3755	Rs/ tonne	949.00
Agartala	kcal/ kg	3755	Rs/ tonne	2182.33

SOURCES:

^ Average gross calorific value for coal used for power generation in India for FY 2004-05, as given in 'The Coal Directory of India for FY 2005-06'

"Average price for E& F grades of coal, http://www.coalindia.nic.in/pricing.htm

Note: Places mentioned in parentheses represent places closest to the chosen location from where distance was available.

Table 2.9 Prices and calorific values of imported coal

	Calorific value~		Price*	
Location	**Unit**	**Value**	**Unit**	**Value**
Delhi	kcal/ kg	5800	Rs/ tonne	4266.17
Faridabad (Gurgoan)	kcal/ kg	5800	Rs/ tonne	4246.27
Korba (Bilaspur)	kcal/ kg	5800	Rs/ tonne	4088.77
Bharuch (Vadodara)	kcal/ kg	5800	Rs/ tonne	3733.77
Vishakapatnam	kcal/ kg	5800	Rs/ tonne	3357.97
Allappuzha (Kochi)	kcal/ kg	5800	Rs/ tonne	3641.07
West Bengal (Durgapur)	kcal/ kg	5800	Rs/ tonne	3357.97
Dhanbad	kcal/ kg	5800	Rs/ tonne	3625.67
Agartala	kcal/ kg	5800	Rs/ tonne	4723.77

SOURCES:

~ Indonesian Coal Price Index (ICI), Grade 2 coal considered. Details available at http://www.coalindoenergy.com, accessed on 5th November 2007

* Based on price build-up prepared by TERI, prices have been calculated from the closest distance available from the respective plant locations.

Note: Places mentioned in parentheses represent places closest to the chosen location from where distance was available.

2.1.3.3. Exchange rate

For the purposes of estimating financial cost of all the fuel options including imported coal and LNG, USD exchange rate is assumed to be Rs.40.24/ USD.[28]

2.2 Key findings

Table 2.10 and figure 2.1 summarizes the Base Case for financial cost of power generation based on various fuels. Detailed component wise cost build up has been given in Annexure 1.

Table 2.10 Financial Cost of Generation (Rs/kWh)

	Fuel Options			
Plant Locations	**Domestic Coal**	**Imported Coal**	**Domestic Gas**	**LNG**
Delhi	2.61	3.35	2.63	3.98
Gurgoan	2.61	3.34	2.63	3.98
Bilaspur*	1.88	3.25	2.63	3.98

[28] As per Reserve Bank of India (RBI) Reference Rate, details available at http://www.rbi.org.in/home.aspx, accessed on 19th September 2007

	Fuel Options			
Plant Locations	**Domestic Coal**	**Imported Coal**	**Domestic Gas**	**LNG**
Vadodara	2.59	3.12	2.63	3.98
Vishakapatnam	2.10	2.92	2.63	3.98
Kochi	2.90	3.06	2.63	3.98
Talcher*	1.82	2.97	2.63	3.98
Dhanbad	2.05	3.05	2.63	3.98
Agartala	2.93	3.56	2.63	3.98

SOURCE TERI's estimates
*Pithead plants

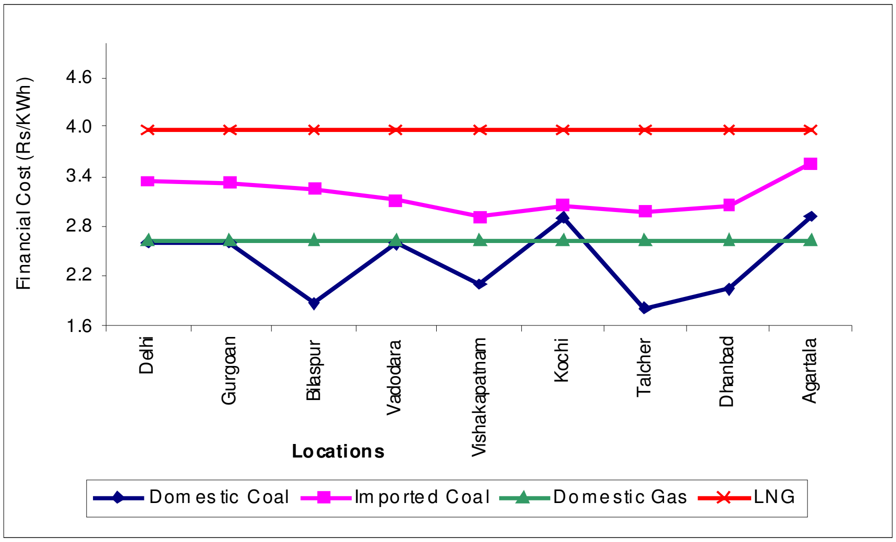

Figure 2.1 Financial cost of generation (Base Case)
SOURCE TERI's estimates

2.2.1 Summary of base case analysis

The following points emerge from the analysis:

- **Domestic Pithead coal based generation cost works out to be much lower than the non-pithead coal based generation.** In fact, cost of domestic coal based power generation at Kochi (non-pithead) is 59% higher than that at Talcher (pithead). One of the main reasons for this substantial difference in cost is the share of transportation cost in the total fuel cost. At Kochi, freight constitutes nearly 70% of the delivered price of coal at the power plant. This clearly highlights high incidence of freight in the fuel cost at locations away from the pithead.
- **Imported coal, though having a high calorific value, is not as competitive as domestic coal due to its higher cost.** However, imported coal based power generation at coastal locations such as Kochi, which is at a distance of nearly 1944 km from the coalmine (Talcher Coal fields), becomes a competitive option vis-à-vis domestic coal based power generation.
- **Per unit cost of power generation using domestic natural gas/ LNG is constant**

irrespective of location of the plant. This is because a fixed transmission charge is levied on natural gas, which is irrespective of the distance travelled. At present, gas transmission charges are levied on postage stamp basis, implying a uniform charge irrespective of the distance travelled. This is an important consideration in the determining the favourability of economics of natural gas vis-à-vis other fuels. If the transportation tariff methodology changes from postage based to distance linked then the financial economics may undergo a change.

- **Domestic natural gas, though having a higher per unit financial cost of generation, becomes competitive at locations where domestic coal needs to be sourced from a long distance.** For example, at Kochi the cost of domestic coal based power generation becomes uncompetitive, while natural gas becomes a preferable option. The main reason for this is the postage stamp based transmission charges for gas, which make it competitive in comparison to domestic coal at places farther away form source of fuel.
- **As the price of LNG increases it loses its competitive edge over imported coal.** In the Base Case (Table 2.10), price of LNG is assumed as USD 7.11/MMBtu, which is reflective of the international spot market prices. At this price, cost of power generation is Rs 3.98/kWh, which is not competitive to that by imported coal.

In conclusion, while taking only financial costs into consideration power generation based on domestic coal has a definite advantage over that based on natural gas. Coal based generation is the most economical at the pithead. However, a key determinant of relative financial costs of power generation is the domestic freight charges levied on various fuels. The method adopted for calculating freight charges and its share in the total fuel cost are important aspects of cost economics.

CHAPTER 3: Financial cost-scenarios

In the Base Case, for estimating the financial cost of power generation by different fuel types, all operating parameters have been considered based on norms as defined by CERC (Terms and Conditions of Tariff) Regulations, 2004. However, in practice some of these parameters may vary. Also there may arise variations in fuel prices due to volatility in international and domestic markets. Thus, in this chapter some of the important aspects related to cost determination shall be altered in the scenarios to bring forth their impact on the financial cost of power generation.

Scenarios to be considered include:

- Change in cost of debt, which in turn affects the discount factor and thus impacts the cost of power generation.
- Changes in fuel prices of imported coal, natural gas and LNG, which impact the cost of power generation significantly.

3.1 Changes in discount rate

In the Base Case, the discount rate has been assumed to be weighted average cost of capital (WACC) of the cost of equity and cost of debt. Cost of equity is assumed to be 14%[29] and cost of debt is assumed to be equal to the current prime-lending rate (PLR) i.e. 13%[30]. For computing WACC, a normative debt-equity ratio of 70:30 has been assumed. However, based on TERI's relevant experience of working with various power generating utilities, it has been seen that large developers or big houses are able to source debt at a lower rate of interest even when interest rates are high. For instance, Tata Steel, distribution licensee in Jamshedpur, sources loan at 8.23%.[31] Thus, in the analysis cost of debt is assumed to be 8% to show the impact of reduction in cost of debt on financial cost of power generation.

WACC/discount factor then becomes 9.8% (taking cost of debt as 8%) as against 13.30% in the Base Case[32]. This reduction in cost of capital benefits power project developers.

Figure 3.1 summarises the impact of change in cost of debt on cost of power generation.

[29] Based on norms as defined by CERC (Terms and Conditions of Tariff) Regulations, 2004

[30] Current PLR ranges from 12.75% to 13.25%. The average of the same has been taken. Source: http://www.rbi.org.in/home.aspx, last accessed on 30th October 2007

[31] Tariff Order 2005-06 for Tata Steel, details available at http://www.jserc.org/tariff.html, accessed on 15th October 2007

[32] Assuming normative Debt-Equity ratio of 70:30

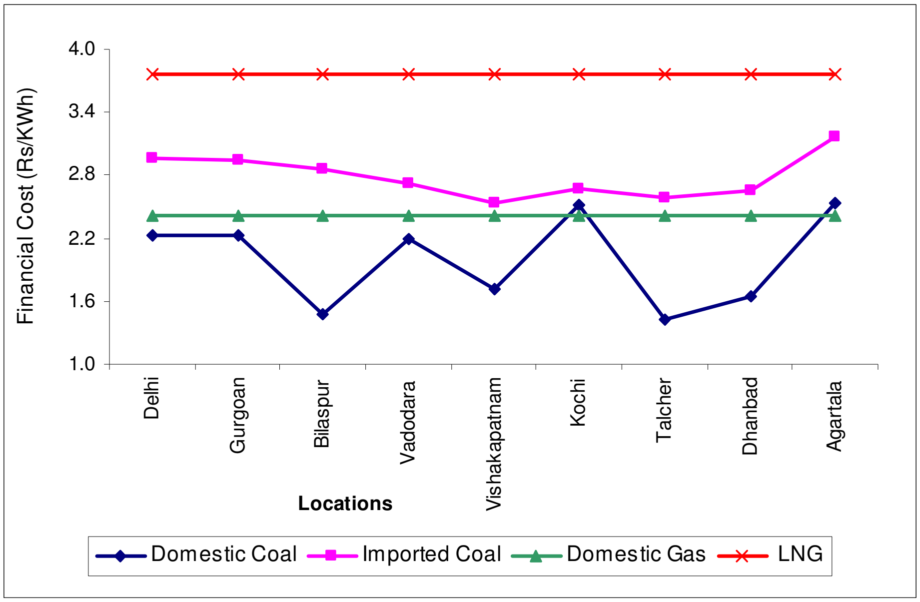

Figure 3.1 Financial cost of generation taking cost of debt as 8%
SOURCE TERI's estimates

With a 38% reduction in cost of debt (from 13% in Base Case to 8% here), the financial cost of power generation in case of coal based plant (domestic and imported) decreases by 12-17%, while cost of power generation of gas based plant (domestic natural gas and LNG) decreases by a smaller percentage of around 6-9%. This difference in impact on cost of coal-based power generation vs. gas-based power generation can be attributed to the difference in their capital costs and estimated life of plant. Coal based power generation involves higher capital costs along with longer gestation period, and hence the impact of reduction in cost of debt is larger in case of coal based power generation compared to gas based power generation.

Consequent to change in cost of debt, coal based power generation becomes even more preferable option. Domestic coal becomes a viable option at almost all locations. Even at locations where domestic natural gas was clearly a preferable option in Base Case, for example at Kochi & Agartala, domestic coal now becomes a competitive option. Similarly, imported coal based generation becomes a more viable option at coastal locations such as Vishakapatnam, Kochi, etc. as compared to the base case.

3.2 Changes in fuel prices

3.2.1 Imported coal at fob price USD 90/tonne

The Base Case assumes imported coal to be priced at USD 56.66/tonne, which is reflective of fob price of coal imported from Indonesia. However, international coal prices have been rising, for quite sometime. If India enters the coal market for substantially increased imports, it is expected that the imported coal price will be much higher than the price assumed in the Base Case. Thus to make the analysis in tandem with the recent developments and present trends, a scenario has been created taking imported coal fob price at USD 90/tonne.

Figure 3.2 summarizes the impact of increase in imported coal prices on cost of generation of imported coal based plant.

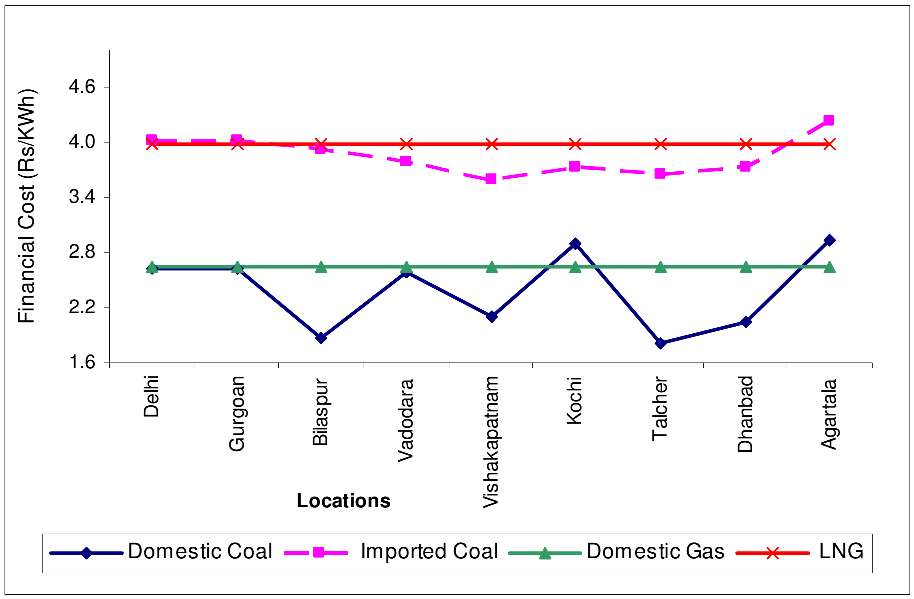

Figure 3.2 Financial cost of generation taking Imported Coal at fob price USD 90/tonne
SOURCE TERI's estimates

The cost of generation of imported coal based plant increases on an average by 21% given a 59% increase in price of imported coal (ceteris paribus). Such an increase in fuel price of imported coal, makes domestic coal and gas a preferable option vis-à-vis imported coal at all locations. LNG, which was not a viable option earlier, under this scenario becomes competitive vis-à-vis imported coal at non-coastal locations such as Delhi and Agartala.

3.2.2 Domestic gas at APM price Rs 3200/tcm

At present, market determined and administered pricing co-exist in the natural gas sector. While developing the base case (see Chapter 2) the market price[33] of the Reliance natural gas has been considered, however existence of administered price natural gas cannot be ignored. Thus for sensitivity analysis a scenario has been developed with domestic gas price equal to the APM price i.e. USD2.4/MMBtu[34] (Rs 3200/tcm).

Figure 3.3 summarizes the impact of decrease in domestic gas prices on cost of generation of domestic gas based plant.

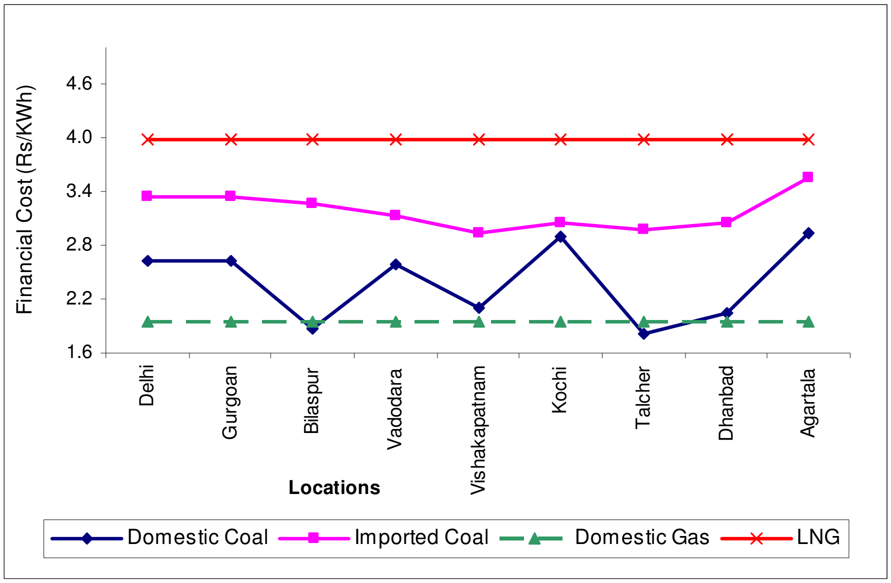

Figure 3.3 Financial cost of generation taking Domestic gas at APM price USD 2.4/MMBtu (Rs 3200/tcm)
SOURCE TERI's estimates

Comparing the Base case and the sensitivity developed it is noticed that consequent to 38% decrease in domestic natural gas price, the cost of domestic natural gas based power generation decreases by 26% (ceteris paribus). Such a decrease in fuel price makes domestic gas the most preferred option at all locations excepting pitheads where domestic coal is still more economical. At present, the availability of natural gas under the APM regime is declining. However, there have been discussions under the Production Sharing Contract regime followed in New Exploration Licensing Policy (NELP) to collect profit gas in kind instead of cash. In such a scenario, it is expected that profit gas obtained by government under this regime shall be supplied to priority sectors at subsidized prices.

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[33] The recently government approved price of USD 4.2/MMBtu (price inclusive of royalty amounting to Rs 6710/tcm) for Reliance Industries Ltd (RIL) natural gas flowing from K G Basin
[34] Price not inclusive of royalty

3.2.3 LNG at pooled price USD 4.33/MMBtu

In the Base Case, the LNG price is assumed to be USD 7.11/MMBtu, which is reflective of international spot market prices. However, in India, recently pooled pricing mechanism for LNG from Petronet LNG has been introduced. Under this pooled price mechanism, all LNG being sourced by Petronet LNG operating Dahej LNG terminal is being pooled to arrive at a price lower than the prevailing international LNG prices. In view of this a scenario has been developed taking LNG price at pooled price of USD 4.33/MMBtu. Figure 3.4 summarizes the impact of decrease in LNG price on cost of power generation of LNG based plants.

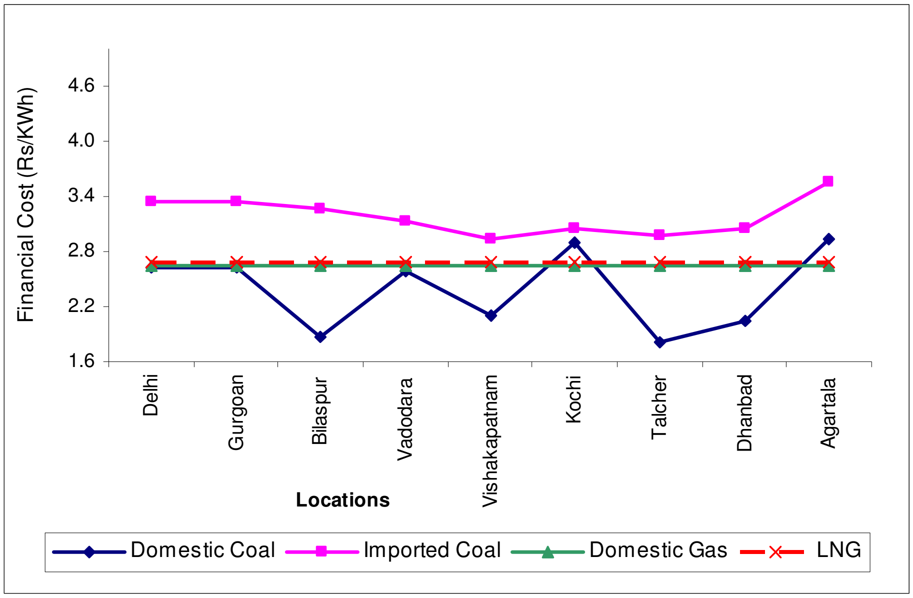

Figure 3.4 Financial cost of generation taking LNG at pooled price USD 4.33/MMBtu
SOURCE TERI's estimates

The cost of power generation of LNG based plant decreased by 33% given a 42% decrease in price of LNG (ceteris paribus). Such a decrease in LNG prices makes LNG a viable option vis-à-vis imported coal and a competitive option vis-à-vis domestic gas at all locations. In fact at coastal locations such as Kochi it becomes more preferable option as compared to domestic coal.

3.2.4 Summary of scenario analysis

- **If the cost of debt decreases and consequently the discount factor is lower than that assumed in the base case, domestic coal becomes clearly a preferable option vis-à-vis all other fuels** excepting for imported coal at a coastal location like Kochi or for domestic gas at a location like Agartala which is far away from the pithead; at Kochi and

Agartala imported coal and domestic natural gas respectively will be close competitors.

- **If imported coal is priced at USD 90/tonne as against USD56.66/tonne assumed in the base case, domestic natural gas becomes favourable to imported coal** at all locations and even LNG becomes competitive vis-à-vis imported coal at locations like Delhi or Gurgaon
- **If LNG is available at the currently pooled price (allowed for Petronet LNG at Dahej) of USD 4.33/MMBtu as against USD7.11/MMBtu assumed in the base case, LNG becomes preferable to imported coal at all locations and is at par with domestic natural gas.**
- **In short, while domestic coal and domestic natural gas will always be preferable to other fuels for power generation, the choice between imported gas (LNG) and imported coal will depend very significantly on the way these two prices move in the international market.**

CHAPTER 4: Carbon emissions in electricity generation and their monetisation

4.1 Introduction

The Fourth Assessment Report (2007) of the Intergovernmental Panel on Climate Change (IPCC) confirms that it is "unequivocal" that Earth's climate is warming and that it is pregnant with dire consequences for the human lives. [35] The Report also acknowledges that the climate change is to a large extent human induced and stresses upon controlling the increasing greenhouse gas emissions through conscious efforts.

In India, coal based electricity generation contributes about 55% of the total electricity generation and the share of electricity sector in total CO_2 emissions is the largest.[36] Moreover, it is expected that the coal based electricity generation will continue to dominate in the future. According to the TERI[37] estimates, over the next about 25 years, under the business as usual (BAU) scenario, the total generating capacity would increase to 795 gigawatt (GW) in 2031 from 125 GW in 2001, an increase of 6.3 times. Figure 4.1 shows the fuel mix in total electricity generation for the projected period. The share of coal in the total electricity generation ranges from 45% to 60% over the entire period. However, such high dependence on coal for meeting the huge power demand has major implications in terms of greenhouse gas emissions.

[35] Some of the possible adverse effects of climate change predicted in the report are: Reduction in water availability in regions supplied by melt–water due to decline in water supplies stored in glaciers and snow, Increased risks for coastal areas due to coastal erosion led by sea-level rise, Increase in socio economic costs as a result of expected high frequency of extreme weather events, Impact on health of millions of people, particularly those with low adaptive capacity, through: increased malnutrition and consequent disorders, with implications for child growth and development; increased deaths, disease and injury due to heat waves, floods, storms, fires and droughts; increased burden of diarrhoeal disease; increased frequency of cardio-respiratory diseases due to higher concentrations of ground level ozone related to climate change; and, altered spatial distribution of some infectious disease vectors. Working Group II Contribution to the Intergovernmental Panel on Climate Change (IPCC)– Fourth Assessment Report Climate Change 2007: *Climate Change Impacts, Adaptation and Vulnerability: Summary for* Policymakers http://www.ipcc-wg2.org/index.html accessed on 31st May 2007

[36] http://www.natcomindia.org/activities.htm#inv accessed on 30th October 2007

[37] PSA/2006/3, "National Energy Map for India, Technology Vision 2030", Study by TERI for Office of the Principal Adviser to the Government of India.

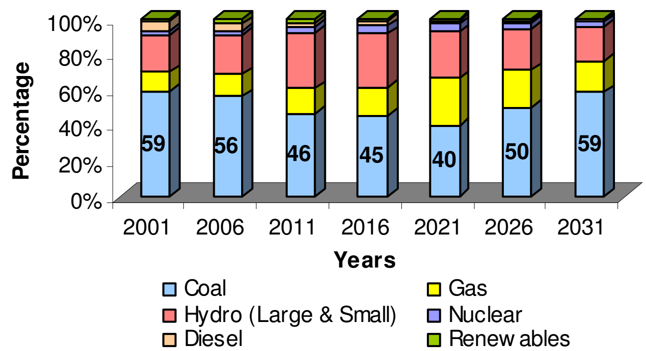

Figure 4.1 Percentage Share of fuel mix in total electricity generating capacity (business as usual scenario)
SOURCE PSA/2006/3, "National Energy Map for India, Technology Vision 2030", Study by TERI for Office of the Principal Adviser to the Government of India.

The generation of electricity using carbon-based fuels such as coal and natural gas takes into account only private costs and benefits, which leads to a market equilibrium that does not correspond to the social optimum. A standard economic remedy for internalizing external costs is a per-unit tax on the pollutant generated or providing subsidy for avoiding the generation of pollutant or abating the pollution level. Such a tax/subsidy will raise the effective price of power generated from coal or decrease the effective price of power generated from natural gas and thereby give respective electricity generators incentives to shift from coal to natural gas.

The objective of present chapter is to examine the implications of using natural gas as a fuel for power generation vis-à-vis other fuels, especially coal, while internalising some of the environmental implications. The full environmental implications of using fossil fuels should take into account a number of factors such as air, water, soil pollution apart from health and related effects.
A true picture of the environmental implications of using fossil fuel for power generation can emerge if all such factors are fully analysed. However, data in respect of all these factors, particularly ex-ante data, are not easily available. A number of separate studies are necessary to capture such a total picture.

It is because of all this and the fact that Carbon dioxide (CO_2) is the most abundant anthropogenic (human caused) GHG that the present study concentrates only on carbon emissions in power generation from these two fuels i.e. coal and gas. The opportunity gains in carbon emissions for gas based power vis-à-vis coal based power has been attempted to capture in the study. To illustrate the case, costs differential in electricity generation using different fuels while accounting for the carbon emissions for a standard size electricity generating plant of 500 MW has been computed.

Section 4.2 highlights the methodology of computation and estimates of CO_2 emissions per unit of electricity generation using different fuels. The process of monetization of carbon emissions and their estimates are provided in section 4.3.

4.2. Carbon emissions in usage of fuel for power generation

In order to evaluate the level of CO_2 emissions saved due to shift from coal to natural gas in electricity generation, it is necessary to estimate the extent of GHGs emissions emitted from both sources.[38] For estimating the GHGs emissions, these can be tracked at three levels: (i) at the extraction stage because GHGs such as methane and CO_2 are primarily released during mining of coal beds and flaring of gas respectively; (ii) at the transportation stage as transportation of fuels to the point of power generation require expending energy that in turn produces large quantities of GHGs; and (iii) at the Busbar because combustion of fuels in the thermal power plant leads to CO_2 emissions. In this study, emissions arising due to the extraction of the fossil fuels and combustion at the busbar have been estimated while emissions arising due to transportation of fuel have not been considered.

The IPCC report has been followed for the computation of GHG emissions[39]. It adopts three approaches for estimating GHGs emissions, namely Tier I, Tier II and Tier III. Tier I approach involves estimation of emissions from the fuels on the basis of quantities of fuel combusted and the default emission factors as given by the IPCC. Tier II approach is similar to that of Tier I; however, in this case country specific emission factors are used instead of default emission factors given by IPCC. In case of India, these emissions factors are given in the India's Initial National Communication (NATCOM) to United Nations Framework Convention on Climate Change (UNFCCC). NATCOM is responsible for the preparation of inventories of

[38] Carbon dioxide is considered as the major contributor to global warming hence GHGs emissions are calculated in terms of CO_2. All methane emissions are converted to CO_2 equivalent numbers. GHGs other than CO_2 and CH_4 have not been considered in this analysis.

[39] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, India's Initial National Communication, Final Report, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, The Reporting Instructions (Volume1), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, The Workbook (Volume 2), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reporting Instructions, the Reference Manual (Volume3).

basket of GHGs for India such as CO_2, Methane (CH_4), Nitrous Oxide (NO_2) and fluorinated compounds as per the provisions of Article 4 and 12.1 of the UNFCCC.[40] Tier III, in this approach either detailed emission models or measurements and data at individual plant level are used where appropriate.

For this study, Tier I and Tier II approaches have been used to estimate emissions at the busbar. Estimates using these approaches would be fairly accurate as CO_2 emissions depend only upon the total carbon in the fuel and are independent of combustion technology. In case of estimating emissions for the non- CO_2 gases such as NO_2, Tier III approach becomes important as it depends on many factors such as technologies, maintenance etc which, in general, are not well known and are extremely site specific.

4.2.1 Emissions from coal mining

The process of coal formation, commonly called coalification produces large quantities of by product gases; 90-95% of the gas produced from coal seams is methane (and other hydrocarbons) and the rest are mostly inert gases (e.g. Nitrogen, carbon dioxide etc). The amount of CH_4 generated during coal mining depends primarily on the depth of and type of coal being mined. Depth is an important factor because it affects the pressure and temperature at the coal seam, which in turn determine amount of CH_4, generated during coal formation. A deeper seam will hold larger amounts of CH_4 because of higher pressure at lower depths, ceteris paribus. As a result, the methane emission factor for underground mining of coal is assumed to be higher than for surface mining of coal.

Methane is also emitted from the post- processing activities such as coal processing, transportation and use. As part of coal processing, coal is broken into smaller pieces, crushed and thermal dried; exposing an increased surface area that allows more methane to desorb from the coal.

In India, most of the coal production is from opencast mining, which contributes around 87% of the total raw coal production while the share of underground mining is only 13% (2006-07). Moreover, the production of coal from underground mining has been declining over the years. From 69 MMT in 1997-98, it has declined to 57.75 MMT in 2006-07.[41] Thus assuming a BAU scenario, it is expected in foreseeable future coal would be produced mainly from opencast mining.

[40] http://www.natcomindia.org/activities.htm#inv accessed on 30th October 2007
[41] CCO (Coal Controller's Organisation). Provisional Coal Statistics 2006-07. Kolkata: CCO, Ministry of Coal, Government of India

Hence emissions through surface mining have been considered in the analysis.

The following formula is used for calculating emissions from the coal mining per unit of electricity produced

$$\text{Emissions (t } CH_4\text{)} = \text{Emission factor (} m^3\ CH_4/t\text{)} \times \text{Coal production (tonnes)} \times \text{Conversion factor (} Gg/10^6\ m^3\text{)}$$

Where,

$$\text{Emission factor (} m^3\ CH_4/t\text{)} = \text{Surface mining emission of } CH_4 + \text{Post mining } CH_4 \text{ emissions}$$

Also, CH_4 emissions were converted into CO2 equivalent by the following formula:

$$CO_2 \text{ equivalent emissions} = CH_4 \text{ emissions from mining} \times \text{Global Warming Potential}$$

India specific emission factors have been used in computing emissions for surface mining both during mining and post mining activities.[42] Conversion factor implies the density of CH_4 and converts volume of CH_4 to mass of CH_4. The density is taken at 20^0 C and one atmospheric pressure and has a value of 0.67 $Gg/10^6 m^3$. Global Warming Potential[43] (GWP) has been considered based on IPCC third Assessment Report. Table 4.1 highlights the CO_2 equivalent emissions/kWh from coal mining in India.

Table 4.1 CO_2 equivalent emissions/ kWh from coal mining in India

Steps	Element	Unit	Value
A	Methane Emission Factor during mining	m^3/t	1.80
B	Methane Emission Factor post mining	m^3/t	0.20
C	Total Methane Emission Factor from Mining	m^3/t	2.00
D	Coal production	t	1
E	Conversion factor (0.67 $Gg/10^6m^3$)	Gg/m^3	0.00000067
F	Emissions for 1 tonne of coal extracted	Gg CH_4	0.00000134
G	Emissions for 1 tonne of coal extracted	t CH_4	0.00134
H	Emissions for 1kg of coal extracted	t CH_4	**0.00000134**

[42] India's Initial National Communication, NATCOM Final Report, chapter 2 GHG Inventory Information pg 48
[43] Global warming potentials (GWPs) are used to compare the abilities of different greenhouse gases to trap heat in the atmosphere. Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. Global warming potential (GWP) indexed multipliers have been established to calculate a longevity equivalency with carbon dioxide taken as unity. By applying unique GWP multipliers to the annual emissions of each gas, an annual CO_2 equivalency may be summed that represents the total GWP of all climate-forcing gases considered.

Steps	Element	Unit	Value
I	Specific coal consumption	kg/kWh	0.65
J	CH_4 Emissions from one unit of electricity produced	t CH_4/kWh	0.0000008743
K	Global Warming potential	CO_2 equivalent methane	23
L	**CO_2 equivalent emissions from one unit of electricity produced**	**kg CO_2/kWh**	**0.02**

SOURCE TERI's estimates

4.2.2 Emissions from production of natural gas

Emissions from production of natural gas essentially arise due to the flaring of natural gas. Flaring is the controlled burning of that natural gas which cannot be used or sold. Flaring is often viewed as a safe and economical means to dispose of excess gas.[44] Natural gas production occurs either as associated gas along with crude oil or as non-associated gas from gas fields. While calculating emissions from production of natural gas, only non- associated gas has been considered. Emissions arising from associated gas are due to crude oil production and have no link to its use in power sector. Further, flaring of non-associated gas is mainly on account of technical and safety requirements. This is estimated at 1% of total gas production in the country. [45]When natural gas is burnt, CO_2 remains the main product of combustion

Table 4.2 highlights the CO_2 emissions/ kWh from flaring of natural gas in India.

Table 4.2 CO_2 emissions/ kWh from flaring of natural gas in India

Steps	Element	Unit	Value
A	Gross Production in India	Million Cubic Metre	32202
B	Percentage Gas Flared to Gas Production	%	1
C	Heat rate	kcal/ kWh	1850
D	Calorific Value	kcal/scm	10000
E	Specific Gas Consumption (net)	scm/kWh	0.185
F	Specific Gas Consumption (gross)	scm/kWh	0.187
G	Flaring of Natural Gas	scm/kWh	0.002
H	1 Cubic Meter of gas	Btu	35300.00
I	Flaring of Natural Gas	Btu/kWh	65.96
J	Flaring of Natural Gas	MMBtu/kWh	0.00006596
K	1MMBtu	TJ	0.0010551
L	Flaring of Natural Gas	TJ/kWh	0.00000007
M	Emission Factor	tC/TJ	15.3

[44] http://www.cantoxenvironmental.com/sectors/oilgas/naturalgas/, accessed on 18 November 2007
[45] Source: discussions with experts from ONGC

Steps	Element	Unit	Value
N	Conversion Factor	44/12	3.67
O	Carbon Oxidisation Factor	1	1.00
P	**Total CO_2 Emissions**	**tCO_2/ kWh**	0.000003905

SOURCE TERI's estimates

4.2.3 Emissions from combustion of fuels

The most predominant combustible material in all fuels is carbon and the combustion of the fuels leads to the emission of CO_2. The amount of carbon in fuels per unit of energy content varies significantly by fuel type. Coal contains the highest amount of carbon per unit of energy while natural gas contains about 45% less carbon than coal.[46]

4.2.3.1 Estimation of CO_2 from the combustion of domestic coal

The following formula is used for calculating CO_2 emissions from the domestic coal per unit of electricity produced

CO_2 Emissions in tonne per unit of electricity produced = Heat Rate of the plant (kcal/kWh) ×Conversion factor (TJ/kcal) ×Emission factor (tC/TJ) ×44/12× Carbon oxidization factor

4.2.3.2 Estimation of CO_2 from the combustion of imported coal

In order to estimate CO_2 emissions from the burning of the imported coal (sub bituminous), the IPCC default emission coefficients have been used.

The following formula is used for calculating CO_2 emissions from the imported coal per unit of electricity produced

CO_2 Emissions in tonne per unit of electricity produced = Heat Rate of the plant (kcal/kWh) ×Conversion factor (TJ/ kcal) ×Emission factor (tC/TJ) ×44/12× Carbon oxidization factor

4.2.3.3 Estimation of CO_2 from the combustion of domestic natural gas and LNG

In order to estimate CO_2 emissions from the burning of the natural gas, the IPCC default emission coefficients have been used. The use of default emissions factors would be fairly accurate due to relatively low variation in quality of the fuel across the globe, as compared to coal[47].

The following equation was used for calculating emissions from the domestic natural Gas per unit of electricity produced

[46] India's Initial National Communication, NATCOM Final Report, chapter 2 GHG Inventory Information pg 36
[47] India's Initial National Communication, NATCOM Final Report

CO_2 Emissions in tonne per unit of electricity produced = Heat Rate of the plant (kcal/kWh) ×Conversion factor (TJ/kCal) ×Emission factor (tC/TJ) ×44/12× Carbon oxidization factor

The methodology used to estimate emissions from LNG is similar to that used for domestic natural Gas.

In the computation of emissions during the combustion of fossil fuels CERC norms for heat rate of power plants has been used. Moreover, India specific emission factor have been used for domestic coal[48] and for imported coal[49], domestic natural gas and LNG[50] IPCC default emission coefficients have been considered. The use of default emissions factors for domestic natural gas and LNG are fairly accurate due to relatively low variation in quality of the fuel across the globe, as compared to coal. [51] Carbon oxidation factor[52] is also based on IPCC guidelines. Table 4.3 highlights the CO_2 emissions/ kWh from combustion of fuels at the Bus Bar.

Table 4.3 CO_2 emissions/ kWh from combustion of fossil fuels in India

Step	Element	Unit	Domestic Coal based plant	Imported Coal based plant	Domestic natural Gas based plant	LNG based plant
A	Heat Rate	kcal/kWh	2450.00	2450	1850	1850
B	Conversion	TJ/kcal	0.00000000419	0.00000000419	0.00000000419	0.00000000419
C	A*B	TJ/kWh	0.0000103	0.0000103	0.0000077	0.0000077
D	Emission Factor	tC/TJ	26.13	25.8	15.3	15.3
E	Conversion Factor	44/12	3.67	3.67	3.67	3.67
F	Carbon Oxidisation Factor	1	1.00	1.00	1.00	1.00
G	**CO_2 Emissions**	**$kgCO_2$/kWh**	**0.983**	**0.970**	**0.435**	**0.435**

SOURCE TERI's estimates

Estimate of CO_2 equivalent emissions for per unit of electricity generated reveals the following points:

- CO_2 equivalent emissions at the coal mining stage are much lower as compared to the emissions at bus-bar.

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[48] India specific CO_2 emission factor for Coal (tCO_2/TJ), India's Initial National Communication, NATCOM Final Report, chapter 2 GHG Inventory Information pg 37
[49] Source 2006 IPCC guidelines for National Greenhouse Gas Inventories
[50] Default CO_2 emission factor given by2006 IPCC guidelines for Natural Gas (tCO_2/TJ). NATCOM has also considered the same emission factor for Natural Gas.
[51] India's Initial National Communication, NATCOM Final Report
[52] During the combustion of a fuel a small fraction of the carbon is not oxidised. This fraction is usually small (99-100% of carbon is oxidised) and so 100% oxidization of carbon is assumed. Source 2006 IPCC guidelines for National Greenhouse Gas Inventories

The former is about 2% of latter's emissions. Therefore, more efforts need to be made at the busbar to curtail the emissions.

- Burning of fossil fuels at the busbar accounts for the largest share in the total emissions of GHG.
- In terms of a inter fuel comparison, natural gas is less polluting as compared to coal. Per unit emissions from domestic natural gas is 56% lower than domestic coal.
- Further, unlike emissions from coal, emissions from natural gas are source neutral.

4.3. Monetization of carbon emissions

Subsequent to calculation of the amount of CO_2 emissions from coal and natural gas per unit of electricity generation, the next step is to monetize these emissions. The monetized emission costs shall facilitate in estimation of opportunity gains due to shifting from coal to natural gas.

According to Pigouvian economics, the tax/subsidy rate should be equal to the marginal damages due to CO_2 emissions. However, it is nearly impossible to get the true or reliable estimates of the marginal damages due to CO_2 emissions as these emissions have global implications. Therefore, in the absence of true estimates of damage cost, one can use the estimates of the marginal abatement cost or the marginal gains due to saving in carbon emissions. At the equilibrium point the avoided marginal total damage from coal should be equal to the marginal opportunity gains due to saving of carbon emissions by consuming natural gas.

In order to estimate the marginal opportunity gain function for CO_2 emissions extensive data has been used from European Climate Exchange (ECX). The ECX has the largest volume of exchanges, with over three quarters of all exchange volumes (excluding exchange-for-physical, where OTC transactions are cleared through the exchange).[53] Given the market price of CO_2 emissions in the ECX [54], it has been assumed that at the equilibrium point the marginal gains due to saving in carbon emissions is equal to the market price of the emissions.

[53] Carbon 2007 – A new climate for carbon trading (Point Carbon)
[54] The European Union has established a greenhouse gas emissions trading scheme for the cost-effective reduction of such emissions in the Community. The ECX market recognises joint implementation (JI) and clean development mechanism (CDM) credits as equivalent to EU emission allowances, except for those from land use, land use change and forestry activities. Credits from JI projects are called "emission reduction units" (ERU), while credits from CDM projects are called "certified emission reductions" (CER). The carbon emissions saved using natural gas in place of coal may be treated as CER and may be traded at EET market.

Daily trade volumes and prices of the ECX CFI Futures Contracts have been used for the estimation of marginal gain function.[55] For the purpose of estimation we use weekly average figures of carbon price and quantity traded. To get the weekly average figures from daily figures two stage averaging has been done; first daily average has been computed of the prices and quantities of the future trades related to the period 2008 to 2012. Second, based on these daily averages computed, weekly average figures have been generated. The source provides price and volume traded information both for on spot and future trades up to 2012.[56] The estimated marginal opportunity gain function is as follows:

$$\text{Log (marginal opportunity gain)} = \underset{(0.28)}{0.022} + \underset{(3.728)}{0.208} \text{ log (volume traded)}$$

$\overline{R}^2 : 0.273$

The term in parentheses is 't' statistics. The estimated slope parameter is statistically significant at 1% level and the 0.273 value of adjusted R^2 shows the goodness of the fit. The value of about 0.21 of the slope coefficient indicates that if we make change in the volume of CO_2 emissions by 1%, the corresponding marginal opportunity gain will change by 0.21% (Figure 4.2).

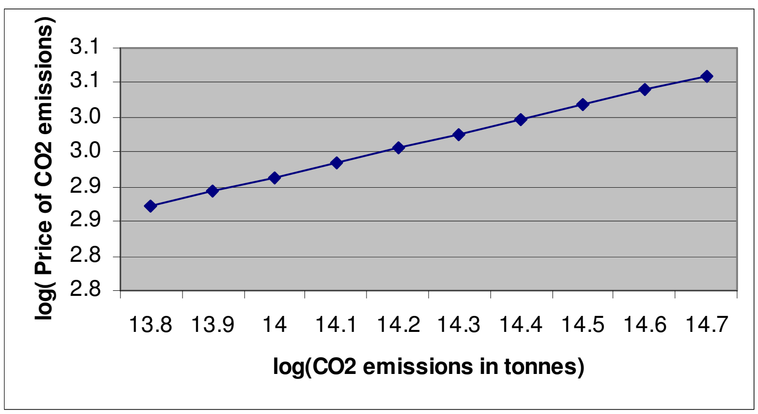

Figure 4.2 Price of CO_2 emissions as a function of volume traded at ECX

Table 4.4 provides a summary of the methodology adopted for estimating the marginal opportunity gains (in euro/tCO_2) for replacing coal based power generation with that based on natural gas. The table illustrates the marginal opportunity gains for a 500 MW of power generation plant. Using the parameter estimates of marginal opportunity gain function, the marginal

[55] http://www.europeanclimateexchange.com/default_flash.asp accessed on 30th September 2007

[56] As the study is concerned with the future generation of electricity using alternative fuels, we take the data for the years 2008 to 2012 related to CO_2 emissions trade for estimating the abatement cost function.

opportunity gains for the emissions saved is computed to be Euro 23.46 / tCO_2 (using the average weekly figure of volume traded) and Euro 25.19/ tCO_2 (using the highest value of weekly volume traded).

Table 4.4 Estimated CO_2 Emissions Saved and Marginal Abatement Cost

Parameter	Unit	Value
Capacity	MW	500
PLF	%	80%
Electricity Generation	MU	3504
	kWh	3504000000
Emission Coal	tCO_2/kWh	0.001003
Emission NG	tCO_2/kWh	0.000445
Diff	tCO_2/kWh	0.000564
Total CO_2 Emissions saved	tCO_2	1956254
Average of weekly average volumes	tCO_2	1469082
Total volumes after CO_2 Emissions saved by the power plant are added to the international market	tCO_2	3425336
Average Actual Price	**Euro / tCO_2**	**23.46**
Highest Actual Price	**Euro / tCO_2**	**25.19**

SOURCE TERI's estimates

Table 4.5 illustrates the external costs imposed by the electricity generators using different fossil fuels in terms of carbon emissions per unit of electricity generated. This table reveals that the external costs imposed using the domestic coal is about Rs1.33[57] per kWh of electricity and if the plants use LNG or domestic natural gas the cost estimate is about Rs0.59/ kWh. On the basis of these calculations the external cost differential between using domestic coal and domestic natural gas is about Rs 0.74/kWh.

Table 4.5 CO_2 Emissions Costs/Electricity (kWh) Using Different Fuels

		Total Emissions			
Element	Unit	Domestic Coal based plant	Imported Coal based plant	Domestic natural Gas based plant	LNG based plant
Emissions due to Mining/ Production of fuels	tCO_2/kWh	0.0000201	NA	0.000003	NA
Emissions due to Combustion of Fuels	tCO_2/kWh	0.000983	0.000970	0.000435	0.000435
Total Emissions	**tCO_2/kWh**	**0.001003**	**0.000970**	**0.000438**	**0.000435**

[57]

Conversion Rate for CER		
Items	Units	Amount
Price of CER	Euro/tonne of CO_2	23.46
Exchange rate	Rs/Euro	56.7
Price of CER	Rs/tonne of CO_2	1329.7

Cost of Emissions	Unit	Domestic Coal based plant	Imported Coal based plant	Domestic natural Gas based plant	LNG based plant
Due to Mining/Extraction	Rs/ kWh	0.027	NA	0.005	NA
Due to Combustion of fuels	Rs/ kWh	1.305	1.29	0.578	0.578
Cost of Abatement	**Rs/ kWh**	**1.332**	**1.29**	**0.583**	**0.578**

SOURCE TERI's estimates

On the basis of this analysis, the notional cost of power generated through coal is higher by Re 0.74/kWh compared to power generated through natural gas, if we put a value to the opportunity gain in terms of CO_2 abatement opportunities. There are clear policy implications of tax and subsidy in such a scenario.

CHAPTER 5: Economic cost analysis

This chapter puts together the financial and the abatement costs associated with the fuel used for power generation in India. It also brings out the comparison between financial and economic cost (i.e. financial plus abatement costs) of power generation using these fuels.

Table 5.1 and figure 5.1 summarize the Base Case for economic cost of power generation based on various fuels. The table is derived based on summation of table 2.10 and table 4.5.

Table 5.1 Economic Cost of Generation (Rs./kWh)

Plant Locations	Fuel Options			
	Domestic Coal	Imported Coal	Domestic Gas	LNG
Delhi	3.95	4.63	3.23	4.56
Gurgoan	3.95	4.63	3.23	4.56
Bilaspur*	3.21	4.54	3.23	4.56
Vadodara	3.92	4.41	3.23	4.56
Vishakapatnam	3.43	4.21	3.23	4.56
Kochi	4.23	4.34	3.23	4.56
Talcher*	3.15	4.26	3.23	4.56
Dhanbad	3.38	4.34	3.23	4.56
Agartala	4.26	4.85	3.23	4.56

SOURCE TERI's estimates

* Pithead plants

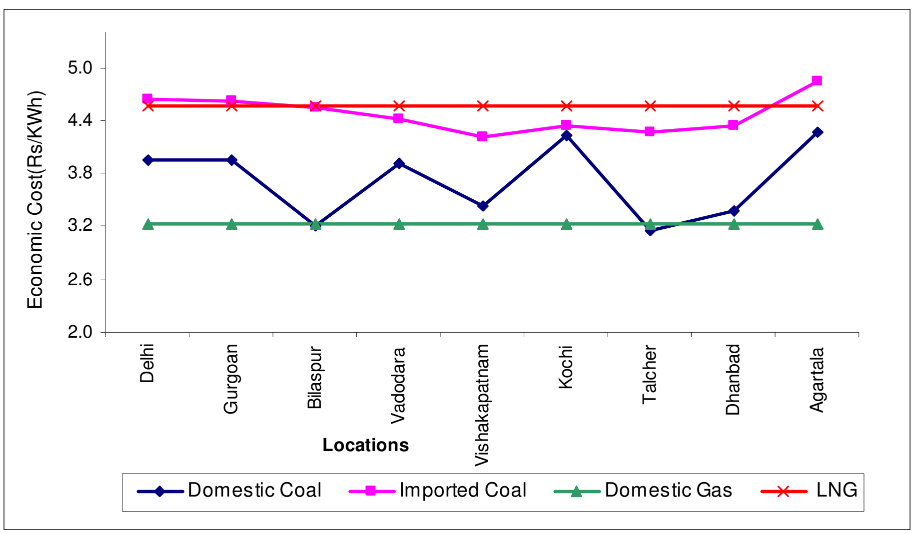

Figure 5.1 Economic cost of generation (Base Case)

SOURCE TERI's estimates

The following points emerge from the base case analysis:

- Cost of power generation increases with inclusion of CO_2 abatement costs. The cost increases by a greater percentage in case of coal than that in natural gas.

Abatement costs form on an average 36.2% and 18.3% of economic cost in case of domestic coal and domestic natural gas, respectively.

- Pithead coal based power generation is one of the cheapest fuel options considered. At all other locations, domestic natural gas turns out to be most favourable.
- Although even after incorporating the abatement costs pithead coal based power generation is competitive to domestic natural gas based generation, its competitiveness has decreased substantially compared to the base case. The cost differential (i.e. difference in the cost of power generation using domestic natural gas and domestic coal) has reduced by over 97% and 90% at Bilaspur and Talcher respectively. This is due to the fact that cost of pithead coal based power generation at Bilaspur and Talcher has increased by 71% and 73% respectively, while the cost of domestic natural gas based power generation at these locations increased by only 22%.
- LNG becomes competitive vis-à-vis imported coal taking into consideration the economic costs of power generation[58]. Environmental costs forms on an average 29% of economic cost in case of imported coal and 12.6% in case of LNG.
- LNG though has a higher per unit fuel economic cost of generation; it becomes competitive at locations where imported coal needs transported to the interiors of the country. This is primarily on account of high incidence of domestic freight rates in the total fuel cost. For example at Agartala, freight constitutes 29% of total fuel cost.

To sum up, when economic costs are considered, domestic natural gas based generation improves its competitiveness vis-à-vis coal based power. This is primarily because of higher abatement costs for power generation units associated with fuels such as coal. Inclusion of CO_2 abatement costs on an average increases economic cost of power generation from environmentally harmful fuels, domestic and imported coal, by 57% and 41% respectively, while the increase in cost of power generation using environmentally friendly fuels, domestic natural gas and LNG, increases at a relatively lower percentage i.e. 22% and 15% respectively.

[58] Economic cost is inclusive of carbon di oxide abatement cost.

5.1 Scenarios

As discussed earlier in the financial analysis, power generation is significantly impacted by price of fuels. Therefore, to account for wide variations/volatility and likely range of the prices of fuels, different price scenarios have been considered in this Section. These are namely: -

- Imported coal at fob price USD 90/tonne
- Domestic natural gas at APM price Rs 3200/tcm (USD 2.4/MMBtu)
- LNG at pooled price USD 4.33/MMBtu

5.1.1 Imported coal at fob price USD 90/tonne

With the change in the price of imported coal from USD 56.66/tonne to USD 90/tonne, it becomes the costliest fuel for power generation. In the base case, imported coal was competitive to LNG at some locations, but with the increase in fuel prices by 59%, imported coal based power generation becomes uncompetitive to LNG based power generation even at the coastal locations. Figure 5.2 summarizes the impact of increase in imported coal prices on cost of generation of imported coal based plant.

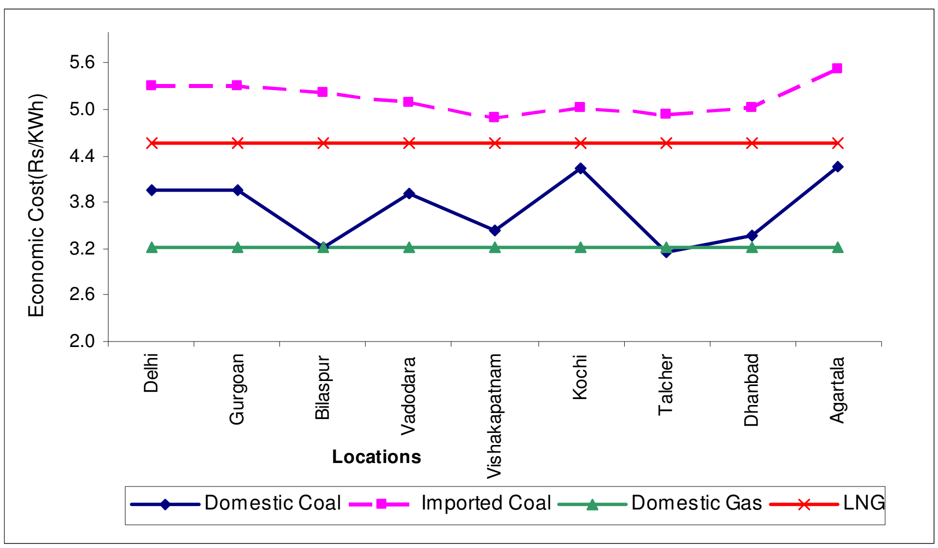

Figure 5.2 Economic cost of generation taking Imported Coal at fob price USD 90/tonne
SOURCE TERI's estimates

5.1.2 Domestic natural gas at APM price Rs.3200/tcm

Until now, pithead coal based generation was the cheapest among all fuels. However, when domestic natural gas is supplied at APM prices (USD 2.4/MMBtu[59]) and abatement costs are also taken into consideration, domestic natural gas based power generation becomes the most favoured/cheapest among all

[59] Price not inclusive of royalty

fuels. At pithead locations i.e. Bilaspur and Talcher, the cost of power generation using domestic coal turns out to be higher than that by natural gas by 26% and 24% respectively.

Figure 5.3 summarizes the impact of decrease in domestic gas prices on cost of generation of domestic gas based plant.

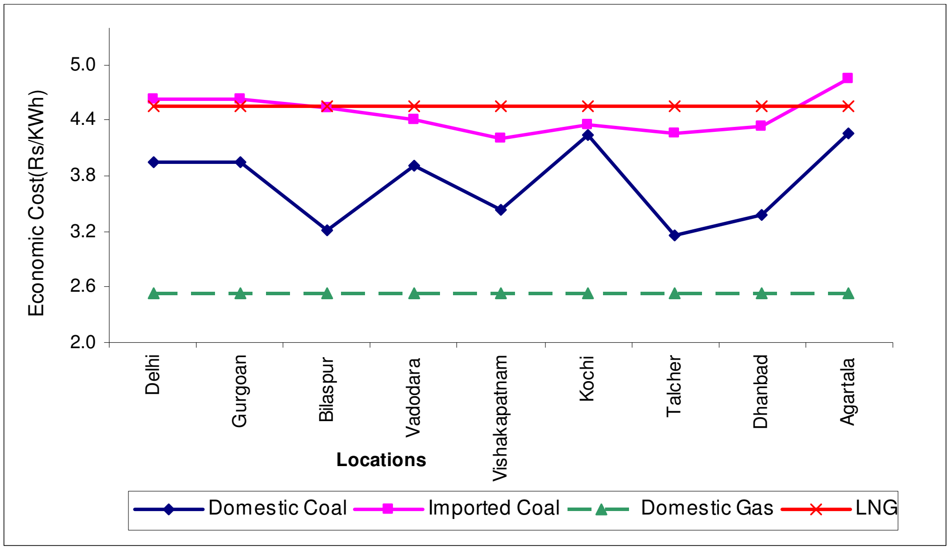

Figure 5.3 Economic cost of generation taking domestic natural gas at APM price USD 2.4/MMBtu (Rs 3200/tcm)

SOURCE TERI's estimates

5.1.3 LNG at pooled price USD 4.33/MMBtu

When LNG is considered at pooled price of USD 4.33/MMBtu, it becomes competitive to domestic coal and domestic natural gas based generation.

- LNG competes with domestic pithead coal based power generation. Difference in the cost of generation using domestic coal and LNG at pithead i.e. Bilaspur and Talcher reduces drastically to only 1.6% (0.05paise/kWh) and 3.4% (0.11 paise/kWh) respectively.
- LNG competes with domestic natural gas at all the locations, with difference in cost of generation being less than 1% (0.03p/kWh).
- Imported coal becomes the costliest source for power generation.

Figure 5.4 summarizes the impact of decrease in LNG price on cost of generation of LNG based plants.

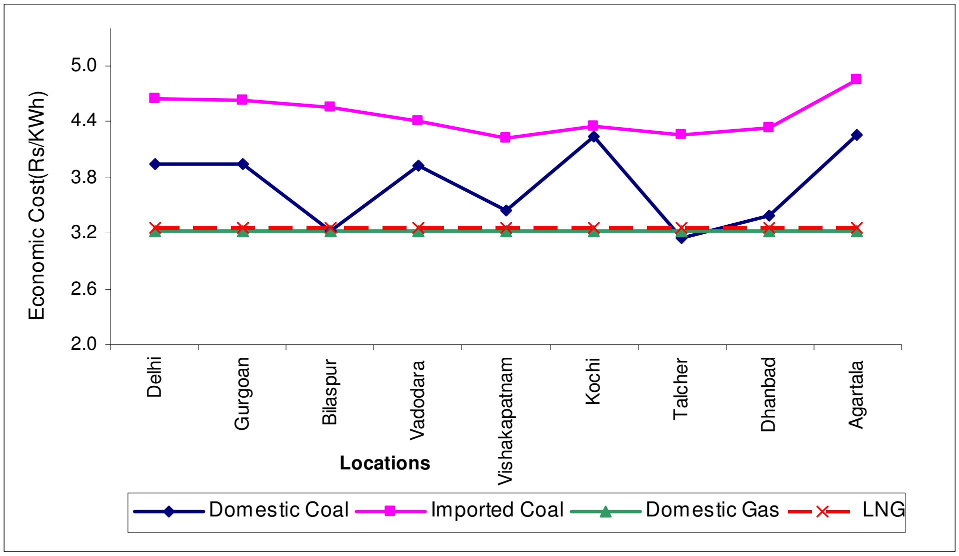

Figure 5.4 Economic cost of generation taking LNG at pooled price

SOURCE TERI's estimates

5.2 Summary

- **Power generation based on domestic coal no longer remains the cheapest option after inclusion of abatement costs, which increases the economic cost of domestic coal based power generation by 57%.** On the other hand, market determined priced natural gas becomes the most favourable option for power generation at all locations except at pithead.
- **At pithead, domestic coal based power generation continues to be the cheapest**, though its competitiveness vis-à-vis market determined priced natural gas based generation reduces substantially by over 90%.
- **LNG no longer remains the costliest fuel for power generation at USD7.11/MMBtu.** It becomes favourable at demand locations and at interiors. At all other locations it competes with the imported coal based generation as inclusion of abatement costs increases the economic cost of imported coal based power generation cost by 41%.
- **In the alternate scenario where LNG is considered at the pooled price, it becomes favourable to domestic coal at all locations,** except at pithead and competes with domestic natural gas at all locations. Imported coal at USD56.66/tonne becomes the costliest fuel for power generation in this scenario.

CHAPTER 6 Recommendations and way forward

To ensure a move towards low carbon - sustainable economy, key questions that need to be addressed by the energy policy are:

- Are domestically available fuels sufficient to meet the enormous power requirement?
- Is it prudent to consider coal as the overwhelmingly dominant for the power sector? Would India be able to maintain its energy security with such an approach?
- Is there a need to diversify the power fuel basket? Given multiple uses associated with natural gas, to what extent domestic natural gas can help diversification of the basket?
- Are there any alternatives that should be considered?
- Is importing of fuels inevitable? Is imported coal the only solution?
- Should not abatement costs related to CO_2 emissions be considered while formulating power sector strategy?

These are some pertinent questions that not only impact the present policymaking in the country but will also have far reaching implications on future policies.
The subsequent sections of this chapter suggest certain policy recommendations, based on the analysis done in the previous chapters, which will facilitate in addressing these issues.

6.1 Recommendations

6.1.1 Power generation requirements

As mentioned in the previous chapters, coal based electricity generation contributes about 55% of the total electricity generation in India and it is expected that coal based electricity generation will continue to dominate in the future.
TERI estimates [60] suggest that over the next about 25 years, under the business as usual (BAU) scenario, the total generating capacity would increase to 795 GW in 2031 from 125 GW in 2001. Out of the total required capacity, nearly 59% is expected to be coal based. This would imply an annual fuel requirement of nearly 1185 million tonnes of coal.

6.1.1.1 Domestic Coal Availability for Power Generation

In this context, a key question that needs to be examined is whether the domestic coal reserves are sufficient to meet this huge power requirement?

[60] PSA/2006/3, "National Energy Map for India, Technology Vision 2030", Study by TERI for Office of the Principal Adviser to the Government of India.

The answer is clearly no, as the country's annual domestic coal production is expected to be about 561 million tonnes by the end of 2031.[61] Also, while looking at the longevity of domestic coal reserves, the Integrated Energy Policy comments that the present extractable coal reserves in the country, at an annual growth rate of 5% in production, will be exhausted in about 45 years. Thus, domestic resource endowment will be insufficient to meet the growing coal based power needs and it is imperative to look at alternatives to bridge this demand supply gap.

6.1.1.2 Alternative means of power generation

6.1.1. 2.1 Nuclear power

One of the alternatives that is attracting a lot of attention nowadays, and is considered to have a huge potential to meet the power needs, is nuclear power. However, at present there are a number of uncertainties such as geopolitics and availability of uranium that limit its use in the present scenario and it is expected to make significant contribution in the power sector only in a time frame beyond 2020-2025.

6.1.1.2.2 Renewable

Renewable power is a clean source of energy. However, it has high upfront cost and low capacity utilization and these should be promoted in increasing access of power in remote areas as decentralized power generation options.

6.1.1.2.3 Natural Gas

Therefore, natural gas becomes an obvious alternative that needs to be considered for power generation. As compared to coal, it is more efficient and an environment friendly fuel. However, restricted availability of domestic natural gas and multiple demands on it from various sectors namely fertiliser, petrochemicals, transport and domestic use, raise the question on adequacy of its availability to meet the power generation demand.

Domestic natural gas, at present, is available at two different prices – first, subsidised Administered Pricing Mechanism (APM) gas from nominated blocks and second, is market priced gas from joint venture and NELP blocks. Availability of APM natural gas from the nominated blocks is not only already committed but is also on decline. Even now, the APM natural gas already allocated to the power sector is inadequate to operate the power plants at the required level. Hence the possibility of any further APM natural gas for power generation

[61] PSA/2006/3, "National Energy Map for India, Technology Vision 2030", Study by TERI for Office of the Principal Adviser to the Government of India.

is very remote. As regards market priced domestic natural gas, it would be contracted and used by the industrial, transport and domestic sectors to replace more expensive liquid petroleum products in the absence of a utilization policy to encourage its use for power generation.

From the above, it is clear that *in the long-term to meet the power requirements, India needs to diversify its energy resources and focus not only on coal but also on natural gas. Use of these fuels for power generation is dependent on their relative financial costs. If we are considering only domestic resources as fuel for power generation based on the analysis done in previous chapters, the following can be concluded:*

- *Coal based power generation at pithead turns out to be the cheapest and hence should be continued to utilize domestic coal resources.*
- *At demand centres and interior locations in the country, domestic natural gas based power generation turns out to be favourable compared to that based on coal. Thus, natural gas based power generation should be encouraged at these locations.*

6.1.2 Imported fuel resources

Since, domestic resources will fall significantly short of the requirement of the power sector both in the medium and long term, import of appropriate fuel for power sector, whether coal or natural gas becomes inevitable. As an alternative the current policy discusses imported natural gas and imported coal based power generation, but prefers importing coal rather than natural gas due to its favourable financial costing.[62] However, with the increasing demand supply gap and rising international coal prices, uncertainties with regards to its availability at a reasonable price shall continue and thus the thrust on imported natural gas becomes necessary.

6.1.2.1 Increasing volatility in the international coal markets

In 2006, 815 million tonne of coal was exported by various countries. Primary exporters among these being Australia (28%) and Indonesia (16%) and importers being Japan (22%) and Korea (10%).[63] Indonesia is the biggest exporter of non-coking coal in the world. At present, India imports only about 20 million tonne of non-coking coal of which around 72% is imported from Indonesia.[64] Imports by countries such as China have also increased substantially during the same time. This has

[62] PSA/2006/3, "National Energy Map for India, Technology Vision 2030", Study by TERI for Office of the Principal Adviser to the Government of India.
[63] Key World Energy Statistics-2007, IEA Publications, numbers are for year 2006
[64] Provisional Coal Statistics 2006-07, Coal Controller's Organisation, Government of India, Kolkata.

created immense pressure on the international coal markets, which has resulted in unprecedented increase in international prices of coal. This is evident from the empirical data about price trends as illustrated in figure 6.1, which traces non-coking coal prices along with the volume of coal imports by various countries. While the compound annual growth rate of international coal trade was 7 %, the corresponding price increase was 11%. This shows that prices are likely to increase at a faster pace in the coming years with such pressures on supply expected to continue. Current prices are much higher than those indicated in figure 6.1.

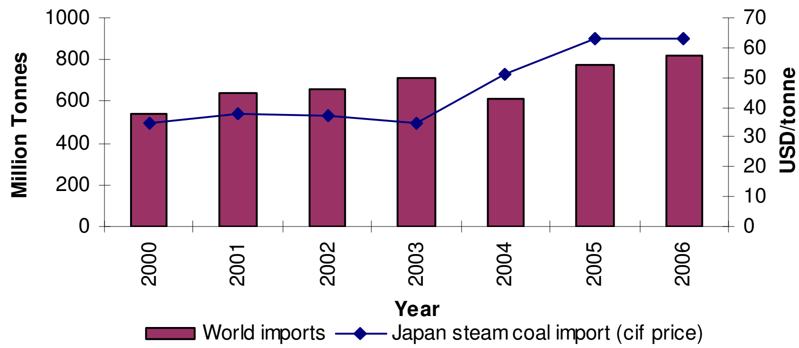

Figure 6.1 World coal imports and prices (2000-06)
SOURCES BP Statistics 2007 and various issues of Key World Energy Statistics

There will, thus, always be a question mark for both price and availability of coal. The possibility of import of natural gas (both piped if feasible and LNG) therefore needs serious consideration.

6.1.2.2 Imported coal vs. LNG

To decide which of these fuels will have larger role in meeting the power demand, one of the considerations shall be their relative financial costs.

From the analysis it is clearly brought out that though in the base case imported coal at a price of USD56.66/tonne seems favourable; in the alternative scenario its favourability reduces by 90% when its price is considered at USD90/tonne and in that situation LNG becomes viable at certain locations. It is noteworthy to mention that as the price of imported coal increases above the price of USD90/ tonne to about the price range of USD105-110/tonne and above then the financial cost of power generation based on LNG at USD7.11/MMBtu becomes favourable.

Another related aspect is that inefficiencies exist in the entire value chain for fuel supply, for instance, even after being a cleaner fuel, natural gas attracts higher sales tax as compared to coal. On an average the sales tax on natural gas is 12.5% (in most of the states of India) and in some states such as Delhi, it is as high as 20%. On the other hand, the sales tax levied on coal is only 3% as it enjoys a declared goods status. This adversely impacts the relative financial economics of natural gas as compared to coal. This is relevant if imports are not being made by power generating companies directly.

Looking at a specific location Delhi, table 6.1 presents the various price levels at which a cost of generation from both imported coal and LNG is equal. This can be an important determinant for a power producer while evaluating the relative financial cost of power generation for both the fuels.

Table 6.1 Financial costs- Breakeven point Analysis at DELHI for imported coal vs. LNG

Price of Imported Coal (USD/tonne)	Comparable Break Even Price for LNG (USD/MMBtu)	Comparable Break Even Price for LNG (USD/MMBtu) with declared goods status for LNG	Cost of generation (Rs/kWh)
56.66	5.36	5.92	3.35
88.00	7.11	7.81	3.98
90.00	7.22	7.93	4.02
110.00	8.33	9.13	4.42
130.00	9.47	10.36	4.83
150.00	10.58	11.56	5.23
175.15	12.00	13.09	5.74
228.60	15.00	16.33	6.82

SOURCE TERI's analysis

Thus even if we do not take into account the abatement costs, LNG becomes competitive to imported coal in certain scenarios.

6.1.3 Inclusion of abatement costs in power generation

As elucidated in the previous chapters, there are substantial CO_2 emissions associated with the power generation. These emissions are a clear example of a negative externality of the power sector that imposes significant costs on a global scale and also has a considerable impact on climate change. Therefore, effective mitigation and adaptation strategies that provide incentives to promote clean fuels for power generation need to be implemented. It is generally assumed that there are huge costs of mitigation however, according to IPCC mitigation would cost only 3% of the global GDP by 2030, which can be recovered within one year! Figure 6.2 depicts the impact on the global GDP with and without incorporating the cost of mitigation. The range of GDP reduction due to the mitigation costs, in 2030 under various scenarios taken by IPCC lies between –0.6% (gain) to less than 3% and reduction of average annual GDP growth rates in percentage point basis lies in the range of less than 0.06 to 0.12. The reduction in GDP due to the adoption of mitigation options can be regained in less than one year. Nevertheless, the mitigation options adopted will certainly have favourable impacts in the form of health, food security etc that cannot be quantified.[65]

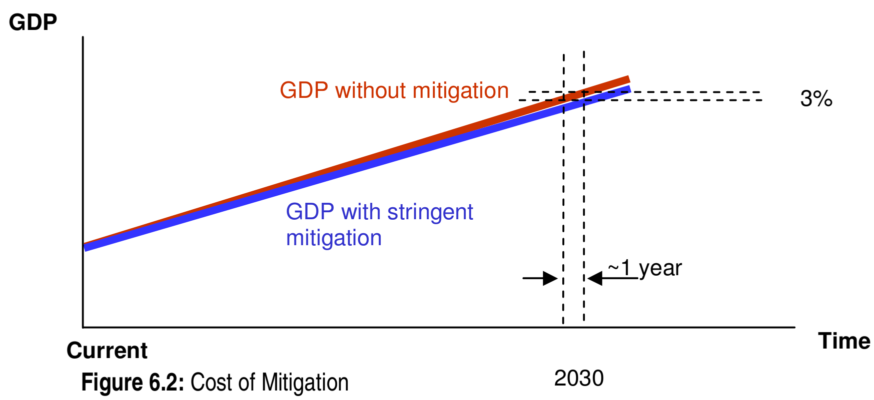

Figure 6.2: Cost of Mitigation
Source: Pachauri R.K, Chairman, IPCC and Director General, TERI "Climate change and key vulnerabilities in Asia", Parliament of India, New Delhi, 14th March 2008

Mitigation is even more relevant to the power and the energy sector as the latter accounts for 61% of the total CO_2 equivalent emissions, and within it, major emitters are energy and transformation industries (47 %) constituting mainly electric power generation.[66] Thus, to make any significant impact in the long run there is a need for possible mitigation options to be taken on an immediate basis in the energy sector in general and power sector in particular as it accounts for majority of the GHG emissions. The first step for mitigation can be adoption of cleaner fuels such as natural gas. Table 6.2 summarizes the breakeven prices between the imported coal and LNG in case the cost of abatement for CO_2 is included in the cost of generation. The table clearly highlights that with inclusion of abatement costs, LNG becomes favourable at a higher fuel cost vis-à-vis the same price of imported coal.

[65] Pachauri R.K , Chairman, IPCC and Director General, TERI "Climate change and key vulnerabilities in Asia", Parliament of India, New Delhi, 14th March 2008
[66] India's Initial National Communication, NATCOM Final Report, chapter 2 GHG Inventory Information pg 48

Table 6.2 Economic costs- Breakeven point Analysis at DELHI for imported coal vs LNG

Price of Imported Coal (USD/tonne)	Comparable Break Even Price for LNG (USD/MMBtu)	Comparable Break Even Price for LNG (USD/MMBtu) with declared goods status for LNG	Cost of generation
52.90	7.11	7.82	4.56
56.66	7.34	8.06	4.64
90.00	9.20	10.07	5.31
110.00	10.31	11.23	5.71
130.00	11.45	12.50	6.12
140.00	12.00	13.10	6.32
150.00	12.56	13.70	6.52
193.46	15.00	16.34	7.40

SOURCE TERI's analysis

One more point that must be noted here is that as the price of carbon increases above what is assumed in the study, the results derived will change in favour of domestic natural gas and LNG at most of the locations. Also, if distortions in fiscal regime such as those in the sales tax are addressed, this would further increase the favourability of natural gas.

In fact in country like USA, having large reserves of coal, traditional coal fired plants have come under pressure from states and environmentalists, while the US Congress considers several bills that would cap greenhouse gas emissions.[67] Further the three banks- Citigroup, J.P. Morgan Chase, and Morgan Stanley have announced that they will require utilities seeking finance to prove the new plants would be economically viable under an expected federal cap on greenhouse gas emissions.[68]

Also, P Chidambaram, Finance Minister, India, adhering to the principle of "common but differentiated responsibility"[69] in his budget speech of 2008-09 said with respect to climate change

Quote
"we can - and we must - do a number of things in our self-interest. We can promote clean technology products; we can review fuel emission and efficiency regulations; we can replace wood by solar as the fuel of common use; ***we can encourage the use of gas which is the most benign hydrocarbon****"*
Unquote

[67] Lee L "Banks to Weigh CO_2 Emissions in US Power Lending", Planet Ark, World Environmental News, 5th February 2008
[68] Brownstein M "Banks Consider Risks in Financing Coal Plants" 4th February 2008
[69] This means that developed countries which have polluted the most, should have a higher responsibility in mitigating the climate change compared to the developing countries.

This reflects that Indian policymakers have also recognised the importance of mitigating climate change.

In view of these recent developments wherein increasing importance given to curb CO_2,, it is recommended that cost of abatement of CO_2 be internalised for the purpose of evaluating economics of generating power based on different fuels at the locations under consideration.

Along with the suggested policy initiative there are a wide variety of policy interventions available to reduce CO_2 emissions. According to IPCC Fourth Assessment Working Group Report, "these include regulations and standards, taxes and charges, tradable permits, voluntary agreements, subsidies, financial incentives, research and development programmes and information instruments. Other policies, such as those affecting trade, foreign direct investment, consumption and social development goals, can also affect GHG emissions".[70] Such policies, if integrated with other government polices, can contribute to sustainable development significantly. Incorporating abatement costs in the financial costs of power generation can shift the entire balance towards the cleaner fuel-natural gas as is summarized in tables 6.3 and 6.4.

Table 6.3 Location wise analysis (Domestic coal and domestic natural gas)

Locations	Domestic Coal Vs. Domestic Natural Gas					
	Financial costing			Economic Cost		
	Base case*	Scenario		Base case*	Scenario	
		Dom NG at Rs.3200/tcm	Borrowing rate at 8%		NG at Rs.3200/tcm	Borrowing rate at 8%
Demand Centre	Dom Coal	Dom natural gas	Dom Coal	Dom natural gas	Dom natural gas	Dom natural gas
Coastal location	Dom Coal	Dom natural gas	Dom Coal	Dom natural gas	Dom natural gas	Dom natural gas
Pit Head	Dom Coal	Dom Coal	Dom Coal	Dom Coal	Dom natural gas	Dom Coal
Interiors	Dom NG	Dom natural gas	Dom natural gas	Dom natural gas	Dom natural gas	Dom natural gas

Source: TERI analysis

Note- Dom Coal: domestic coal and Dom natural gas is only domestically available natural gas

*Borrowing at 13% and Dom natural gas at USD4.22/MMBtu

[70] 'The IPCC Fourth Assessment Working Group Reports: Key findings' Presentation by Dr. R K Pachauri, Chairman, IPCC & Director General TERI; United Nations Headquarters, New York City, 24th September 2007

Table 6.4: Location wise analysis (Imported coal and LNG)

Locations	Imported Coal Vs. LNG							
	Financial Cost				Economic Cost			
	Base case*	Scenario			Base case*	Scenario		
		LNG at USD4.33/MMBtu	Imp Coal at USD90/tonne	Borrowing rate at 8%		LNG at USD4.33/MMBtu	Imp Coal at USD90/tonne	Borrowing rate at 8%
Demand Centre	Imp Coal	LNG	LNG	Imp Coal	LNG	LNG	LNG	LNG
Coastal location	Imp Coal	LNG	Imp Coal	Imp Coal	Imp Coal	LNG	LNG	Imp Coal**
Interiors	Imp Coal	LNG	LNG	Imp Coal	LNG	LNG	LNG	LNG

Source: TERI analysis

Note- Imp Coal: Imported coal

** these calculations are based on imported coal price of USD56.66/tonne. In case the price is changed to the realistic imported coal price of USD90/tonne, the economic cost will be in favour LNG.

* Borrowing at 13%, LNG at USD 7.11/MMBtu and Imp Coal at USD 56.66/ tonne

It is clear that with the resource constraint of domestic coal and domestic natural gas; the prospect of steep increase in imported coal prices and the need to diversify power mix to ensure energy security, LNG requires serious consideration in the Indian long term planning for power generation. Hence, efforts need to be made, on an urgent basis, to ensure long-term availability of the fuel and strike long- term LNG deals. Further, a policy push including appropriate fiscal reengineering also needs to be given to promote LNG similar to that given to imported coal. For instance, similar to Ultra Mega Power Projects (UMPPs) planned on imported coal; UMPPs based on LNG can also be planned.

6.1.4 Integrated approach for energy and environment planning

The analysis in the preceding sections brings out the three important factors as regards the fuel basket for power generation in the country:

i. In the backdrop of requirement of very large new generation power capacity, domestic resources, be they coal or natural gas, will not be sufficient to meet the fuel requirement.

ii. Keeping in view the rising prices of imported coal as witnessed in the preceding sections, imported natural gas may very well be competitive vis-à-vis imported coal under different scenarios, even if only relative financial cost is computed.

iii. Considering the importance of mitigating CO_2 emissions arising from power generation, there is an emerging need for internalizing the cost of abatement of CO_2 in working out relative economics of imported coal versus LNG for power generation.

However, we also need to acknowledge that the present policy prescriptions are not as comprehensive as would be required to address the increasing environmental concerns. While there has been emphasis on Clean Coal Technologies, in India adoption of these technologies is still at nascent stage. Until then, increased emphasis on coal will have its adverse impact on GHG emissions as has been brought out in the preceding sections. Any long term strategy for energy will be unsustainable if the linkage with environment is not clearly established and fully provided for in our policies and plans.

In such an approach, use of natural gas and significant additions to the infrastructure would also have to be planned for. Major investments are required in natural gas infrastructure and transportation systems. However, while these are developed, it must be ensured that these are energy efficient as well as climate- resilient over the long term. Government leadership can facilitate this by creating national frameworks, setting guidelines, and incentivising public and private investments. *Prioritising low- carbon technologies today will yield benefits tomorrow in the form of an industrial economy ready to compete in a carbon – constrained future.*[71]

There are close linkages between energy and environment and this need to be reflected in the policy. Comprehensive energy and environment-linked policy would lead to not only economic benefits but also reduce pollution and CO_2 *emissions. Such a holistic approach has become even more relevant today than ever before because of the increasing concerns about GHG emissions and the consequent implications for climate change.*

6.2 Way forward

Based on the above recommendations the value proposition for all stakeholders that emerges from the study and the recommendations is summarized in Box 6.1.

[71] Salvin T and Mehra M 'Climate change: What are we waiting for?', Monsoons and Miracles: India's search for sustainable future, Green futures special publication, January 2008

Box 6.1 Value proposition of the study

Box 6.1 Value Proposition for the stakeholders

Policymakers

- Tax distortions on cleaner fuels (natural gas) need to be corrected urgently. Cleaner fuel should attract lower taxes as compared to other fuels. One such intervention could be to give natural gas the declared goods status.
- Similar to UMPPs based on imported coal, a policy needs to be devised for promoting LNG based UMPPs
- To enhance energy security of the country strong policy push is required to ensure diversification of the fuel mix for power generation. Although dependence on domestic fuels is expected to continue with domestic coal dominating the fuel mix; for all incremental fuel requirements LNG should be promoted vis-à-vis imported coal.
- Considering the adverse impact of GHG emissions and the need for low carbon economy, abatement cost for CO_2 emissions should be considered while evaluating relative economics of fuels for power generation.
- Forms of energy and environment are closely related. Therefore, while formulating any energy policy environmental implications should be duly accounted for

Oil and gas Industry

- Recognizing natural gas a cleaner fuel and the need to limit CO_2 emissions the oil and gas industry need to make concerted efforts with the concerned authorities to have a suitable policy framework promoting natural gas for power generation.
- Requisite infrastructure, LNG terminals, transmission and distribution pipelines for natural gas need to be developed on an urgent basis by the industry.
- Tie up supplies for LNG based on demand estimates including power generation

Power Industry

- Domestic Coal being most favorable at pithead locations, its usage at these locations should be continued.
- Besides GHG emissions, coal based generation also has adverse local health impacts attached. This discourages its use in big cities having high population and large power demand. Hence, in such cities usage of cleaner fuels such as natural gas should be promoted.

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