Think Global, Act Local – A Policy Prescription towards Sustainable Energy System in India

By

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Abstract:

India faces three major energy challenges – energy access, energy security and environmental impacts. Besides, India's energy system demonstrates unsustainable patterns of development characterized by growing dependence on imported fossil fuels, rising energy demand and growing CO2 emissions. With the exclusion of the unintended impacts resulting from the energy production and consumption by the market forces, resource gets allocated suboptimally. As a result, damage to air, soil, and water quality backfires on the rapid economic growth in the form of health impacts. Further, developing countries like India cannot adopt an exclusive climate-centric development pathway as it might prove very expensive and create large mitigation and adaptation burden as compared to sustainable development pathway. Hence, the challenge is to alleviate and reverse these adverse trends to achieve a truly sustainable energy system, while preserving the equilibrium of ecosystems and encouraging economic development. In this research, the life cycle analysis is deployed for full accounting of externalities of energy use for electricity production. The assessed impacts are then monetized providing an estimate of corresponding welfare losses. The estimated impacts are considered robust and, if needed, can be used as the basis for decision-making independently of the monetary values. A "bottom-up" partial equilibrium modeling framework ANSWER-MARKAL is then used to internalize the external costs from the static life cycle analysis to generate dynamic energy system equilibrium and to make comparative policy assessment for India's energy system. Several key results arise from this research having strong public policy implications. The result demonstrates that the shift from the current inefficient equilibrium to an efficient frontier is made at very low cost by introduction of technologies which mitigate emissions of local air pollutants like SO2, NOx and SPM. Internalization of local externalities too results in co-benefits including strong decarbonisation impact and hence local pollution control comes out to be the most preferred solutions amongst all the scenarios examined. This result comes as an immediate aid and relief to Indian policy makers who are desperately searching for that elusive silver-bullet through direct CO2 mitigating actions to resolve India's growing CO2 emission. The renaissance of coal is observed only when it is coupled with low polluting technologies such as DeNOx, DeSOx and CCS. It then becomes imperative to have strong policy and technology intervention in the coal sector to make India energy secured.

Abbreviations: CCS: Carbon dioxide Capture and Storage; CO2, carbon dioxide; DeNOx, nitrogen oxides abatement, denitrification; DeSOx, sulphur oxides abatement, desulphurisation; EC, European Commission; ExternE, externalities of energy; FGD, flue gas desulphurisation; GHG, greenhouse gas; GDP, Gross domestic product; IGCC, integrated coal gasification combined cycle; IPCC, intergovernmental panel on climate change; PHWR, Pressurized Heavy Water Reactor; LWR, light water reactor; MARKAL, market allocation model; NGCC, natural gas combined cycle; NOx, nitrogen oxides; RES, reference energy system; SO2, sulphur dioxide; SRES, special report on emission scenarios;

Unless otherwise mentioned, all prices are of 2005 price level. One US Dollar ($) is assumed to be 45 Indian Rupees (Rs)

1. INTRODUCTION

India faces three major energy challenges: energy access, energy security and energy related environmental impacts. Besides, India's energy system demonstrates unsustainable patterns of development characterized by growing dependence on imported fossil fuels, rising energy demand and growing CO2 emissions. With the exclusion of the unintended impacts resulting from the energy production and consumption by the market forces, resource gets allocated suboptimally. This incentivizes market forces to generate too much of an activity where diseconomies prevail and too little where economies hold. As a result, damage to air, soil, and water backfires on the rapid economic growth in the form of health impacts. Further, developing countries like India can not adopt an exclusive climate-centric development pathway as it might prove very expensive and create large mitigation and adaptation burden as compared to sustainable development pathway.

Hence, the challenge is to alleviate and reverse these adverse trends to achieve a truly sustainable energy system, while preserving the equilibrium of ecosystems and encouraging economic development. Two recent instructions from the Prime Minister's Office (PMO) summarizes the best of the current concerns in the India's energy system : first, to work out a system for computing the country's green GDP(Economic Times,15th September 2008) and second, to make appropriate energy pricing a key component of energy policy (Economic Times,20th September 2008). In order to understand if India's current energy system is sustainable or not, life cycle analysis (LCA) is deployed in this paper for full accounting of externalities of energy use for electricity production. The assessed impacts are then monetized providing an estimate of corresponding welfare losses. The estimated impacts are considered robust and, if needed, can be used as the basis for decision-making independently of the monetary values. A "bottom-up" partial equilibrium modeling framework ANSWER-MARKAL is then used to internalize the external costs from the static life cycle analysis to generate dynamic energy system equilibrium and to make comparative policy assessment for India's energy system.

This paper is organized as follows. In section 2, the context and the associated literature to this topic is described in brief. In section 3, externality monetization is shown. In section 4, the modeling framework and results are discussed. In section 5, analysis on carbon dioxide capture with enhanced oil recovery is discussed. Finally in section 6, broad recommendation and conclusion is derived.

2. CONTEXT AND LITERATURE REVIEW

Since Pigou (1920), concept of "external cost" came into the domain of the debate as to why market mechanisms often fail in many of the provisioning of goods and services and eventually results in suboptimal solutions. The usual assumption of market based solution in providing a welfare maximizing outcomes relies on a fundamental prerequisite such as price should reflect the social cost which is the sum of private and external cost (Baumol and Oates, 1975). In the energy sector, the prerequisite for an efficient and sustainable market is to get the price right so as to reflect the marginal social cost (Stiglitz, 2006) so that scarce resources are efficiently allocated. This helps consumers and producers decide about the fuel mix, future investments and initiatives in R&D. Without the correct price signals, the market remains distorted and even if the market is competitive it remains far from the socially optimum one. This would eventually lead to a market clearing price which is lower than the marginal social cost. Since the environmental damage costs or benefits are not getting internalized in the market cost, neither the producer nor the ultimate consumers of this product have to bear the full cost of this service. In other words, certain inefficient energy technologies even though having high social costs would get implemented because of its low private production cost.

Hall (1990) goes on to argue that even if the full cost estimate may not be accurate, a mere examination of this aspect helps decipher the divergence between private and social cost thereby enabling greater economic welfare. Exploring the full cost energy pricing will throw open issues that are relevant not only to climate change policy but also to the debate over national energy strategy. One of the policy instruments for internalization could possibly be to introduce additional charges into the production cost of electricity reflecting the cost of the associated negative environmental and health impacts from local pollutants and climate change, impacts on terrestrial ecosystems, effects of water use and pollution, quantification of ozone damages, noise and amenity, visual amenity etc. Incorporating these externalities shall be helpful while assessing different energy options in terms of the damage – benefits associated with each one of them and then ranking them according to trade-offs. In the Indian context, the energy policy formulation is a very recent phenomenon and it remains detached from many of the pragmatic issues like pricing, externalities, sustainability and climate change etc. This detachment is discernible in the coal sector whose dominance in India's energy mix is likely to continue but on the downside, opencast mining for many years with scant regards for the environment has led to severe land degradation on a large scale, environmental pollution and reduced quality of coal. This puts a huge burden on the society: the cost of electricity does not represent the complete costs borne by the society such as costs of adverse human health impacts along the value chain i.e. fuel mining or exploration and drilling, transport by road, rail or pipeline, power generation and finally waste disposal. Both the power producers and the consumers reflect their preference for polluting fuels say, coal since it comes cheap as they do not have to pay for the externalities created on the society which are hitherto not getting incorporated in the cost-calculations.

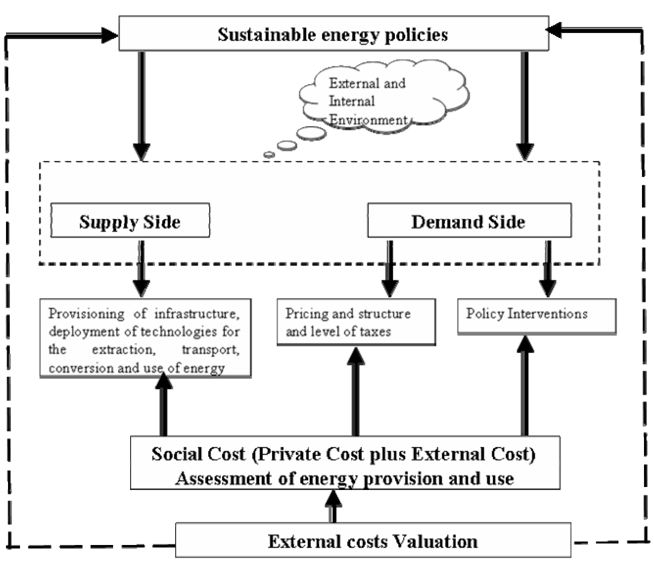


Figure 2.1 Framework of Context

The framework as suggested above in figure 2.1 above identifies how life cycle costing helps formulate sustainable energy policy. It invokes both demand and supply side adjustment in terms pricing, technology adaptations and regulatory or policy interventions. The demand and supply side adjustments are made with respect to external environment such as climate regime, oil price shocks, terrorist attacks and geopolitics and internal environment such as local green lobbies, gas and oil discoveries, GDP projections and policy impetus to various sectors etc.

To put these factors in an Indian perspective, it is suffice to say that India is caught between a huge demand side pressure on energy needs on one side and issues like energy security, climate change, sustainable usage of energy resource and societal welfare on the other. One of the ways to resolve this conundrum is to get the price right so that it reflects not only the impacts on environment but also the stress on local ecosystem and in this context life cycle cost becomes a linking thread. This study tries to reach out to these themes not in a vertical fashion by exploring each of these units i.e. energy security, climate change and sustainable development in depth but by a horizontal way through life cycle costing and energy market modeling.

3. EXTERNALITY EVALUATION AND RESULTS

3.1 Externality Evaluation: The Approach

The external cost as defined in this work exclusively addresses impacts of outdoor emission related health impacts. Impacts such as noise and visual amenity, ecosystem, GDP were not analyzed in the present work. In relative terms and considering the technologies of interest, these impacts seem to be of low significance compared to the dominant ones. The methodology developed within the ExternE Project of the European Union (ExternE, 2005) has been essentially employed for the estimation of health and environmental external costs associated with air pollution from normal operation of the various energy chains.

Coal, India's most important domestic energy resource, contributes 69 per cent of total electricity generation. Natural gas supplied by national Oil Companies (NOCs), private producers and imported Liquefied Natural Gas (LNG) supplies another 7 per cent of electricity. Nuclear electricity generated by the 15 pressurized heavy water reactors (PHWRs) and 2 light water reactors (LWRs) contributes 2.8 per cent to the total power generation (CEA, 2006). The Indian nuclear chain involves activities like mining, transport, fuel fabrication, electricity generation and waste repositories spread in the country. With the recent onshore gas discovery and the signing of Indo-US nuclear deal, share of natural gas and nuclear in power generation is likely to increase substantially in near future. Further, India is also one of world's largest producers of sugarcane and hence bagasse based electricity generation is also making inroad. Keeping these things in mind, the externality evaluation has been done in detail for coal, natural gas, nuclear and bagasse fuel chain ending with electricity generation. External costs for renewables like wind and solar has been extrapolated from ExternE country studies.

The following three stages i.e. Mining, Transportation from the mine to the power plant and Power Generation, have been taken into consideration while assessing the externality. For each of the fuel chain, a specific power plant and its associated supply source was taken as case study. External cost valuation for power generation is based on the methodology adopted by European Commission (EC) ExternE Project (for details see ExternE, 2005), while external cost for mines operation control cost or abatement or control costs methodology is used. The control cost methodology has been adopted with the assumption that regulators has the perfect foresight to choose optimal control technologies - those equating abatement costs and benefits at the margin, rather than on a political, health, or distributional basis (ORNL RFF Coal Fuel Cycle, 1994). The control-cost approach ideal where there is an urgent need to establish some back-of-the-envelop calculations. For some fuel cycles where neither control-cost nor damage-cost methodology could be applied, results of ExternE have been adjusted to reflect India's situation by considering the proportion of population density and GDP between India and the respective EU country (Wong et al. 2008; Wang and Nakata, 2009).

The methodology framework adopted for various stages of fuel cycle is as follows:

3.1 Table 1 Control and Damage cost application

Fuel Cycles	**Methodology Adopted**	**Remarks**
Upstream (Mining, Transport)	Control Cost,	
Power Generation	Damage Cost	For renewables, other country study has been adapted after suitable calibration

Extensive data collection was done from the coal and nuclear mines, LNG terminals; coal, nuclear, natural gas, bagasse power plants; pollution control boards, census office, health authorities and websites of various ministries. Expert opinions have also been sought to reconfirm some of the values.

3.2 Dose Response Function and Value of Statistical Life

Within literatures, no dose-response functions (DRF) specific to India are available. Usage of DRFs from Ostro (1994) has support from previous Indian studies (Brandon and Homman, 1994 and Shah and Nagpal, 1997) and hence has been used while evaluating health impacts from power generation. For India, no consensual value of statistical life (VSL) could be obtained from literature. To be on a conservative side, it is decided to rely on the lower bound results of IGIDR (1994). This value also has support from the recent government report (CSO, 2006) and hence a VSL of US$ 17734 (equivalent Rupees 798000 at 1US$ = Rs 45) at 2005 price is used in this analysis. The DRF gives additional mortality, additional Respiratory Hospital Admissions (RHA), additional Emergency Room Visits (ERV), additional Restricted Activity Days (RAD), additional Lower respiratory illness in children (<17yrs), additional daily Asthma attacks per asthmatic person, Respiratory symptoms days per person, and Chronic bronchitis cases with respect to unit increase in SO_2 and NOx level beyond the acceptable limit. Multiplying this with the health cost (Shah and Nagpal, 1997), gives the monetized health impacts from power generation.

3.3 Results

By adopting control costs and damage cost methodologies as described earlier, external costs with respect to various fuel cycles are calculated (see appendix 5,6 & 7 for details) and the summary is shown in below table.

Table 2 Summary of External Costs

Type	External Cost (cent / kWh)	Cost of Generation (cent / kWh)		External cost as % of Cost of Generation
		Min	Max	
Coal Pithead		1.94	6.03	
Coal Non-Pithead	**4.43**	4.76	10.73	93%
Gas	**0.81**	2.35	12.31	34%
Nuclear	**0.25**	3.09	4.62	8%
Wind	**0.13**	4.44	5.56	3%
Solar	**0.28**	17.78	35.56	2%
Bagasse	**0.31**	4.44	6.22	7%

A comparison with the market cost i.e. the cost of generation in our case, is then done to show the forgone amount not getting captured in the existing market pricing mechanism. The above table represents data for a specific site and technology and hence should not be construed to be representative of all the sites and technologies existing in India.

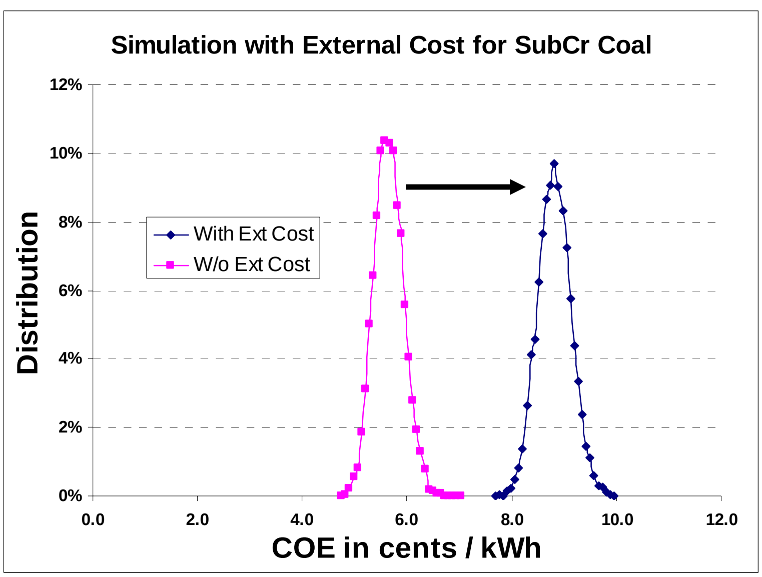


Figure 2.2 Simulation result of Sub-Critical Coal technology with external cost

The results in the above table 2.2 sound a bit static and in order to bring in dynamic analysis to it, simulation was carried out for generating levelised cost with and without the external costs. Input parameters such as capital cost, fuel cost and external cost are assigned triangular distribution, while heat rate, plant load factor (PLF), auxiliary consumption, discount rate and interest rate are assumed to be having uniform distribution. However, the simulation was done only for non-pithead subcritical coal power plant so as to demonstrate the impact of external costs. As shown in the above figure 2.2, external cost addition shifted the levelised cost of electricity (COE) regime completely out of its earlier periphery to a new efficient frontier. The figure also reveals that even the highest cost of electricity without the external cost is still less than the lowest one with external cost.

4. MODELING FRAMEWORK

Once the external costs for various power generation technologies have been derived, we then propose to carry out further modeling analysis as depicted in figure 5.2.

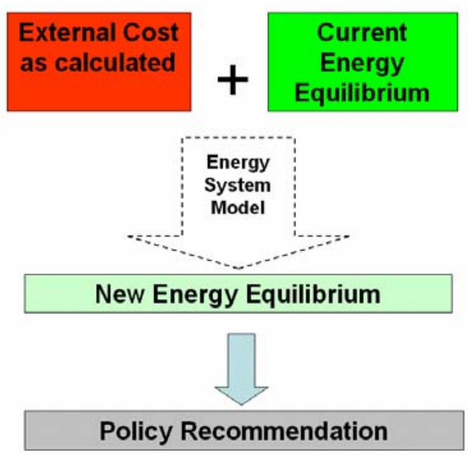


Figure 2.3 Framework for Analysis

The current energy equilibrium exists without the external costs. Now with its availability, external costs get inputted to the current modeling framework to generate new energy equilibrium. The new equilibrium by virtue of its characteristics is then become the Pareto one which then finally helps generate policy prescriptions.

MARKAL is a mathematical model for evaluating the energy system of one or several regions. MARKAL provides technology, fuel mix and investment decisions at detailed end-use level while maintaining consistency with system constraints such as energy supply, demand, investment, emissions etc. A detailed discussion of the model concept and theory is provided at the ETSAP website (Loulou, et. al., 2004). To calculate the end-use demands, it is assumed that Indian economy is presently on a high growth path; demand for goods in the end-use sectors is witnessing high growth rates. The experience from developed countries has shown that these growth rates are going to saturate as the economy modernizes. The approach used in the past is to model the demands using a logistic regression (Edmonds and Reilly, 1983; Grubler et. al., 1993). First the long term GDP projections are made using the past data available (Ministry of Finance, 2007). Logistic regression using past data is then used to estimate the sector specific shares from industry, transport, commercial and agriculture. These sectoral shares on multiplication with GDP projections give us gross valued added (GVA) for each sector. The last step involves estimation of elasticity of each sub-sector (e.g., industry is divided into eleven sub sectors like steel, cement, etc.) with the sector specific GVA. The elasticity is then used for estimating the future demand from each sector (Details in Appendix 1).

4.1 Scenario definitions and drivers

In this analysis, we have followed Scenario Analysis (Placet, Humphreys and Mahasenan, 2004; Shukla, 2006; and Siddiqui and Marnay, 2006) that entails developing a Business As Usual (BAU) scenario or dynamics as usual scenario and then generating alternate scenarios around BAU (Kanudia, 1996; Rafaj and Kypreos, 2007). The embedded story-line for our BAU is same as B2 scenario reported by the Special Report on Emission Scenarios by IPCC (IPCC, 2000). Some of the salient features of this scenario are as follows:

- High economic growth so as to reduce the disparities across regions
- Environmental concerns and sustainability approach remain high on agenda

The BAU case assesses a projection of the evolution of the Indian energy system from 2000 through 2050 while GDP grows at the rate of 8 per cent. Five-year periods are considered and a discount rate of 8 per cent is applied. The BAU case has been generated using best estimates for the values of model inputs, such as the characteristics of existing and future technologies, energy service demands, and regulations on criteria pollutant emissions.

Scenario Descriptions

Around the BAU, four scenarios are created for this analysis, namely, the Local-Damage Scenario (LDS), Global-Damage Scenario (GDS), Nuclear Cooperation Scenario (NUCC) and High Carbon Scenario (HIGHCARB).The key drivers of the two scenarios and their parameterizations are given in the below chart.

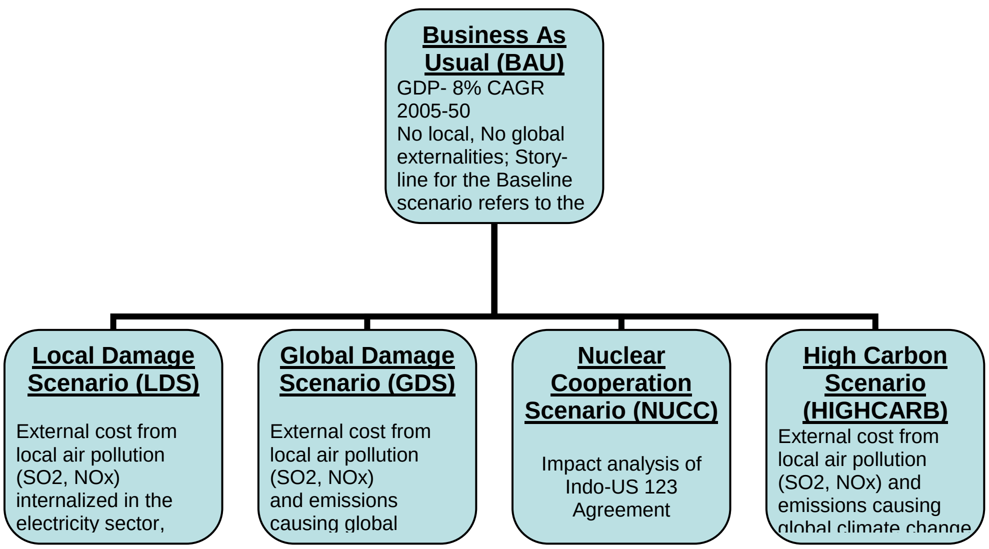


Figure 2.4 Framework for Analysis

All these scenarios are created keeping in mind the research questions that we posed at the beginning. Primarily, it revolves around the BAU with additional imposition of local pollution and then global pollution. Once they are internalized, in order to examine its implication on climate change, energy access and energy security NUCC and HIGHCARB are created. Besides, two external environment i.e. Indo-US nuclear deal and strong climate regime in future, forced us to look at the NUCC and HIGHCARB scenario in detail.

Scenario Drivers

Macro Economic

GDP for period 2005-2032 is 8 per cent which is similar to Planning Commission's GDP Scenario (Government of India (GOI), 2006). Population projections are based on UN Population Medium Scenario, Version 2004 for India (UNPD, 2006) since population projections given by Census of India are only available till 2026 (CoI, 2006). The complete population and GDP assumptions are given in Table 3 below.

Table 3 BAU scenario Drivers

Year	GDP (2005 prices) (Bill. Rs.)	Population (Million)	Period	Growth rate	
				GDP	Population
2005	32833	1103	2005-30	8.10%	1.10%
2030	229573	1449	2030-50	5.90%	0.50%
2050	774673	1593	2005-50	7.10%	0.80%

Energy Prices

A variety of prices are observed in the Indian energy markets especially for coal and gas. The regulatory regime tries to keep prices aligned to the cost of production. Using the regulated prices information available in public domain[2] supply curves are created, using a step wise linear structure (Loulou et. al., 2004). The price assumptions for imported fuels are based on price projections given by IEA (IEA, 2006b)

Carbon Prices

Carbon price trajectory for BAU scenario and HIGHCARB scenario are linked to CO_2e stabilization targets of 650 ppmv CO_2e concentration target and 550 ppmv CO_2e respectively. The price trajectories are obtained from outputs from global Second Generation Model (SGM) results (Edmonds, 2007).

[2] Information related to coal prices can be obtained from website of ministry of coal whereas information on oil and gas prices was taken from Infraline database (www.infraline.com)

4.2 Internalization of external costs

MARKAL has a very elaborate representation of the fuel cycle starting from the mining to power generation. This gives the opportunity to assign the externalities at each stage. External costs are implemented in the model by assigning it as an additional variable O&M cost from each power plant during each time period i.e. VAROM input in MARKAL. In this way, it is assured that the external costs are directly charged to every unit of generation from each power plant. An alternative approach that could be used to internalize the damage costs for different pollutants is to levy an environmental tax per unit of pollutant (e.g., Indian Rupees 1000/tNOx) on the entire energy system (Rafaj and Kypreos, 2006). Since our analysis is explicitly focused on the externality impacts on the power generation sector, the externalities are normalized by generation output i.e. kilowatt hour (kWh).

External costs as derived in section 3.3 based on the ExternE (2005) methodology reflects characterization of a site-specific technology of different value chains of a particular fuel. This becomes a static analysis and is devoid of dynamic characters when the energy sector traverses into the future. Factors such as population density in regions, fuel quality expressed as the content of the sulphur in coal and oil, technology specification with respect to installation of the emissions control systems, and finally, the possible improvement in conversion efficiency over time horizon must get embedded in the static cost so as to reflect the evolution of myriad of technologies that get evolved over the time horizon (Rafaj and Kypreos, 2007). However, given the data availability and the time constraint, it becomes imperative not to consider some of the above factors so as to keep things simple and result-oriented. It should also be kept in mind that the whole purpose of this exercise is to demonstrate the rituals of external cost methodology and how to internalize it in the MARKAL model rather than come out with precise number. Given this background, changes in the population density over time are not considered and whatever improvement in externality going to happen in future is assumed to be coming through efficiency improvements in generation. This assumption makes the future external cost EC_t as inversely related to efficiency of generation i.e. with improvement in efficiency we are going to see less of environmental impacts. Mathematically, it can be expressed as

$EC_{t} = EC_{0} \times Eff_{0} / Eff_{t}$, where 0 and t represents the time period

External costs for various generation technologies in fossil as well as non-fossil domain have been calibrated using the above equation as well as Rafaj and Kypreos (2007).

4.3 External costs representation in MARKAL

Coal External Cost

Coal has the largest share of utility power generation in India, accounting for approximately 68 per cent of all utility-produced electricity (Electricity Statistics, CEA, 2007). Therefore, understanding the environmental implications of producing electricity from coal is an important component of any plan to reduce total emissions and resource consumption.

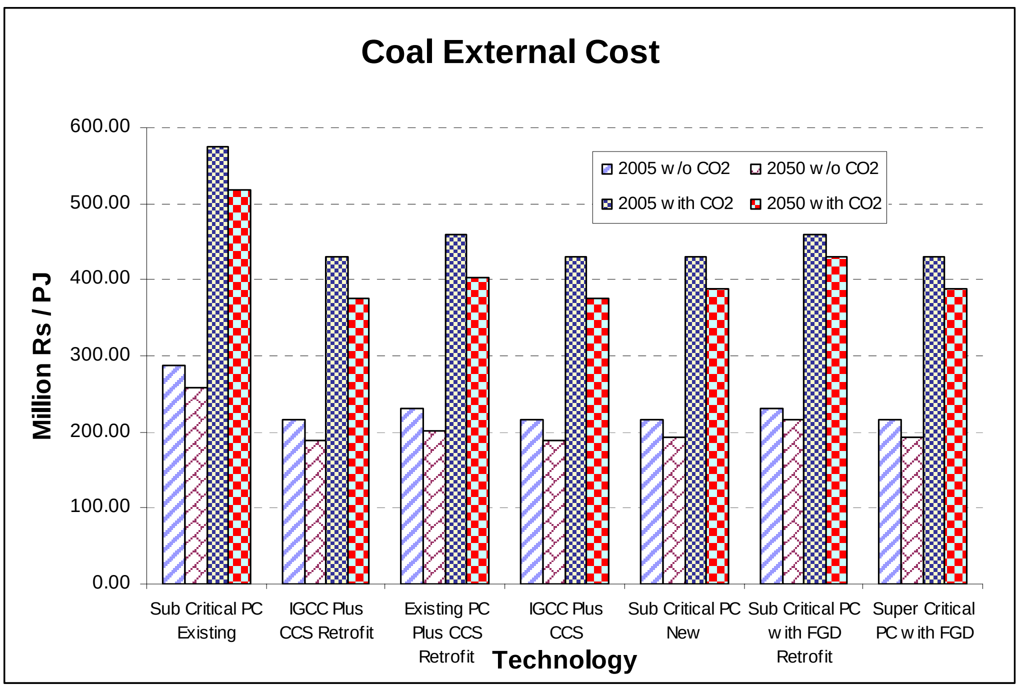


Figure 2.5 Coal External Cost

Natural Gas External Cost

With the recent gas discovery in Krishna-Godavari basin and policy maker's thrust on developing more LNG terminals and transnational pipelines, natural gas will probably contribute more and more to the

India’s future electricity generation. The reference technology for natural-gas base-load power plants is combined cycle gas turbine (CCGT), fuelled with part Liquefied Natural Gas (LNG) shipped from Persian Gulf and part domestically produced natural gas. The energy requirements for state-of-the-art LNG liquefaction, shipping and regasification have been considered. When data were lacking, conservative assumptions were made; for example, all extracted natural gas, independent of origin, is considered to have the same emission discharges as mentioned against Asia / Australasia region in Oil and Gas Producers (OGP) report 2006.

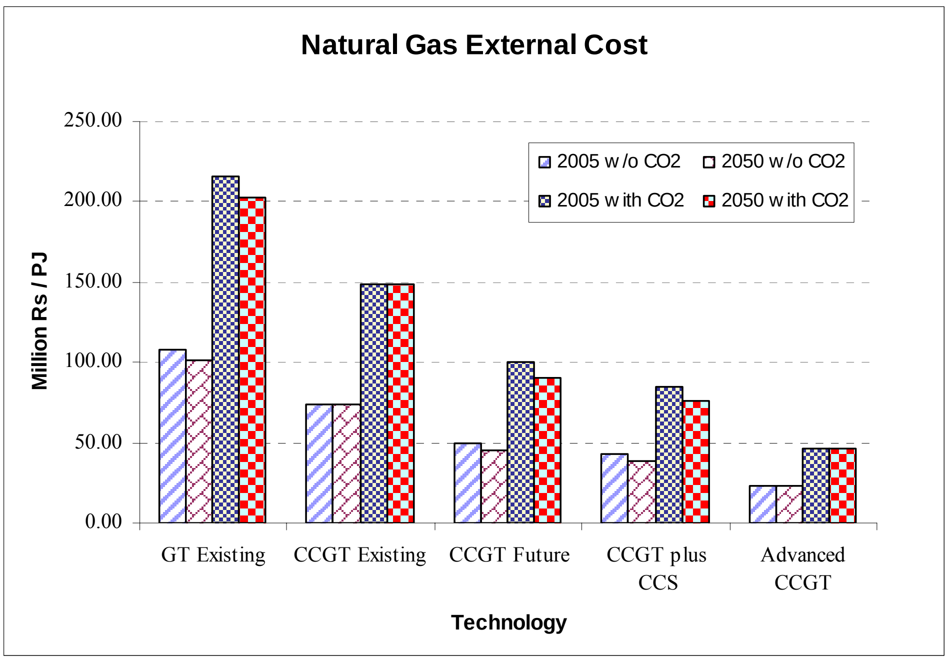


Figure 2.6 Natural Gas External Cost

Nuclear and Renewable External Cost

This study conservatively models a currently operating standard Pressurized Heavy Water Reactor (PHWR) of 440 MW though advanced power plants including Vodo-Vodyanoi Energetichesky Reactor; Water-Water Energetic Reactor (VVER) and light water reactors (LWR) types are operational in India. The reference nuclear chain chosen was an open cycle without reprocessing and compared to the closed cycle, it produces higher non-radioactive emissions. The uranium currently used in the generation of nuclear power is all domestically extracted by in situ leaching. However, post Indo-US nuclear deal the future requirements and availability of nuclear fuel shall change entirely. It is assumed that the spent fuel will be deposited in deep geological strata after encapsulation. Statistics on radioactive emissions from the Indian nuclear chain were lacking. Therefore, a rough estimation of the relatively small contributions to health effects based on average French values has been included. The French value has been suitably adjusted by calibrating it with respect to GDP and population.

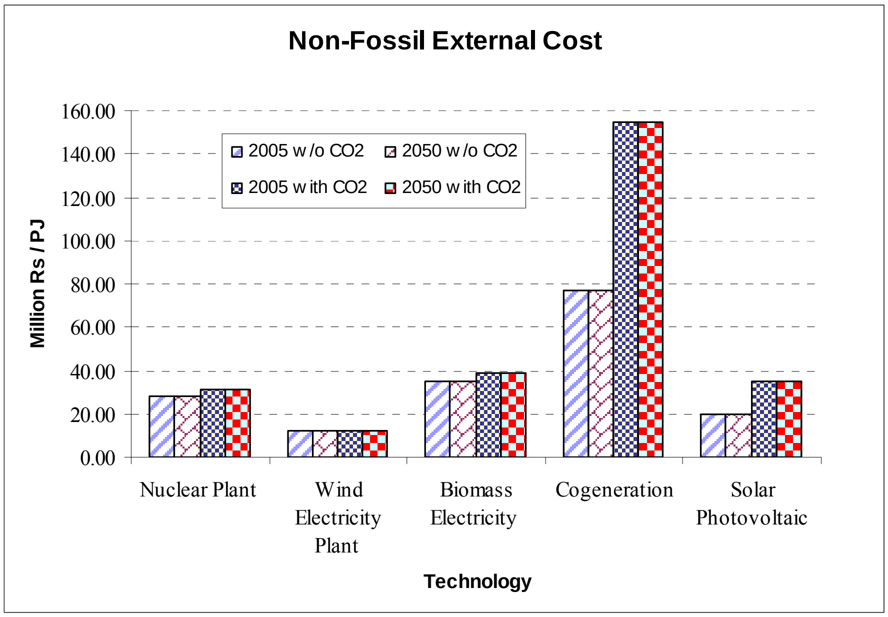


Figure 2.7 Non-Fossil External Cost

4.4 Scenario results summary

4.3.1 Primary Energy Supply

This decrease in primary energy (PE) is observed in LD scenario and this could be because of the switch to other fuels than electricity in the final energy demand such as combined heat and biomass. Further, the efficiency gains from electricity to others could be higher resulting in lower primary energy supply. Local pollution resulting from transport and residential sectors are also arrested because of measures and hence results in PE decrease. As seen from the figure 7.4 above, the HIGHCARB scenario consumes more primary energy compared to LDS and GDS. Reason being, since this scenario depicts a strong carbon regime, energy system as a whole has to pay energy penalty to generate same output as other scenarios.

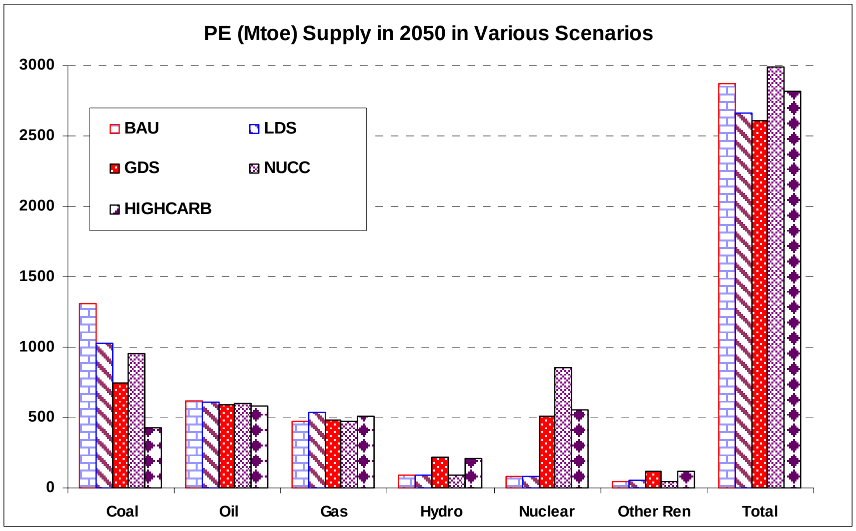


Figure 2.8 Comparison of PE Supply

4.3.2 Electricity Generation by fuel

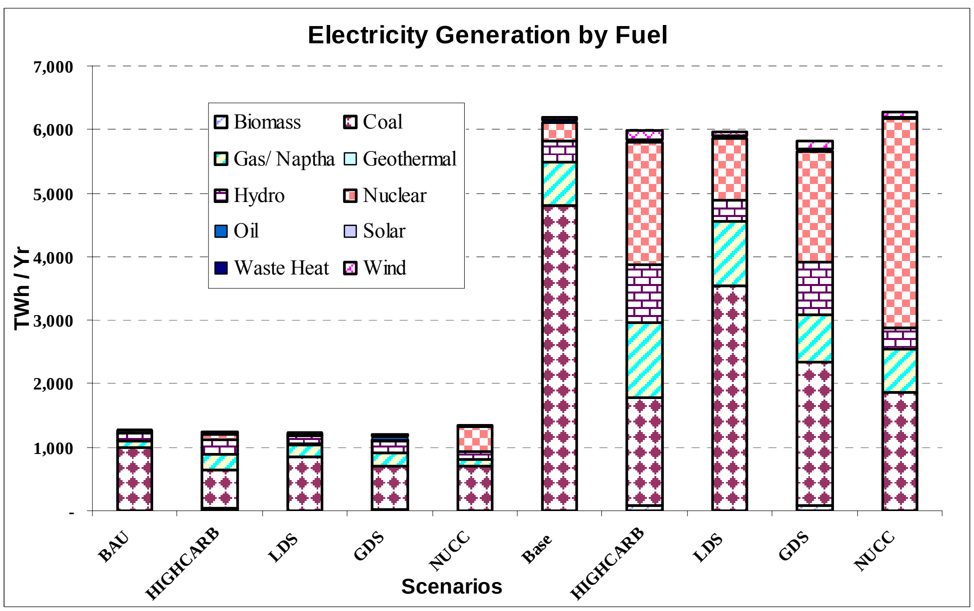
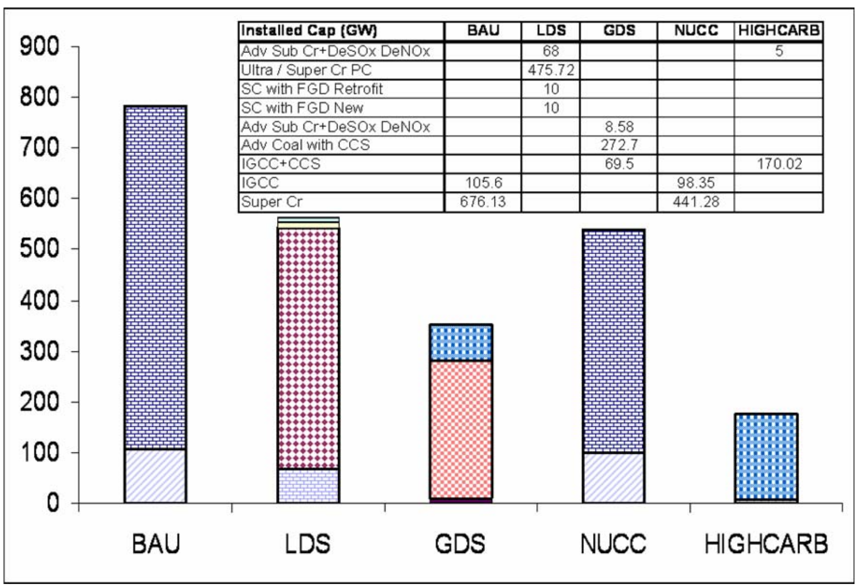


Figure 2.9 Electricity Generation by fuel in various Scenarios

Overall, the coal share in the generation mix is getting reduced (figure 2.6) and substituted with natural gas and renewables. The resulting enlarged energy portfolio calls for lesser reliance on coal and would therefore pose higher energy security risks. The energy security risks are further exacerbated if India undertakes carbon emissions constraints i.e. in the HIGHCARB scenario. Due to high coal content in India's business-as-usual scenario and highest carbon content per energy unit for coal, the carbon constraint has most severe impact on coal use compared to any other fuel.

4.3.3 Coal technology transition across scenarios

In all the scenarios, coal installed capacity is getting reduced as compared to BAU. Polluting technologies like the sub critical pulverized coal is getting substituted by advanced generating technologies like Integrated Gasification Combined Cycle (IGCC) with Carbon dioxide capture and Storage (CCS) and Super Critical with Desulphurization (DeSOx) and Denitrification (DeNox). Installed capacity of IGCC remains highest at 170 GW in HIGHCARB scenario.



Installed Cap (GW)	BAU	LDS	GDS	NUCC	HIGHCARB
Adv Sub Cr+DeSOx DeNOx		68			5
Ultra / Super Cr PC		475.72			
SC with FGD Retrofit		10			
SC with FGD New		10			
Adv Sub Cr+DeSOx DeNOx			8.58		
Adv Coal with CCS			272.7		
IGCC+CCS			69.5		170.02
IGCC	105.6			98.35	
Super Cr	676.13			441.28	

Figure 2.10 Coal technology transition across various Scenarios

One thing that came clear of this research is that cheaper electricity options (figure 2.8) without environmental impacts are difficult propositions for India, at least in the near term. By adding externality

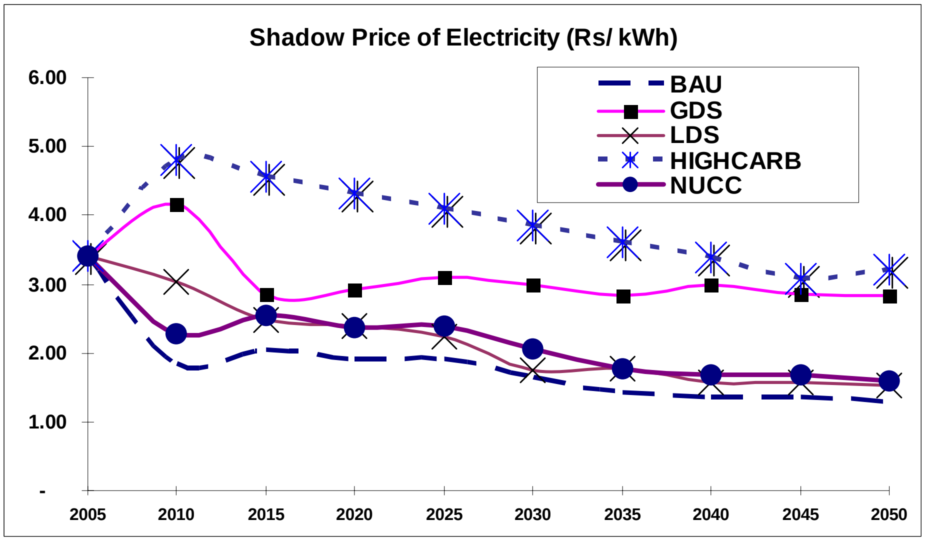


Figure 2.11 Shadow price of electricity under various scenarios

cost into the generations it is shown that energy mix portfolio is going be diversified as opposed to a pure coal dominated one.

5. FINDING, POLICY RECOMMENDATIONS & CONCLUSIONS

Several key findings arise from this research.

First, the lack of internalization of life-cycle externalities in India is resulting in significant distortions in energy prices. This is contributing to inefficient use of energy resources, higher demand and suboptimal investments on supply side.

Second, the internalization of life-cycle environmental costs have highest implications for coal based power generation system, leading to early introduction of advanced coal burning and clean-coal technologies.

Third, the shift from the current inefficient equilibrium to an efficient frontier is made at very low cost by introduction of technologies which mitigate emissions of local air pollutants like SO2, NOx and SPM. Besides, the efficient equilibrium also includes substitution of coal by natural gas and to a lesser extent also by the renewable energy and nuclear technologies. Evidently, India's environmental policy therefore should include mandatory use of FGD, ESP and SCR technologies in the coal-based electricity generating units.

Fourth, the long-run marginal cost of electricity is significantly altered if life-cycle external costs are internalized. The resulting enlarged energy portfolio calls for lesser reliance on coal and would pose higher energy security risks.

Fifth, the energy security risks are further exacerbated if India undertakes carbon emissions constraints. Due to high coal content in India's business-as-usual scenario and highest carbon content per energy unit for coal, the carbon constraint has most severe impact on coal use compared to any other fuel.

Overall, it is clear from this research that the way India is producing and consuming energy is unsustainable in the long run. The impact has already started manifesting itself in the form of health impacts, land degradation and impacts on ecosystem. Many of the decisions that India must make to arrest such impasse such as energy pricing to reflect social cost, institutional and regulatory capacity buildings, and environmental regime etc , are fortunately local in nature. It was clear from the scenario analysis that Local Damage Scenario (LDS) came out to be a winning strategy for India's policy makers for implementation; not only does LDS consume less primary energy (fig 2.8) than others but it also comes out be highly diversified. This also validates earlier research that stresses on the point that while climate change is obviously a global environmental problem, there is nevertheless potential for policy initiatives at the local level. Small emissions control programmes such as 'cap-and-trade' programmes for emissions of nitrogen oxides (NOx), sulphur dioxide (SO2) and mercury would not only have co-benefits but also would influence national GHG policies as they evolve. Even though these are small compared to those necessary to address global climate change, the lessons learned will undoubtedly impact policy discussions at the highest level.

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Appendix .1. Demand Projection

The Indian economy is currently on a high growth path and this in turn has set the demands for most goods in the end-use sectors on a high growth rates. However, in the long run as economy modernizes, the growth rates are likely to get plateaued. This trend of increased growth rate followed by a saturating trend is best depicted by the logistic curve. In the energy-environment context, similar articulation have earlier used for technology penetration (Edmonds and Reilly, 1983; Grubler et al., 1993). The logistic function used for demand projection is given by equation (1.1).

$$Y_t = Y_0 \frac{\exp(a + bt)}{1 + \exp(a + bt)} \qquad (1.1)$$

where,

Yt is the level of demand at time t

Y0 is the asymptotic limit for the demand Yt, and is estimated based on expert opinion, changed demand elasticity in future and experience of developed countries

a and b are parameter estimated by the linear regression of the log-log form of equation (1.1) based on time series data.

$$\ln\left(\frac{Y_t / Y_0}{1 - (Y_t / Y_0)}\right) = a + bt \qquad (1.2)$$

In order to arrive at the disaggregated end-use demand projections, the long-term projections for gross domestic product (GDP) are made estimated. This is done to achieve macroeconomic consistency. Logistic regression based on past data and estimates for the next ten years available from Planning Commission are used to arrive at this. Under the reference base case scenario, a compounded annual growth rate of 8 percent from 2000 to 2050 is assumed. Since Gross Value Added (GVAs) are taken as drivers for end-use sectoral demands, the GDP projections are then further disaggregated into GVA contributions from industry, transport, commercial, and agriculture sectors.

The GVAs are projected from GDP projections by assuming their intensity with GDP.

$$GVA_t = m_t \cdot GDP_t \qquad (1.3)$$

Where,

GVAt = Level of GVA in time period (year) t

mt = Coefficient representing intensity of GVAt with respect to GDPt

Coefficients mt are projected by linear regression with historical data and future trends in demand elasticity based on expert opinion and experience of developed countries. It is also taken into consideration that as the Indian economy mature, shares of industry, commercial and transport sectors in the GDP increase at the expense of the agriculture sector. Industry here includes various sub-sectors such as iron and steel, cement, fertilizer etc, manufacturing, mining and quarrying, construction, electric power generation, gas and water supply. The commercial sector includes finance and real estate, community and personal services, communication, trade, hotels and restaurants. Within the overall economic growth rate framework, projections are made for Gross Value Added (GVA) contributions from the different sectors based on their historical growth rates, structural changes in the economy, changes in consumption patterns, etc., with mt capturing all these. Finally, each service demand was projected by assuming its intensity with GVA.

$$Y_t = C_t \cdot GVA_t \qquad (1.4)$$

where,

Yt = Level of service demand in time period (year) t

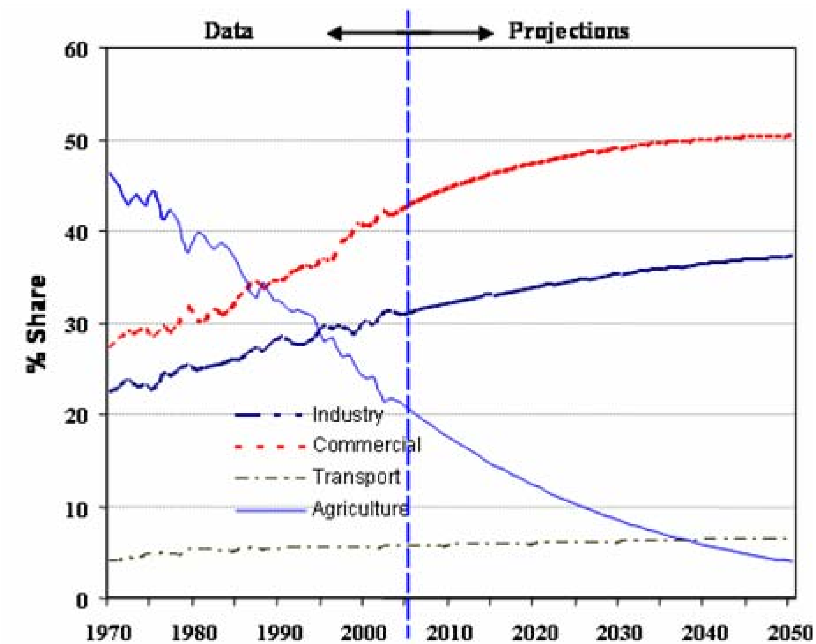
GVAt = Value of driver for service demand Yt in time period t

Ct = Coefficient representing intensity of Yt with respect to GVAt

Ct was either assumed constant and equal to Ct0, the intensity of Y with respect to GVA in the reference year t0, or (Yt0 / GVAt0), or projected assuming a rate of change.

Scenario Drivers

This scenario assumes the future socio-economic development to mimic the resource intensive development path followed by the present developed countries.



Appendix .2. Estimation of Human Health Impacts

The following equations, developed by Ostro (1994), are used to calculate changes in health effects due to incremental changes in ambient PM10 concentrations.

Mortality due to PM10 The relationship between air quality and mortality can be represented as follows:

$$\text{Excess death} = 0.0012 \times ([PM10] - 100) \times P \times c$$

where, P equals the number of people exposed to a specific concentration; c equals the crude rate mortality (0.0058 in Gujarat); and PM10 stands for its annual average concentration (µg/m3),

The PM10 benchmark has been assumed to be 100 µg/m3 which is same as the Indian Standard for SPM in sensitive areas in 24 hour time weighted average. From this relation it is estimated that the excess mortality due to PM10 (and TPS) is about 653 cases for an exposed population of 3.71 million.

Morbidity due to PM10

Dose-response functions:

The dose-response relationships for impact estimation are described below:

1. Change in yearly cases of chronic bronchitis per 100,000 persons is estimated at 61.2 per 10 µg/m3 PM10. The total number of yearly cases of chronic bronchitis per 100,000 persons is thus 6.12 x ([PM10] - 100).
2. Change in restricted activity days per person, per year, per 10 µ g/m3 PM10 estimated at 0.575 and hence the change in RAD is 0.0575 x ([PM10] - 100).
3. Change in respiratory hospital admissions per 100,000 persons is estimated at 12 per 10µg/m3 PM10 and hence the change in RHA per 100,000 persons are estimated at 1.2 x ([PM10] - 100).
4. Number of emergency room visits per 100,000 persons is estimated at 235.4 per 10µg/m3 PM10, and hence the total number ERV per 100,000 persons at 23.54 x ([PM10] - 100).
5. Change in the annual risk of lower respiratory illness in children (<17yrs) is estimated at 0.00169 x ([PM10] - 100). From the Gujarat Census data we find that approximately 39 per cent of the total population is less than 17 years of age.
6. The change in daily asthma attacks per asthmatic person is estimated at 0.0326 x ([PM10] - 100). The number of asthmatic persons is estimated at 3.5 per cent of the population.

7. Respiratory symptoms days per person, per year, are estimated at 0.183 x ([PM10] - 100).
8. Chronic bronchitis cases per 100000 person, per year, are estimated at 6.12 x ([PM10] - 100).

<u>Health Impacts and their valuation</u>

Mortality: Value of Statistical Life (VSL) estimates are derived from aggregated estimates of individual values for small changes in mortality risks (EPA, 2000). For example, if each of 100000 people is willing to pay Rs 40 for a reduction in risk from three deaths per 100000 people per year to one death per 100000 people, the total WTP is Rs 4 million, and the value per statistical life is Rs 2 millions (with two lives saved). This does not mean that any particular individual's life is valued at this amount, but it rather represents what the whole group is willing to pay for reducing each member's risk by a small amount. Using this example, the WTP value is not correctly interpreted as a Rs 2 million value for the single life saved, but rather a Rs 40 value to each of the 100,000 individuals who experience a 10-5 (i.e., 1 in 100,000) reduction in annual mortality risk.

There are two approaches for estimation of mortality costs based on value of life- one is the Willingness-To-Pay (WTP) approach and the other is based on estimation of the Human Capital Approach. The WTP approach is based on surveys conducted to assess how much an individual is willing to pay to avoid the burden of disease. In the United States, EPA (2000) recommends a central estimate of $4.8 million (1990$), updating this figure for inflation produces an estimate of $6.1 million in 1999 dollars. Although transferring such valuation from one country to another is highly debatable, but making correction to this valuation by factoring the per capita gross national product in PPP terms gives us a base figure to start with. Using World Development Indicators (WDI), this factor comes out to be 1500/35190 = 0.042. At an exchange rate of Rs 1 = US$0.0218, this results in a value of Rs 11.75 million per statistical life in India in 2000 price.

In the Human Capital Approach, value of a statistical life (VSL) is computed as the summation of forgone future incomes discounted to its present value. If we take the IGIDR (1993) assumptions in which the average age of population is 26 years, social discount rate 8 per cent, wage per month Rs 2515 and the life expectancy at birth is 65 years, then VSL calculated from the below formula is Rs 383433 (1993 price).

$$VSL = \sum_{t=0}^{39} w / (l + d) t$$

where, w = average annual income, and d = the discount rate.

For India, no consensual VSL value could be obtained from literature. India's VSL has been quoted a low of 0.25 and a high of 4.25 million rupees at 1997 price (Shah and Nagpal, 1997) and when inflated to 2005 price, it comes out to be 0.385 and 6.5 million rupees. Simon et al. (1999) give a compensating wage differential study for Indian manufacturing industry and put estimate of the VSL for India between 6.4 million rupees and 13.7 million rupees. Shanmugam (2000) also provides estimates of the VSL in India using the compensating wage differentials approach of 552 blue-collar employees working in a manufacturing unit in Madras and put VSL to be in the range between 13.8 million rupees and 18.6 million rupees. Using the same data, Shanmugam (2001) later extended his earlier work and increased the VSL to between 55.1million rupees and 56.1million rupees. However, both the Shanmugam studies focused only on a single metropolitan area in India rather than looking at the country as a whole. By contrast, Simon et al. (1999) aggregate data for 53 different industries at a finer level of industrial classification. IGIDR (1994) estimates the value of human life for the population of Mumbai through two approaches i.e. Human capital approach and Wage differential approach and they are 0.38 million rupees and 8.6 million rupees at 1993 price, respectively. Brandon and Homman (1994) present VSL by productive approach and compensative wage approach. In the first method, the authors calculate it by estimating the present value of the wage lost over an assumed additional life span of 10 years with discount rate of 5 per cent. While in the second approach, he directly scales down the USEPA value of life by the factor of India GDP to that of USA.

Table 4 Summary of Indian VSL Studies

Values are in Rs Million			at 2005 price level	
Studies	**Low**	**High**	**Low**	**High**
Shah and Nagpal, 1997	0.25	4.25	0.39	6.55
Simon et al. 1999	6.4	15	16.32	38.25
Shanmugam, 2000	13.8	18.6	18.32	24.69
Shanmugam, 2001	55.1	56.1	69.59	70.85
Brandon and Homman,1994	0.13	1.20	0.24	2.26
IGIDR,1993	0.383	8.6	0.80	17.93

Picking up values from the above studies (as shown above) is not easy, especially when there are high variations within these ranges. One literature related to Bangladesh seems to have favored lower value of Simon et al. (1999) of 6.4 million rupees (see for example, Maddison et al, 2005) and appreciating it to the 2005 price which gives the VSL value of 8.6 million rupees, which seems to be on a higher side. To be on a conservative side, it is decided to rely on the lower bound results of IGIDR (1993). This value also has support from the recent government report (CSO, 2006) and hence a VSL of Rs 798000 at 2005 price is used in this analysis.

Health Cost in India

Description	Unit	Value (2005 Rs)
Value of Statistical Life	Rs per death	798000
Respiratory Hospital Admissions	Rs per case	12512
Emergency Room Visits	Rs per case	337
Restricted Activities Day	Rs per day	36
Minor Restricted Activities Day	Rs per day	36
Respiratory Symptoms	Rs per day	26
Lower respiratory illness in children (<17yrs)	Rs per case	415
Asthma Attack	Rs per case	1297
Chronic Bronchitis	Rs per case	208834

Source: URBAIR report, 1997

Appendix .3. **Coal External Cost Calculation**

A. External Cost Coal Mining is assumed to be summation of external cost arising from mines fire, mines dust, fugitive emission and POL emission.

A.1: Mines Fire

In order to estimate the external costs from mines fire, surrogate cost from has been taken into consideration. It is mentioned in Lok Sabha (2006) that Coal India Ltd. (CIL) steps have been taken to generate an amount of Rs.395 crore per year for implementation of the action plan for shifting and rehabilitation, dealing with fire and stabilization of unstable area in ECL & BCCL. The combined production of ECL and BCCL in 2005-06 is 57.2 MT. When the total planned expenditure is apportioned against this production, external cost because of fire comes out to be 6.91 paisa per kg of coal or 4.14 paisa per kWh.

A.2: Mines Dust

Description	**Qty**	**Unit**	**Cost of Repair (Rs)**	**Total Capital Cost (Rs)**	**Annualized Cost**	**O&M Cost @ 10%**	**Total Cost**
Haul Road Paving	10	Km	40000000	400000000	55626095.81	5562609.581	61188705.39
Transportation Road Paving	6	Km	40000000	240000000	33375657.49	3337565.749	36713223.24
Public Road Paving	4	Km	40000000	160000000	22250438.32	2225043.832	24475482.16
Dust collecting Device - road dust collecting system	1	no	2,000,000	2,000,000	2,000,000	600000	2600000
Control Measures at							
Coal handling Unit							
Excavation Area	1	no	20,000,000	20,000,000	20,000,000		20000000
Overburden Dumps							
Dust Suppression System at the Coal Loading Point	1	no	6,000,000	6,000,000	6,000,000		6000000
					Total Cost		150977410.8
					Per Kg external cost (Paise)		**6.29**
					Per kWh external cost (Paise		3.77

As shown above, the external cost from dust generation is calculated by assessing how much expenditure is going to be incurred to control the sources of emission.

A.3: Fugitive Emission

From literatures, it is estimated that 0.7 Tg of methane emitted in 2004-05 in the form of fugitive emission. This is against a total coal production of 335 MT. By normalizing and then factor in carbon price of 25$ per tCo2, we get the external cost as 3 paisa per kWh

A.4: Raw Material Consumption

From the raw material consumption data, emission in gm CO2e/Kg of Coal produced was calculated and shown in the below table.

	CO2	CH4	N20	CO2 Eqv
HS Diesel	2.721887356	0.110197869	0.022039574	11.78015216
Petrol				
Lubricant	0.157678881	0.006453433	0.001290687	0.688151076
Electricity	1.835766424			1.835766424

Multiplying the carbon price of 25$ per tCo2, we get the external cost as 1.125 paisa per kWh

External Cost Coal Mining is the summation of A1 +A2+ A3 +A4 = 12 paisa per kWh.

B. External Cost from Power Generation

B1: External Cost Local Emission

Neither PM10 nor PM2.5 is systematically monitored in India, so the only measured data available in India is for total suspended particulates (TSP) or Suspended Particulate Matter (SPM). In US studies, a default conversion factor of 0.55 is used to estimate PM10 levels based on measured TSP. Whether this is appropriate in India depends to some degree on location. From the discussions that the researcher had with Gujarat Pollution Control Board (GPCB) officials, it was agreed upon that a conversion factor of 0.66 shall be used to convert SPM to PM10 or RSPM. The data on ambient air quality status around Ahmedabad and Gandhinagar was received from GPCB office. From the average TSPM, PM10 was then calculated out of which it was assumed that the contribution from power sector is 30 per cent.

Apportionment studies do not exist at present; though government efforts are on to establish this for major cities.

From the calculation, it was established that the amount of dose in the form of PM10 is 25.2μg/m3 after suitably factoring in the Indian standard permissible limits. Next, the job is to find out additional effects on receptors i.e. populations with this enhanced dose. The estimate is as follows:

1. Additional Respiratory Hospital Admissions per 100,000 persons is 1126 per year
2. Additional Emergency Room Visits per 100,000 persons is estimated at 22097 per year
3. Additional Restricted Activity Days per person is estimated at 5397406
4. Additional Lower respiratory illness in children (<17yrs) at 58574
5. Additonal daily asthma attacks per asthmatic person is estimated at 107103
6. Respiratory symptoms days per person, per year, are estimated 17177831
7. Chronic bronchitis cases per 100000 person, per year, are estimated at 5745

The assumption while calculating the above effects are as under:

- dose response functions as described in appendix 5
- 3.5 per cent of the population is assumed to be asthmatic
- Demographic distributed as per actual data collected from Census, Gujarat office

Mortality due to PM10 The relationship between air quality and mortality can be represented as follows:

$$\text{Excess death} = 0.0012 \times ([PM10] - 100) \times P \times c$$

where, P equals the number of people exposed to a specific concentration; c equals the crude rate mortality (0.0058 in Gujarat); and PM10 stands for its annual average concentration (μg/m3),
With the health cost given in Appendix 13 and VSL of Rs 0.79 million , the impact of PM10 was found out to be 39.7 paisa per kWh.

B2: External Cost Global Emission

From the Central Electricity Statistics (CEA) database, it was found that the two reference plants emitted on aerage 1.26 kg of CO_2 per kWh of electricity generation in the year 2005-06. Multiplying this with carbon price, we get external cost as 141 paisa per kWh.

Appendix .4. **Nuclear External Cost Calculation**

Collective doses for the different stages of the fuel cycle

Collective doses (man.Sv/TWh)	Public local	Public regional	Public global	Public total	Occupational	Total
Mining and milling	4.92E-01	5.31E-01	6.08E-04	**1.03E+00**	6.49E-01	**1.67E+00**
Conversion	1.39E-04	5.79E-05	5.52E-06	**2.03E-04**	1.33E-02	**1.34E-02**
Enrichment	1.29E-04	2.47E-05	2.26E-06	**1.55E-04**	4.83E-05	**2.04E-04**
Fuel fabrication	2.03E-06	5.13E-05	3.00E-08	**5.34E-05**	4.14E-02	**4.14E-02**
Reactor construction	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	**0.00E+00**
Electricity generation	8.23E-03	1.03E+00	1.15E+01	**1.25E+01**	1.17E+00	**1.37E+01**
Decommissioning	8.40E-04	0.00E+00	0.00E+00	**8.40E-04**	1.25E-01	**1.26E-01**
Reprocessing	1.18E-03	3.52E-01	5.91E+01	**5.97E+01**	1.02E-02	**5.97E+01**
LLW disposal	7.36E-05		1.49E-01	**1.49E-01**	5.79E-04	**1.49E-01**
HLW disposal	7.88E-01			**7.88E-01**	3.48E-06	**7.88E-01**
Transportation	5.50E-03	0.00E+00	0.00E+00	**5.50E-03**	6.60E-03	**1.21E-02**
Total	**1.30E+00**	**1.91E+00**	**7.07E+01**	**7.41E+01**	**2.02E+00**	**7.59E+01**

Source: Author's own estimate from Dreicer, Tort and Margerie, 1995

Summarizing these doses in terms of electricity production, the total number of expected health impacts is then calculated. Gopinath (2007) has assumed a value of 0.05 expected cancer mortality per man.Sv for India and in this analysis the same value has been adopted.

Total collective dose as per the above table per TWh	75.9man.Sv
Expected cancer mortality per man.Sv	0.05
Hence, total cancer mortality per TWh	75.9 x 0.05= 3.8

Fatal and Non fatal cancers

The statistical value of life 0.798 million rupees has been used for the monetary valuation of a fatal cancer, deaths and accidental deaths. At this time, no values for the willingness-to-pay to avoid non-fatal cancers have been identified. As described in Maddison et al. (2005), the value for non-fatal cancer is assumed to be 0.58 times VSL (Magat et al., 1996). By applying the same ratio to Indian context we get an estimate of 0.462 million rupees for a case of non-fatal cancer.

Non-Radiological Health Effects

At present, no willingness–to-pay based values are available in India for the non-radiological impacts. Instead, the cost that the Railway Claims Tribunal pays for the compensation of working-days-lost (WDL) and permanent disability (PD) has been used for this valuation. At this time, 1 WDL is considered to be 193.73 rupees and 1 PD is considered to be 0.4 million rupees[3]. Injuries from accidents are valued at 0.35 million rupees based on statistics from the railway.

The impact valuation has been calculated under three categories i.e. monetization of impact because of nuclear fuel cycle radiation exposure, monetization of impact because of GHG emissions during mining and monetization of impact because of non-GHG emissions.

Summary of nuclear fuel cycle external cost

A. Because of Nuclear Fuel cycle till generation ***Radiological impacts / TWh***	***Incidence per TWh***	***Monetary Value per TWh***	***Monetary Value in Million Rs per kWh***	***Monetary Value in Paisa per kWh***
Fatal Cancers	3.77	32.38143761	3.23814E-08	3.238143761
Non-Fatal Cancers	9.09	45.36390321	4.53639E-08	4.536390321
Hereditary Effects	0.75	0.647628752	6.47629E-10	0.064762875
Non-Radiological impacts / TWh				
Deaths	0.10	0.896716734	8.96717E-10	0.089671673
Permanent Disability (PD)	5.56	2.224413603	2.22441E-09	0.22244136
Working-days-lost (WDL)	1714.65	0.332179562	3.3218E-10	0.033217956
Public Deaths because of transportation	0.00	0.014945279	1.49453E-11	0.001494528
Occupational and Public Injuries because of transpo	0.01	0.003446683	3.44668E-12	0.000344668
				8.19E+00
B. Because of Mining Emission (GHG)				1.33E-01
C. Because of Mining Emission (Non-GHG)				2.98E+00
D. Because of transportation of U3O8 fro mines to Hyderabad and from here till the Power plant				2.51E-03
		Grand Total (paisa / kWh)		**11.30**

Total External Cost = $C_{Radiationi\ nFuelCycle} + C_{\min ing\ /\ GHG} + C_{\min ing\ /\ Non-GHG} + C_{Transporta\ tion}$

The final cost that comes out of this nuclear fuel cycle analysis is 11.3 paisa per kWh.

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[3] http://pib.nic.in/archieve/lreleng/l0999/r080999.html