REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

(PHASE V)

TATA ENERGY RESEARCH INSTITUTE
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Examining the Replacement of coal by natural gas in utility and industrial application

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Introduction

The current debate on climate change has resulted in the suggestion of several short term, no regrets measures to help alleviate the problem. One such measure that has gained considerable currency is that of substituting higher carbon fuels by lower ones. While the renewable energy technologies are the ultimate end, an intermediate solution lies in the increased utilisation of natural gas, thereby substituting fuels such as coal. The debate has generated sufficient controversy in India to require a detailed analysis in terms of reserves, utilisation, allocation between alternate end-users and the associated costs. This paper is a preliminary foray into this field; a more detailed analysis of several of the aspects covered is, however, required.

The paper is divided into 3 sections: the first discusses the allocation of natural gas in the market on the assumption that neither reserves nor capital are constraints. Some aspects, not adequately quantifiable at present, have been qualitatively discussed in the section. The cost of generation of electricity from coal and gas (open and combined cycle) based plants, and the value added/replacement value of natural gas use in the fertiliser industry are also touched upon. The second part deals with the reserves (in the Western and Southern regions of the country) and expected demand and supply of fossil fuels and electricity till 2010. Section 3 covers the environmental costs of changing the additional coal based capacity to gas based generation.

PART I

Natural gas occurs either as gas in underground reserves (dry gas or free gas) or can be liberated from crude oil (termed as associated gas). Methane is the dominant component and comprises 75 to 95 per cent of the gas. The remaining portion is made up of higher hydrocarbons such as ethane, propane, butane, in decreasing fractions. Natural gas can also contain some sulphur compounds, eg. hydrogen sulphide, and other contaminants such as carbon dioxide, nitrogen, water, trace metals, etc. Prior to use natural gas requires treatment and purification (termed as sweetening). Given that the fractioned liquids from natural gas fetch a higher price in the market than the gas itself, it lies in the interest of the producers of natural gas to pipe/distribute only the stripped lean gas.

Given the abundant reserves of coal in the country and the existing infrastructure for its extraction and distribution, it is unlikely that a widespread replacement of this fuel will occur in the near future. Further constraining the switchover to gas is the uncertainty surrounding the estimates of gas reserves, which makes it difficult to commit investment for its utilisation. Thus, for most regions where coal is easily available at a low cost, i.e. where the costs of transportation are not significant, it would remain the preferred fuel (assuming no pollution/carbon taxes are levied). However, in regions characterised by large industrial agglomerations and long distances from a coal source, alternate fuel sources would have to be considered on a priority basis. One state that does face such constraints is Gujarat. Given Gujarat's location - distant from coal sources but close to gas reserves - combined with the existence of several industrial towns, the continued use of coal from neither an economic nor environmental viewpoint can be justified. Hence, while a case for the increased utilisation of gas within the state can be made, the intersectoral distribution of the gas would have to be worked out.

For most regions, competitive claims would be made on the limited reserves of gas. In such regions or in regions where supply falls short of demand, allocation of the limited resource would be best achieved on the basis of the imputed value of the gas or value added. The imputed value of gas basically is the value of gas at which the cost per unit output from the gas based plant is equal to the cost per unit from a plant based on an alternate fuel/feedstock. In other words, it is the consumer's prices based on his willingness to pay. Despite the fact that the fertilizer and power sectors currently consume the bulk of the gas sold, several other end users, such as sponge iron units, are foreseen.

The estimate of the imputed value of gas depends on the distance of movement of the alternate feedstock/fuel and the consumption norms used. Hence, the imputed value of gas would have to be estimated on a location specific basis.

Review of Economic and Financial Costs of Natural Gas

Several estimates of the imputed value of gas for various end uses are available; some of which compute both the financial and economic replacement cost.

Sub group on natural gas availability, distribution and utilisation

The most recent estimate is that of the Report of the Sub-group on Natural Gas Availability, Distribution and Utilization, Eighth Five Year Plan (1990 - 1995). The sub-group estimated the imputed value of gas for the Bombay region. The results were as given below:

Table 1 : Economic replacement value

Use	Fuel Replaced	Price (Rs/1000 cu.m)
Peak load power	HSD	4337
Sponge iron (w quality improvement)		3700
Intermediate load power	HSD	3513
Peak load power	Naphtha	3502
Peak load power	Fuel oil	3000
Methanol	Naphtha	2813
Sponge iron (w/o quality improvement)		2770
Fertiliser	Naphtha	2728
Intermediate load power	Naphtha	2679
Base load power	Coal	2655
City gas distribution	LPG	2548
Intermediate load power	Fuel oil	2021

It can be seen that the maximum value added for gas is in its use for peak load power replacing fuels like HSD, naphtha and fuel oil. Use in the fertilizer sector, replacing naphtha has a higher value than the replacement of coal in base load power. If the above study were to form the basis for the distribution of gas, gas use would primarily be for meeting peaking power requirements. In regions where existing hydel capacity is limited or further expansion is constrained (eg. southern and, to limited extent, the western region), this might be useful, unless it replaces the existing hydel peaking capacity.

<u>Kelkar Committee</u>

The Report of the Committee on Pricing of Natural Gas, Department of Petroleum and Natural gas, May 1990 (also referred to as the Kelkar Committee Report) has calculated both financial and economic replacement costs of natural gas for 2 cases for fertilizer and power plants; Case I where both gas and coal based plants operate for 5500 hours per annum and the naphtha based fertiliser plants operate at 80 per cent efficiency; and Case II where gas based power stations operate for 7000 hours per year and the fertiliser plants operate at 90 per cent efficiency, as against 5500 hours for a coal based plant and 80 per cent efficiency for naphtha based fertilizer plants.

Table 2 : Financial Replacement Value of Natural Gas (1989 prices)

	Price (Rs/1000 cu.m)
Fertiliser	
Case I	2495
Case II	2951
Power	
Case I	
Pithead	1942
500 km	2503
1000 km	3024
Case II	
Pithead	2199
500 km	2760
1000 km	3280

Table 3 : Economic Replacement Value of Natural Gas (1989 prices)

	Price (Rs/1000 cu.m)
Fertiliser	
Case I	2784
Case II	3258
Power (coal)	
Case I	
Pithead	1917
500 km	2289
1000 km	2519
Case II	
Pithead	2196
500 km	2567
1000 km	2797
Power (fuel oil)	2082
Sponge iron plant	3760

For sponge iron plants, the economic replacement value is Rs.3760 per thousand m^3. Given that this is the highest (replacement) value, it indicates that adequate incentive exists to switch from coal to gas.

Given that gas stations do operate at higher efficiencies, the estimates derived in Case II appear to be more relevant. The results indicate that the replacement of coal in sponge iron plants is the most efficient, followed by naphtha in fertilizer plants and coal in thermal power stations.

<u>Advisory group on perspective plan for natural gas</u>

Based on the Advisory Group on Perspective Plan for Natural Gas, the imputed value (1990-91 prices) for natural gas in various end-use sectors was as given below:

Table 4 : Imputed Value of Gas (1990-91 prices)

Use	Fuel Replaced	Price (Rs/1000 cu.m)
Peak load power 1500 km	coal	2921
Base load power 1500 km	coal	2856
Peak load power 1000 km	coal	2761
Base load power 1000 km	coal	2610
Peak load power 500 km	coal	2600
Methanol	naphtha	2514
Fertiliser	naphtha	2466
Peak load power	naphtha	2407
Base load power 500 km	coal	2368
Peak load power	HSD	2296
Base load power pithead	coal	1975
Sponge iron	coal	1909
Peak load power	fuel oil	1776
City gas distribution	fuel oil	1708
CNG road transport	diesel	1154
Fertiliser import	urea	735

Assumptions for the above table:

1. Fertilizer consumption as per normative figures
2. For peaking stations, coal replacement also considered since coal based plants are run on partial load to meet the requirement.

This study is the only one to conclude that replacing coal by natural gas in base load generation would yield a higher imputed value to gas. All other studies recommend the replacement of coal by natural gas for peaking purposes. The next best option generally is the replacement of naphtha and fuel oil in the fertiliser sector.

Projects and Development India Limited

The most dated study on the economic price of natural gas was conducted by the Projects and India Development Limited (PDIL) in 1985. While, the study might not be of direct use in deciding the current economic replacement value of gas in different end-uses, it could aid in the ranking of alternatives. Adopting this as a yardstick, however, assumes that inflation in all sectors has been uniform.

Table 5 : Economic Price of Natural Gas Rs./1000 m^3

	Natural gas	Naphtha	Fuel oil
Fertiliser	-	3080	4672
Thermal energy* use in			
(a) domestic and commercial	4461		
(b) industrial	2510		
Thermal power (captive)	3063		
Methanol	2977		
Hydrogen	2658		
Oxo alcohol	2651		
Utility power (CC)	2036		
Sponge iron	1986		

* for Vadodara

The study concludes that the most advantageous use of natural gas lies in its replacing fuel oil in the fertiliser industry. This is followed by substitution in the domestic and commercial sector, and then in the fertiliser industry, replacing naphtha. Replacement of coal in the utilities for base load generation yielded a lower value of gas than its alternate use in producing methanol.

Summary and critical analysis

Most of the estimates made in the various studies are limited by the paucity of firm cost data. Further, if environmental impacts are also included, i.e. ash disposal problem that arises from coal combustion, the replacement values, for cases where gas replaces coal, could be expected to increase.

Table 6 : Comparison of the Studies (Rs/1000 m³)

Use	Fuel Replaced	VIII plan (current 1990-91 prices)	Kelkar committee (1989 prices)	Advisory group (1990-91 prices)	PDIL (1985 prices)
Peak load power	HSD	4337		2296	
Sponge iron (w quality improvement)		3700	3760	1909	
Intermediate load power	HSD	3513			
Peak load power	Naphtha	3502		2407	
Peak load power	Fuel oil	3000	2082	1776	
Methanol	Naphtha	2813		2514	2977
Sponge iron (w/o quality improvement)		2770			1986
Fertiliser	Naphtha	2728	3258	2466	3080
Fertiliser	Fuel oil				4672
Intermediate load power	Naphtha	2679			
Base load power pithead	Coal	2655	2196	1975	2036
City gas distribution (domestic and commercial)	LPG/ fuel oil	2548		1708	4461
Gas distribution (industrial)	LPG/ fuel oil				2510
Intermediate load power	Fuel oil	2021			3063
Hydrogen					2658
Oxo alcohol					2651
CNG road transport	diesel			1154	
Fertiliser import	urea			735	
Peak load power 1500 km	coal			2921	
Base load power 1500 km	coal			2856	
Peak load power 1000 km	coal			2761	
Base load power 1000 km	coal		2797	2610	
Peak load power 500 km	coal			2600	
Base load power 500 km	coal		2567	2368	

All the studies reveal higher economic prices of natural gas substituting naphtha in fertiliser plants as compared to replacing coal at pithead power stations. However, it only the Advisory group that suggests that replacement in coal based power stations 1000 kms away from the coal source has a higher economic value. Economic prices arrived at by the various committees appear to show consistency for substitution options like naphtha in fertiliser plants. This, however, has to be viewed in light of the fact that the costs have been arrived at for different years and a true comparison would involve bringing all prices to a common base. This requires the development of inflation indices for all the uses of natural gas, something beyond the purview of the study.

A point to note is that since the cost of coal varies with the distance over which it is transported (as against a flat rate for gas supplied through the HBJ pipeline), the cost of (electricity) generation is sensitive to the distance over which the coal is transported. A 10 per cent change in capital costs of transport infrastructure is estimated to result in a 1.7 per cent change in cost of generation (TERI, 1987). Such considerations do enter into the analysis when a specific state like Gujarat is considered. Most of the studies indicate that substitution of fuel oil and naphtha in fertiliser plants yield a higher value added than for base load generation, replacing coal. Hence, if the market were to allocate the gas independent of external levies, replacement in the fertiliser industry is the most efficient.

Current economic price of natural gas

In the course of the study, an attempt was made to estimate the replacement value of natural gas at fertiliser plants and at power stations. For the fertiliser plants cost data for natural gas based plants was obtained from Projects and Development India, Limited (PDIL), NOIDA. Based on the capital investment estimates obtained from here, the capital costs given in the PDIL, Sindri (1985) report on the Economic Gradation for Consumers of Natural Gas, were inflated to 1991 prices. (As a cross check, inflation in the fertiliser industry at current prices was also calculated. Both were found to tally, i.e. 11 per cent).

Table 7 : Cost of Production of Fertilisers

	Natural gas	Naphtha	Fuel oil
Investment (Rs. crores)	509	548	512
Foreign Exchange Premium (Rs crores)	51	55	51
Cost (Rs. crores)	559	603	563
Annual capital cost/unit output (Rs./t)	10	11	15
O & M/unit output (Rs/t)	1883	3580	4231
Cost/unit (w/o fuel) (Rs/t)	1893	3591	4246
Fuel (Rs/t)			
natural gas	4024		
naphtha		6723	
fuel oil			8054
water	8	1	1
electricity	105	226	410
Total (Rs/t)	4137	6950	8465
Total Cost (w fuel) (Rs/t)	6030	10541	12711
Replacement value	-	9043	11213

The assumptions and data on which the above table is based are

a. costs of natural gas based plants were obtained from PDIL, NOIDA. Based on these estimates and those available in the PDIL, Sindri study, 1985, all figures in the study were appropriately inflated to arrive at current day (1991) prices. From the above method as well as from the price index (National Accounts Statistics) the average rate of inflation of fertilizer infrastructure/investments was found to be 11 per cent per annum.

b. On the same comparative basis mentioned above, O & M costs in the fertilizer industry were found to inflate at the rate of 19 per cent per annum.

c. The apportioning of O & M costs between ammonia and urea plants in naphtha and fuel oil base fertiliser plants was assumed to be in the same proportion as that in natural gas based plants.

d. Specific energy consumption in naphtha and fuel oil based plants was taken from the 1985 PDIL study. This, therefore, ignores any efficiency improvements in these two technologies over the years.

e. Efficient prices for natural gas and fuel oil were obtained from the TERI, 1991 study on Integrated Energy Pricing. Since the study had not included an estimate of the price of naphtha, export prices for the financial years were obtained from the Petroleum and Natural Gas Statistics, 1990-91. Based on the price index, this was extrapolated for the year 1990-91.

f. Transportation costs for coal and fuel oil were obtained from the RITES study, 1985. Using the inflation rate for the railways, the cost per unit transported was computed in current (1991) prices.

g. The capital costs for fertilizer units have been assumed to include capital servicing charges. h. A utilization rate of 90 per cent has been assumed for all fertilizer plants.

h. The imported component of the capital has been taken as 25 per cent, based on discussions at PDIL, NOIDA, and a premium of 40 per cent has been added, since the estimates pertain to the period prior to the decontrol of foreign exchange.

i. A 12 per cent discount rate has been assumed on the capital costs.

The analysis reveals that the highest replacement value of gas occurs with the replacement of fuel oil, followed by naphtha, in fertiliser production. This is consistent with the conclusions of most of the studies conducted so far.

An similar attempt to estimate the costs of generation in the power sector was carried out. The analysis does not include pollution control costs, except for electrostatic precipitators in coal based power plant since their installation is mandatory. Tables 8 and 9 summarise the main assumptions underlying the estimates (given in Table 10).

Table 8 : Power Plants Comparative components

	TPS	GT	CCP
Capacity (MW)	420	373	362
Units sent out (GWh)	2079	2079	2079
Auxiliary consumption(%)	0.1	0.05	0.02
Gross generation (GWh)	2311	2189	2122
Plant load factor (%)	0.628	0.735	0.735
Coal consumption (tpa)	1892440		
Fuel oil consumption (kl)	18484		
Gas consumption (mcm)		692	499
Economic life (years)	25	15	15
Interest (%)	0.12	0.12	0.12
Interest during construction (%)	0.07	0.07	0.07
CRF	0.1275	0.1468	0.1468
O & M costs	0.025	0.025	0.025

TPS - Thermal Power Station
GT - Gas Turbine
CCP - Combined Cycle Plant

Table 9 : Phasing of Investment (%)

Phasing of investment			
	TPS	GT	CCP
year 1	0.10	0.15	0.15
year 2	0.25	0.30	0.30
year 3	0.30	0.40	0.40
year 4	0.30	0.15	0.15
year 5	0.05		

Table 10 : Comparative Cost of Generation

	TPS	GT	CCP
Investment + interest during construction (Rs million)	16	245	249
Annual Capital Cost (Rs)	2063659	35980579	36543200
O & M (Rs)	404639	6126471	6222270
FUEL (Rs)			
coal charge	1.34e+09		
fuel oil charge	7.20e+07		
natural gas charge		1.04e+09	7.47e+08
fuel charge	1.42e+09	1.04e+09	7.47e+08
Total Cost (Rs)	1.42e+09	1.08e+09	7.90e+08
Cost/unit generated (Rs/kWh)	0.614	0.492	0.372

The underlying assumptions and data are as given below

a. It has been assumed that the gas turbine availability is 90 per cent (TERI, 1985, for GAIL), and the load factor is 81.7 per cent. This is assumed to hold for both the gas turbine as well as the combined cycle plant. The two were used to determine the utilisation factor (73.53 per cent).

b. The ratios of installed capacity of gas and steam turbines has been assumed to be 1:0.48

c. In computing the total installed capacity of the gas based plants a 9 per cent allowance for deterioration in operating conditions has been made.

d. Auxiliary consumption for the plants has been considered as follows 2 per cent for the CCP, 5 per cent for the open cycle plant, and 10 per cent for the TPS.

e. Efficiencies of the three units have been assumed at 43 per cent for the CCP, 32 per cent for the open cycle and 30 per cent for the TPS.

f. Calorific value of the fuels have been taken to be 8500 kcals/cu.m for gas and 3500 kcals/kg for coal.

g. Capital costs were obtained from NTPC and were for the latest projects. All costs have been converted to 1991 prices using a 10 per cent rate of inflation. For gas projects, the investment in a spur line 20 kms long has also been included. Interest during construction was taken to be 7 per cent per annum.

h. Disbursement profiles for the three schemes have been obtained from CEA and a 7 per cent interest rate during this period has been assumed.

i. The imported components of the three plants have been obtained from NTPC and were 66 per cent for a TPS, 50 per cent for an open cycle plant and 55 per cent for a CCP. A 40 per cent premium has been added to this portion of the investment.

j. Economic price of gas and coal were obtained from the pricing study (TERI, 1991). The price of gas at landfall point was used while for coal pithead values were taken. Transportation costs from the RITES study,1985 were brought to 1991 prices using an inflation rate of 11 per cent for the railways (National Account Statistics, 1990-91)

k. Fuel consumption was determined on the basis of the efficiency of the system and the calorific value of the fuel.

l. Auxiliary consumption (of fuel oil) in a TPS was the norm given by NTPC.

m. Economic life was as mentioned by NTPC, i.e., 25 years for a TPS and 15 years for both the open cycle plant as well as the CCP.

n. A 12 per cent discount rate on capital costs has been assumed in determining the CRF.

o. O & M costs for all three systems was taken as 2.5 per cent of the capital investment.

The above analysis yielded per unit costs of generation in the three systems. With high efficiencies of operation and a high calorific value of the fuel, the generation costs for a CCP are the least. If pollution control costs were to be added, costs of coal based generation would increase more than the others, since the removal of additional pollutants of particulates and ash disposal would be necessary. All systems would require controls for oxides of sulphur (if the gas has not been sweetened prior to combustion) and nitrogen.

Based on the results arrived at above, the study attempted to determine the economic, efficient price of natural gas in the two sectors, substituting three fuels. The results are as tabulated below.

Table 11 : Economic Price of Gas

Use	Fuel replaced	Rs./1000 cu.m
Fertiliser	Naphtha	9256
Fertiliser	Fuel oil	11477
Power station (1072 km)	Coal	1114

The results indicate that the maximum price, in terms of replacement value, of natural gas is when it is substituted for fuel oil in the fertiliser industry. The second best is the substitution of naphtha in the same industry, followed by the replacement of coal at a power station located 1072 kms away. Hence, if the market were to allocate natural gas, the demands of the fertiliser industry would be met prior to that of the power sector (for base load generation).

Substitution in the domestic sector

Currently there exists a major debate as to whether natural gas should be used for electricity generation or industrial sector applications, given the acute domestic fuel shortage facing the country. The current domestic fuel mix reveals a major share of traditional fuels, commercial energy contributing less than 50 per cent of the consumption. The effort in the subsequent section is to highlight the issues in the use of natural gas in the domestic sector.

The C3/C4 portions of the enriched stream of natural gas are fractioned out for the production of LPG. The gas left is basically comprised of lean gas (C1 fraction), with some part of C2 and C3 fractions. Depending on demand, these fractions of C2 and C3 are important feedstock in the petrochemical industry. Hence, the fraction traditionally left behind for meeting thermal energy requirements of the industrial, power and domestic sectors is the C1 stream. This comprises 75 - 95 per cent of the volume of the gas. The calorific value of this stream, which is primarily composed of methane, is around 8500 kcals per cubic meter (cu.m).

If one were to assume that only two competing demand sectors existed - the industrial and domestic sectors - and the allocation of the lean gas between the two was to be based solely on the basis of the willingness-to-pay criteria, the industrial sector would pre-empt a majority of the supplies. Within the domestic sector itself, the issues are complex. Replacement values of natural gas would have to be considered for a number of substitution options, eg. firewood, kerosene, and LPG. Given that kerosene is highly subsidized, a replacement with natural gas would never be cost effective to the consumer, if only convenience and market prices were considered. Hence, the argument on gas use in the domestic sector centres on the direct use through a distribution network thereby releasing LPG for use in other regions or expansion of existing LPG distribution facilities and piping the gas to areas not currently under the LPG distribution system. If convenience and ecological/environmental considerations are added, the viability of LPG or natural gas might be proved.

Natural gas can be directly used in the domestic sector, through a distribution network. Such a facility would involve a substantial investment in the supply network and would be limited to areas near gas reserves (in the case of off-shore gas, to the landfall point). On a comparative basis, the distribution of the same quantity of gas to industries would be substantially cheaper, given the tendency of industries locate at a nodal point. In the domestic sector, given the interests and political compulsions of various groups in the economy and the consumer education required, city gas distribution networks appear to be the most likely, thereby resulting in the replacement of LPG. A counter argument put forth is that such a distribution network would release LPG stocks currently being used to meet the city's demand for distribution in areas short of LPG (in most cases smaller urban centres). In this case what has to be considered is the desirability of replacing the existing LPG bottling and distribution network with a new infrastructure for piping the gas to houses. However, the replacement would occur between equally efficient fuels, varying only in terms of locational availability. The extension of facilities that are both more efficient and ecologically friendly to areas that are currently deprived of access to these fuels might serve the cause of promoting social justice as well as reducing harmful environmental consequences of deforestation.

The section has reviewed past studies and has attempted to estimate the economic price of natural gas for various end uses. If the choice of using natural gas was solely between the fertiliser and power sectors and the market effected the distribution, the need of the fertiliser sector would be met first. However, despite not quantifying the replacement value of gas in the domestic sector, the demands of this sector cannot be ignored. Further study/analysis for the same would be required.

PART II

This section deals with the current reserves and demand/supply scenarios in the country. As of 1991, the proven and indicated balance recoverable resources of natural gas were 730 billion cu.m. (bcm). These reserves are located mainly along the west coast between the Gulf of Cambay and Bombay and in the NE region of Upper Assam. This can be broadly disaggregated as (i) Bombay high offshore basin (484 bcm), (ii) Cambay Basin (93 bcm), (iii) Upper Assam (includes reserves in Tripura, Nagaland, Tamil Nadu, Arunachal Pradesh and Andhra Pradesh) (152 bcm), and (iv) Rajasthan (1.22 bcm). A part of the natural gas occurs as associated gas, the production of which is related to fuel oil production.

National gas consumption is still extremely low with well over 40 per cent of the gas produced being flared. Industry accounts for approximately 98 per cent of gas consumed, largely in the fertilizers and petrochemicals industries (non-energy) and for power generation.

A break up of gross production in 1990-91 shows onshore production at 3916 million cubic metres (mcm), with upper Assam accounting for 2011 mcm, Tripura and Tamil Nadu for 180 mcm and Gujarat 1696 mcm. Most of the production was from the offshore source of Bombay High, i.e., 14082 mcm. Gross and net production can further be stated in the following:

Table 12: Gross and Net Production of Natural Gas@ (million cubic metres)

	Gross Production	Re-injected	Flared	Net Production
Gujarat	1696	-	402	2194
Assam	2220*	102	681	1437
Bombay High	14082	-	4047	10035
Total	17998	102	5130	12766

* includes Tripura/Tamil Nadu & Andhra Pradesh
@ Provisional estimates

Industry wise offtakes of natural gas reveal that about 74 per cent is consumed for power generation and in the fertilizer industry. The trend can be seen from Table 13.

Table 13 : Industry-wise off takes of Natural Gas Energy Purpose (million cubic metres)

	Power Generation	Industrial fuel	Tea plantation	Domestic fuel	Captive use/LPG shrinkage	Total
1970-71	261	116	15	-	68	460
1974-75	354	164	29	6	80	633
1980-81	492	163	45	14	176	890
1984-85	1454	250	62	18	721	2505
1990-91*	2211	1178	71	47	1178	5285

Table 13 : (cont.) Non-energy purpose

	Fertilisers	Petro chemicals	Others	Total	Grand Total
1970-71	187	-	-	187	647
1974-75	318	-	-	318	951
1980-81	611	5	16	632	1522
1984-85	1603	10	23	1636	4141
1990-91*	7345	38	98	7481	12766

* Provisional

While the trends have been as mentioned above, the Varadarajan report recommended that preference be given for the supply of gas to the power sector. This has been suggested, given that the option to import fertilizers exists and is simultaneously a less expensive alternative. Further, since capital costs of gas based power plants are lower and gestation periods shorter than for coal based plants, gas generation has been encouraged in the VIII Plan. The report also mentions that for gas to be provided for base load generation, the power station should necessarily be far way from pitheads and use associated gas. Free gas, given the greater control possible, should be used for peaking purposes.

Future demand scenarios

In order to estimate future gas demand scenarios, an attempt has been made to provide snapshot pictures of future energy demands, based on past growth and patterns and energy demand. Sectoral growth patterns have been were estimated and useful energy norms applied; the useful energy norms being distributed over various fuel alternatives accounting for efficiencies of utilization, availability of fuel types and present distribution patterns. Future scenarios are computed on the basis of a GDP growth rate of 5 per cent per annum and a population growth of 2.01 per cent per annum till 1999-2000 and 1.81 per cent per annum thereafter.

In all subsequent sections the focus will be on the southern and western regions, given that the principle aim here is to determine the viability of gas based power stations in these regions.

Electricity

Past trends reveal that electricity demand over the last two decades has grown at an annual average rate of 8 per cent and that of coal and oil at 5.6 & 5.8 per cent respectively. Based on the above assumptions, the growth in electricity demand over the next 20 years is expected to be around 6 per cent. This could be a result of factors like conservation, more efficient use (of energy) in agriculture, technology/process change in industry, etc. However, natural gas consumption increases at nearly 9 per cent annually.

Demand projections for electricity, disaggregated to the regional level reveal that demand in industry grew the most rapidly followed by that of the domestic and transport sectors. Projections till the year 2009-10 are given the tables below:

Table 14 : Demand projections for electricity (GWh)

1989-90	Western	Southern	All India
Industry	32873	25077	90604
Transport	1055	1015	4933
Domestic	11060	7821	33840
Agriculture	7484	9414	45302
Others	5830	4814	19409
Total	58302	48140	194088

Table 15 : Demand projections for electricity (GWh)

1994-95	Western	Southern	All India
Industry	47807	36137	128130
Transport	1320	1209	6078
Domestic	13849	11259	47375
Agriculture	18802	16400	92175
Others	9086	7223	-
Total	90863	72228	

Table 16 : Demand projections for electricity (GWh)

1999-2000	Western	Southern	All India
Industry	65622	51393	175365
Transport	1435	1310	6801
Domestic	15896	13955	58818
Agriculture	21464	19143	105211
Others	11602	9523	38466
Total	116019	95233	384661

Table 17 : Demand projections for electricity (GWh)

2004-2005	Western	Southern	All India
Industry	93370	72712	247748
Transport	1998	1752	9421
Domestic	18106	17287	73445
Agriculture	24540	22365	120389
Others	15335	12680	50111
Total	153349	12696	501113

Table 18 : Demand projections for electricity (GWh)

2009-2010	Western	Southern	All India
Industry	134712	106791	359369
Transport	2772	2337	12998
Domestic	22743	21657	94946
Agriculture	28095	26157	138021
Others	20925	17438	67259
Total	209247	174379	672593

In terms of percentage shares, the electricity consumption in the industrial sector is expected to increase from the present level of approximately 47 per cent to over 53 per cent in 2009-10. Shares of both domestic and agricultural sectors are expected to decline to 14 & 21 per cent from 17.5 and 23 per cent, respectively. The all India peak demand is estimated to increase from 42000 MW in 1989-90 to 115000 MW in 2009-10. The lower rate of growth of peak power as compared to that of electricity will probably be due to the increasing share of the industrial sector which has a relatively smoother load profile vis-a-vis the domestic sector.

Fuel demand

Looking at primary fuel source (coal, oil and gas) requirements to meet power demand in the two regions over the next 20 years, one finds that demand for the three fuels increase substantially.

Table 19 : Demand Projections for Coal (MT)

Year	Western	Southern	All India
1989-90	40	20	115
1994-95	59	29	169
1999-2000	74	40	222
2004-05	90	56	287
2009-10	115	80	389

The share of the power sector in total coal consumption is expected to increase from about 57 per cent to 60 per cent. This will be at the expense of the industrial sector. The percentage share of the western region in total coal consumption is expected to decrease, while that of the southern (and northern) regions increase.

Table 20 : Demand Projections for Oil ('000 t)

Year	Western	Southern	All India
1989-90	451	912	2609
1994-95	655	1327	3794
1999-2000	907	1667	4998
2004-05	1253	2023	6451
2009-10	1802	2587	8759

The share of both the western and southern regions in total oil consumption increase marginally in the period 1994-95 but remain constant thereafter. Overall, the share of power (in total oil consumption) is expected to remain constant i.e., around 5 per cent. Demand projections for natural gas are as indicated in Table 21.

Table 21 : Demand Projections for Natural Gas (mcm)

	Western	Southern	All India
1989-90			
Industry	2942	942	5870
Power	1230	353	3380
Total	4172	1295	9250
1994-95			
Industry	3237	1037	6458
Power	6138	1760	16869
Total	9375	2796	23327
1999-2000			
Industry	5308	2003	10779
Power	9774	2702	25969
Total	15083	4704	36748
2004-05			
Industry	7874	2996	15929
Power	11547	3273	30875
Total	19421	6269	46804
2009-10			
Industry	11959	4624	23924
Power	14366	4181	38673
Total	26325	8805	62597

The table indicates a likely increase in natural gas consumption at the rate of 9 per cent per annum over the period 1989-90 to 2009-10. The power sector would account for close to 62 per cent of this demand; the rest by industry. The shares of the western and southern regions in total consumption are expected to increase.

Overall a change in the fuel mix is expected, with the south increasing its share of both coal and gas consumption (and electricity as well), and the west reducing its dependence on coal by increasing the use of gas.

Energy supply

Supplies of major fuels have been considered. Traditionally supplies of most major conventional, commercial energy sources have been constrained by the non-availability of capital resources. Energy supply scenarios till the year 2010 have been constructed, keeping in mind the resource constraints and consistent with energy demand projections. This has been done by extrapolating the relationship between GDP and actual/planned investment in the energy supply subsectors.

Based on the above, the comparative availability of the three major fuel forms has been considered.

Table 22 : Estimates of Projected Coal Production (MT)

UG/OC	CC/NCC	1989-90	1994-95	1999-2000	2004-05	2009-10
Western	Total	75.2	86.7	99.2	114.0	125.9
OC	CC	0.9	1.2	1.5	1.8	2.0
OC	NCC	54.1	70.9	88.4	106.9	120.61
UG	CC	2.5	1.8	1.2	0.7	0.4
UG	NCC	17.6	12.8	8.1	4.7	2.9
Southern	Total	17.8	36.8	42.4	47.3	47.8
OC	CC	-	-	-	-	-
OC	NCC	7.5	23.4	29.4	36.0	37.5
UG	CC	-	-	-	-	-
UG	NCC	10.3	13.4	12.9	11.4	10.3

UG: underground
OC: opencast
CC: coking coal
NCC: non coking coal

All India production of coal has been divided over regions on the basis of the percentage share of total coal reserves in each region. The distribution of coking and non-coking coal is assumed in a similar fashion. Total coking coal production is projected at over 141 Mt by 2009-10, a major portion of which would be of poor quality, most suitable for use in industrial/utility boilers as fuel.

Lignite production, as a percentage of total coal production, is assumed to remain the same, i.e. 5.7 per cent. Given that major reserves are in Tamil Nadu, production for the southern region is maximum.

Table 23 : Estimates of Projected Lignite Production (MT)

Region	1989-90	1994-95	1999-2000	2004-05	2009-10
Western	1.1	1.9	2.0	2.1	2.2
Southern	10.5	14.8	20.0	26.4	34.5

So far, only about 25 per cent of the prognosticated hydrocarbon reserves have been proven. Certain indices with regard to basins in the southern and western regions are provided below.

Table 24 : Hydrocarbons - Basin Particulars

	Prognosticated reserves (mtoe)	Reserve /Production ratio	Expected discovery index (t/m)	Total Development drilling cost (Rs/m)	Gas oil ratio (cm/t)
Onshore	7772				
Western Region					
Cambay	1650	10	188	10917	249.9
K. Saurashtra	263	15	257	10917	835.1
Southern					
K.Godavary	217	15	286	16702.2	2796.5
Cauvery	166	15	273	10917	835.1
Offshore	12773				
Western Region					
K. Saurashtra	497	15	832	46324.8	436.9
Bombay High	7390	15	701	39258	455.8
Southern					
K.Godavary	543	15	1374	46324.8	549.8
Cauvery	374	15	643	43183.8	829.1
Kerala Konkan	1630	15	696	39259.8	2919.2

Projections of associated gas production indicate an annual average growth rate of 7.24 per cent; the potential increasing from 18.10 bcm to 53.13 bcm in 2009-10.

Table 25 : Projections of Associated Gas Production (bcm)

	1989-90	1994-95	1999-2000	2004-05	2009-10
Onshore					
Western Region					
Cambay		1.652	1.767	1.889	2.020
K. Saurashtra		0	0.001	0.002	0.051
Total		1.652	1.768	1.891	2.070
Southern					
K.Godavary		0.008	0.049	0.283	1.653
Cauvery		0.209	0.315	0.475	0.715
Total		0.218	0.364	0.758	2.368
Offshore					
Western Region					
K. Saurashtra		0	0.001	0.005	0.265
Bombay High		14.996	18.528	22.892	28.285
Total		14.996	18.529	22.897	28.550
Southern					
K.Godavary		0.212	0.452	0.963	2.052
Cauvery		0	0.006	0.106	1.882
Kerala Konkan		0	0	0.006	1.046
Total		0.212	0.458	1.076	4.979
TOTAL					
Western		16.648	20.297	24.788	30.62
Southern		0.43	0.822	1.834	7.348

The power supply industry in India is one of the fastest growing subsectors. It is estimated that about 25150 MW of new capacity will be added between April 1990 and March 1995, 29750 from April 1995 to March 2000, 34480 MW from April 2000 to March 2005 and 51770 MW between April 2005 & March 2010. The gross and net generation in the western & southern regions are as detailed below:

Table 26 : Projections for Gross & Net Generation (GWh)

	1994-95	1999-2000	2004-05	2009-10
Gross generation				
Western				
Coal	90719	113994	138298	176924
GT/CCP	21805	34720	41020	51030
Southern				
Coal	44801	62049	85667	123201
GT/CCP	6251	9597	11627	14854
Net generation				
Western				
Coal	81647	102594	124468	1592328
GT/CCP	21260	33852	39995	49754
Southern				
Coal	40321	55844	77100	110881
GT/CCP	6095	9357	11336	14483

The table has been constructed from projections of capacity addition on the basis of the following assumptions (a) for coal fired plants, gross generation is 4900 kWh/kW installed capacity and 10 per cent of gross generation, (b) for gas fired plants, gross generation is 7000 kWh/kW and auxiliary consumption 2.5 per cent of gross generation, (c) specific consumption of coal is 0.65 kg/kWh and gas 0.2815 cum/kWh, (d) efficiency of a TPS is 30 per cent and a CCP 43 per cent.

Table 27 : Coal Shortage (MT/y)

	1994-95	1999-2000	2004-05	2009-10
NCC				
Western	15.6	25	39.2	69.1
Southern	12.6	22.7	35.4	67.2

Table 28 : Demand Shortfall of Gas (bcm)

	1994-95	1999-2000	2004-05	2009-10
Western	-	-	-	-
Southern	2.366	3.882	4.435	1.458

It is assumed that these shortfalls will be compensated by the increased production of free gas, thereby equating production to demand, keeping flaring negligible.

Table 29 : Power Shortage (%)

	1994-95	1999-2000	2004-05	2009-10
Western	1.02	0.32	7.19	12.33
Southern	20.17	19.78	22.16	22.45

Table 30 : Peak Shortage (%)

	1994-95	1999-2000	2004-05	2009-10
Western	10.45	9.76	14.44	17.61
Southern	7.91	10.36	16.01	18.38

The section gives an indication of the extent of reserves, though not abundant ones, in the country. Currently considerable speculation with regard to the estimation of reserves has been raised; the most contemporary thought being that the reserves have been overestimated. Hence, the previous expansion plans in terms of setting up gas based capacity are undergoing serious rethinking. The discussion above also suggests major shortages of power and peak load. Shortfalls in the supply of coal are also envisaged. There appears to be a shortfall in the availability of gas in the southern region to meet current planned expansion activities. Given this backdrop and that additional hydrobased power is unlikely, given interstate disputes, ecological problems long gestation periods and monsoon failure/lack of assured supply of water, the utilisation of gas for peaking purposes could be suggested as an initial step. Once a clearer picture on the reserves is known, the desirability of expanding gas utilisation networks can be investigated. The increased use of gas in the western region, however, can be suggested.

PART III

The preceding sections have individually highlighted on the viability of combined cycle plants vis-a-vis conventional coal plants and the current reserves of fossil fuels in India. Further, the forecasted trends in demand of electricity have been mentioned in order to focus on the expected CO_2 emissions in the coming years. While the viability of CCP is proven beyond doubt, its widespread application in India is suspect, given the limited reserves of gas and the current speculation surrounding the estimates of the reserves. The paper is not an attempt to prove or to suggest the retrofitting of all conventional coal plants in the Southern and Western regions of the country. Given the large reserves of coal in the proven category, it is unfeasible for such a widespread substitution to take place. However, there are certain regions such as Gujarat that are far from sources of coal but close to substantial gas reserves. For such regions the changeover to gas based generation might prove to be a cheaper alternative. However, were the changeover to be viewed purely from an environmental point of view, the suggestion would be to replace all coal based plants by gas based generation. (This would suggest that neither reserves nor capital are constraints, both of which are untrue for a country like India, but this aspect has been excluded from the analysis for the present). The replacement of a fuel with a high carbon value by a fuel with a lower value is environmentally more benign in terms of reduced CO_2 emissions. This sections, thus, attempts to estimate the costs associated with reducing CO_2 emissions.

Table 31 gives an estimate of the electricity requirements in the western and southern regions till the year 2010.

Table 31 : Projections of Gross Generation (GWh)

	Apl'90-	Apl'95-	Apl 2000-	Apl'05-
	March 1995	March 2000	March 2005	March 2010
Western Region				
Coal	90718.6	113993.6	138297.6	176924
GT/CCP	21805	34720	41020	51030
Total	112523.6	148713.6	179317.6	227954
Southern Region				
Coal	44800.7	62048.7	85666.7	123200.7
GT/CCP	6251	9597	11627	14854
Total	51051.7	71645.7	97293.7	138054.7

Given the above generation mix, the estimates of fuel consumption are arrived at on the basis of the following specific consumption norms coal consumption - 0.65 kg/kWh and gas consumption - 0.2815 cm/kWh (this is weighted average of the specific consumption in an open cycle and combined cycle plant in the ratio of 65:35). Table 32 gives the fuel requirements for the business-as-usual (BAU) scenario, while Table 33 gives fuel requirements for the case where only gas is used for power generation.

Table 32 : Fuel Requirements for BAU Scenario

	Apl'90	Apl'95	Apl 2000	Apl'05
	March 1995	March 2000	March 2005	March 2010
Western Region				
Coal (Mt)	59	74	90	115
GT/CCP (mcm)	6138	9774	11547	14365
Southern Region				
Coal (Mt)	29	40	56	80
GT/CCP (mcm)	1760	2702	3273	4181

Table 33 : Requirements of gas

	Apl'90	Apl'95	Apl 2000	Apl'05
	March 1995	March 2000	March 2005	March 2010
Western Region				
gas (mcm)	31675	41863	50478	64169
Southern Region				
gas (mcm)	14371	20168	27388	38862

The fuel mix outlined in Table 32 and 33 yield CO_2 emissions as mentioned in Tables 34 and 3

Table 34 : CO_2 Emissions from BAU Strategy (Mt)

	Apl'90	Apl'95	Apl 2000	Apl'05
	March 1995	March 2000	March 2005	March 2010
Western Region				
Coal	126.19	158.57	192.38	246.11
GT/CCP	21.62	28.21	31.43	36.54
Total	148	187	224	283
Southern Region				
Coal	62.32	86.31	119.17	171.38
GT/CCP	13.67	15.38	16.42	18.07
Total	76	102	136	189
Total	224	288	359	472

Table 35 : CO_2 Emissions from the Gas Option

(Mt)

	Apl'90	Apl'95	Apl 2000	Apl'05
	March 1995	March 2000	March 2005	March 2010
Western Region				
gas	67.94	86.42	102.05	126.89
Southern Region				
gas	36.55	47.07	60.17	80.98
Total	104	133	162	208

From Tables 34 and 35, the net reduction in CO_2 emissions consequent to the adoption of an all gas based generation policy are arrived at. These are given in Table 36 below.

Table 36 : Net Reduction in CO_2 Emissions (Mt)

	Apl'90	Apl'95	Apl 2000	Apl'05
	March 1995	March 2000	March 2005	March 2010
Western Region	79.87	100.36	121.76	155.76
Southern Region	39.44	54.63	75.42	108.47
Total	119.31	154.99	197.18	264.23

To arrive at the financial commitments for the two alternate strategies, costs derived in Part I of the paper have been used. The unit cost of generation from coal based plants is Rs 0.614/kWh and Rs 0.414/kWh for gas based plants (weighted average in the ratio of 35:65 for a GT and CCP).

Table 37 : Financial Requirements for Combined Strategy Rs. million)

	Apl'90	Apl'95	Apl 2000	Apl'05
	March 1995	March 2000	March 2005	March 2010
Western Region				
Coal	55723	70019	84948	108674
GT/CCP	9033	14383	16993	21140
Total	64756	84403	101941	129814
Southern Region				
Coal	27518	38113	52620	75675
GT/CCP	2590	3976	4817	6153
Total	30108	42088	57436	81828

In the case where only gas based generation capacity is installed, the investment requirements would be as given in Table 38.

Table 38 :Investment Requirements for Gas Strategy (Rs. million)

	April '90-March 1995	April '95-March 2000	April 2000-March 2005	April '05-March 2010
Western Region				
GT/CCP	46615	61607	74285	94433
Southern Region				
GT/CCP	21149	29680	40305	57191
Total	67763	91287	114590	151624

On the basis of the above, the cost per unit CO_2 abated works out to be Rs (-) 227.13864 /t CO_2 abated. This implies a net benefit from the switch over from coal based to gas based generation.

While the analysis does prove that switching from coal to gas is environmentally friendly and economic, for a country like India with limited reserves of natural gas, availability will have to be accorded due consideration prior to any investment decision/commitment being made.

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Legal Liability versus Administrative Regulation: The Problem of Institutional Design in Global Environmental Policy

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1. Introduction

The salient features of environmental damage are first, that they are external effects of the activities of others, and therefore a potential adversarial relationship exists between the agents responsible for the activity and the victims experiencing the externality. Second, that it is often extremely difficult, if not scientifically impossible, to categorically link a particular impact (e.g., degradation of a resource, onset of a disease) to a particular environmental cause (e.g., elevated GHGs concentrations, toxic water pollution). Further, even when damage can be definitely linked to specific environmental causes (e.g., "signature diseases" such as mesothelioma caused by asbestos exposure), it is frequently extremely difficult to identify which of many polluting agents bear responsibility. This is particularly true when the (variable) natural environment (e.g., "background radiation") is itself a significant source of environmental risk.

This characterization does not deny the fact that there may indeed exist environmental damage situations in which the cause as well as the party at fault can be unambiguously identified (e.g., the large scale toxic release at Bhopal). The point is that institutional design for regulating environmental risks should concentrate on situations of risk which are spatially and temporally diffuse, both in cause and in effect, because such cases are ubiquitous.

This paper seeks to contrast two distinct regimes for regulating environmental harms. The rival regimes are, first, a legal liability system, in which agents with claims to compensation[1] for injury confront alleged injurers in (environmental) courts. Second, and alternatively, an administrative regulation regime which seeks to regulate the activities themselves by means of policy instruments, which may be fiat or incentive based. In the latter regime, compensation (or adaptation costs) to victims may be provided, relying on resources generated by the application of the regulatory instruments. However, administrative regulation may employ such revenues for other policy objectives as well, or instead. While the administrative regulation regime may involve the oversight of courts by way of review of agency action and enforcement of regulatory requirements, the principal regulatory institution is administrative in character, rather than a court. The regimes are considered to be rival in the global environmental domain by

[1]We exclude from this discussion the question of criminal liability from environmental harm.

assumption, i.e. an institutional structure embodied in protocols for a given environmental problem would involve one and not both regulatory regimes. Employing both concurrently would place polluters in double jeopardy and, as a matter of judgement, would probably be acceptable. However, this assessment is tentative and future negotiations could possibly look at various combinations of the two regimes.

This paper is structured as follows: Sections 2 and 3 respectively discuss the fundamentals of legal liability and administrative regulation regimes. Section 4 looks at externality pricing, Section 5 at behavioral norms, and Section 6 at markets for rights, in each case, under both regimes. Section 7 reviews the international practice of legal liability, while section 8 does the same for the administrative regulation, in each case in relation to the environment. The last section discusses the feasibility of the alternative regimes for multilateral regulation of Global Warming.

2. Fundamentals of Legal Liability

Legal liability is the concern of civil disputes in courts. The defendant is liable when a court awards damages against him for harm or loss caused to a plaintiff. Legal scholars view liability law as pursuing three distinct objectives: compensating victims, deterring harmful actions, and spreading risk in society. Economists, by contrast, tend to analyze liability law in terms of (economic) efficiency in incentives and risk-bearing (Cooter: 1991). In liability law the term "perfect compensation" refers to a payment to the victim which restores him to his pre-harm level of welfare. In actual liability awards, compensation may equal, be lower than, or exceed the perfect compensation level. (In the latter case, the award is said to contain a "punitive" element). In some situations courts award an "injunction" i.e., an order to the defendant to perform a specific act, e.g., restore the previous condition of the property of the plaintiff. The device of injunctions avoids the necessity of making a monetary determination of harm, but clearly applies to a limited set of liability situations.

Three distinct concepts of legal liability figure in law. "Strict liability" requires the injurer to compensate the victim even if the injurer is not at fault in any moral or legal reckoning.[2] "Negligence rules" impose a legal norm of reasonable behaviour, and

[2]It is an established legal principle that liability can be imposed even for damage caused as a result of actions not necessarily prohibited by law. This is expanded upon below.

injurers are liable only when they fail to comply with the norm. Finally, "exchanges of liability rights" refers to a strategy enabling trades in such rights (in the context of a legal rule conferring such rights), as if they were property.

Legal institutions for determining legal liability are characterized by a focus on resolving individual disputes between particular parties, requiring each plaintiff to establish a reasonably clear cause and effect linkage between a defendant's activity and the plaintiff's harm.[3] The process is adversarial and the perspective is post-hoc, i.e., after the injury has occurred.

3. Fundamentals of Administrative Regulation

Administrative regulatory regimes, though backed by law, rely mainly on administrative institutions. The administrative agency typically seeks to regulate the level of activity causing environmental harm, either directly, by fiat type instruments, or indirectly, by incentive based instruments. (Net) revenues may be yielded in the application of the regulatory instruments, and may be employed in either compensating (actual or potential) victims, or as accretion to general revenues, or both. Revenues may exceed, equal, or fall short of the valuation of aggregate damage.

Three main classes of regulatory instruments which have been discussed in the literature, (and also employed in conventional environmental situations) are "pollution taxes", "standards", and "tradeable permits". Pollution taxes are levied on each unit of a specified pollutant discharged, thus pricing the external effect of the discharge to the polluter. Standards represent a norm of pollution emissions, (e.g., tonnes of TSPs that may be emitted by a given power plant in a year). This norm may be violated only at a cost, representing a penalty which may be an actual monetary payment, or some other (e.g., shutting down the offending plant). Tradeable permits are rights to pollute (by a given agent, over a defined region in a year) assigned by, or purchased from the regulator, which may be traded in a market for such rights.

Intuitively speaking, the three classes of regulatory instruments bear correspondence with the three legal liability doctrines. Strict liability and pollution taxes both price the externality to the polluter, while negligence rules and standards both

[3]In certain case involving significant damage, courts have shifted the burden of proof to the damage causing party.

impose behavioral norms whose violation results in a penalty. On the other hand, markets for liability rights and tradeable permits, both refer to voluntary exchanges of property rights over the externality.

3.1. Comparing the Institutions

In typical environmental harm situations with long periods of latency, transactions costs under legal liability regimes may be high, in relation to individual harms. Individual victims may, therefore, desist from suing, particularly if the burden of proof in such cases is on the plaintiff. While class action suits may reduce individual litigation costs, "sufficient" evidence still needs to be adduced to prove the fact of harm in respect of each plaintiff, that the harm was due to the particular environmental externality, which in turn is attributable to the activity of the defendant. The evidentiary burden is non-trivial even in the "clearest" of cases, and may be impossible where a cause and effect relationship cannot be scientifically established. Further, in the case of long latency periods, an identifiable, solvent defendant may not even exist, having declared bankruptcy or been long dissolved. Finally, given that liability damages are finally awarded, the defendant(s) pockets may not be deep enough, so that the plaintiffs remain (partly) uncompensated.

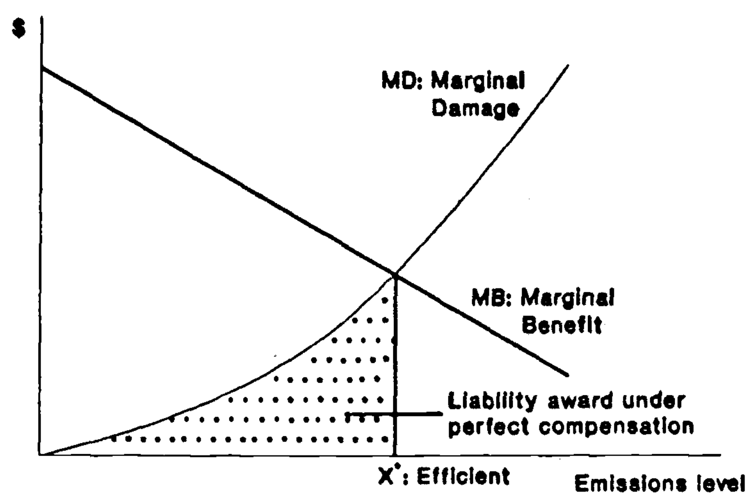
An administrative regulation system, on the other hand, relies on public institutions to reduce transactions costs in regulating environmental harms. Further, by exacting penalties, taxes, or collecting the proceeds of auctioned tradeable permits, at the time the activity causing harms is undertaken, it protects victims' interests from the possibility of injurers disappearing or being unable to meet liability obligations after the harm is manifest.

In addition, administrative regimes furnish an important source of flexibility in public policy. Since penalties etc. are not linked directly to harms, the revenues may be employed for policies which maximize societal welfare, rather than to simply compensate the specific harms. This may be especially relevant where victims are hard to identify, e.g., where lung cancer is contracted by non-smokers through exposure, among other things, to cigarette smoke exhaled by smokers. A pollution tax on cigarettes may yield incremental general revenues. These may be spent, for example, on infant care schemes, or sanitation, which may mean a large reduction in statistical deaths in society. This may be preferable from a societal welfare perspective in comparison to compensating by money a group of older lung cancer patients, whose condition is uncertainly (statistically) related to their exposure to cigarette smoke.

4. Externality Pricing : Strict Liability and Pollution Taxes

Both strict liability and pollution taxes are viewed by economists as devices to achieve efficiency by internalizing to the injurer the external social costs of the polluting activity. In the case of strict liability, if perfect compensation prevails, enforcement by courts is perfect and there are no transactions costs, (aggregate) marginal damage (MD) to victims equals the marginal benefit (MB) to the injurer. In this case the activity (pollution) level is efficient, assuming further that the polluter is risk neutral and rational. The situation is depicted in Figure 1.

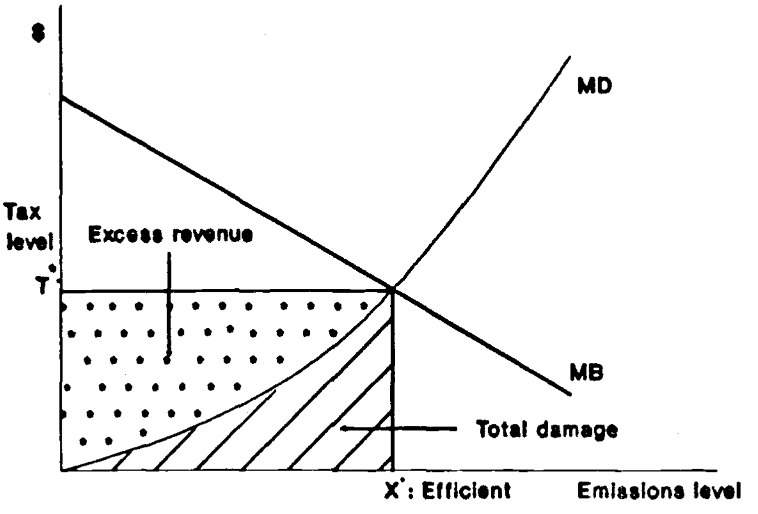
Fig 1: Efficiency in a Strict Liability Regime



Note that compensation to the victims flows directly from the liability award, and no payment in excess of the value of damage is extracted from the polluter, if compensation and enforcement are perfect.

A pollution tax regime, similarly achieves efficiency if the regulator has perfect knowledge of the MD and MB curves, and fixes the tax rate at the level where they are equal. Once again, we need to assume the absence of transactions costs and perfect enforcement, and that the polluter minimizes costs. In this case, revenues in excess of the total damage to victims is yielded, given conventional shapes of the MD & MB curves. The situation is shown in Fig. 2.

Fig 2: Efficient Pollution Tax



In the case of pollution taxes, compensation to victims requires a separate action of the regulator, and is not automatic. Determination of compensation amounts on the basis of valuation of actual damage may be costly.

4.1 Relaxing Some Assumptions

We now relax a few of the above assumptions. In the case of strict liability, actual compensation awards may be lower or higher than the efficient (perfect compensation) level. Under compensation may result from the practice of courts to disallow "ephemeral" harms (e.g., fear of injury), or "speculative" losses (e.g., lost economic opportunities) or where the harms are "too remote" to have been foreseen by the injurer as a probable effect of his actions. Over compensation may result if the court neglects preexisting risk, and attributes all of the harm to the polluting activity. In particular, courts frequently adopt a "50% rule" i.e., full compensation when the probability of a given injury from an activity exceeds 50%, and nothing if the likelihood is lower. Clearly the result will be either over compensation or under compensation. In each instance, the level of pollution will be inefficient. See Figs. 3 & 4 below:[4]

[4]It is interesting to note that in the case of undercompensation (overcompenstion) the compensation paid to the marginal victim is less (greater) than the "true amount," whereas the aggregate compensation paid out may exceed (be less than) its "true" counterpart.

Fig 3: Effect of Under Compensation in a Strict Liability Regime

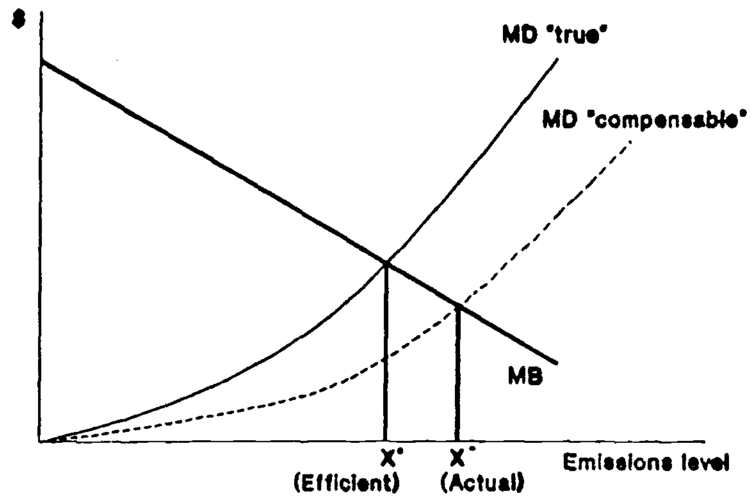
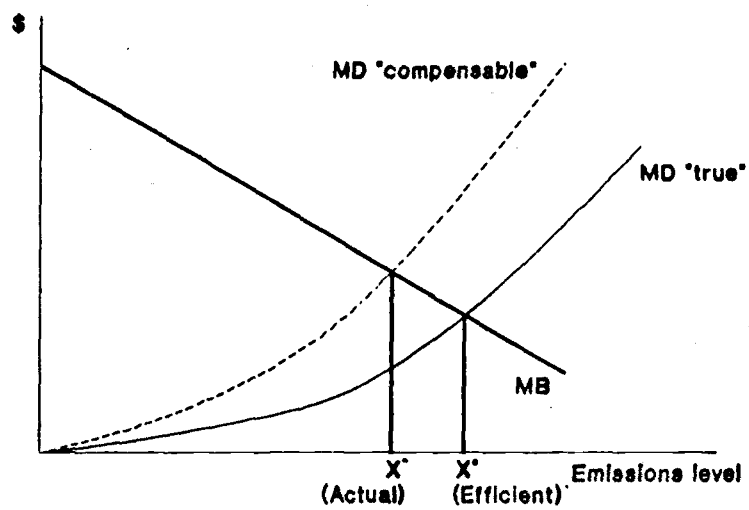
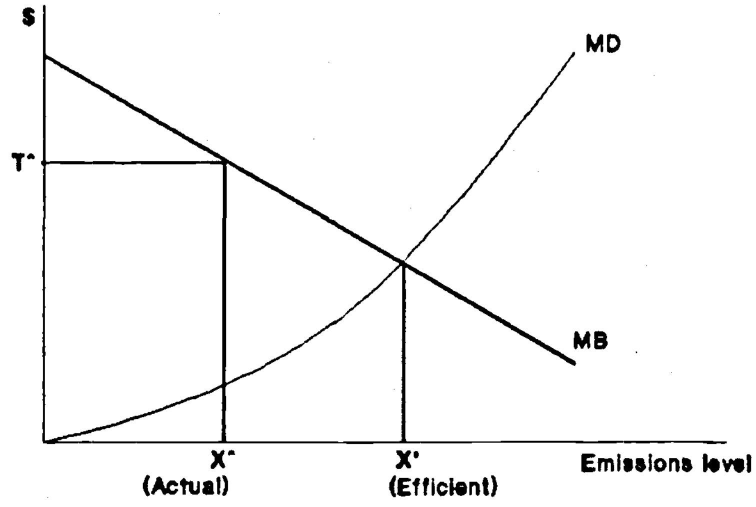


Fig 4: Effect of Over Compensation in a Strict Liability Regime



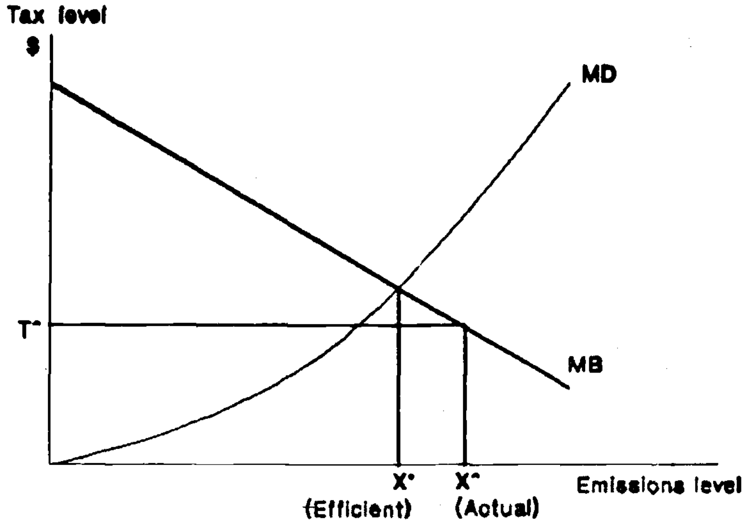
The corresponding situation in the case of pollution taxes is that the regulator may not (indeed is unlikely to) know the exact shapes of the MD & MB curves.[5] In consequence, the pollution tax may be set too high or too low, and the level of polluting activity achieved will be inefficient. These situations are shown below in Figs. 5 & 6.

Fig 5: Effect of a Pollution Tax which is too High



[5]Indeed, a similar situation could arise in the case of strict liability where the victim may not corrrectly perceive the level of harm inflicted, or be able to "prove" a level of harm which is different (perhaps higher) than the actual.

Fig 6: Effect of a Pollution Tax which is too Low



Further, enforcement in liability trials may be imperfect, perhaps because of the difficulty of establishing causation. In such cases, while prior to trials the pollution level may be efficient, a succession of court verdicts (or one seminal verdict) disallowing damages for a given class of harms would induce increased polluting activity.

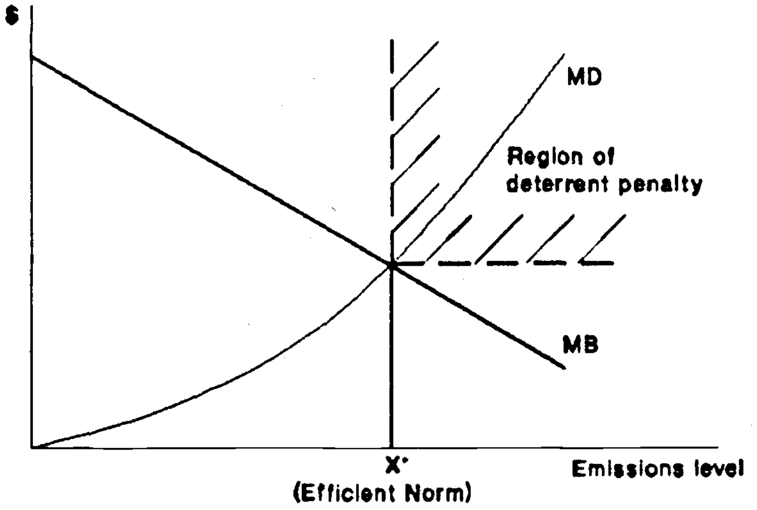
In some situations, courts may shift the burden of proof to a class of defendants where it is difficult to establish which member is responsible for a given damage. Even so, the victim must establish a clear link between his condition and an activity. Similarly, imperfect monitoring and/or enforcement of a pollution tax may be expected to result in inefficiently high pollution levels.

Strict liability is often employed simultaneously with the doctrine of "Joint and Several Liability", i.e., any one member of a class of defendants is liable to the full extent of damage. The advantage is that it may ensure that a "deep pocket" is available to compensate victims. However, the effect of joint & several liability on polluters' behaviour is uncertain. One effect could be that smaller polluters become reckless in their polluting behaviour, and at the first signs of being called to liability, retreat into bankruptcy.

5. Behavioral Norms: Negligence Rules and Standards

Each of these regimes impose a penalty when some norm of pollution discharge is violated. Economic efficiency, in either case, requires that the norm should be set at the level at which marginal benefits equals (aggregate) marginal damage. Further, if the polluter is rational and risk averse, deterrence requires that the penalty for discharges above the norm exceed the marginal benefit at that point. Fig. 7 illustrates these principles:

Fig 7: Efficient Pollution Norm and Deterrent Penalty



Note that as long as the emissions norm is adhered to, no payment, either as compensation or as penalty, is due from the polluter. Accordingly, if efficient, the entire social cost, if any of pollution is borne by the victims under the normative regimes.

The trick under negligence rules as well as under standards, is of course, to determine an efficient norm. In liability regimes when a community based norm exists, courts often adopt it. As long as no externalities befall third parties (i.e., apart from the injurers and victims), such community based standards may be efficient, owing to the structure of the incentives of the actors in which the norm emerges (Cooter: 1990).

Courts have formalized the notion of an efficient norm in the so called "Hand rule". In effect this rule states that an act is impermissible if the benefit to the injurer from the act is less than the expected (i.e. in a statistical sense) marginal damage to the victims.

In the case of administrative regulation attempts to determine the normative standard by reference to the locations of marginal cost & marginal damage curves, are likely to fail, owing to the rather intensive nature of the information required on the part of the regulator.

5.1 Relaxing Some Assumptions

If the probability of enforcement is too low, a rational injurer may violate a pollution norm, under both legal liability and administrative regulation regimes. Enforcement may be imperfect in the case of a legal liability regime if the victims are unaware of the injury, unable to prove its occurrence, unable to prove who caused it, or unable to prove that the negligence standard was violated. Enforcement may be imperfect in administrative regulation if monitoring is ineffective or expensive.

In either regime, the extent of compliance may be increased if the penalty for violation of the norm includes an element of punishment. This is calculated by imposing a penalty at least $(1/p)$ times the perfectly compensatory level, where p is the (subjective, Bayesian) probability of enforcement, whether as liability award, or as administratively imposed penalty. Suppose, on the other hand, the norm and/or penalties are not sharp but fuzzy. In this case, under either regime, one may expect that if polluters are better organized and have greater resources than potential victims, considerable effort involving transactions costs would be expended by the polluters to ensure that quantitative interpretations of the standard or penalty are liberal.[6] Clearly, there is scope for rent-seeking by the regulator (legal or administrative) when the statute possesses this feature.

6. "Exchanges in Rights": Markets for Liability Rights and Tradeable Permits

In a legal liability regime, liability rights may be viewed as property, and a legal framework for voluntary exchanges in such rights creates a market in liability rights. In

[6]In the context of global environmental issues, it is possible that reverse might also hold true in the case where the victims -- represented by nation-states -- are well organised. In that case, the victims might spend resources to "establish higher levels of damage than the actual.

such a framework, a victim may be said to possess a liability right, and if he sells the right and suffers harm, the injurer owes damages to whoever owns the liability right at that time.

Similarly, an administrative policy instrument for pollution regulation is the "tradeable permit", in which an initial assignment of pollution rights (by auction, political largesse, or howsoever) may be traded in a market for such rights. The tradeable permits assigned must sum to the aggregate pollution emissions envisaged.

Both regimes will achieve economic efficiency, given some assumptions. These are first that in the case of liability rights perfect compensation may be claimed, and in the case of pollution permits the aggregate quantity of emissions allowed conforms to the efficient level. Further, that the markets in such rights are competitive, there is symmetry in transactions costs (or that these are absent), and in the case of a legal liability regime, that damages are perfectly compensated by the courts. By the Coase Theorem (Coase: 1960), as long as transactions costs do not block exchange, the initial assignment of property rights is irrelevant from the efficiency standpoint. Thus, the fact that under a legal liability regime the traded property is the victims' (matured or potential) liability rights, while in an administrative regulation regime it is the injurers right to pollute, makes no difference to the efficiency outcome. Of course, the initial assignment of such property rights will affect the distributive consequences of regulation. Figures 8 and 9 illustrate these cases.

Fig 8: Efficiency under a Tradeable Permits Regime

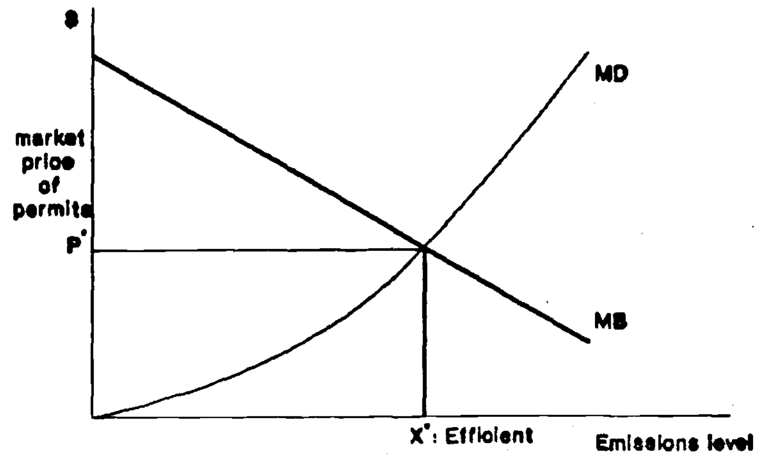
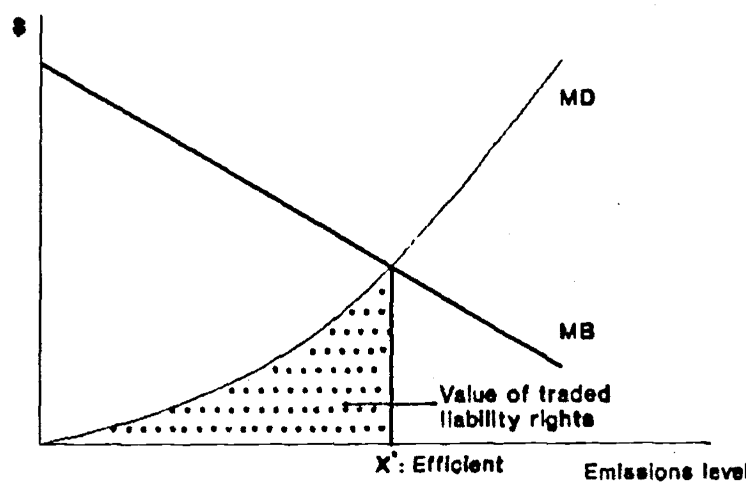


Fig 9: Efficiency under a Regime of Exchanges in Liability Rights



6.1 Relaxing Some Assumptions

Efficiency may result from exchanges in externality rights, but only when the markets for such rights are competitive. Causes of market failure may include market power: monopolies (monopsonies), or cartelization, as well as ineffective monitoring & enforcement. Additionally, some legal doctrines may, for example, by forbidding the plaintiff from assigning the entire value of a liability claim to his attorney as a contingency fee ("rule against champerty"), block the formation of efficient markets. Alternatively, the regulated agents may not conform to the paradigm of cost minimization, for example in the case of price regulated utilities, or nation states subject to an international regulatory regime. These sources of market failure are common to both regimes.

7. International Practice of Legal Liability

The basic principle that guides much of international environmental law arises from three main cases: the Trail Smelter Arbitration, the Lac Lenoux Case and the Corfu Channel Case. Of these the Trail Smelter Case is the most important. The Arbitration grew out of air pollution from sulphur dioxide fumes from a smelter in Trail, British Columbia, owned by a Canadian corporation. The United States claimed compensation from Canada on the basis that the fumes had caused damage in the State of Washington. Canada was held responsible by the Special Arbitral Tribunal appointed for the case and was directed to pay injunctive relief and an indemnity. The main principle on which the judgement was based was that a state has a duty to protect other states against injurious acts by individuals from within its jurisdiction. The Lac Lenoux case arose out of a treaty between France and Spain of 1866, relating to the flow of boundary water which safeguarded the right of Spain to the natural flow of water into the river Carol, an outlet of Lac Lenoux. A French proposal to use the waters for hydro generation was objected to by Spain, because it would change the natural flow. The arbitral award, in favour of France, held that the new use would still provide the previous quantity of water and therefore did not violate the treaty. The principle relevant to environmental law was that the state making the change from the norm was required to ensure that the new situation did not leave the other affected parties worse off. In the Corfu Channel Case, the United Kingdom sought to hold Albania responsible for damage caused to warships by mines moored in the Corfu Channel in Albanian territorial waters. The International Court of Justice decided in 1949 that Albania had a responsibility to notify shipping in general of the existence of a minefield in its territorial waters and in warning the approaching British warships of the imminent danger, something that it had failed to do. In other words, nothing was done by Albania to prevent the disaster, which made it responsible. The case established a duty to inform of activities (here these were past activities) that were likely to cause serious harm to the nationals of another country.

The principle that emerges from the three cases is that states are obliged to take measures, to the extent possible, to conform to international principles and standards and to prevent or reduce injury to the environment of another state or areas beyond its jurisdiction. They are obliged to conduct activities so as not to cause injury to such states or areas. States are held responsible for the violation of this principle and of injury caused by such violation.

The causing of injury naturally leads to the question of reparation for damages suffered i.e. liability. As indicated earlier, this paper concentrates on civil aspects of liability.

The history of international liability for environmental harm and the current status of the law indicates that such liability is an extremely problematic area of international law. The Stockholm Conference recognised it as an area that required development, but all that could be ultimately agreed upon was an undertaking to "further develop the international law of liability and compensation." The effort since has been to develop general principles, something that has proved extremely difficult in the absence of state practice and international adjudication. The Trail Smelter remains the main arbitral award.

The main problem of attaching liability in international law is that much of the external harm is caused by activities performed in the exercise of their legal rights by states or agents within states.

Two doctrines address the situation.

(a) The first doctrine addresses the case when rights are abused i.e. when a person makes use of his/her property rights solely to cause harm to another person. This is not usually the situation in international environmental harm, because the person causing harm is not motivated by the desire to harm persons injured beyond international frontiers.

(b) The second doctrine makes an otherwise rightful use of one's property rights wrong if it causes harm, unless the user compensates the person injured by the use.

The International Law Commission (ILC) has been studying the problem of international harm under the rubric of "international liability for injurious consequences arising out of acts not prohibited by international law." It has provisionally considered whether a state's obligation in connection with transboundary injury to other states should include a duty to prevent, to inform, to negotiate and to repair. Thus far, it has concluded, that only the failure to "repair" the injurious consequences would result in international liability.

Apart from general principles, specific liability arrangements have been provided for in various treaty arrangements in international environmental law. These in turn have had an effect on the progressive development of these principles. An examination of some of these frameworks illustrates the type of treaties that allow for different interpretations of the liability rule and the related problems of making states agree to open themselves to claims for compensation.

7.1 Strict Liability

The number of treaties/international arrangements that have provided for strict liability are extremely limited, with not much expected in the future that would pull the law in that direction. The 1972 Convention on International Liability for Damage Caused by Objects Launched into Outer Space is the only multilateral convention open to all states that imposes full liability on launching states. Other conventions that provide for "strict liability" do so in respect of the private operator of the damage causing facility and some of these provide that the operators's state is liable on a subsidiary basis if the operator or his insurer cannot pay. An example of this is the Vienna Convention on Civil Liability for Nuclear Damage, 1963.

The imposition of strict liability would therefore imply a major shift from classical principles of state responsibility under international law, under which responsibility and consequent liability for compensation arises only in the case of a violation of a rule of international law. The ILC has framed the problem in terms of primary and secondary norms. The primary norm has traditionally been the violation of a rule of international law and secondary norms include the imputation of responsibility to the state and the obligation to compensate damage. Strict liability would make the payment of reparation the primary norm.

This principle finds expression in domestic legal systems, which recognise that the activity in question need not be illegal for the injurer to be held liable. Strict liability regimes evolved to regulate activities that were considered inherently extremely dangerous. The argument was that since the operator benefited from the activity s/he should bear the cost of injury, especially since s/he was in a better place to manage the risks. In many countries this has been extended to cover many acts involving general (not necessarily ultra-hazardous) risks.

These reasons for the imposition of strict liability have been modified and translated into the international arena. Strict liability has been called for in cases of disastrous accidents involving ultra-hazardous technologies. The argument is that the problems victims would face to prove negligence would be far too great and would make compensation unlikely or meaningless. There are problems with this doctrine, evidenced by the failure of affected states to claim compensation in cases that could have involved the above principles, as in Chernobyl and Basel.

7.1 Qualified Versions of Strict Liability

These have evolved as a consequence of government intransigence on the subject. The regime being developed by the ILC would have the state of origin compensate an affected state for appreciable harm caused by its (or its agents') activities. This would apply to internationally lawful activities and the harm must *in principle* be fully compensated (Barboza: 1990). The qualifications are as follows. First, reparations would be decided by negotiation between the state of origin and the affected state. Second, states are required to be guided by equity based criteria in determining the reparation. Compensation might be reduced if the nature of the activity and the circumstances of the case would mandate or imply equity through cost sharing. These special circumstances could arise when significant amounts have already been spent by the injurer on risk reduction, when damage in the affected state is less than other beneficial side effects or when states are limited in their ability to take preventive measures. In essence the ILC proposal would impose strict liability for all transboundary injury, but would leave it to the states involved to decide reparation in each individual case, on the basis of equity and balance of interests. A refusal even to negotiate would be considered a dereliction of international obligation.

The main problem with such a formulation would be the setting up of an institutional arrangement to oversee these cases. Experts consider it likely that the ILC draft articles will be adopted by the Commission as a recommended basis for either an international convention or simply to guide state practice (Schachter: 1990). It is improbable that they will become a binding treaty, but they may become a model for specialised treaty regimes applicable to well-defined activities involving a significant risk of transboundary injury.

7.2 Negligence Standards

State liability under negligence standards fits in more closely with classical notions of state responsibility for wrongful conduct. Certain environmental impacts that have international consequences are dealt with under different treaty arrangements. These establish rules and standards for activities that create risks of transboundary harm. Such rules and standards vary from detailed ones such as those established for nuclear plants to broad, general formulations of due diligence/due care. In these situations, a failure to comply with such rules or standards could be wrongful international conduct, with state responsibility and consequent liability arising from it.

There are two interpretations of the negligence standard formulation. The first is the obvious one that if a state is party to a convention that establishes or agrees to follow certain standards, it would be responsible and liable for damage arising out of a violation of the rule. The second is that generally adopted standards by international organizations would be a basis for liability even though the standards were not legally or otherwise binding for the violating state.

7.3 Due Care

Negligence standards have been further adapted into approaches that would give effect to standards adopted by international organizations not as law but as a criteria of the due diligence or due care required of all states in regard to activities that create an appreciable risk of transborder injury (Schachter: 1990). This can be thought of as going beyond a system that would use internationally binding rules and standards.

An advantage of following a due care standard is that it focuses on the specific activity and its circumstances, while not condemning the activity. In addition, it would probably allow the activity to be balanced against foreseeable injurious circumstances. Going along the same path is a proposal to shift the burden of proof from the victim to the source of injury, something that has been established by Japanese courts in the domestic context.

7.4 International Legal Persons

An issue that queers the pitch in international law (unlike in domestic legal systems) is the question of identifying an "international legal person".[7] Such an entity is capable of possessing rights and duties and has the capacity to bring certain types of cases in the international sphere. In the traditional view only sovereign states could be subjects of international law, though in practice, many other entities have at various times been recognised as legal persons of a qualified nature for specific purposes. As in any legal system, not all categories of subjects of international law have identical rights.

Contemporary international law has seen a widening of the concept of international personality beyond the sovereign nation state. This has been necessitated in part by the entry into the international sphere of entities such as public international organizations, multinational corporations, international NGOs, regional organizations and movements of insurgent communities and national liberation.

The extension of legal personality to individuals is a further issue. The progressive internationalization of human rights and the development of a body of law around this issue has pushed the law towards increasing (albeit qualified) acceptance of the individual as an occasional subject of international law. Some institutional arrangements specifically allow individuals to bring complaints against their own governments, following the exhaustion of domestic remedies. Examples of such arrangements are found in the Optional Protocol to the International Covenant on Civil and Political Rights and in the European Convention for the Protection of Human Rights

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[7] Also known as a subject of international law.

and Fundamental Freedoms. A small body of case law has developed under the latter convention.

Forums for individual redress for transfrontier environmental damage have also developed most in Europe. The emerging principle here is that in so far as states recognise an international duty to prevent or reduce transfrontier environmental damage, a case can be made for rights of redress by injured parties who are not residents or nationals of the originating state. Several West European countries afford citizens of neighbouring states access to their courts and administrative proceedings on the same footing as citizens. Under the Nordic Convention on the Protection of the Environment of 1974, Norway, Sweden, Denmark and Finland handle national pollution discharges causing damage beyond national frontiers in the same way that they handle discharges causing local damages. In environmental suits for compensation or injunctive relief, the Nordic Convention guarantees citizens of the four countries equal access to their countries courts (World Resources 1987). In 1976, the European Court of Justice decided that within the EC, the victims of transboundary pollution may sue either in their own national courts or in the tribunals of polluter states.

8. International Practice of Administrative Regulation

There are extremely few examples of administrative regulation in the international sphere. The only international arrangements that establish regulatory regimes for environment related issues are the Convention on Long Range Transboundary Air Pollution and the Montreal Protocol on Substances that Deplete the Ozone Layer.

The former, signed in Geneva by 34 countries under the framework of the Economic Council for Europe was the was the first multilateral agreement on air pollution, as also the first environmental accord involving all the nations of East and West Europe and North America. The subsequent Thirty Percent Protocol to the Convention (1985) in which the signatories pledged to reduce sulphur emissions by thirty percent is one of the few instances involving multilateral acceptance of a specific quantitative environmental goal.

Problems related to increased acidity of lakes and streams were brought to the Stockholm Convention by Norway and Sweden, since these countries asserted that the problem emanated from beyond their borders. The agreement was a compromise between the insistence of Norway and Sweden on "standstill" and "rollback" clauses and the reluctance of West Europe's largest polluters, West Germany and the United Kingdom to commit themselves to *any* formal agreement. Norway and Sweden argued for a number of years that the benefits of abatement outweighed the costs, and finally, by the time of the Stockholm Conference on the Acidification of the Environment in 1982, most countries were convinced of the advantages of following the treaty provisions.[8] Subsequent conferences in Ottawa, Munich and Amsterdam built international consensus for concerted action and led to the Thirty Percent Protocol.

The other international agreement involving specific timetables and standards for environmental protection is the Montreal Protocol to the Vienna Convention for the Protection of the Ozone Layer. The purpose of the Protocol is to inhibit production, consumption and trade in some of the compounds that deplete stratospheric ozone. Ozone depleting compounds are divided into two groups of "controlled substances," Group I (certain CFCs) and Group II compounds (specific halons), each subject to different limitations. The Protocol makes a distinction between two groups of countries, the first with relatively high levels of consumption of ozone depleting substances and the second, developing countries with relatively low levels of consumption.

The principal difference between the developed and the developing countries is the timing of production and consumption limitations. From mid-1989, the developed countries have had to freeze production and consumption at 1986 levels. Group I compounds must be cut to 50% of 1986 levels over the next 10 years; Groups II substances may remain at 1986 levels. The developing countries are given a 10-year grace period (beginning in 1989) during which they are free to increase production and consumption within certain limits. Then, they too must cut production and consumption of Group I compounds over a further 10-year period and freeze consumption and production of Group II compounds. These obligations of developing countries are conditional on prior fulfilment of transfers of finacaes and technology by industrialized countries. The Montreal Protocol can (and may have has started to) significantly inhibit the worldwide growth in the consumption of compounds that deplete stratospheric ozone around the earth.

[8]West Germany and Canada by now were facing their own acid rain problems and had a greater interest in the successful conclusion of the treaty.

10. **Regulating Global Warming**

We now briefly look at the problem of designing a multilateral regulatory framework for Climate Change.

The issue of Climate Change is characterized by first, the global, multigenerational spread of potential injurers and victims. Secondly, by great uncertainty in the extent, nature, and spatial and temporal distribution of the impacts. Since the implicated emissions result from major economic activities: manufacturing, transport, agriculture, domestic heating, etc., significant costs are involved in any contemporary regulation of the sources of emissions. On the other hand, if emissions are unabated, actual damages may be high, possibly catastrophic, and even adaptation measures to preclude harm may involve large resources. However, great scientific uncertainty attaches to causal links between emissions and actual impacts.

The nature and choice of regime will involve a prior equity determination. There is therefore an underlying value judgement in all approaches to global environmental regulation, especially since the damages are unlikely to be symmetrical over space and time. Equity can be involved in both an initial formulation which allocates differential responsibilities, and by the choice of a particular regime/instrument. In the case of the former, equity may be determined by a tentative formulation that requires states to contribute negotiated amounts to, say, a global environment fund that would then be used to mitigate the effects of global warming, or for abatement measures. In the case of the latter, the choice of instrument will be deeply intertwined with the equity outcome or determination.

In this case, equity could be implicated in two different ways. First, there is an issue of justice or fairness in the sense of legal torts issue between those causing the damage and those who suffer from it. While in this case, the parties invloved could be individuals or other entities within states, in this paper we assume that the regulating regime recognises soverign nations as parties or agents. Second, there are equity considerations between nations or groups of nations, in the sense of sharing of global resources, implying real resource flows. The structure of the regime will have to be so devised that it will affect equity at the particular level that is desired. This can be illustrated by comparing equity under strict liability and under carbon taxes.

A strict liability regime, by definition, would address only the first level of equity identified above. As pointed out in an earlier section, one of the main legal rationales for liability is to compensate victims *vis a vis* those causing the damage, i.e. to perform compensatory justice. Figure 1. shows the liability award under perfect compensation. There, the dotted area under the marginal benefit curve is the amount paid out to those suffering the damage. Note the entire remaining area under the curve remains with the producer.

Note further that in the case of a carbon tax (Figure 2), a greater portion of the excess revenue collected (the dotted area) can be used for effecting distributional objectives, after victims suffering damage have been compensated. In the global context, therefore, a tax can be used to fulfil both equity objectives, provided the excess revenues are converted into flows to countries that are entitled to such funds, and therefore is more flexible. Similarly, different equity outcomes can be realised under each of the other instruments, whether legal or administrative. We now go on to examine more specific equity implications of the rival regimes.

Consider first, the possibility of a legal liability regime, imposed through global environmental courts established by international agreement, whose awards are binding. Since the actual victims and injurers (individuals, economic agents) are likely to be numerically very large, such a regime would need to recognize sovereign states as legal representatives of the actual victims and injurers, by analogy with class action suits. A problem at the outset would be that of enforcement, since the institutional mechanism for international enforcement is poor, short of coercive, adversarial measures such as sanctions and war.

In such a regime, irrespective of the actual legal doctrine adopted (i.e., strict liability, standards, or markets for rights), states with claims for damages would first need to prove before the court that the damages are indeed attributable to Global Warming. Because of great uncertainty and complexity of climatic processes, it is unlikely that scientific standards of proof would be forthcoming. Thus, for example, desertification of a region could be claimed as resulting from Global Warming. On the other hand, in a particular instance, it may also have more proximate anthropogenic causes, e.g., deforestation, livestock grazing, etc. Science may be unable to apportion responsibility for the damage in such cases to different antecedent causes. In addition, global climate is not constant in any case, and is subject to natural viability. The question of whether a particular impact is attributable to crossing of a natural threshold by anthropogenic interventions may be hard to determine.

Suppose that in a given suit, despite these problems of proof, a court accepts the plea of a particular impact having resulted from Global Warming. Assume further that anthropogenic emissions of GHGs from different countries over time are well documented. In that case, the further question of assigning responsibility for the damage would arise, which would be fundamentally be affected by the initial equity determination. This is because of the concept of "excess emissions," i.e., not GHGs emissions as such, but their excess over the share of global natural sinks assigned to the polluter should be the basis of apportioning responsibility. The question of equity is involved in sharing these sinks. The problem is made more complex by the fact that the capacity of the sinks is not constant, but at least upto a limit, increases with increase in emissions. Further, since different countries emit different proportions of individual GHGs species, and relative environmental impacts of different GHGs depend on the period of integration, a further equity issue is involved in choosing the integration period.

Additional problems with a legal liability regime arise from the fact that since states are considered as legal representatives of classes of agents, the long time periods involved in Global Warming may seriously undermine such representative roles. States themselves may undergo fundamental political change, including of their borders, in a few decades while the identities of polluters may be erased in the same time spans. Major evolution in "successor state" doctrines would thus be necessary for any legal liability regime to work.

Further problems may be anticipated in applying each of the three legal liability doctrines to Global Warming regulation. Strict liability cannot be enforced by injunctions to restore the pristine condition of the damaged resource, because the impacts of Global Warming are likely to be irreversible. On the other hand, adaptation costs are likely to seriously undervalue the damage suffered. Some impacts (e.g., changes in cropping cycles) may entail lifestyle and cultural changes, and thus, be essentially uncompensable. Applying an international version of the "joint and several" liability doctrine (together with strict liability) may be grossly iniquitous, as damages may be awarded against the most vulnerable, rather than the largest polluters. Also, as described in the previous section, precedents for the imposition of strict liability in the international sphere are few and treaty framers are unlikely to accept a formulation that would constitute a major departure from current positions in international law.

If, on the other hand, a negligence standard is adopted, the issue of emissions entitlements of different countries cannot be avoided. Unless the (aggregate) standard were fixed at a threshold only over which damages would be perceptible, this would mean that all of the costs of damage would be borne by the victims. This threshold, if it exists, is likely to be highly uncertain in location, and a globally risk averse strategy may entail too low an (aggregate) standard, meaning that polluters may encounter unduly (i.e., inefficiently) high abatement costs.[9] Negligence standards, however, score in the sense that they are where current international law doctrines and state practice seem to be at, and would therefore be more acceptable to international lawyers.

Given that large uncertainties would prevail regarding causation and in the actual Climate Change impacts in different times and on different regions, it is unlikely that markets for liability rights from Climate Change would be efficient. Further, since asymmetry of information on impacts between ICs and DCs is likely, and also because ICs are better organized, have greater resources, and are fewer in number, cartelization of the liability rights market is likely and thus the distributive effects may also be regressive.

A frequent criticism of liability regimes of any sort is that they often involve disproportionately high transactions costs. However, in the case of global warming, this might not be a significant issue, since the transactions costs may be small relative to the value of possible damage.

Consider now the alternative of administrative regulation of GHGs emissions by a multilateral agency under a negotiated Protocol. Carbon taxes and tradeable permits for GHGs would constitute market based instruments, while emissions standards would be a fiat based approach. In each case, the regulated agents would be the contracting states. Considerations of sovereignty would require that the regulation of domestic

[9]In the case of a regime based on standards, an interesting situation might arise if an global negligence standard nevertheless allows for serious *local* environmental impacts. For example, a state might choose to fulfil its international commitment by regulating only in a part of the country, and may leave industries in other areas to continue to pollute, with harmful local effects.

agents (firms, consumers) to ensure compliance with national obligations under the protocol, be left to domestic authorities.

Standard environmental economics results are that market based instruments ensure cost minimization for achieving any given environmental quality (or aggregate emissions).[10] This result, however, hinges critically on the assumption that the regulated agents minimize costs, and additionally, in the case of tradeable permits, that the markets for permits are competitive. Neither assumption can be reasonably considered to be valid in the Global Warming context. Sovereign states are not profit maximizing firms, and these are good (positive as well as normative) reasons why they would not minimize costs (Ghosh: 1991). Further, cartelization of tradeable permits markets (whether during initial auctions or in subsequent exchanges) is clearly feasible for reasons similar to the liability rights market. One may conclude, therefore, that without further research, it is imprudent to suppose that market based instruments would minimize (global) costs of abatement.

The focus on efficiency in the environmental (and indeed in the neoclassical) economics literature generally is based on the premise that governments have at their disposal a suite of policy instruments (direct taxes, subsidies, etc.) which enable the country to ensure that its equity objectives are met, corresponding to any level of national income (efficiency). In that case, increases in efficiency are unambiguously desirable.

In the global context, this assumption is clearly untenable because, as stated above, the choice of any regulatory regime would involve a prior determination of the equity issue. Considerations of convenience would suggest that the choice of policy instruments is restricted to those which would yield significant revenues to the regulator. This would enable funds to be kept aside for adaptation strategies or compensation, as well as meeting the requirements of equity. These instruments are carbon taxes, and auctioned tradeable permits.

The likelihood of cartelization of permits market may, however, result in financial resource flows from poor to rich countries, and would impede equity. On the other hand

[10]If, additionally, there is no uncertainty about the locations of the MB & MD curves, each of these classes of instruments (market based as well as fiats) may be adjusted for efficiency. This requirement of information is so stringent, that at least in the global warming context it may be a non sequitur.

a permits system has the advantage of ensuring a pre-determined level of aggregate emissions. This cannot be accomplished by carbon taxes, although over time, the level of aggregate emissions for a given level of tax, would be fairly predictable. Carbon taxes also allow the possibility of different tax rates for different (classes of) countries, as another means for equity, although the effects of such a scheme have not been analyzed in the literature.

The discussion in this section is premised on monitoring and enforcement in multilateral regulation being perfect, under both legal liability and administrative regulation. The feasibility of at least effective monitoring and enforcement is a critical question, and needs sustained research.

Combinations of different policy instruments (e.g. pollution taxes combined with standards) have also been discussed in the environmental economics literature. Quite likely, one may also devise liability regimes which combine different doctrines (e.g. strict liability with markets for rights). The present study must however terminate at this point, and these possibilities for Global Warming regulation left for future research.

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Incremental Costs of GHGs Abatement Programs : A first cut at a definition.

Prodipto Ghosh
Neha Khanna

Introduction

Negotiations for a Framework Convention on Climate Change have been completed, and the convention will be adopted at Rio de Janeiro in June 1992. The proposed convention involves provisions for transfers of technology and financial resources from industrialised countries (ICs) to developing countries (DCs) to enable the latter to fulfil their (differentiated) responsibilities under the convention. Transfers of finances are for meeting the "agreed full incremental costs" of measures which may lead to reductions in future growth rates of GHGs emissions.

This paper addresses the question of defining such incremental costs. It develops definitions and a Linear Programming (LP) model to arrive at a concept of "minimal incremental costs", i.e., a notion of economic costs involved in meeting Global Warming responsibilities which policy makers could agree upon as the *least* that would be involved in such programs. The model assumes two alternative formulations of Global Warming responsibilities under a future protocol. The first specifies a time path of GHGs *emissions* in the economy as a whole. The second, supposes that such a protocol would specify a time path of GHGs *intensity* in the economy (which may be a vector disaggregated by sector).

The "costs" considered in this paper are economic, not financial. The principal difference is that financial costs, as typically determined by an accountant, involve only actual financial expenses (on capital, labour, materials, taxes, depreciation). Economic costs, on the other hand, are "opportunity costs", i.e., the benefits foregone by not utilizing a given resource in the best alternative use. Consider for example, an owner who manages her own retail store and pays herself no salary. Since no monetary transaction occurs, an accountant would not recognise any costs. On the other hand, for the economist there exists an opportunity cost equalling the highest salary that the owner could have earned by working elsewhere.

Further, economic costs exclude transfer payments such as taxes and subsidies, since these do not represent any direct claims on the resources of the economy. They merely represent a transfer of control over the resources from one agent to another within the economy. For example, when a firm pays taxes to the government these do not form a part of the economic costs since all that occurs is a transfer of purchasing power from the firm to the government. However, if the government were to use the funds so obtained to, say, construct a dam, then these expenditures would constitute economic costs.

Economic costs also correct for market failures -- for e.g., by including externality costs, which are costs passed onto third parties not involved as producers or consumers of the good/service in question. In the case of environmental externalities experienced by the society in question, it is assumed that these externality costs refer to local, not global impacts. In other words, it is assumed that the protocol either ensures that the global emissions profile is such that no Global Warming impacts are perceptible, or that all costs of adaptation or damage would be met under other regulatory arrangements or provisions.

Techniques for computation of the elements of economic costs (and benefits) are detailed in several standard texts on cost-benefit analysis, and will not be repeated in this paper. What we attempt in this paper, assuming that individual elements of costs & benefits (including of local environmental impacts on amenities) can be computed, is the following :

First, we furnish a definition of "minimal incremental costs" of an abatement alternative, which policy makers would generally agree on as representing the least economic costs involved. Second, we develop the specification of a general Linear Programming (LP) model to compute the cost thus defined, over a national abatement program for a specified time-period under alternative regulatory assumptions.

2. Possible regulatory protocols:

A multilateral regulatory framework (protocol) may, in our judgement, take one of two forms. One, it may specify for each country (or category of countries) a path of future aggregate GHGs emissions over time. Alternatively, it may specify (perhaps for each defined sector, say steel making, in given categories of countries or each country) a time path of GHGs intensities of output (i.e., tonnes of GHGs emitted per tonne of steel produced). These are illustrated in Figures 1 & 2 overleaf:-

Fig 1: Timepath of GHGs emissions in an economy

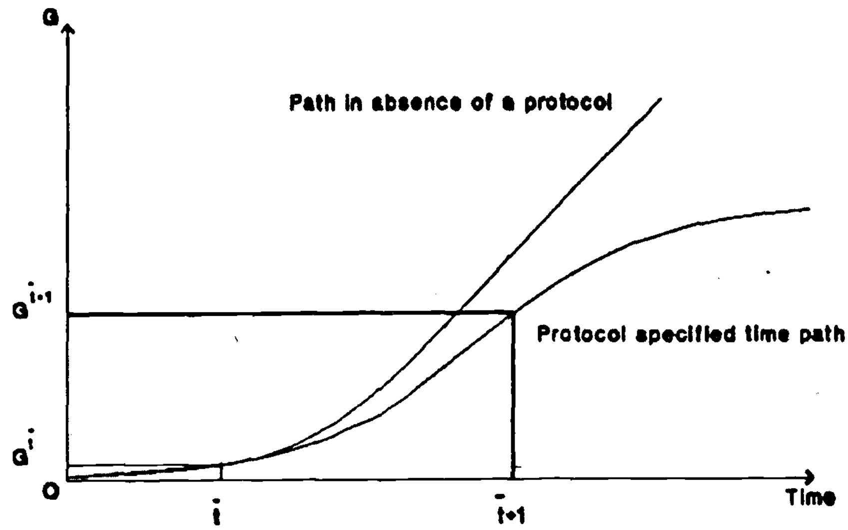
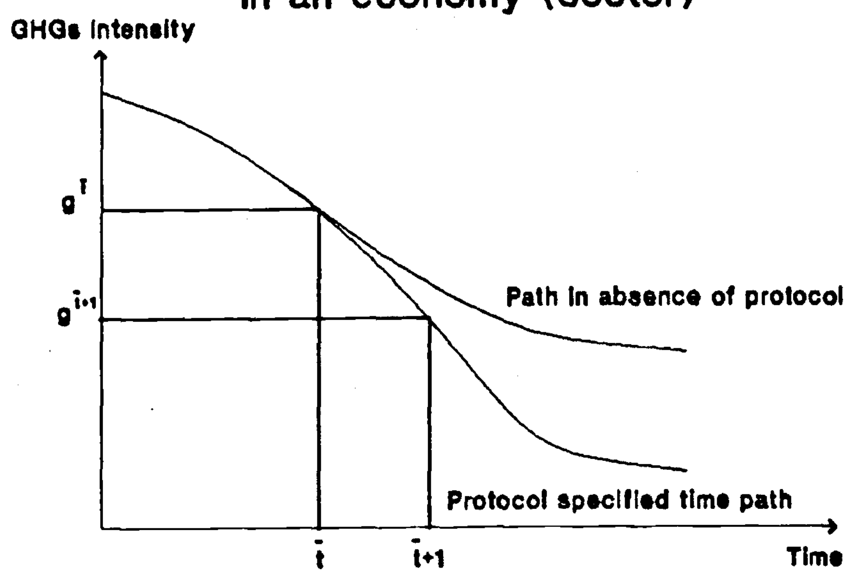


Fig 2: Time path of GHGs intensity in an economy (sector)



The shapes of the time paths depicted in each case may be explained as follows:

In the case of DCs, it is unlikely that any protocol in the foreseeable future would provide for actual reductions in GHGs emissions. However, the adoption of benign technologies would, over time, tend to reduce the growth rates of GHGs emissions, and at some time in the future, the aggregate GHGs emissions may stabilize. On the other hand, in the absence of a protocol, GHGs emissions growth rates may be unchanged, or increase, as the economy grows and undergoes structural change biased towards energy intensive sectors. Figure 1 is thus explained.

Further, increasing use of benign technologies in the economy generally, and in particular in energy intensive sectors, would reduce the GHGs intensity over time. In the absence of a regulatory protocol, GHGs intensity may also be expected to fall with time, because of autonomous technological change, which may induce energy efficiency. These considerations help explain Figure 2.

3. Costs and Benefits of a Given Project

In this section we briefly review how net economic benefits of a given project are computed.

Figure 3 depicts a typical project profile of costs and benefits. Each project is associated with a stream of benefits and costs over time. However, these values are not strictly comparable since agents (individual, firm, society) typically have a (positive) time preference, i.e., they prefer to reap benefits earlier and pay costs later. Discounting reduces these values to a common denominator ie., the present value of a stream of benefits (costs) over time. The discount rate used is the social (rather than the private) discount rate since we are considering the problem from the viewpoint of the policy analyst)[1]. The perspective is deterministic, i.e., no uncertainty attaches to any element of costs or benefits associated with the known (set of) technologies. Net economic

[1]Note that the social discount rate represents a societal choice, i.e., the respective weights attached to identical benefits (costs) occurring at different times. Techniques for computing social discount rates are also elaborated in the cost-benefit literature. They are some what controversial, but we do not go into these aspects in the present paper.

benefits or net present value (NPV)[2] is computed as the sum of each year's benefits less costs, discounted by the discount factor. Mathematically.

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+S)^t} \qquad (1)$$

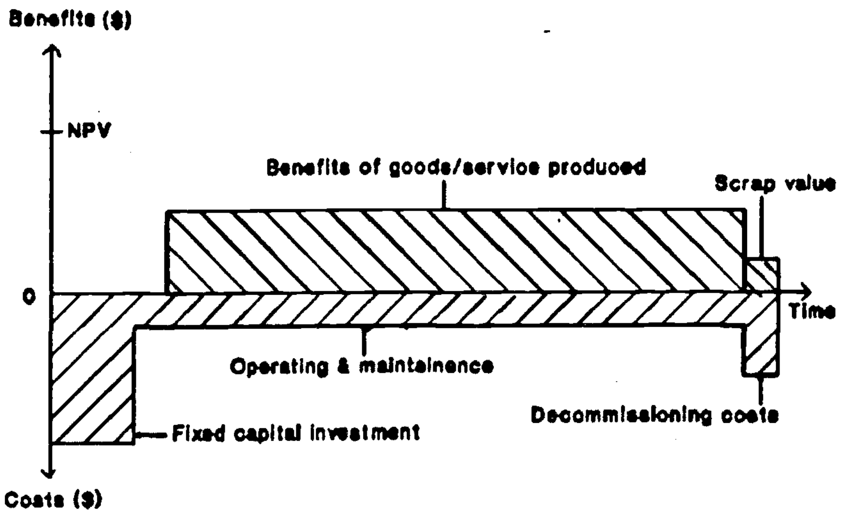
where:

B_t : Benefits at time t

C_t : Costs at time t

S : Social discount rate.

Fig 3: Typical profile of costs and benefits of a project

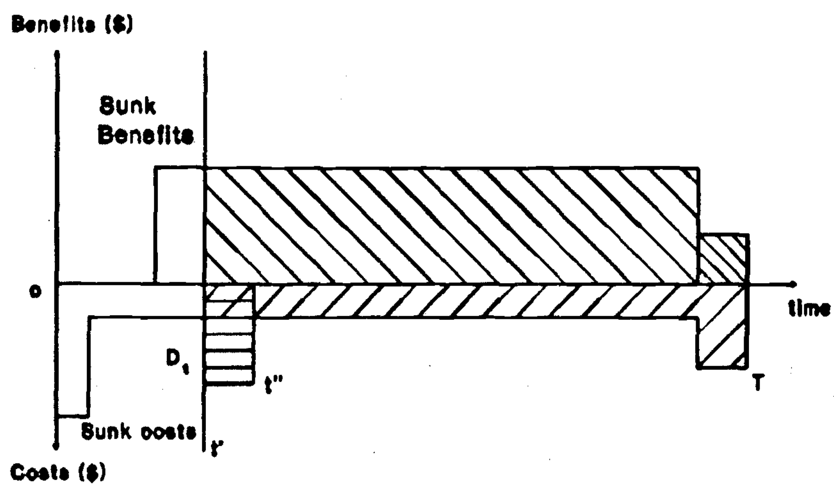


[2]The NPV is the criteria of ranking alternative projects on the basis of the respective gains in economic efficiency that they yield.

4. **Costs & benefits of an "interrupted" project:**

An abatement program may involve the interruption of an existing plant before its "normal"[3] economic life is over, and its replacement by another plant embodying a (more) GHGs benign technique. We explain below how the net benefits over the remaining normal economic life of the existing project are to be computed. Figure 4 graphically depicts the costs & benefits of project interruption.

Fig 4: Computing foregone costs & benefits of project interruption



The project commenced at t = 0, and its lifetime (without interruption) would be till t = T. However, it is interrupted at t = t' and decommissioned, over the period t = t' to t".

All "past" benefits and costs of the project (i.e., in the period t = 0 to t') are considered "sunk", and the foregone costs and benefits are reckoned over the period t' to T. The "net foregone benefits" (NFB) at t' is accordingly the discounted value of all costs and benefits foregone by the interruption, less the net costs of the

[3]"Normal" in the sense of in the absence of a GHGs abatement program.

decommissioning operation, where all streams are discounted to the point of decommissioning. Mathematically:

$$NFB^{t'} = \sum_{t=t'}^{t=T} \frac{(B^{t}-C^{t})}{(1+S)^{(t-t')}} - \sum_{t=t'}^{t=t''} \frac{D_t}{(1+S)^{(t-t')}} \qquad (2)$$

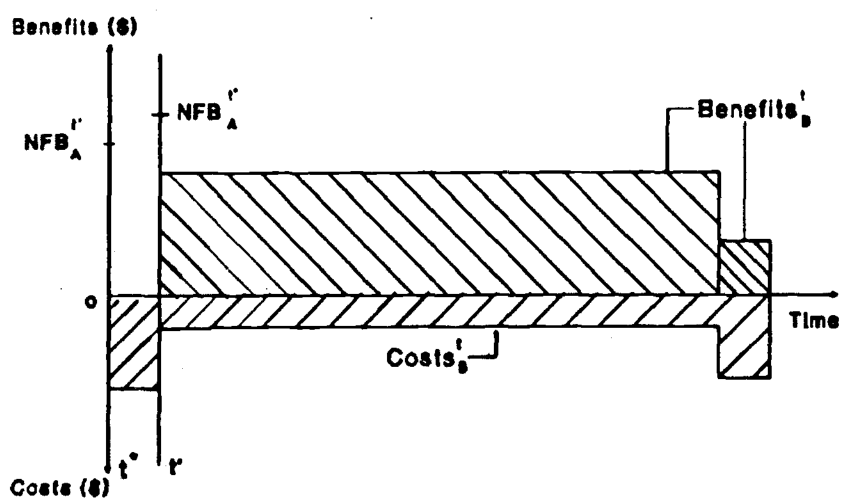
where D_t is the net costs of decommissioning (i.e., inclusive of any scrap value).

5. **Definition of "minimal incremental cost of an abatement option"**:

We now employ the concepts developed above to define the minimal incremental costs (MIC) of an abatement option involving the interruption of an existing plant and its replacement by another (GHGs benign) technique. The situation is depicted in Figure 5 (where the phasing of costs and benefits of the replacement plant are illustrated, not those of the existing plant).

The existing plant is termed A, and the replacement plant B. Both plants are assumed in this definition to yield the same level of service (e.g., MW of electricity).

Fig 5: Costs & benefits of a replacement project



The NFB of the existing project A, which is interrupted at t = t' when the replacement project B goes on stream, so that there is no interruption of service, is $NFB_A^{t'}$ computed as explained in the previous section. Discounting this value to t^*, the point of time when investments in the replacement project B commence, we arrive at the NFB of project A at time t^* as:

$$NFB_A^{t^*} = \frac{NFB_A^{t'}}{(1+S)^{(t'-t^*)}} \qquad (3)$$

The NPV of project B at t = t^* may be computed as described above (by using equation (1)). We now define the "minimal incremental cost of switching from A to B at time t^*" as the difference between the net foregone benefits of the existing project A and the net present value of the replacement project B, both reckoned at the time when investment in the replacement project commences. That is:

$$MIC_{AB}^{t^*} = [NFB_A^{t^*} - NPV_B^{t^*}] \qquad (4)$$

6. **From project level to program minimal incremental costs:**

An abatement program in response to a regulatory protocol will, in the case of a diversified economy, involve a large number of options. While one may work out the MICs of particular abatement options, an important policy question is how to choose a least cost set of abatement options over a planning period, given two types of constraints. First, the economy should adhere, in each period, to the GHGs (emissions or intensities) path specified in the regulatory protocol. Second, that capacity in each sector of the economy at the following period is known or determined exogenously in the current period.

A detailed Linear Programming (LP) model is set out in the Appendix to both define, and determine, the minimal incremental costs of such a program. The main features of the model are briefly explained below.

The policy objective is assumed to be the minimization of the total economic costs of adhering to the abatement path at each planning period[4]. This is in keeping with the provisions of the convention that any abatement measures undertaken by the DCs are contingent upon the transfer of finances (and technology) from the ICs.

The planning horizon is one period, since it is assumed that future capacities in each sector are known only up to one period in advance. Additionally, the set of available techniques is fixed only for one period in the future. The economy adheres to the protocol specification (of GHGs emissions or intensities) at the beginning and end of the period. There is a (large) discrete set of techniques, which may be embodied in current and future plans. An abatement option consists of a switch from an existing plant to another employing a (more) GHGs benign technique. However, the set of pairs of such technique switches are restricted to those in the same sector. For example, an electric thermal power plant may be replaced by another electric power plant employing a more GHGs benign technique, but not by say, an aluminium smelter.

Apart from switches in technique involving the same levels of service, the economy may make fresh investments (retirements) in each technique, in keeping with its growth/economic structure objectives, detailed in the set of sectoral capacities at the next period.

Minimal incremental costs are involved in each abatement technique, and there are net benefits (net foregone benefits) in each case of fresh investment (retirement). Expressed as costs (i.e. net benefits are negative costs), these are aggregated into the total costs of the abatement program.[5] A LP model is then specified, minimizing these total costs, subject to the sectoral capacities and the GHGs emissions (intensities) stipulated in the protocol, in the next period in each case.

A numerical solution of this LP model may be obtained by standard algorithms (e.g., the Simplex or Karmarkar methods). The solution will furnish the "optimal" levels

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[4]One may suppose as an alternative, that the policy objective could be to minimize the sum of the minimal incremental costs of individual options. As a planning objective for DCs this is implausible because it would not ensure that the total costs of remaining on the specified abatement path, given the society's growth objectives, are also minimized.

[5]Where negative costs (net benefits) are involved in a particular abatement option these are excluded from reckoning of total costs on the assumption that these options may be adopted anyway, i.e., even in the absence of a protocol ("no regrets" strategies).

of switches of pairs of techniques, as well as the set of fresh investments (retirement) in each technique for each period. These elements of the solution may be employed to determine the "minimal"[6] incremental cost of the abatement program in each period.

7. Concluding comment:

The present exercise is a very limited one. The definitions of "minimal incremental costs" at both the project and program levels are rather restrictive, and are aimed at locating a datum of incremental costs which, perhaps, all analysts may agree upon as representing the minimum direct economic costs involved.

Any actual abatement option or program will doubtless involve other direct and indirect costs. These may be in the nature of transactions costs in planning and implementation, including domestic regulation, as well as costs of dissemination of abatement techniques. Major costs may also be involved in remedying social impacts, e.g., the retrenchment, retraining and rehabilitation of coal mining communities. Macroeconomic effects of any significant abatement program may involve costs by way of changes in relative price levels and welfare levels of different classes, due to general equilibrium effects. Such macroeconomic effects may be difficult to apportion between the abatement and growth/structural change components of the overall program. A major research challenge for the near future is to develop appropriate notions of incremental costs which take account of these elements.

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[6] "Minimal" in the sense that these are the incremental costs associated with the minimum of the total costs as determined by the LP. Moreover, they are determined on the basis of the MIC associated with each switch from technique i to j.

Appendix

In this appendix we give the detailed mathematical structure of the LP model for computing the minimal incremental costs of an abatement program which ensures that the economy remains on a protocol mandated emissions path and at the same time does not jeopardise its growth objective.

The elements of the LP model are :

(1) A discrete set of techniques :

$$\{i\} = \{1,2,......,N\}$$

(2) A discrete set of time periods :

$$\{t\} = \{1,2,t,......,T\}$$

(3) GHGs intensity of each technique (GHGs emitted per unit of capacity, however defined

e.g., MW of electricity) g_i, and without loss of generality (w.l.o.g.) $g_i > g_{i+1}$ for all i ; i.e : the more benign techniques are numbered lower in the series and $g_i \geq \leq o$; i.e. techniques may be sources, sinks, or zero net emitters of GHGs.

(4) Capacity installed in each technique at time t :

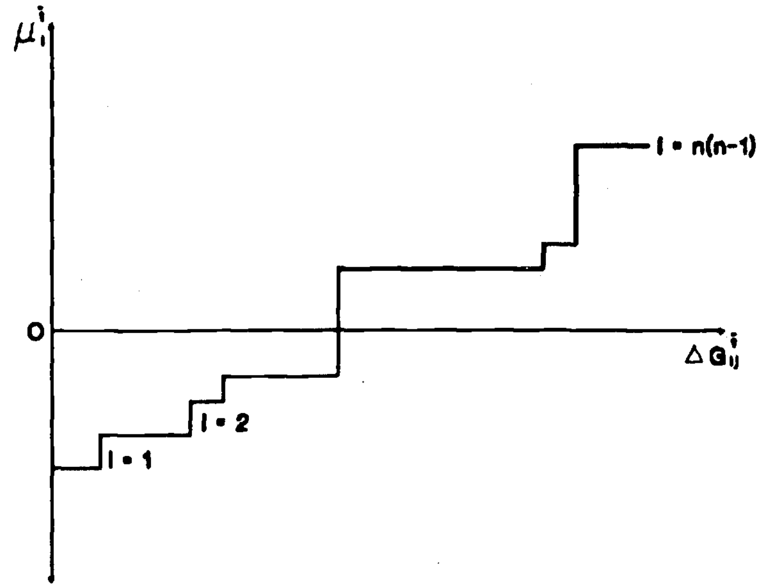
Q_i^t, for all i

(5) Specific cost of a given change in technique at time t:

$$\mu_{ij}^{t} = \frac{MIC_{ij}^{t}}{Q_i^{t}} \qquad (A1)$$

where MIC_{ij}^t is the minimal incremental cost of a change in technique from i to j at time t (see main text).

The specific costs may be illustrated as follows:



where:

$$\Delta G^t_{ij} = (g_i - g_j) Q^t_i \qquad (A2)$$

i.e., the abatement potential of the change in technique i to j at time t, and

$$\mu^t_l = \mu^t_{ij}; \qquad \{l\} = \{ixj \backslash l\} \qquad (A3)$$

and w.l.o.g

$$\mu^t_l < \mu_{l+1}{}^t$$

(6) An allowable set of technique changes:

$\{h \text{ x } k\} \subseteq \{i \text{ x } j\}$ (A4)

$h > k, i > j$

The definition of an allowable set may be such as to allow only changes in technique within given sectors. Additionally, the allowable set may exclude abatement options which are repugnant to other policy considerations.

(7) Protocol mandated paths, which may be, either

(i) Target GHGs intensity of the economy :

$$\overline{g_t} = \frac{\sum_i g_i Q_i^t}{\sum_i Q_i^t} \qquad (A5)$$

or

(ii) Target aggregate emissions :

$$\overline{G_t} = \sum_i g_i Q_i^t \qquad (A6)$$

Model :

The starting model assumption is that the protocol mandated path is adhered to at the current period t. The LP model calculates the minimal costs of a program to ensure that the economy remains on the protocol mandated path at time t + 1, given the economy's growth objectives. These are specified as capacity levels in each sector at time t + 1. The planning objective (by assumption) is that the policy maker minimizes the net costs (maximizes net benefits) of the transition along the protocol mandated path for each period.

Suppose the economy at t moves to t + 1, along the protocol path. Then the change in capacity of each technique j, is given by :

$$\Delta Q_j^t = \sum_{i<j} q_{ij}^t - \sum_{k>j} q_{jk}^t + k_j^t \qquad (A7)$$

where: $\Sigma_{i<j}\, q_{ij}^t$ is the aggregate of switches to j from less benign techniques;
$\Sigma_{k>j}\, q_{jk}^t$ is the aggregate of switches from j to more benign techniques; and
k_j^t is the new capacity (retirement) in j at t

The incremental program cost is then given by :

where a_{ij} etc. is a logic driven parameter, such that :

$a_{ij}^t = 1$ if $\mu_{ij}^t > o$,

$= o$ otherwise

$$IPC^t = \sum_j \left(\sum_{i<j} a_{ij}^t \cdot \mu_{ij}^t \cdot q_{ij}^t + \sum_{k>j} a_{jk}^t \cdot \mu_{jk}^t \cdot q_{jk}^t \right) \qquad (A8)$$

This definition of IPC^t includes the net costs of only those switches which have positive net cost.

Now, let C_j^t be the specific net cost (positive net benefit) of new capacity in j, and r_j^t the specific net cost (positive net benefit) of retirement of j, at t in each case. The total cost of the program is then given by :

$$TC^t = \sum_j \left[\left(\sum_{i<j} a_{ij}^t \mu_{ij}^t q_{ij}^t + \sum_{k>j} a_{jk}^t \mu_{jk}^t q_{jk}^t \right) + f_j^t c_j^t k_j^t + h_j^t r_j^t k_j^t \right] \qquad (A9)$$

where f_j, h_j are logic driven parameters :

$f_j^t = 1$ if $k_j^t > o$,

$= o$ otherwise

$h_j^t = o$ if $k_j^t > o$,

$= 1$ otherwise.

(The total program cost nets out the net costs of technique switches having positive net benefits)

The growth constraints may be written as :

$$\sum_{j \in s} \left[Q_j^t + \Delta Q_j^t \right] \geq \bar{Q}_s^{t+1} \qquad (A10)$$

The right hand side is an exogenous specification of capacity in sector s, {s = 1, 2,--, n}, where s represents different sectors of the economy.

The policy problem is then written as :

Minimize TC^t

q_{ij}^t, q_{ik}^t, k^t

s.t. (1)

$$\sum_{j \in s} [Q_j^t + \Delta Q_j^t] \geq \bar{Q}_s^{t+1}$$

(2) Either :

$$\sum_i g_i Q_i^{t+1} - \bar{G}_{t+1} \leq 0$$

(aggregate GHGs constraint by protocol),

or

$$\bar{g}^{t+1} \sum_i Q_i^{t+1} - \sum_i g_i Q_i^{t+1} \leq 0$$

(economy's GHGs intensity constrained by protocol).

(3) $\{hxk\} \subseteq \{ixj\}$

(only allowable set of technique changes may be considered).

As with all LPs, only specific numerical solutions are possible, employing computer based algorithms. The solution will yield the following sets : $\{q_{ij}^{t}\}$, $\{q_{jk}^{t}\}$, $\{k^{t}_{j}\}$. The first two will enable the computation of the least cost IPC^t, using equation (A8) given above.

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Technology Transfer in the Context of Global Environmental Issues

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Prodipto Ghosh

1. **Introduction**: Multilateral regulation of the global environment sought to be accomplished through Conventions and Protocols, (for example, the Conventions on Climate Change and Biodiversity adopted at Rio in June 1992, and the earlier Montreal Protocol on Ozone depletion, 1990), involves two broad classes of technology transfer issues for Developing Countries (DCs). First, technology transfers are essential in order that DCs may meet their differentiated responsibilities (not necessarily mandatory) in abating environmental damage. For example, a less greenhouse gases (GHGs) intensive growth path in the case of India and China may involve switches from Conventional Pulverized Coal Thermal Power technologies to more energy efficient or "advanced" Coal Power technologies. Research and Development in respect of the latter have, for the most part, been carried out in Industrialized countries (ICs), whose firms accordingly own the relevant IPRs. Technology transfer from the owners to the relevant agents in DCs will be necessary, and the important questions here relate to the terms (depth) of, who pays for, and how much, for such transfers. Second, most clearly in the case of biodiversity conservation, environmental protection (and perhaps traditional knowledge) will furnish important positive externalities to the process of technology generation (e.g. pharmaceutical products, agricultural crops) and the question is how to enable DCs to realize payments for these external benefits to technology producers. This issue is distinct from the question of paying the opportunity costs of biodiversity conservation. Each of these broad issues is spiked at the core with considerations of equity between nations, and across generations. However, this paper is not primarily an exploration of such equity issues. Injecting a little terminology for convenience, we refer to the first

set of issues as the "transfer question", and the second set as the "rent sharing" question.

In the next section we look briefly at the theoretical under-pinnings of IPRs, including a brief restatement of DCs perspectives.

2. **Theoretical Basis of IPRS:**[1] The standard justification for grant of property rights over intellectual property is that such rights furnish incentives for creative work. Further, such rights are sought to be fine-tuned so that the incentives maximize the difference between the value of the resulting intellectual property and the social cost of its creation, including administration-and transactions costs. In other words, the specifics of IPRs regimes are designed to realize economic efficiency. Some further questions are involved:

First, IPRs regimes are premised on the belief that prospective financial returns in fact drive private creators of intellectual property. In other words, that such private creators will have sufficient incentives only if they have the ability to capture at least some of the value that users place on such property: If they are unable to do so, the amount of innovative activity may be inefficient.

Second, there is the issue of whether innovative activity takes place at least social cost. This may depend upon the extent to which creators may borrow ideas or concepts from earlier work. For example, rights to "derivative work" are typically vested in the authors under copyright law, resulting in increased costs to subsequent authors.

[1]The following discussion borrows from Besen and Raskind (1991).

Third, somewhat related to the second issue, is whether the IPRs regime maintains a proper balance between creating and disseminating intellectual property. A particular incentive structure may result in resources being assigned to the creation of many new works. If however, these innovations are not widely used, the net societal benefits may be less than in the case where fewer resources are employed in creativity, but the intellectual property created is more widely disseminated. This issue focuses attention on two important questions on the appropriate scope of protection. One, what is the optimal duration of IPRs protection, for example in case of patents. Two, what is the optimal tradeoff between the duration and breadth of IPRs protection.

Another way of looking at this issue is in terms of tradeoffs between static and dynamic efficiency. The former would require that innovations resulting from resources invested by private agents be made widely available to all who are willing to pay the (low) marginal cost of dissemination. Accordingly, public policy should facilitate the widespread use of these assets, implying minimal property rights in them. Dynamic efficiency considerations, on the other hand would suggest that with minimal property rights, the creators may not recover their initial investment, let alone attain sufficient returns to motivate them to undertake such chancy activities in the first place. Accordingly, property rights should be stronger ("exclusive") than would be implied under static efficiency.

Formally, IPRs are domestic policy instruments, granted by national authorities. However, since innovations embodied in products (or by themselves) cross borders, the question of IPRs protection in international transfer is important. On the other hand countries have differing perspectives on the socially optimal tradeoffs between duration and breadth, and indeed, on what categories of knowledge may be conferred IPRs protection. The question of harmonization of IPRs laws across countries and transboundary protection are important current issues of international political economy. A brief account of perspectives of DCs in this debate is furnished below:

2.1 **Developing Country Perspectives** [2]: We take as a model of an IPRs regime incorporating typical DCs concerns, the current Indian IPRs system. This regime diverges from typical OECD countries IPRs regimes in three major aspects:

First, several categories of products and processes are excluded from IPRs protection. These include horticulture, agriculture, and food processes, and medicinal and drugs products. The reasons are that a major part of the population depends on agriculture and horticulture for its livelihood; that the purchasing power of the poor for food is limited; and because basic health care is scarce.

Second, while the system rewards innovators, it is not intended to confer monopoly rights in manufacture or imports. Accordingly, the regime permits compulsory licensing for working patents in India.

Third, the regime seeks to promote diffusion of existing technologies and innovation of technologies which create economic opportunities for a late industrializing economy. Accordingly, in several sectors (e.g., pharmaceuticals) processes may be protected while product patents are disallowed, facilitating the

[2] This subsection relies on Nayyar (1992)

wider use of the products as well as local R&D in alternative manufacturing processes.

These features of the Indian IPRs regime, are at bottom, expressions of equity and (technological) development concerns. Equity within the society is sought to be realized teleologically, focusing on the need to enhance entitlements to basic needs by the poor, particularly in respect of livelihood, food and medicine. This is attempted to be accomplished through the IPRs regime itself, rather than a separate overall policy framework for social welfare. Accordingly, in pursuit of equity, property rights (in respect of both duration and breadth) for creators is weakened.

The second policy imperative, that of facilitating technology development, derives from the fact that comparative advantage across countries based on knowledge requires a policy framework which accelerates knowledge (and skill) acquisition. Accordingly, this policy objective justifies narrower IPRs protection, besides exclusions from patentability.

These considerations are sought by DCs to justify differentiated IPRs regimes in ICs and DCs.

DCs scholars have argued that the draft agreement on IPRs at GATT (the "Dunkel Draft") neglects these concerns, focusing instead on the interests of ICs. Thus the proposal "seeks to expand the scope of the IPRs system, increase the life of privileges granted or rights conferred, extend the geographical spread where the privileges or rights can be exercised, reduce the restrictions on the use of rights conferred and, above all, create an enforcement mechanism with retaliation across sectors "(Nayyar, 1992). More specifically, exclusions from patentability would be restricted to life-forms, implying that exclusions on product patents would be disallowed. Further, the burden of proof in suits for violation would be reversed with the onus on the alleged infringer. In addition, compulsory licensing would be severely restricted, and imports deemed as working the IPRs. The period of protection would be extended (from 14 currently in India) to 20 years. These are important deviations from, for example, current Indian patent law. Serious consequences are prognosticated: Essential technologies may become unaffordable; the emergence of domestic technological capacity may be stymied; transfers of technology may be retarded; and restrictive business practices by TNCs may increase. These impacts would accentuate inequalities between ICs and DCs.

Some other scholars (e.g. Sengupta, 1991), on the other hand, have argued that strengthening IPRs protection in DCs (albeit not on the lines of the Dunkel draft) would ensure continued Foreign Direct Investment. This is because of a perception in the international business community that investing in countries with weak IPRs protection is risky. Empirically however it has been noted, that the laws governing foreign investment and technology transfer, as well as the general industrial environment, play a greater role in determining investment and technology flows than IPRs protection levels. Accordingly strengthening IPRs protection may neither adversely affect developmental concerns, nor necessarily attract foreign investment and technology flows.

In the next two sections, we present descriptive accounts of some key IPR instruments, as well as modes of technology transfer.

4. **Principal types of IPRs**: The two principal types of intellectual property, relevant for technology transfer in the global environmental policy context are "patents" and "trade secrets".

4.1 **Patents**: A patent may be granted by designated public authorities in a country on "any new and useful process, machine, manufacture, composition of matter, improvement and plant as well as to new, original and incremental design for an article of manufacture" (Chisum, 1989). In India, patents are granted under the Indian Patent Act 1970, which was based on the report of the Tek Chand/Iyengar Commission on the subject. There are important departures in the Indian statute from typical patent laws in OECD countries, relating largely to duration, and patentability, i.e., exactly what kinds of innovations may be patented. These differences are discussed elsewhere in this paper. What exactly are the terms of the property right conferred on a patent holder? In exchange for disclosure of the subject matter of the innovation to the public (which would include actual and potential rivals), the patent holder (patentee) is enabled to exclude all others from making, selling, or using the subject matter of the patent for a specified period. During this term, any use of the subject matter of the patent requires permission of the patentee, usually by means of a license involving royalty payments. The patentee can even prevent an independent subsequent inventor of the same subject matter from making, using or selling it. At the end of the period of protection, the subject matter enters the public domain.

Many questions about patents are still widely debated. There is little agreement among economists on the impact of patent protection on the growth of technology (Kitch, 1986), or on the optimal (dynamically efficient) duration of patents (McFetridge and Ratiquzzaman, 1986). Further, the evidence on whether patents have helped cartelization is inconclusive (Hall, 1986).

Patents are frequently the subject of court proceedings, often by suits by patentees alleging infringement. Courts may interpret the patent claim literally, or infringement may be found if there is a "substantial, functional identify between the patent claims and the contested item" (Besen & Raskind, 1991) i.e., the "doctrine of equivalents". In fact, one important legal issue is whether a patent effectively covers more than the literal disclosure in the patent application, or also includes the prospective technology that follows.

Four principal lines of defence are open to alleged infringers. The grant of the patent may itself be challenged as, first lacking the requirements of novelty and non-obviousness. Second, fraudulence by the patentee may be alleged by misrepresenting the prior art in the patent application. Third, a patent is invalid if it was patented elsewhere or described in a printed publication. Finally, the "doctrine of misuse" relates to the use of a patent beyond its statutory scope. For example, if the license involves a tying arrangement, i.e., the licensee must purchase another product from thepatentee.

4.2 **Trade Secrets:** Trade secrets are specific commercial information. One definition (U.S Uniform Trade Secrets Act, 1979) is "information including a formula, pattern, compilation, program, device, method, technique, or process, that: (i) derives independent economic value, actual or potential, from not being generally known to, and not being readily ascertainable by proper means by, other persons who can obtain value from its disclosure or use, and (ii) is the subject of efforts that are reasonable under the circumstances to maintain its secrecy".

Trade secrets are thus, by definition and unlike patents, not disclosed. Trade secret law only protects such information from "improper" disclosure, but not against independent discovery or by reverse engineering (e.g. determining the chemical formula of a pharmaceutical product through chemical analysis). The incentive to create intellectual property protectible as trade secrets derives from their potential value. Trade secrets also differ from patents in respect of subject matter and duration of protection. While innovation or novelty is required of the subject matter for patent protection, commercial value is the sole criterion for protection as a trade secret. Moreover, the duration of trade secret protection is indefinite, limited only by the accident of independent discovery (or improper disclosure).

"Improper" disclosure requires either a breach of duty by an employee (with access to the trade secret) to maintain secrecy. Alternatively, the improper act includes theft, bribery, misrepresentation, commercial espionage; in fact anything that would count as wrongful conduct even outside trade secret law. Relief against improper disclosure includes injunctions and damages.

Clearly, many categories of inventions may be eligible for protection under either patents or trade secrets law (but obviously not both). Although trade secrets law offers lesser protection, because filing a patent application involves heavy transactions costs, while the costs of preventing disclosure of a trade secret may be less, a trade secret is often the preferred course. Alternatively, the disclosure required of patent applications may convey sufficient useful information to potential rivals engaged in a race for related or for the next generation of innovations.

5. **Modes of Technology Transfer**: Technology transfer is defined as the process by which technology, knowledge and/or information developed in an organization, in a given area, or for a particular purpose is applied and utilised in a different setting or context.

Bell (1990)[3] distinguishes categories of transferrable technology and has identified them as three flows:

i. Flow A : Capital goods, Services and Design Specifications embodying technology.

ii. Flow B : Skills and Know-How for Production.

iii. Flow C : Knowledge and Expertise for Generating and Managing Technical Change.

Flow A : Capital goods, Services and Design Specifications:

Technology here refers to hardware or machinery and equipment, which is acquired and brought into operational use during investment projects. Other technological and managerial services included in investment projects cover execution of planning and feasibility studies, types of design engineering, project management services, etc.

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[3] Bell, M., Continuing Industrialization, Climate Change and International Technology Transfer. A report prepared in collaboration with the Resource Policy Group, Oslo, Norway. Science Policy Research Unit. University of Sussex. (1990)

The flow of capital goods and services add to the transferee's production capacity, or in the case of equipment designs, provide domestic capital goods producers with specifications for setting up similar facilities.

Flow B : Skills and know-how for production:

Included in most technology transfer agreements is the flow of know-how required to operate and maintain new or improved production facilities. There are two main components in this flow:

a. 'Paper embodied technology': in the form of manuals, schedules, flow charts, including operating procedures, maintenance and repair procedures, routine quality control, and possibly procedures for marketing outputs and purchasing inputs.

b. 'People embodied technology': refers to knowledge and expertise required to carry out procedures, which in turn includes training of individuals in requisite skills, or in dealing with situations not covered in manuals and routines.

This flow (which includes know-how and expertise) also adds to the production capabilities of the transferee.

Although Flow A and Flow B add to the production capacity of the transferee, they do not contribute substantially to his 'technological capacity'. Neither do the transfer of capital goods or of know-how (which aid in production of a product) add to the expertise and experience required to change, adapt and develop the product or process in the future. The prospects of subsequent improvements are neglected in Flow A or Flow B.

Flow C : Knowledge and expertise for generating and managing technical change ("Know-why"):

Like Flow B, it also consists mainly of information and people embodied knowledge and expertise. It differs from Flow B, in that it is concerned with changing technical systems. There is obviously some overlap between Flow B and Flow C.

The depth of knowledge and information about the technology in Flow C would be greater than that required for routine operation and maintenance. The other (and crucial) component is the expertise required to undertake various engineering design studies, or the evaluation of alternative plans and designs, or the incorporation of technology in improved production systems. Through this flow, continuous technical change could be realized in existing production facilities.

The transfer of technology can occur from a supplier to a recipient by various mechanisms. The modes of technology transfer may be classified as commercial or non-commercial. Commercial transfers are contracted primarily through markets, and non commercial transfers occur primarily through non-market institutions.

The principal commercial methods of transfer are:

(1) Direct foreign investment in a host country subsidiary or a joint venture.

(2) Licensing of intellectual property rights, usually on royalty payments.

(3) Technical assistance.

(4) Sale, importation, installation, and servicing of machinery and other capital goods; and

(5) Franchising of consumer goods and services.

Some of the non-commercial methods of technology transfer are:

(1) Advisory groups.

(2) Personnel Exchanges.

(3) Information Dissemination; and

(4) Education.

It must be noted though that successful transfers are usually a combination of several (all) of these mechanisms. The effectiveness of transfer is a function of the stage of technological development, characteristics of end users, its potential for absorption within the recipient country, besides other factors. Two principal commercial modes of technology transfer are discussed below in more detail:

5.1 **Direct Foreign Investment**: Technology transfer is often a component of foreign direct investment, although each may also stand alone. The flow of technology to developing countries has frequently constituted a part of foreign direct investment, typically by large transnational corporations (TNCs).

Technology transfers between affiliates constitute a significant share of such transactions. Transfers involving the parent firm and their branches, or wholly (or majority) owned subsidiaries are usually done informally, and do not include formal agreement(s). In contrast, when the foreign investment is a joint venture where the local partner is a majority owner, then a formal agreement/license is typically negotiated between the technology supplier and the recipient.

The mechanism of transfer through direct foreign investment may appeal to the supplier because he retains control and earns dividends rather than royalties. Control of the local enterprise is often comprehensive: management, operation and marketing, quality control of products. This facilitates control of the technology itself as a trade secret rather than submitting to the disclosure required by patents. From the viewpoint of the recipient, foreign investment brings in capital in the form of foreign exchange, and the security of the foreign partner's long-term commitment. However, local innovative improvement of the imported technology may be thwarted by the supplier quite deliberately.

5.2 **Licensing of Intellectual Property Rights:** Technology transfer can occur independently of direct foreign investment by means such as intellectual property licenses.

A patent license transfers to the licensee several of the exclusive rights of the patent. The license is usually obtained by the payment of lump-sum fees or royalty, although other commercial arrangements are also possible.

Such an agreement enables a foreign licenser, unwilling to risk his capital in a developing country, or uncertain of a project's profitability, or unable to invest in unfamiliar conditions, to benefit from his intellectual property holding.

In countries where foreign investment is regulated and local entrepreneurship is strong, technology licensing is increasingly used. Similarly where host country foreign investment laws are restrictive, either in the form of prohibition of foreign equity participation in certain sectors of the economy, or legislation requiring a phased 'fade-out' of foreign ownership in local subsidiaries/joint ventures, it encourages TNCs interested in penetrating these markets to opt for licensing agreements in place of foreign investment. This has been the typical experience in India till recently.

Licensing is also convenient in that it is for a finite duration. From the recipient's point of view, licensing leaves him free of control and interference. The recipient may also benefit from interaction with his own government in ensuring that the agreement is equitable. However, government interference may also result in restrictive licensing arrangements.

6. **Role of Government in Technology Transfer**: The role of the government in facilitating transfers of technology should not be underestimated. It is responsible for the economic framework of the recipient country, a factor which would influence investment decisions of TNCs. The signals government gives to industry may discourage or encourage R&D as well as influence modes and depth of technology transfer. Governments are also heavily involved in funding or organizing R&D. In India 80 per cent of scientific R&D is in the public sector, a situation similar to that in France. In the US, Government funding accounts for 50 per cent of the total R&D investments. Further, governments are heavily

involved in setting up the IPRs framework, as well as in negotiating the international IPRs regimes.

India had earlier followed a development path of import substitution, and in an effort to substitute imported technologies, indigenous technological capacity was encouraged by a restrictive regime of technology imports. No significant relationship between protection and degree of innovation has however been observed (Sengupta 1991). Recent policy changes have significantly liberalized technology imports.

IPRs regimes may impact the BOP situations of countries in several ways. First, a strengthening of IPRs may mean that transferees would have to pay increased royalties in foreign exchange. On the other hand a loss of IPRs earnings due to weak IPRs protection in transferees' countries could worsen a trade deficit. For example, it is claimed that the US loses 60 billion dollars a year due to IPRs "violations". Government policy also affects technology transfer through regulation of foreign direct investment, in terms of restriction on import of capital goods, and control of technology licensing. For example, India had earlier insisted on a majority domestic equity share of at least 51 per cent. If however, the transferred technology was closely held, or if the industry was a designated priority industry, or if the industry had a dominant export commitment, the foreign share could go upto 74 per cent.

7. **Appropriate technology**: The technologies under consideration for transfer should be 'appropriate' from the viewpoint of the recipient country. Some of the considerations determining whether a technology is appropriate are first, that it

conforms to the development goals of the recipient country, second it harmonizes with its resource endowments, and third that the conditions under which the transfer occurs relate to its circumstances.

Developmental goals may relate to promotion of self reliance, removal of inequalities in income, increasing employment opportunities etc. Resource endowments relate to availability of natural resources, manpower, managerial skills etc. The prevailing conditions include the existing infrastructure, markets, and other institutional structures.

Accordingly, for example, capital intensive technologies originating in some developed countries are not considered appropriate to India's labour rich economy. Appropriate technologies in this context would include those that are labour intensive, use local materials, are not capital intensive and could be operated on a small scale.

8. **Context of Global Environmental Agreements**: The two global environmental agreements which have important technology transfer implications are the Climate Change and Biodiversity Conventions, both of which were adopted at Rio in June 1992.

The Climate Change Convention commits DCs to three specific actions:

(a) To prepare national inventories of GHGs emissions and sinks.

(b) To formulate and implement publicly notified plans for abatement and adaptation, and

(c) To minimize any adverse effects of abatement or adaptation measures on the economy, public health and the environment.

Additionally, DCs may submit specific abatement (reduction of GHGs), projects for funding inclusive of technology transfer. In these the DCs are entitled to financial resources, outside of normal developmental assistance, including for transfer of technology. The quantum of assistance is described as the "agreed full incremental costs". If such assistance is not forthcoming, DCs have no commitments.

Technology transfer is thus visualized in respect of both abatement and adaptation measures, and to ensure that any harmful impacts of the measures themselves are minimized. No concessional or non-commercial terms of technology transfer are envisaged; only that the financial component (in the terminology employed) shall qualify as grant. Further, no attenuation of IPRs protection of the technologies are contemplated.

We have noted above that commercial technology transfers may occur in a dense set of modes and their combinations, from direct foreign investment protected by trade secrets, to transfer of in-depth R&D capability ("Flow C") under patent licenses on the other. What exactly constitute "full incremental costs" will clearly depend on the depth of technology transfer agreed to between the parties. On the other hand, in respect of Climate Change concerns, the duration of the technology transfer (in the case of patent licenses), or the geographical limits in which the transferred intellectual property right may be exercised, are relatively uncontroversial. The former must extend to whatever limits apply to the IPR protection itself, because Climate Change is a continuing, long-term concern. The latter must extend to (at least) the boundaries and national jurisdictions of the transferee, i.e., the limits over which it has abatement or adaptation commitments.

An important issue for future negotiations is clearly the elaboration of "agreed full incremental costs". Negotiations may proceed either multilaterally, involving all ICs and DCs parties, or they may be bilateral, i.e., between particular DCs and the agencies entrusted with administering funding.

On the question of technology transfer, one may expect differences in perception among DCs. Any multilateral approach to the problem may involve various compromises or tradeoffs within the set of DCs (G-77), possibly with linkages to other issues. On the other hand, such cross linkages would be more difficult to establish in direct negotiations, in the case of individual projects between DCs and the administering agencies. In such cases, the strongest (most liberal) interpretation of the scope of such financial transfers would tend to be valued as precedents. Accordingly, before including interpretations of "agreed full incremental costs" on the multilateral negotiating agenda, it would be appropriate to study the strategic bargaining aspects on depth.

Technology transfer issues are also at the heart of the biodiversity convention. At its core, this convention attempts to set up a framework by which access to genetic resources are granted (typically by DCs to ICs) in exchange for transfer of the technology embodying the genetic resource. Because it is physically impossible to deny access to the genetic pool conserved in-situ, the framework stipulates (in the official Indian interpretation) that non-disclosure of the fact of use of particular genetic resources shall constitute a legal wrong. The parties shall conduct the exchange on "mutually agreed terms", meaning commercial contractual agreements involving royalty payments.

In this case, since what exactly comprises "technology transfer" remains undefined, ICs may endeavour to place the least restrictive interpretation of the term. Apart from depth of transfer, since sharing of IPRs rent are envisaged, questions about duration of transfer and geographical limits over which the licensed (transferred) rights may be exercised are important. Further, because of the contractual nature of the arrangements visualized, little multilateral clarification of the terms of technology transfer are feasible.

It seems that the stipulation of mandatory technology transfer in the framework for contracts confers little advantage to DCs. Apart from the wide room for manoeuvre by ICs that exists in interpreting "technology transfer", we need to note that IPRs rents can be captured equally by licensing IPRs (i.e., by royalties) or by sale of products embodying the technology, (i.e., by dividends). The economics literature would not support a view that IPRs rents visualized in the former case would be substantially lower. On the other hand, if the IPR in question involved a category of trade secrets, any perceived risks of unauthorised disclosure of the technology would lead to a risk premium being added on top of the IPR royalty.

Serious legal issues are raised by the apparent requirement of compulsory disclosure of the source of genetic resources employed, and transferring the "make or license" discretion from the IPR holder to the gene supplier. For one, trade secrets protection may no longer be available. For another, patent protection may significantly lose its exclusionary power. Further, the effectiveness of the new regime hinges critically on exactly what penalties follow in the event of non-disclosure. If the penalties are not severe, the regime would be ineffective.

A great deal of further analysis would be advisable on the specific legal and economic implications of the biodiversity convention. The document itself is complex, and ambitious. Besides, the question of the framework for contracts, other provisions of the convention are also subject to varying interpretations. The term "agreed full incremental costs" has again been employed in the context of commitments outside the contracts. In particular, in respect of conservation measures, DCs need to ensure that the transfer of funds at least equal their opportunity costs from alternative uses of the biosphere protected.

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Strategies to Sustain Energy Efficiency Enhancement in India

Dr. Ajay Mathur

Introduction

Addressing concerns about the greenhouse effect entails efforts to limit carbon dioxide emissions from fossil fuel use. There are four major categories of interventions to accomplish this: enhancement of energy efficiency; substitution of high-carbon fuels by low-carbon fuels; development and deployment of renewable (non-carbon) energy technologies; and sequestering of carbon dioxide emissions. Many technical options exist in each category. There are, often, additional economic and environmental benefits also associated with the adoption of these options; yet, the national economy does not easily adopt them. At present, the key questions concern not the technologies themselves, but the constraints to their effective incorporation into the economy, the strategies necessary to encourage this incorporation, and the policies required for the implementation of these strategies. This paper addresses these issues in the perspective of devising strategies and accompanying policy interventions that encourage sustainable energy-efficiency practices in the Indian economy. The emphasis here is on the development of capabilities that can internally generate processes that continuously create the need for energy-efficiency enhancement, rather than on periodic technology imports that are inefficiently utilized.

Energy Efficiency in the Indian Economy

In a macroeconomic sense, all economies (including the Indian economy) exhibit a decrease in energy intensity (i.e., the amount of energy required per unit of GDP) with increasing affluence (e.g., per capita GDP). Figure 1 shows this trend for a number of countries; note that energy consumption includes biomass fuels. In the initial stages of development, the decrease is due to the switch from biomass fuels (which are utilized with very low efficiencies) to commercial fuels (which have much higher end-use efficiencies). As industrialization progresses, a simultaneous shift in both fuels and technologies, spurred by reasons of economic efficiency, lowers the energy intensity of the economy. Beyond a per-capita GDP level of about $7,000 (at 1980 prices), structural shifts in the economy result in a decoupling of the energy-GDP link (Janicke et al., 1989), and to a continuing decrease in the energy intensity of the economy.

In the present Indian energy scenario, fossil-fuel use accounts for nearly all energy-related carbon dioxide emissions. Net biomass burning results in 0.59 Tg of carbon dioxide emissions annually, while fossil fuels account for 541.52 Tg (TERI, 1990). In the context of global warming, therefore, it is necessary to examine the commercial energy intensity of the economy, rather than the total energy intensity. Figure 2 shows the commercial energy intensity: despite fluctuations, a relatively steady trend is visible. A sectoral examination provides useful insights: Figures 3, 4, 5 and 6 show the energy intensities of the industrial, transport, agricultural and residential sectors, respectively. In the transport and industrial sectors, a decreasing trend is observed, while in the residential and agricultural sectors, the trend is an increasing one. In the latter sectors, this is largely due to the low-base of energy use, as well as because of the continuing shift from biomass to commercial fuels.

The periodicity of energy-intensity decreases in the industrial and transport sectors needs special attention: the decreases correspond to imports of new technologies which result in a short-term increase in energy-efficiency. However, with time, the energy-intensity rises again, till the next round of liberalisation in the economy when a fresh batch of technologies is imported. This indicates the lack of an internal engine for continual energy-efficiency upgradation. The existing path is clearly economically inefficient.

The Indian Energy Market

Pervasive imperfections in the Indian energy market create many opportunities for cost-effective savings: the absence of competitive markets, skewed price structures, and constraints in access to technologies are the most frequently cited imperfections. However, in these tumultuous times, as the country moves towards the establishment of a market economy, these constraints are weakening; there is a growing acceptance of the market as the most efficient mechanism of capital allocation, and of full-cost pricing (especially in the energy sector) as a necessary precondition for financial stability.

In the move towards encouraging marketisation of the energy sector, the lending of the multilateral development banks, particularily the World Bank, has emphasized the dismantling of barriers to competition, and restructuring of institutional configurations (including privatization of public-sector energy enterprises) so as to establish financial and administrative policy regimes that encourage competition, fair pricing, and technological development; establishment of domestic capital markets; ensure access for all to the market; and promote fiscal, rather than physical controls (World Bank, 1989a; 1989b; 1990a; 1990b). These are aimed at ensuring the establishment of energy markets; it is expected that this process of marketisation would be accompanied by increases in efficiency - of capital utilization, of labor productivity, as well as of energy use.

However, it is important to note that one essential component of an efficient market mechanism is still lacking: the corporate technological capability for responding to price signals and other fiscal incentives (and disincentives) for enhanced energy efficiency. Energy conservation and technology transfer literature is replete with examples of unattained goals because of the lack of response capacities; on the other hand, significant relationships between the strength of technological capabilities of firms and their levels (and trends) of energy efficiency, as well as their ability to respond to fiscal signals (aimed at enhancing energy efficiency) have also been well documented (see, for example, Quazi, 1983; Chantramonklasri, 1985; Lall, 1987; Enos and Park, 1988; Pachauri, Mathur and Natarajan, 1989; Carvalho, 1990).

At present, firms and individuals in the economy do not possess the capability to generate and manage change (Bell, 1990) in a large-scale sense; a history of a regulated economy has rendered this capability redundant. Consequently, new technologies often do not operate at design efficiencies, exhibit a downward trend with time, and undergo drastic reductions in efficiency if external conditions force changes in inputs, operating conditions, or of the product specifications (World Bank, 1988; Kumar and Sharan, 1990)

The process of marketisation is expected to encourage the introduction of new and efficient technologies in the Indian markets. It is feared that if this introduction is not accompanied by the simultaneous development of capabilities within the firms to generate and manage change, the large energy savings potential would not be realized. Moreover, as energy efficiency accompanies other efficiencies, its absence could also mark the large-scale failure of technology-based firms in the marketising economies: possibly spelling doom for the process itself.

Capabilities to Generate and Manage Change

What is this capability? What is necessary to acquire it? And, what would it take to encourage its development across the marketising economies ?

Two issues have to be considered while defining this capability. The first is the ability to exploit a technology efficiently, as well as innovate to enhance its performance. The second is the ability to respond effectively and rapidly to economic signals in the market so as to maintain (and enhance) efficiencies of labor productivity, energy use, and capital utilization.

What does it take to achieve this capability? In the highly regulated electricity industry in India, two companies have consistently maintained operating efficiencies far in excess of the national average, demonstrating a capability to rapidly absorb new technology and often operate it with efficiencies higher than they were designed for. Also, in response to changes in the quality of coal and lignite supplied to them, they have successfully carried out technological modifications that enable them to handle fuel of a substantially different quality than what their plants were originally designed for, and still exceed original design efficiencies (Narayan and Kalia, 1989; Soundarajan, 1990).

In both the companies, the prime reason for the success seems to be their conscious development of a group of professionals who continuously interact with both technology vendors and plant operators. These are highly talented people who monitor plant performance and gain an understanding of the problems that hinder efficient operation through discussions with plant operators. They also follow technological development in the electricity industry, are involved in it by way of their interactions with technology manufacturers to solve present operating problems. Over a period of time, they have acquired the ability to understand what it takes for the technology to operate at its most efficient level, and to engineer cost-effective measures to maintain plant efficiency in the face of changing conditions. Their cumulative experience has also been fed forward to improve the engineering of new projects and the quality of recent technology purchases.

These groups are the link between two important processes in the market: the production of goods, and the development of technology for that production. The surprising fact is that though the need for developing these "human-endowed technological capabilities" (Bell, 1990) seemingly self-evident, they are highlighted in the marketising economies only because of their rarity. The reason is largely economic: these capabilities need a long time (on a business timescale) to show results, and require highly-talented professionals (Soderstrom, 1991). Both these translate to additional costs.

And in economic environments where change is slow and regulated, there is no incentive to invest in these capabilities which leads to decline in performance (World Bank, 1990a; 1990b).

Sustaining the process of marketisation will necessitate the large-scale development of human-endowed technological capabilities to generate and manage change. Their importance is best illustrated by examples from countries that have successfully marketised themselves recently. In Korea, the national electric utility's economic and technical performance improved steadily through the seventies and the eighties, and today compares favorably with that in the industrialized countries (UNCTAD, 1985). Behind this trend lies a record of constant learning and training so as to strengthen its technical, managerial, and engineering skills. This involved a variety of efforts that included an emphasis on the learning and understanding of technology equal to that on the acquisition of goods and services while dealing with foreign consultants and technology vendors; training of large numbers of engineers and operators in overseas plants and engineering design organizations; and internal procedures (including financial incentives) to reinforce learning through interaction of experience and training. A consequence of this process is that the managerial and technical capabilities that were developed have seeded other technology-based firms that have been established in Korea; many of which are already major internationally competitive companies.

Strategies to Sustain Energy Efficiency

Any initiative seeking to encourage energy efficiency would have to incorporate the development of change-managing capabilities that encourage the enhancement and sustenence of energy efficiency in firms in the marketising economies. The development of these capabilities requires, first and foremost, corporate commitment. However, in economies in transition, where, till recently, the development of these capabilities could have been a liability, and where the emerging markets, as yet, do not do not actively necessitate their existence, macroeconomic policies are required to stimulate their expeditious development. The differences in the manner in which the economies of the countries in transition operated prior to marketisation, and the differences in the forces which drive the transition, imply that the actual policies and the instruments used to implement those policies, will be country specific. The overall goals and strategies would, however, be similar.

Opportunity Costs of Capability Development

The first strategy would involve the incorporation of the costs associated with capability development in the overall financial framework of the firm. This implies, first, an acceptance that the absence of human-endowed technological capabilities represents lost opportunities. Second, that an assessment of these lost opportunities is required. Such an assessment could be based on a comparison of performances of firms with and without this capability, particularly in the marketising economies. The goal would be to understand, in economic terms, the opportunity cost of developing this capability, and hence the investment justified in its development. Without minimizing the difficulties involved, and the wide variations expected in the assessments because of firm size, nature of business, level of uncertainty in the market, etc., they would provide an explicit rationale for incorporating investments for capability development in financial planning. Assessments and modified cost-benefit procedures should be encouraged by governments, financial institutions, and multilateral agencies such as the World Bank. The latter's role is important because of its pervasive influence and ability to enable cross-country analyses. The assessments themselves would probably be most effectively carried out by independent bodies, such as industry associations and policy research institutions. In the United Kingdom, the Science Policy Research Unit of the University of Sussex has initiated such assessments; in India, so has the Tata Energy Research Institute.

Financial Incentives

Encouraging firms to develop capabilities to manage change by providing them opportunities to expand into new market segments would be the second strategy. A possible configuration to achieve this goal could be the establishment of venture capital funds to finance projects that involve some inhouse engineering before commercial production can commence. Most marketising economies do not have institutions that provide venture capital; most bankers in these countries are not comfortable with risk-based lending that involves pre-commercial development as well. Three years ago, the U.S. Agency for International Development established a program along these lines in

India. Called PACER (Program for the Acceleration of Commercial Energy Research), it is managed by an Indian financial institution, and provides loans to firms on a profit- (or loss-) sharing basis for the commercial production of energy-efficient technologies. The projects necessarily have to involve some technological development activity: often, it is the adaptation of imported technologies to suit the Indian market; at other times, it is the upgradation of existing technologies, or engineering new technologies for which there is a perceived need. It is too early to evaluate the role of PACER in human-endowed technological capability development in the Indian market; anecdotal evidence suggests a positive correlation in the vast majority of the firms involved in the Program.

Scope and Depth of Technology Transfer

The third strategy would be to deepen the content of technology transfer. Bilateral and multilateral agencies can play a more direct role in financing (through mechanisms that may vary from country to country) the costs of developing the capability to generate and manage change in the recipient firms in the marketising economies. It is important to note that this converts a one-step transfer into a long-term process. Typically, the transfers do provide for some training, but the depth and scope of technology transfer would have to be enhanced if indigenous capabilities are to be developed. In terms of capability development and technology absorption, an alternative route that should be followed, where possible, is to acquire technology from another firm in the marketising world, or in the recently marketised countries. In such cases, the experience of the technology vendor in assimilating and utilizing the technology efficiently is of far greater relevance to the technology recipient. The need and the necessity for developing capabilities to manage technological change are also more forcefully impressed on the recipient (as well as on financial institutions).

Longer linkages; involvement of the recipient firms in problem-solving associated with the technology elsewhere in the world; and possibly their involvement in future technological development, would improve capability building in the marketising economies. This complicates the direct connection between financial transfers and the provision of goods and services, but could still be handled in a financially accountable manner by the incorporation of assessments suggested in the first strategy. The mechanisms could be managed in a manner similar to the technical assistance program of the United National Development Program (UNDP). A necessary corollary of this process is that relationships between transnationals and their licensees in the marketising economies would need to be revaluated. It might be beneficial to both parties to invest in joint ventures rather than outright technology licensing. In this perspective, concerns such as intellectual property rights would have to be addressed by the governments of the marketising economies to persuade the transnationals to have deeper ties with their countries.

Energy Efficiency Standards

The development of a process of evolutionary standards in the marketising economies is the fourth strategy to encourage the development of human-endowed technological capabilities to manage change. Product performance and safety standards are necessary to ensure that products can enter the international market. However, in many instances, it may not be possible to impose a one-step change from existing practices to international standards; the governments may then adopt an evolving set of standards that encourages the development of this capability as the most cost-effective means to maintain compliance with standards. Escalating efficiency standards imposed by government on U.S. appliance manufacturers required firms to innovate or exit. In the process, surviving companies developed engineering expertise which has been repeatedly called upon to meet new technical challenges, including finding alternatives to CFCs while simultaneously ensuring compliance with tougher energy standards for refrigerators (Hallett, 1991). While this non-market -driven technology-forcing has been costly, it has resulted in refrigerators which use 55% less energy than in 1972, and is possibly one of the reasons why Japanese refrigerators have not displaced American refrigerators in the U.S. market.

Education and Training

Finally, the governments of the marketising economies will have to recast their education systems. There is a need to provide advanced and applied technological and managerial training to people in whom the capabilities to manage technological change are to be endowed. To a certain extent, this is available in the Soviet Union at its applied technological institutions. However, their focus would have to widen from technological development alone to technological change. Also, as skills to manage change are acquired cumulatively, they are not easily communicated through traditional pedagogy. Short-term advanced courses for working professionals would need to be designed and established. The industrialized countries have institutionalized this process through courses organized by professional organizations, training institutes, etc. Their experience may be utilized, again with the help of organizations like the World Bank and UNDP, to establish similar structures in the marketising economies. The content of these courses would, however, be best culled from experiences in the marketising economies themselves, or from those in the recently marketised economies.

The ability to mould the process of human-endowed technological capability development in the marketising economies also provides a historic opportunity to ensure that environmental concerns are as deeply ingrained as technological and financial concerns in the thought processes of the people who will actually determine the technological structure of the marketising economies. Incorporating environmental analyses and perceptions in the training processes would contribute greatly in ensuring that responses to change by individual firms protect and enhance both environmental quality and the firm's profitability. Over the economy, it could enmesh global sustainability with market sustainability.

In order to illustrate the mix of strategies required, a case-study is presented here which is presently underway. The Tata Energy Research Institute is involved in this exercise, alongwith Indian manufacturers of refrigerators, compressors, and refrigerants, as well as the Ministry of Environment and Forests, Government of India.

The Indian Refrigerator Industry: Opportunities and Constraints

The Montreal Protocol to ban Ozone Depleting Substances (ODS) is the first international agreement to phase out the production and consumption of an entire class of man-made chemicals in the interest of the global environment. This treaty was established with an understanding of the costs that this phase out would entail. The subsequent London amendments to the Montreal Protocol acknowledged the requirement of special provisions to meet the needs of developing countries. These amendments provide for additional financial resources and access to relevant technologies by establishing a Multilateral Fund to meet the incremental costs of switchover to non-ODS technologies. Although India is not yet a Party to the Protocol, the Government has expressed its commitment to join the Protocol once the London Amendments have been ratified by the Parties to the Protocol.

The Refrigerator Industry in India

The current stock of refrigerators in India is about 7 million; and annual production is of the order of 1.25 million, increasing at over 20 per cent per year. It is projected that the stock and annual production would increase to 32 million and 5 million, respectively, by the year 2000, and to over 110 million and 13 million, respectively, by 2010. At that time, the overall penetration of refrigerators in domestic households would still be less than 60 percent. Currently, all the CFC requirements in India (except those of CFC-113 and halons) are met by domestic production. The total production of CFC-11 and CFC-12 is presently about 4,300 tonnes, and growing at about ten percent per year. The refrigerator industry utilized about 600 tonnes of CFC-11 and CFC-12 in 1990. This consumption is expected to increase to about 3,500 tonnes in 2000, and 9,000 tonnes in 2010 (the year by which complete phase out of ODS is expected in India).

The capacities of refrigerators manufactured in India are generally in the 2.3 to 13.4 cubic feet (65 to 380 liters) range, with the 6.8 cubic feet (165 liters) model being the most popular and accounting for 93 per cent of sales in 1990. The preference for the small refrigerator size is largely due to the limited buying power of individual customers, which is accentuated by a tax structure that imposes a large jump in excise duty for refrigerators larger than 6.8 cubic feet. In the tropical climate of India (with an annual average temperature of about 90 degrees Fahrenheit, and relative humidity greater than 85 percent for at least three months of the year), the main service required of refrigerators is the provision of cold water and ice. Fresh produce and milk are refrigerated, but the requirement for maintaining frozen foods is much less. Compressors are overdesigned so as to accommodate the poor quality of electric supply (with voltage fluctuations ranging from 125 to 270 volts, as against the norm of 220 volts). Consequently, average annual electricity consumption of the 6.8 cubic feet refrigerators is of the order of 500 kWh; about 30 per cent higher than the maximum allowable electricity consumption of U.S. refrigerators of the same size.

Strategies for the Commercialization of CFC-free, Energy-Efficient Refrigerators in India

The unique combination of services required from refrigerators in India, the economic and demographic patterns, and the climate dictate the development of a unique refrigerator technology for India. Thus, the choice of ODS substitutes and accompanying component technologies for Indian refrigerators must be undertaken in response to the Indian situation. The electricity shortages in India, and the present level of electricity consumption of Indian refrigerators also imply that immediate quantum jumps in their energy efficiency are necessary. A three-pronged strategy is would be essential for the development and commercialization of CFC-free, energy-efficient refrigerators in India:

India should immediately launch an evaluation and assessment program for the identification of appropriate substitutes and the accompanying component technologies that are best suited to Indian conditions. The present uncertainty regarding substitutes, and the ten-year delay to which developing countries are entitled in implementing the phaseout, allows India time to make a decision. With this perspective, the appropriate strategy would be to test various substitutes and component technologies under Indian conditions so as to decide on the optimal combination for refrigerator performance in India. This is a developmental activity in which only U.S. and other foreign manufacturers with an active interest in the Indian market would be likely to participate. Other manufacturers with an interest in marketing their products to Indian manufacturers might also participate as part of a marketing effort. Such an activity would allow for the interaction of all manufacturers (of refrigerators, insulation, compressors, and refrigerants), without infringing on their proprietary rights. Intellectual property protection is a critical issue from the perspective of the U.S. manufacturers.

The establishment of evaluation and assessment program would benefit from the involvement of U.S. research and development professionals who are also involved in similar activities. The program could be funded by the Global Environmental Facility, by bilateral funds, as well as by the Multilateral Fund of the Montreal Protocol after India becomes a Party to the Protocol.

The Indian refrigerator manufacturers and research and development organizations should immediately take steps to enhance the energy efficiency of refrigerators. In the United States, the switchover from fiberglass to blown foam was responsible for the initial decreases in electricity consumption; subsequent decreases were largely due to redesigned compressors and heat exchangers and improved control systems. These advances were based on CFC technologies; the U.S. manufacturers presently are addressing more stringent 1993 energy efficiency standards in the face of Montreal Protocol phase out requirements. The Indian compressor manufacturers should also upgrade technology, possibly taking advantage of PACER to import the technology and then adapt it to Indian conditions (by incorporating technologies similar to those used in uninterrupted power supplies, etc.) . Voluntary energy labelling may be considered by refrigerator manufacturers till energy efficiency standards are in place.

The Government of India should institute policies that encourage the development, commercialization, and adoption of energy-efficient refrigerators. These policies include:

(a) incentives for energy-efficient refrigerators (for example, by linking the excise duty to energy efficiency, rather than refrigerator volume or technology);

(b) development of energy-efficiency standards for refrigerators which evolve with time;

(c) initiatives for enhancement of power supply quality; and

(d) potential investments in demand side management (for example, the development and adoption of energy-efficient refrigerators) to redirect limited capital to investments in energy services when such investments prove more cost-effective than obtaining additional capacity exclusively through the purchase of additional generating capacity.

Conclusions

A wide range of issues have to be addressed in order to ensure that a sustainable energy efficiency trend is put into place in developing countries. The establishment of competitive markets and rational energy pricing are two essential features of this process. However, by themselves, they may not be adequate because of the lack of a capability in firms in developing countries to generate and manage the inevitable changes that accompany a market economy. The development of this capability is closely related to the overall ability of countries to develop a economic and intellectual culture based on economic efficiency. It must be stressed again here that energy efficiency accompanies other efficiencies (e.g., of capital and labor) in the economy, and consequently, energy efficiency enhancement strategies are necessarily economic efficiency enhancement strategies as well.

Finally, a caveat is in order: this paper addresses the question of energy efficiency enhancement in India only in the part of the economy that is, "organized", in the sense of individuals and groups being linked to each other through their economic enterprise and its associated rewards. There are large fractions of the population who are, in a real sense, outside the organized economy. These people are generally poor and ill-educated and contribute marginally to the national economy; conversely, they are economically insensitive to market changes and signals. The first aim of developing country policies has been to ensure that these millions are also provided opportunities to join the organized economy. Opportunity structures, the provision of educational and health services, and of financial incentives for this purpose require, and are receiving, much attention; they have, however, not been addressed here.

At the present juncture, the development of human-endowed technological capabilities seems to be the crucial issue in attaining energy efficiency in developing countries.Human-endowed capabilities to generate and manage technological change are as essential to the sustainability of the marketisation process as are the rules that ensure competition and fair pricing. After all, markets are an expression of the aspirations and the endeavors of a people - and if the people are unwilling, or unable to exploit the advantages of a market economy, all policy regimes to ensure market efficiency are pointless; both sides of the market coin need to be equally heavy in order to keep it tossing fairly.

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Energy and Sustainable Development in Developing Countries: Paradoxes and Constraints

Dr Ligia Noronha

Sustainable economic development has come to have two interpretations in the literature on the subject, a broad and a narrow interpretation. The broader interpretation conceives sustainable development at the social, economic and the ecological level whereas the narrow definition conceives it essentially in terms of linkages between environmental quality and development. The broader concept is concerned not merely with the problem of the pressure of development activity on natural resources and the environment, a problem seen as an imbalance between supply and demand, but also with development activity in the context of a social system that sets the terms for the access and use of these natural resources. It is thus a holistic concept referring to the entire economy/ecology/society nexus, and is a concept that has come to dominate the agenda of intellectual discourse. This broad interpretation is, however, difficult to operationalize since it encompasses every part, sector, and resource in the system and has to pay attention to economic efficiency, environmental quality, and equity. This difficulty, however, only emphasizes the fact that the debate about its various contours and spaces should, therefore, be regarded as an ongoing debate since no particular nation or generation has either the information base or the ethical prerogative to take final and conclusive decisions. The broad definition thus underscores the importance of democracy and of equity in decision-making. It draws attention to the fact that such decision-making must necessarily occur within an open intellectual system. An epistemological point that must be noted is that the validity of the scientific knowlege on which decisions are based has to be negotiated by the 'relevant' community of discourse. As part of this ongoing process, therefore, this paper will,for purposes of operationalization, employ the narrow definition which is concerned specifically with the maintenance and enhancement of the production possibilites of a society to produce the 'required' economic and environmental goods and services.

Given this operational definition of sustainable development the tensions that have emerged, and are likely to emerge if no corrective action is taken, between energy development and sustainability, is that the intensive use of natural and environmental resources to provide energy services are pressing against the thresholds and limits of such resources. This linkage between energy, environment, and sustainable development applies not only to commercial forms of energy but is equally, if not more, relevant to non-commercial forms of energy. In the context of developing economies one observes a process that is spiralling toward increased environmental degradation with poverty as being both a cause and a result of it. Low incomes mean that the bulk of the population is unable to afford commercial fuels and is heavily dependent on traditional fuels as is evident in Table I which summarises the commercial/traditional shares in total energy consumption and Table II which summarizes the shares of traditional fuels - fuelwood, animal waste, and crop residues for countries of the South Asian Region which include some of the poorest countries of the world. High dependence on these resources and the pressure of increasing populations leads to increasing rates of degradation and declining productivity of these resources.[1] The extent of pressures on forests in various regions of India, based on projections of fuelwood requirements to the year 2010 and sustainable yields, can be seen in Table III.[2]

Paradox of fuel switching in the short term

While in the long run, the solution to environmental degradation is a shift to renewable energy resources, in the short term, with increasing populations, the conservation of forest and biomass resources will be achieved through increased efficiency of bioenergy use and by a greater use of commercial fuels as substitutes to the more traditional energy forms. While

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[1]. Average annual growth rates of population for some countries of the South Asian region, for example, are in excess of 2%, with very high population densities per sq kilometre.

[2]. In the case of India, rising population and demands for forest produce has resulted in per capita productive area under forests to fall to 0.05 hectares from 0.2 hectares in 1951 and it is estimated That at the present level of consumption of forest produce and on the current productivity of forests the country needs a minimum of 0.47 hectares per capita.

this will imply a fall in the total energy consumed because of higher efficiencies of commercial fuels, decision-makers are faced with a paradox as reliance on commercial fuels cause the aggravation or the creation of other kinds of environmental degradation. Commercial forms of energy such as coal, electricity, hydropower and oil and gas have a number of environmental impacts that have to be considered in any plans for their expansion. It is not evident if a replacement of commercial for traditional fuels will worsen or improve the environmental situation in developing economies. Impacts of particular concern are:

(1) Air pollution which is quite critical in a number of major cities of developing economies.
(2) The contribution to global climate concerns associated with CO2 emissions. An ESCAP study estimates that emissions of CO2 from the use of fossil fuels in countries of Asia are expected to double in the period between 1986-2000 in a business as usual scenario and increase by over 70% if there is an emphasis on energy conservation.
(3) The pressure on land and forest resources from the development of coal mines and hydroprojects.

CONSTRAINTS TO OPERATIONALIZING SUSTAINABLE DEVELOPMENT

Operationalizing sustainable development in the context of developing countries runs up against the following constraints:
(1) Lack of methodologies to incorporate environmental concerns in energy planning.
(2) Uncertainty about natural systems and their threshold and limit levels.
(3) Low political profile for environmental issues relative to other developmental and social concerns.
(4) Lack of institutions and capabilities for information generation and analysis and where these exist they are often caught up in interinstitutional rivalry.

(5) Lack of technical and financial resources required for reflecting sustainable development considerations in energy strategies.
(6) The political and economic transformations underway and the instability in a number of developing economies create difficulties for decision-making.

The section that follows deals with these points.

(1) <u>Incorporating environmental concerns in energy planning</u>

(a) <u>Preliminary Analysis</u>

An important feature of sustainable development is the necessity to integrate environmental values in energy planning and decision-making.[3] Least cost investment planning has to mean not only less money and energy resources but also less environmental stress. In order to do so it is necessary to monetise environmental impacts wherever possible and incorporate these values into the economic analysis and then choose that alternative or strategy that is cheapest.

The methodology incorporates the idea that energy choices should emerge from decisions based on socio-economic, political, and environmental values on the one hand and the scientific inputs from environmental studies on the other hand. Alternative energy development opportunities will be subjected to an economic analysis, which would involve taking into account explicitly and wherever possible quantitatively, the range of relevant considerations to all in the community who may be affected by the proposed energy alternative.

Preliminary environmental studies are necessary to understand the type, extent, and the nature of natural resources at risk. A pre-requisite for such studies is to have baseline studies in place that allow the identification of vulnerable areas and resources. Preliminary environmental studies will involve predicting the changes that are expected from the baseline as a result of developing the particular alternative.

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[3]. D.W.Pearce, A.Markandya, and E B.Barbier BluePrint for a Green Economy, Earthscan Publications Ltd.,London, 1989, chapters 1, 2, and 5.

A preliminary decision can be arrived at based on the cheapest alternative both in terms of economic and environmental costs.

By way of an example of how an integration of environmental impacts with energy planning can be done, I refer to a recent study done at TERI as part of a larger study for the Asian Development Bank.[4] This study attempted to predict some environmental impacts of energy development to the year 2010 for India and to integrate these impacts into the planning process. Environmental impacts that were monetized were loss of forests due to coal mining and hydroprojects, cost of land affected by overburden dumps and the social costs of displacing people on account of coal projects. Table IV summarises the impacts and the costs for coal projects and Table V for forests lost due to hydroprojects.

(b) <u>Sensitivity and Risk Probability Analysis</u>

However, uncertainty about environmental parameters requires that the analysis be subject to a sensitivity test both with regard to the discount rates chosen and with regard to the levels of damages assumed to result from energy development. Because of the uncertainty about such predictions it is advisable to subject the preliminary decision to a sensitivity analysis of specific targets by reference to the baseline information. If target/targets are not found to be sensitive, a choice can be made among the alternatives. If a target is considered sensitive then the risks will have to be identified and a risk probability analysis carried out. Having incorporated the results into the main analysis a choice can then be made from this set of alternatives.

Figure I below summarizes the main phases of such an attempt at integrating environmental concerns into decision making.

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[4]. TERI, 'Environmental Conisiderations in Energy Development: India Country Study' [Draft Final Report submitted to the Asian Development Bank, December 1991]

(2) **Uncertainty about natural systems and their threshold and limit levels**

There is however an important element of natural systems that causes some amount of difficulty in all this and that is the uncertainty regarding them. It has been pointed out that uncertainties about natural systems have a number of adverse effects on attempts to achieve sustainable development:[5]

(a) it may be difficult to tell whether a given use pattern is sustainable or not because the natural variation is already so great and collection of statistically significant data can be expensive.

(b) uncertainty creates a tendency to be overcautious and forego development opportunities that may have impacts that are actually reversible

(c) uncertainty about threshold values may also rule out development options that are economically attractive.

(d) uncertainty can also lend itself as support and justification for bureaucratic inertia.

This uncertainty about natural systems requires us to add another phase to our planning process and that is an information update phase, which allows feedback of measurements and midcourse corrections based on scientific research. The difficulties involved in predictions of changes to the environment as a result of the adoption of a particular energy alternative also calls for a continued monitoring of the impacts of the alternative after it has been chosen in order to ensure that adaptive policies to mitigate impacts are adopted when found necessary. This is especially relevant in the context of concerns about sea level rise. For example, if the withdrawal of oil or gas is greatly increasing compaction and subsidence of a coastal area, then it is increasing the vulnerability of the area to inundation if the

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[5]. R.A.Carpenter, views presented in a paper at the Review Panel Meeting in Jakarta on 30-31 July , 1990, reproduced in Asian Development Bank, **Economic Polices for Sustainable Development**, Manila, 1990, pp 16-17.

sea level rises. This will then call for a limit to be placed on the activity or the pace at which it is occurring. On the other hand if the energy alternative itself is vulnerable to sea level rise, as for example, siting constraints on thermal power plants or a reduced supply of biomass fuels, it calls for some adaptive options either technical, institutional, or biological. (Figure II)

(3) <u>Low political profile for environmental issues relative to other developmental and social concerns</u>

Developing countries are faced with a number of development problems that have a higher place in a decision-maker's agenda, simply because there is more information available about these other concerns or because decision-makers have a more immediate interest in addressing those concerns. When a government has difficulty in coping with energy, food and other basic needs of its polity it will use the resources most easily available, utilise that technology that has a proven record and those institutions that are already well established since time is not on its side. The government has to be seen to be delivering and responding to the immediate needs of its population. Despite the severity of the environmental degradation facing a number of developing economies, the political profile of environmental concerns has been low, although rising. Uncertainty about natural systems or impacts of phenomenon such as the greenhouse gas concentration adds to the difficulty faced by governments in convincing its polity of the need for the incorporation of these concerns explicitly in energy decision-making.

(4) <u>Lack of institutions and capabilities for the generation and analysis of scientific information and where these exist they are often caught up in interinstitutional rivalry.</u>

Any attempt to operationalize sustainable development has to pay attention to the scientific and research needs of development. An extended economic analysis that tries to incorporate environmental concerns calls for considerable technical inputs from the scientific community as seen in the discussion above. While far more facilities and skilled personnel are available in developing countries than there were some years ago, the infrastructure still remains weak in many cases and incapable of making full and effective use of the research capabilities available or to even to look elsewhere for assistance in strengthening this capability. In some cases, good research institutions are caught up in bureaucratic red tape or inter- institutional rivalry making it difficult to have access to the scientific information necessary to carry out the decision analysis. In part this is because a number of these institutions are state funded and monopolistic and do not face any competitive pressure to deliver. A major programme is needed to simultaneously assist in building up facilities and trained and skilled personnel and in strengthening national organizational infrastructures. In the context of energy induced environmental problems that are transboundary, a case can be made for assistance for regional cooperation programmes, as often cost effective solutions are found on a regional rather than a national scale. Emphasis on regional scientific programmes may also increase the competition between institutions and thereby enhance their performance.

Planning for the institutional structure for information generation also has a paradoxical element to it. The main purpose of generating information is to enable choices to be made on as wide a base of knowledge as possible. However, it is observed that choosing the appropriate agent to do so is a problematic issue. For example,in the Indian case, when mulitnationals were engaged in the collection of hydrocarbon exploration information, it was found that there was a lot of secrecy engaged in by these companies and the Indian government felt that it was not getting all the information that was being generated. For this and other reasons, the government chose to set up a national oil company who for a number of years was solely engaged in offshore exploration and dominated onshore exploration. A number of state supported research institutes such as the National Institute of

Oceanography, Geological Survey of India, etc. were also set up to assist in this process of generating scientific information. However, over time it was evident that a satisfactory level of interaction did not occur at the level of information dissemination, and hence the national oil company continued to rely on private international service companies for scientific information. This was because in the one case, secrecy was a result of commercial rationality, while in the other it was a result of bureaucratic rationality. In the former, the agent did not share information since it sought to maintain its competitive edge over other companies and a bargaining leverage vis-a-vis government. In the latter, the agent did not share information to maintain its advantaged interest position and as in the former case to maintain its bargaining leverage vis-a-vis government. In either case the national policy-makers were the losers in terms of information deprivation. Governments in developing countries must hence design information generating, processing, and disseminating institutions which enable policy-makers to make decisions with a larger information base. This may involve an institutional mix that has the benefits, but avoids the pitfalls, of both the above strategies.

(5) <u>Lack of technical and financial resources required for reflecting sustainable development considerations in energy strategies.</u>

Costs will have to be incurred by developing countries not only in adopting methods by which environmental concerns are made explicit in energy planning but also in facing up to the implications of such decisions, for example, if a particular development option is being valued which involves high environmental costs in terms of tropical forest loss, a decision may have to be taken to abandon the alternative. In so doing the country may have to forego pressing immediate needs for which it may require assistance both financial and technical. In many cases there may be need for adaptive options and the adoption of sophisticated technologies that the country does not have access to. Hence, the need for considerable attention to be paid to the development of mechanisms for financial and technical transfers to developing countries.

(6) **The political and economic transformations underway and the instability in a number of developing economies create difficulties for decision-making.**

This is especially so in those economies that are changing or reforming from a bureacratic, statist path of development to a a market friendly appraoch. The difficulties stem from number of vested interests that have deep roots in the economy, bureaucratic opposition to loss of control over the economy and perhaps, a lack of faith of the polity that those steering the economy know what they are about. All these factors make it difficult to build and maintain the required political and social consensus and not lose the momentum of reform.[6] Difficulties may also stem from a lack of understanding of what exactly makes the system tick and sick, and what is involved in making the transition to a different style of governance. The problem is especially acute where the solutions to environmental degradation lie in a correction of market failures and policy distortions as these lie clearly within the national policy-making domain and requires some amount of insight and a knowlege base upon which to take corrective action.

A conceptual distinction that is an aid to choice among mitigating strategies is that between the physical and the economic manifestations of environmental degradation. While population pressures, poverty, rapid economic growth, etc. play a role in the physical manifestations of resource depletion and

[6]. A brilliant and clear exposition of the problems faced by decision-makers in economies undergoing economic transformation is found in the Keynote Address of Vaclav Klaus to the World Bank Annual Conference on Development Economics 1990 in World Bank, **Proceedings of the World Bank Annual Conference on Development Economics 1990**, IBRD, 1991.

environmental degradation, market and policy failures are responsible for the economic manifestations of environmental degradation. Economic manifestations of energy-related environmental degradation include the following:[7]

(1) the observed co-existence of energy resource scarcity with overuse, waste and inefficiency in its use. Irrational pricing policies are especially responsible for this phenomenon.

(2) a renewable resource that is capable of sustainable management is exploited as a non-renewable resource with little concern for its regeneration and future harvests. This is evident in the fact that rates of afforestation in developing countries are typically much lower than rates of deforestation.

(3) underinvestment in protection and the maintenance of the resource base.

(4) the irreversible loss of unique ecosystems and species in the quest for development.

These manifestations have been explained with reference to a dissociation that exists between price and resource scarcity, benefits and costs, rights and responsibilities and actions and consequences and the dissociation can be traced back to a combination of market and policy failures. While the former refers to institutional failures attributable in part to the inherent nature of certain resources and in part due to government failure, the latter are a result of inappropriate interventions in fairly well functioning markets or unsuccessful attempts to mitigate market failures that result in worse outcomes.[8] These failures of policy can be traced back to interest groups influencing policy and to the information base available to the policy makers.

The main types of market and policy failures that result in the dissociation and that need to be addressed are given in Chart I.

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[7]. ADB, Asian Development Outlook 1991.

[8]. ADB, op cit, p 236.

Conclusions

By using a narrow interpretation of sustainable development, this paper identified some of the constraints and paradoxes faced by decision-makers in developing countries. It recognized at the outset the uncertain, perhaps deficient, nature of the information environment, a deficiency which placed the requirements of democracy and equity and therefore an openness on decision-making, allowing for modifications with new information updates. Since the other problem areas of sustainable development have been considerably discussed the paper chose to examine the stages of decision-making, an examination which underscored the need to improve the capability by strenghtening the scientific infrastructure to ensure that the scientific community is able to contribute effectively to the formulation and implementation of energy policy. This is a question of institutional design to optimize information availabilities so that the appropriate relations exist between the scientific community and other actors in the energy planning process and execution.

CHART I: SOURCES OF MARKET AND POLICY FAILURES

MARKET FAILURES

(a) insecurity of ownership resources, also known as the common property problem

(b) Unaccounted for externalities

(c) Unpriced resources or the absence of markets

POLICY FAILURES

(a) Distortions of well functioning markets, through taxes, subsidies, inefficient state enterprises, regulations, etc

(b) Failure to consider and internalize environmental externalities of otherwise warranted policy interventions

(c) interventions that result in worse outcomes than the non-intervention case

(d) Failure to intervene when intervention is required.

Source: ADB, Asian Development Outlook, 1991.

Table I: Share in Total Energy Consumption (1989) (%)

COUNTRY	COMMERCIAL	TRADITIONAL
Bangladesh	25	75
Bhutan	17	83
Pakistan	62	38
Nepal	5	95
Sri Lanka	26	74
Myanmar	N.A.	N.A.
India	50	50
Maldives	-	-

Source: WEC Report 1991.

Table II : Percent Shares of Traditional Energy (1989)

COUNTRY	FUELWOOD	ANIMAL WASTES	AGRO-WASTES
Bangladesh	21	15	64
Bhutan	100	-	-
Pakistan	56	16	29
Nepal	80	9	11
Sri Lanka	85	-	15
Myanmar	N.A.		N.A.
India	65	18	17
Maldives	-		-

Source: WEC Report

TABLE III

The level of pressure on forests because of fuelwood requirements

	Degree of shortage				
	1991	1995	2000	2005	2010
EASTERN					
Bihar	se	se	se	se	se
Orissa	no	no	no	no	si
West Bengal	se	se	se	se	se
NORTHERN					
Gujarat	se	se	se	se	se
Haryana	se	se	se	se	se
Himachal Pradesh	no	no	no	si	si
Jammu & Kashmir	su	su	no	no	no
Punjab	se	se	se	se	se
Uttar Pradesh	se	se	se	se	se
NORTHEASTERN					
Arunachal Pradesh	su	su	su	su	su
Assam	si	si	ma	ma	ma
Manipur	su	su	su	su	su
Meghalaya	su	su	su	su	su
Mizoram	su	su	su	su	su
Nagaland	su	su	su	su	su
Sikkim	su	su	su	su	su
Tripura	no	no	si	si	si
SOUTHERN					
Andhra Pradesh	ma	ma	se	se	se
Karnataka	ma	ma	ma	ma	se
Kerala	se	se	se	se	se
Tamil Nadu	se	se	se	se	se
WESTERN					
Goa, Damand and Diu	si	no	no	no	no
Madhya Pradesh	no	no	no	no	no
Maharashtra	ma	se	se	se	se
Rajasthan	se	se	se	se	se

se-severe; no-none; si-significant; su-surplus; ma-major;

Source. [see footnote 4]

TABLE IV

Submergence and displacement in dam sites

Region	Capacity (MW)	Displacement (No.of people)	Forest submerged (ha)	Affected forest type
NORTH				
Salal	345	-	0	STDE
Chamera	540	-	785	TDD
Dhauliganga	280	550	19.2	TDD
Sawalkot	600	2460	165.5	STDE
Uri	480	1070	0	STP
Dulhasti	390	0	0	STDE
Baglihar	450	1370	12.82	STDE
Thein	600	9595	852	TDD
Srinagar	330	0	202.84	STP
Vishnuprayag	480	0	80	HMT
Lakwarvyasi	420	3502	699	TDD
Maneri 2	304	150	2	HMT
Naphtajhakri	1500	750	0	STP
Kohl	800	2652	989.3	STP
Tehri	1000	46000	1600	STP
Kishau	600	2403	3031	STP
WEST				
Bansagar	348	100000	4478	TMD
Koyna stg IV	1000	0	80	TMD
Narmada&				TMD
S.Sarovar	2450	300000	55000	TMD
Hasdeobango	120	12500	10250	TMD
Ghatghar	250	300	91	TMD
SOUTH				
Srisailam	990	0	0	TDD
Kalinadi	270	1979	1214.5	TMD
Puyankutty	240	87	1900	TMD
EAST				
Ramman	50	600	0	TMD
Koel karo	710	25000	1003	TMD
Upper indra-vati	600	17500	708	TMD
NORTH-EAST				
Rangit	60	225	6.5	MWT
Teesta	1200	40	12	MWT

STDE: Sub-tropical Dry Evergreen; STP: Sub-trópical pine;
TDD: Tropical Dry Deciduous; TMD: Tropical Moist Deciduous;
HMT: Himalayan Moist Temperate; MWT: Montane Wet Temperate.

Source: [See footnote 4]

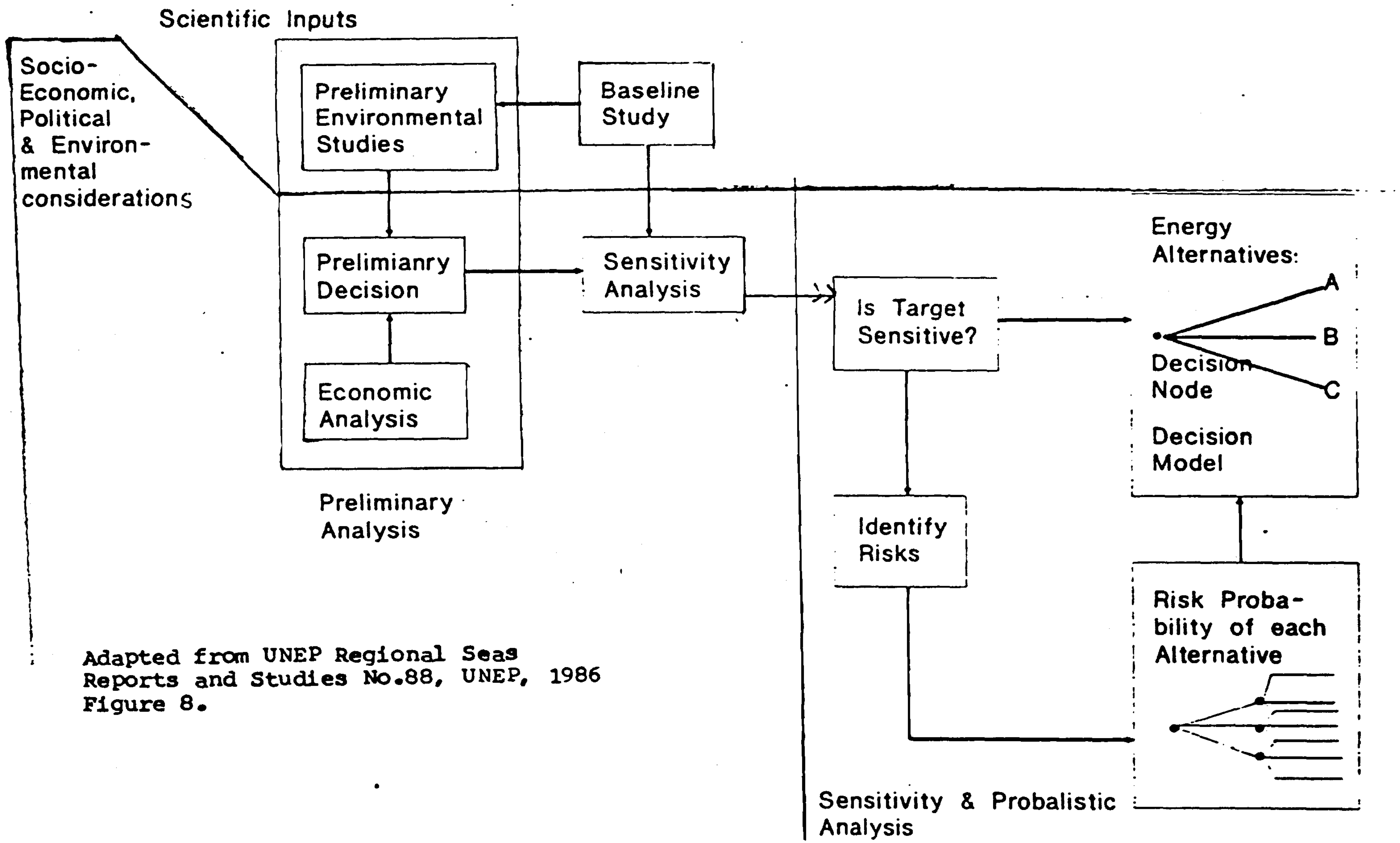
Table V

SOME ENVIRONMENTAL IMPACTS OF COAL MINING PROJECTS (1990/91-2009/10)

REGION	ADD.COAL PRODUCT. (mmt)	FAMILIES DISPLACED (no.)	LAND REQUIREMENTS FOR EXTERNAL OVERBURDEN DUMPS (ha)	ADD. FOREST AREA REQD. (ha)	TYPE OF FOREST
EAST	245.27	29964	4741	34661	TDD
WEST	48.01	10106	1753	10999	TDD+ TMD
SOUTH	17.36	3508	583	12885	TMD
N-E	2.3	494	83	225	TWE
ALL INDIA	312.94	44063	7160	58770	

Source: [see footnote 4]

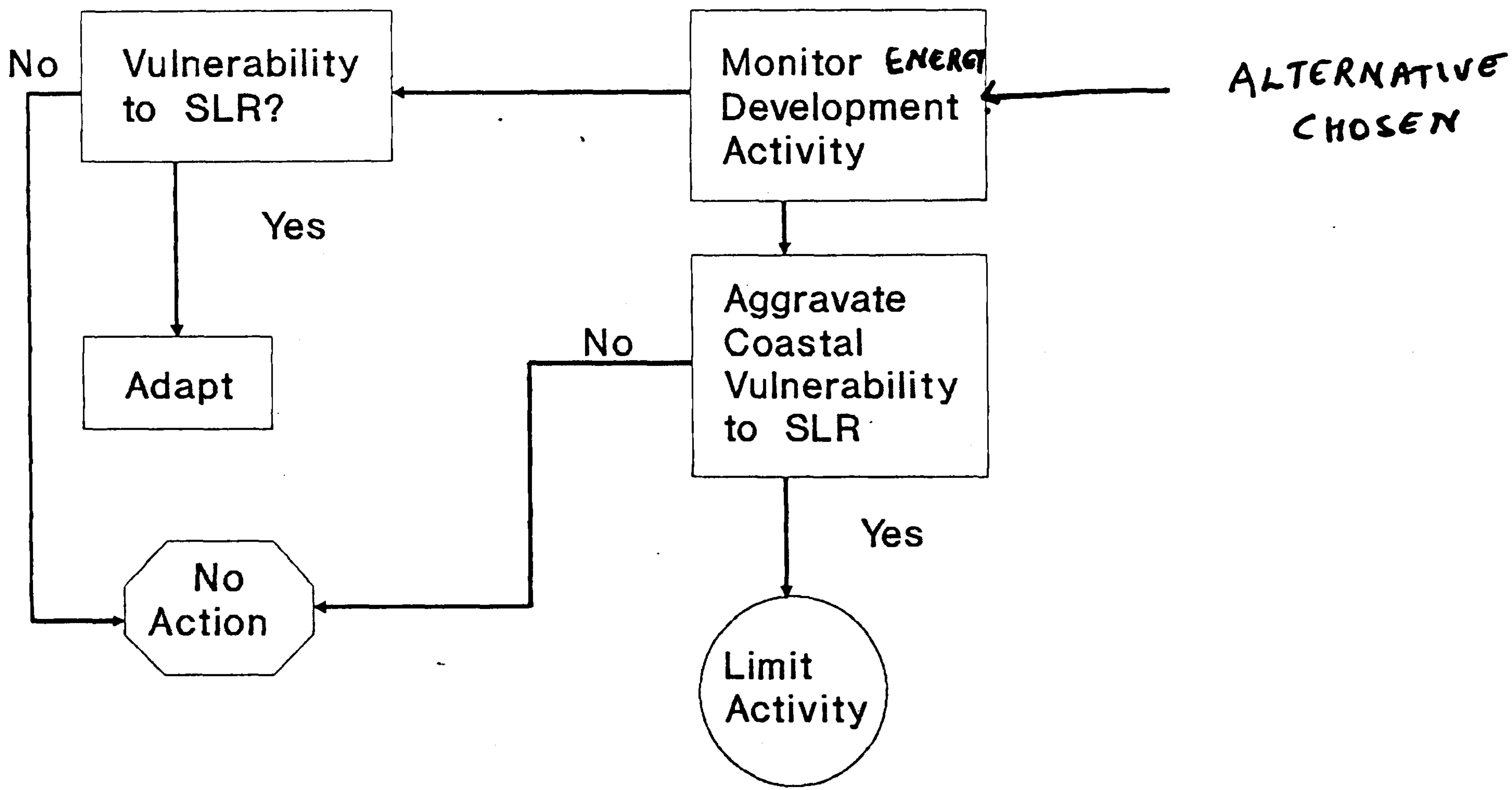
Figure I. Planning & Scientific Assessment Loop



Adapted from UNEP Regional Seas
Reports and Studies No.88, UNEP, 1986
Figure 8.

FIGURE II

Monitoring & Adaptation Loop



Adapted from UNEP Regional Seas Reports and Studies No.80, Figure I, p.5.