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Cost of reducing CO_2 emissions from India

Imperatives for international transfer of resources and technologies

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This paper evaluates the cost, capital and foreign exchange requirements associated with restraining the growth of CO_2 emissions in India through a range of technological alternatives. The different options include higher-cost efficiency improvements, fuel switching from coal to oil to gas and increasing the use of renewables. The paper also examines the types of actions required at both the national and international levels to effectively curtail India's CO_2 growth. The development of a coupon system, which would allow carbon-restraining technologies to be transferred from the industrialized to the developing world, is one of the novel mechanisms suggested in this analysis.

Keywords: Carbon constraints; India; Technology-choice model

The production and use of commercial energy in India led to the generation of 110 million tonnes of carbon in 1985, or 10% of all carbon emissions emanating from the developing world. Long-term scenarios indicate that, if current patterns of energy use continue, India's emissions of CO_2 will increase six-fold by 2025.[1] From a global perspective, India will account for 18% of the increase in carbon emissions produced from energy use in developing countries between 1985 and 2025.[2] In light of the growing awareness of the links between emissions of CO_2 and global climate change, it is critical for India to assess the efficacy and associated costs of various measures aimed at restraining the growth of CO_2.

India's opportunities for curtailing its emissions of CO_2 include rectifying its currently uneconomic allocation of fuels and inefficient energy-use patterns. For example, inefficient and highly carbon-intensive coal resources satisfy almost 50% of India's commercial energy demand at present. In recent years, the costs of coal production and transportation (including the foreign exchange component) have risen due primarily to changes in technology and low productivity levels. This increase has led to the argument that more efficient fuel options (primarily oil and natural gas and, in certain instances, renewables) could serve as economically viable substitutes for coal in the future.[3,4]

Determining which alternatives provide the most cost-effective means for India to restrain the growth of CO_2 entails a thorough economic evaluation of the available options. Economic evaluations of reducing carbon emissions have focused on taxation policies in the industrialized countries.[5] The assessments have sparked a debate over the level of taxes required to effectively restrain the growth of emissions, the extent to which 'costless energy-efficiency improvements' will occur[6] and the cost of non-carbon-intensive (backstop) technologies. Recently, a study on Egypt addressed the opportunities for using taxation measures to restrain CO_2 growth using a general equilibrium model of that economy,[7] and an analysis of Indonesia employed a system dynamics model to show that policies aimed at improving the technological base of the Indonesian economy can simultaneously increase the nation's GDP and curtail levels of carbon emissions.[8] However, in most developing countries, where fiscal

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and technological resources are scarce, any effective emissions-abatement strategy must go beyond evaluating the impact of domestic changes on levels of carbon emissions. These efforts must identify the types of energy-supply and energy-use technologies needed to restrain the growth of carbon and must assess the capital investment and foreign exchange requirements needed to acquire less carbon-intensive technologies and fuels.

In order to address this issue, this paper presents a technology-choice model for India which uses a technology-specific representation of the Indian energy system. The model serves as an instrument for determining the least-cost options for providing energy services, evaluating the resulting levels of CO_2 associated with each option and estimating the impact of reducing emissions on the nation's capital and foreign exchange requirements.[9] Based on this analysis, the paper identifies a number of policies and measures to be implemented at both the national and international levels which could make a major contribution to restraining the growth of carbon emissions in India.

STRUCTURE OF THE MODEL

This exercise uses a multisector linear-programming model in which the objective function being minimized is the economic cost to society of meeting the estimated energy services in India's five major end-use sectors. The model was run for two target years: 2005 and 2025.

The model evaluates the many energy-producing activities (eg, crude oil and natural gas production, electricity generation from a wide range of resources, energy imports and exports, energy transportation, etc) and links them with energy-using activities in the demand sectors through demand–supply balance equations. In total, the energy system is represented by a set of 129 different activities which together make up the total energy inputs into the economy. This set includes a range of different options for satisfying the energy requirements of the same end-use. For example, the model considers various options for providing lighting services in households, including kerosene, conventional light bulbs and fluorescent light bulbs.

Supply options

The supply sources considered here include conventional primary energy resources, such as crude oil, natural gas, coal and petroleum products (eg, naphtha, diesel, petrol, kerosene and jet fuel), and non-conventional renewable supply options, like wind, solar, biomass and nuclear power. The model takes into account the need for imports of a range of fossil fuels to augment domestic energy production. In the case of refinery products, the analysis considers both domestic end-use needs and the trade of petroleum products. For example, demand for one component of a refinery product can lead to the excess supply of another less desirable component, which then must be exported.

Each major supply option is represented separately. Several different technological options are identified for refining crude oil, all of which have different product yield coefficients, investment requirements and productions costs. Similarly, the analysis examines four different options for coal production. These options fall into two broad categories, coal production through open-cast or underground mining, which are broken down further to represent existing options and those that require new investment funds. In the case of electricity generation, the model considers three broad categories of electricity generation from hydro resources, three from coal and one each from fuel, oil, natural gas and nuclear energy sources. In order to keep the model simple and computationally manageable, supply options are not further disagregated by engineering processes. This simplification does not significantly alter the results, since the costs and carbon emissions of options with different processes are similar.[10]

End-use options

The energy-using activities considered in this model span all the major end-use sectors: agriculture, industry, transport, urban and rural residential and commercial.

A total of 11 of the 29 different options are applied to the agricultural sector. The two major energy-using activities identified involve land preparation and water pumping, which depend on either diesel or electricity. In the case of agricultural pumping, the model considers a range of alternative fuel options as well, including biogas, photovoltaics, solar, thermal and wind energy.

The model treats the industrial sector as an aggregate body of productive activities, comprised of manufacturing, mining and other industrial enterprises. Seven options are applied to this sector as a whole (not to specific industries). Major options represented include the introduction of a range of more energy-efficient devices, such as improved belts, better motors and power factor correction.

The transport sector is disaggregated into a range of freight and passsenger transport modes, spanning

rail, road, coastal shipping and air travel. The primary options are electric and diesel traction for railways and petrol, diesel and renewable fuels for the various road modes (ie, trucks, buses, cars and two wheelers). In all, 18 options are considered for the transport sector.

The analysis of rural and urban households focuses on three major end-use activities: lighting, cooking and appliance use. For each end-use activity, the model assumes the same useful energy requirements regardless of the type of fuel used to satisfy the given end-use. The options considered here range from the use of traditional fuels, like biomass and softcoke, in rural households to the use of liquid petroleum gas (LPG) and electric stoves in urban homes. For lighting, choices vary from kerosene and ordinary bulbs in rural areas to fluorescent bulbs and specular reflectors in urban areas. While the latter two choices are considered unavailable to rural households in 2005, by 2025 rural households gain access to all of the above-listed options. In all, the exercise considered 19 urban and 12 rural end-use options for the household sector.

Approach

The energy service requirements for 2025 were estimated using the analysis by TERI for that year.[11] Those for 2005 are derived from a report prepared by the Indian Planning Commission using the MEDEE model.[12] Given the requirements of satisfying these energy services, the model determines the lowest cost combination of options for meeting each particular service by evaluating the total costs incurred from the point of generation to the point of end-use. The costs associated with each option take into account fuel efficiency at each step along the fuel chain. For example, in the case of lighting, each of the three options provided (kerosene, incandescent bulbs and fluorescent lamps) has a unit cost for providing a given level of useful energy (ie, lumens) which incorporates the efficiency of that fuel for providing that energy service (eg, kerosene has a very low efficiency for lighting compared to electricity). The model chooses the combination of options with the lowest unit cost.

With the inclusion of carbon constraints, the model chooses a different set of options to satisfy the same energy service.[13] For example, in the case of lighting, the exercise compared the costs and emissions levels of using a larger quantity of kerosene with those associated with providing electricity at the margin. In this case, electricity would be preferred only when the unit cost and CO_2 emissions of the complete fuel chain for providing electricity were lower than for supplying kerosene.

Data sources

Cost coefficients for each of the energy supply sources were calculated using government publications, annual surveys of industries, statistics on national income, reports of the planning commission on the energy sector and reports of concerned ministries. These coefficients were calculated for both production and transportation costs of coal, crude oil, natural gas, petroleum products and electricity transmission. For the calculation of yield coefficients from the various refining options, Indian petroleum and natural gas statistics were used. Relevant data were also drawn from reports by the Oil and Natural Gas Commission, the Department of Petroleum, the Department of Non-Conventional Energy, the Department of Power, the Central Electricity Authority, Coal India Ltd and the Department of Coal.

The cost analysis assumes that the price of imported crude oil in 2005 remains unchanged from the 1985 price of US $28.5/bbl. By 2025, the price increases to $38/bbl. The prices of imported petroleum products maintain the same margins to crude oil prices as in 1985. The price of imported natural gas is assumed to be the same as the price of crude oil. The economic cost of domestic fuels is based on the cost of producing and transporting each fuel. The costs are expressed in 1985 constant currency, and the 1985 exchange rate of Rs 12.5 to US $1.0 is used throughout the analysis.

SCENARIOS

Description

Table 1 describes the characteristics of three scenarios for 2005 and 2025. For each scenario, the activity levels are determined so as to minimize the economic cost to society of meeting the estimated requirements for the identified energy services. In each case the model calculates the associated carbon emissions and the requirements for capital and foreign exchange.

Scenario 1 freezes the efficiency of demand and supply technologies at their 1985 levels. Consistent with current trends, the fuel switching that occurs in this scenario consists of a small increase in renewable energy sources but no additional imports of natural gas. The strategy illustrated in this scenario is constrained only by the availability of indigenous and imported resources. Carbon emissions are not constrained.

Table 1. Description of scenarios.

Scenario	Carbon constraint	Characteristics
Scenario 1	None	Energy efficiency of supply and demand technologies frozen at 1985 levels. Follows current trends for fuel switching.
Scenario 2	None	Efficient technologies permitted in 2005 and 2025. Follows current trends for fuel switching.
Scenario 3		
Case 1	Yes	Estimates lowest carbon emissions consistent with meeting demand for energy services. Allows for further fuel switching and efficiency improvements.
Case 2	Yes	As above with greater reliance on renewables.

The assumptions made in this scenario are consistent with the historical trend of little or no improvement in the efficiency of energy use and supply in India. This pattern has led India to allocate an increasingly larger share of GDP to satisfy the capital and foreign exchange needs of the energy sector. As our analysis shows, the share may increase to proportions that may not be sustainable without severe economic restructuring.

Scenario 2 allows for efficiency improvements in supply and demand technologies and pursues fuel-switching policies that comply with current trends. The cost of providing energy services is lower than in Scenario 1 since energy-efficiency improvements cost less than supply expansions.

The assumptions in this scenario imply that the energy sector would operate in a manner so as to minimize the cost of providing energy services, which also lowers capital and foreign exchange requirements. Although this is a desirable scenario, the many barriers to achieving this in practice are likely to prevent its full implementation.

In both cases of Scenario 3, carbon emissions are successively reduced until the model determines that the energy system is unable to satisfy the final demand for energy services and products. The cost of providing energy services is higher than in Scenario 2 since the carbon constraint requires the use of more expensive, but less carbon-intensive, options. In the second case of Scenario 3, the same level of constrained carbon emissions is achieved primarily through the increased use of renewables. This scenario would be implemented only if the Indian government were convinced of the importance of reducing emissions and only if external assistance were available to offset the increased cost of providing energy services.

Results

In Scenario 1, carbon emissions increase from 110 million tonnes in 1985, to 390 million in 2025 and to 920 million in 2025 (Table 2). Carbon emissions increase faster than GDP because the demand for energy services rises rapidly, but no improvements in energy efficiency occur. The higher proportion of renewables and natural gas moderates the increase to a certain extent. Due to supply expansion, the capital and foreign exchange requirements increase disproportionately faster than GDP. Investment in the energy sector, as a percentage of GDP, increases from 4% in 1985 to almost 7% in 2005 and 2025. Similarly, foreign exchange requirements as a percentage of GDP increase from 1.9% in 1985 to 4.4% in 2005 and 2025. In each case, the sharp increase will require that financial resources be transferred to the energy sector away from other sectors which will also clamour for more capital and foreign exchange.

In Scenario 2, efficiency improvements are permitted both on the demand- and supply-sides. The results of Scenario 2 show that, through appropriate policy changes, it is possible to reduce CO_2 emissions in India by as much as 50 million tonnes of carbon (13%) in 2005 and 250 million tonnes (27%) in 2025 compared to Scenario 1. These reductions can be achieved without any additional cost because the marginal return from efficiency improvements is higher than their marginal cost.

Economic development is assumed to spur some reduction in transmission and distribution losses. Transmission and distribution (T&D) losses decrease from 27% in 1985 to 22% in 2005 and to 15% in 2025. We do not account for the intangible cost of reducing transmission and distribution losses through control of theft and pilferage, although these may be substantial.

This efficiency improvement combined with additional improvements in end-use and power generation efficiencies, which have associated costs, reduce the generation of electricity by 10% in 2005 and 32% in 2025 compared to Scenario 1. They also reduce the level of investment required for coal power plants and mines. Similarly, opting for efficient technologies (like improved pumping in agriculture, more efficient vehicles in transport) reduces the demand for the import, and subsequent refining, of crude oil.

Hence, the total cost of providing energy services declines by 13% in 2005 and by 23% in 2025 relative to Scenario 1. As a result of the substantial efficiency improvements, the investment and foreign exchange requirements decline by 27% and 4% respectively in 2005 compared to Scenario 1. As a percentage of

Table 2. Economic implications of reducing carbon emissions (1985 billion Rs).

	1985	2005	2025
GDP	2 410	6 400	16 970
GDP/capita	3 200	5 350	10 000
Scenario 1[a]			
Emissions	110	390	920
Cost	470	1 340	4 070
Investment	100	450	1 160
Investment/GDP (%)	4.1	7.0	6.9
Foreign exchange	45	280	750
FE/GDP (%)	1.9	4.4	4.4
Scenario 2[b]			
Emissions	110	340	670
Cost	470	1 170	3 170
Investment	100	330	740
Investment/GDP (%)	4.1	5.1	4.4
Foreign exchange	45	270	590
FE/GDP (%)	1.9	4.2	3.5
Scenario 3[c]			
CASE 1[d]			
Emissions	110	280	520
Cost	470	1 190	3 430
Investment	100	290	665
Investment/GDP (%)	4.1	4.5	4.1
Foreign exchange	45	310	950
FE/GDP (%)	1.9	4.8	5.6
CASE 2[e]			
Emissions	110	280	520
Cost	470	1 310	3 640
Investment	100	400	970
Investment/GDP (%)	4.1	6.2	5.7
Foreign exchange	45	290	560
FE/GDP (%)	1.9	4.5	3.3

Notes: [a] Scenario 1: Efficiency frozen at 1985 levels; [b] Scenario 2: Includes efficiency improvements; [c] Scenario 3: Lowest carbon emissions; [d] Case 1: Lowest carbon emissions through greater fuel switching and fuel efficiency; Case 2: Lowest carbon emissions through increased reliance on renewables.

GDP, the investment in the energy sector increases more slowly than in Scenario 1. The investment-GDP ratio rises from 4.1% in 1985 to 5.1% in 2005 and 4.4% in 2025, and the foreign exchange/GDP ratio increases from 1.9% in 1985 to 4.2% in 2005 and 3.5% in 2025. As we discuss later, these ratios are not impossible to achieve.

The results of Scenario 3, Case 1, show that further potential exists to reduce carbon emissions by 18% in 2005 and 22% in 2025 relative to Scenario 2 (Table 2). While this scenario allows for further efficiency improvements, because Scenario 2 exhausts all of the possible efficiency options, the further reduction of carbon emissions is achieved through switching to less carbon-intensive fossil fuels and renewables. These measures require either additional foreign exchange or investments. The percentage of the emissions reduction is higher in 2025 than in 2005 because the 40-year time span allows for the retirement of existing coal power plants, permits much higher levels of gas imports and facilitates the greater use of renewable sources of energy.

Due to the higher utilization of imported gas, Scenario 3, Case 1, requires lower investment and higher foreign exchange requirements than Scenario 2 in 2005 and 2025. In Scenario 3, Case 2, the use of more renewables increases the investment and costs of providing energy services. Foreign exchange requirements decline because renewables displace imported fuels.

Table 3 illustrates the increase in unit cost of conserved carbon in Scenarios 1 through 3 as the amount of carbon saved rises (Case 1 of Scenario 3 is used in these estimates). By conducting alternate runs of Scenario 2 and placing progressively tighter constraints on carbon emissions, the cost of conserving carbon at levels between those in Scenario 2 and 3 were determined. For example, the cost of conserved carbon is Rs 0.2 per kilogram (kg) when emissions are reduced from 340 million to 300 mil-

Table 3. Unit cost of conserved carbon (1985 Rs/kg).

Carbon emissions (Mtonnes)	CCC	Carbon emissions (Mtonnes)	CCC
390		910	
340	−3.4	670	−3.6
300	0.2	610	0.8
280	0.6	580	1.0
		550	1.0
		520	5.1

lion tonnes (Table 3). This figure rises to Rs 0.6, with greater overall carbon savings.

How sustainable are the scenarios?

The above discussion highlights the scope for reducing carbon emissions and the consequences of these reductions in terms of capital investment and foreign exchange requirements. The impact of these changes on India's GDP will largely determine the feasibility of the scenarios.

Over the time period under consideration, both parameters increase faster than GDP in all of the scenarios. Clearly the introduction of efficiency measures (in Scenario 2) reduces the need for both capital investment and foreign exchange. As a proportion of GDP, investment increases marginally in Scenario 2 from the 1985 levels. If efficiency improvements are not forthcoming, then investment needs increase drastically faster than GDP as illustrated in Scenario 1, which extrapolated the current trends in fuel use. In the past, an increasing fraction of the government budget has been devoted to the energy sector. During the Sixth Five-Year Plan, 1980–85, the government allocated 27.2% of its plan outlay to the energy sector.[14] This share increased to 30.6% during the Seventh Plan. Given this large fraction of government outlay for the energy sector, the further increases illustrated in Scenario 1 for future outlays to the energy sector are not sustainable.[15] Hence, it is imperative that these increases be controlled through energy-efficiency improvements as illustrated in Scenario 2.

The foreign exchange requirement increases rapidly in every scenario, which is clearly a cause for concern. In order to satisfy the heightened foreign exchange requirements, Indian industries would have to increase exports and/or the government would have to devalue the rupee. However, an examination of South Korea's fuel import bill reveals that the levels of GDP devoted to foreign exchange in Korea are higher than the highest foreign exchange/GDP ratio in Table 2.[16] While this comparison suggests that the foreign exchange/GDP ratios in all of the scenarios would not be impossible to achieve, to successfully do so, India would need to earn substantially higher quantitities of hard currency. The notable differences in the Korean and Indian economic structures suggest that this goal could only be reached through a radical resturcturing of the Indian economy.

Costs decrease at first because improving efficiency proves less costly than expanding the energy supply. Costs then increase as more expensive fuels are substituted. The increase in cost is modest in 2005 since the present allocation of fuels in the Indian economy is not economically efficient, and thus, the introduction of substitute fuels does not lead to radical increases in cost. The pattern is similar in 2025, but costs increase sharply to Rs 5.1/kg as limited amounts of renewable energy are introduced.

If the global community determines that the option of reducing carbon emissions in India at a marginal cost of Rs 0.6/kg is less when compared with the cost of conserved carbon in other countries, then it may be desirable to do so from a global viewpoint even when the marginal costs are too high from the Indian perspective. Under these circumstances, India will require global investment and foreign exchange compensation to support its efforts. The perceived impact of various carbon-abatement efforts on the Indian economy will largely determine the level of resource transfers that India will be able to obtain from the international community to carry out these measures. However, depending upon which vision of India's future is assumed to be the most plausible, the assessment of the financial burden that such actions will place on India will differ. For example, as Table 4 illustrates, if the frozen-efficiency scenario (Scenario 1) is identified as the reference scenario, the cost of achieving the target level of carbon emissions set in Scenario 3 can be achieved at negative cost to the Indian economy. However, if the lowest cost scenario (Scenario 2) is assumed to be the base scenario, the carbon emissions' goal embodied in Scenario 3 can only be achieved at positive cost. In all likelihood, India's future development path will fall somewhere between those suggested in Scenarios 1 and 2, as will the associated costs of conserving carbon.

Table 4. Cost of conserved carbon (1985 Rs/kg) in Scenario 3 with two different base scenarios.

Base scenario	2005	2025
Scenario 1	−1.4	−1.6
Scenario 2	0.3	1.8

POLICY OPTIONS

Restraining the growth of carbon emissions in India will require policy imperatives at both the international and national levels.

International actions

Since the benefits of the carbon reduction would be enjoyed by the international community, India would be justified in seeking funds from the community for this purpose. Indian policymakers feel the nation is not in a position to meet the additional investment needs and, hence, believe the entire burden should be borne by the industrialized countries. If the industrialized world refuses to accept this, India will continue to try to minimize its capital investment and to choose technologies without any concern for carbon emissions. One possible vehicle for providing the necessary funds is the Global Environment Facility (GEF),[17] which could contribute a substantial amount to help meet these additional capital needs.

To facilitate international resource transfers and technology improvements, a scheme to provide carbon credits to developing countries with lower-cost options should be considered. The GEF can play a larger role by serving as clearinghouse or market for brokering between countries for the implementation of projects.

For example, a series of cross-country comparisons could be carried out to identify the countries with lower-cost options for reducing greenhouse gas emissions (GHG). The GEF then could provide coupons to those countries with the lower-cost options. The coupons would be issued to cover the difference in cost between more GHG-intensive technologies (coal options) and less GHG-intensive technologies (photovoltaic or higher efficiency options). Developing countries could use the coupons to import the less GHG-intensive technology. Such a scheme would serve two key ends: first, it would ensure that the funds allocated for reducing GHG emissions get used for that purpose and, second, it would enable these funds to flow back to the industrialized countries, where equipment would be purchased. Firms in industrialized countries would compete to earn these coupons. Coupons could be used for purchasing finished generation equipment or for buying the equipment necessary to manufacture generators and the like. Hence, developing countries would have the opportunity to reduce their dependence on imported technology.

Coupons could also be used to manufacture similar technology indigenously. In this case, the coupons would be worth less than those used for importing equipment. The lower value of coupons would account for the premium allocated to foreign exchange. If the country concerned were to buy cheaper technology, it would be allowed to keep the coupons and use them for further reducing their GHG emissions through other means.

Coupons could also be used to pay for energy conservation projects. Since the economic cost of these projects may be lower than that for conventional supply projects, the coupons would be used primarily to pay for the foreign exchange component of the project and/or for demonstration of higher efficiency options.

The industrialized-country industries providing the technology would turn over the coupons to GEF for reimbursement. The amounts reimbursed then would be debited from the government associated with each industry. In the case of multinational industries, which are not affiliated with any particular national government, an equitable formula for reimbursement would have to be developed. The total amount of coupons which could be debited would be decided based on a country's contribution to the GEF. In a climate change negotiation process, particular governments of industrialized countries would then be able to take credit for reducing GHG emissions in developing countries.

In summary, such a scheme would allow industrialized country governments to take credit for reducing GHG emissions at a relatively lower cost while ensuring that the funds provided for such credits flow to industries in their country. The developing country would benefit: first, by the development of environmentally cleaner technologies which also have local environmental benefits; and, second, by gaining access to technologies, funds for which otherwise might not be readily available.

National actions

At the national level, India should focus on developing and implementing a national energy policy and a complementary 'action plan' to carry out the policy's stated goals.

Although India has national policy statements directed at various other major sectors (eg, industry, water resources), the nation has yet to create a comprehensive policy for its crucial energy sector. Increasingly, this lack of an effective framework has taken its toll on the Indian economy. India's growing energy demand has continued to surpass available supplies. Combatting the resulting shortages has necessitated large investments in back-up systems

(such as diesel generators, diesel pumpsets and voltage stabilizers); as a result, the total cost to the economy of meeting the nation's energy demands has risen substantially. In cases where alternative sources are not available or are too expensive, energy shortages have led to lower industrial output and unemployment. The extent of these inefficient energy-use patterns and high costs currently are reflected in India's energy intensity (energy use per unit of GDP), which is among the highest in the developing world. By clearly outlining its national objectives and identifying the policy instruments necessary to implement an effective energy strategy, India could begin to reverse some of these past trends.

To ensure the efficacy of this national energy policy statement, India should embark on an action plan, aimed at providing the necessary economic incentives and creating a suitable environment (including the required institutional structures) to achieve the outlined objectives within three to five years. The plan should identify specific policy measures to encourage both demand management and supply augmentation.

Improving the management of energy demand will entail reviewing and modifying the energy-intensive strategies currently being relied upon in the agricultural, industrial and transport sectors. In the agriculture sector, these efforts should focus on the development of price and technology policies aimed at promoting the more widespread use of fertilizers and/or lower levels of water pumping (eg, by discouraging the use of pumping for rice and sugarcane cultivation). Trade and industrial policies that encourage the domestic manufacture of highly energy-intensive products (eg, aluminum, fertilizers, petrochemicals and cement) need to be revamped. This effort would entail reducing tariffs/barriers, decontrolling output prices and setting tariffs at levels which reflect the real economic costs (opportunity costs) of energy supplies. Measures in the transport sector should emphasize promoting the electrification of India's railways and substituting rail modes for road, coastal shipping and inland waterway options.

To facilitate the more rapid penetration of energy-efficient technologies into the Indian economy, the action plan should include a requirement for industries to comply with an 'Energy Efficiency Impact Statement' when producing new commodities and units. In addition, energy service companies could be developed to accelerate the replacement of existing inefficient technologies for newer models.

Essential to the action plan will be the formulation of integrated energy pricing. The aim of this policy would be to ensure that the costs of all forms of energy reflect the real economic costs of providing this energy to the consumer. The one exception to these price adjustments would be the case of kerosene prices and life-line rates for electricity supplies used by the urban and rural poor. Administrative controls have typically led to major distortions in the prices set by energy producers (natural gas companies, refineries, coal companies and electricity boards); these controls should be lifted, and producers should be allowed to determine their own prices (subject to the protection of the poor). Readjusting the pricing system will entail developing more responsive tax policies and keeping the use of subsidies to a bare minimum. The only justifiable areas for investment support – either in the form of tax benefits or cash contributions – would be in technologies (eg, wind generators, solar-thermal or photovoltaic systems, biogas plants) where externalities and other considerations, such as environmental benefits, typically are not reflected in the calculation of economic costs and benefits.

Supply-side options would include encouraging more investments in natural gas exploration, development, production and use, increasing the share of large-scale hydro in India's energy supply mix and promoting the use of micro-hydro, solar-thermal and photovoltaic alternatives in selected situations where they prove profitable even in the light of high initial costs.

By removing price and quantity controls, the electricity boards will have greater incentives to pay the avoided costs to electricity suppliers that use renewable energy technologies (eg, wind power companies or biomass power companies) to generate electricity. Simultaneously, energy consumers will pay lower costs than those incurred when purchasing electricity through private providers (eg, through high cost diesel systems). Changes in the legislation that currently governs the generation, distribution, purchase and pricing of electricity will play an essential role in the success of this endeavour.

CONCLUSION

The analysis indicates that if the current patterns of fuel use in India continue, the resulting increases in the requirements for capital investment and foreign exchange as a proportion of GDP will not be sustainable over the long run. Scenario analysis suggests that efficiency improvements are imperative in order to restrain the growth of investment in the energy

sector to manageable levels. However, efficiency improvements alone will not suffice as a means for restraining the growth of foreign exchange requirements for fuel imports. To compensate, the Indian economy would need to earn far higher export earnings than it currently generates.

Efficiency improvements in India also will benefit the global environment by helping to restrain the growth of carbon emissions. This analysis indicates that there is potential for further minimizing emissions by switching to less-carbon intensive fuels. Because this transition would result in additional costs to the economy, India would be justified in seeking additional financial resources from the international community. Simultaneously, India must implement an action plan aimed at improving its energy efficiency and allocation of fuels.

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[8]The results of this study indicate that the implementation of such policies can reduce carbon emissions by 6% in 2020 relative to the reference case level. Deregulation of fuel prices and differential taxes on the basis of carbon content of fuels would further reduce carbon emissions by 33%. See S. Sasmojo and M. Tashrif, 'Measures for CO_2 emission reduction through energy price deregulation and fossil fuel taxation: a case study for Indonesia', *Energy Policy*, this issue.

[9]Economic costs: The annualized costs of providing energy services, including capital, operation and maintenance and fuel costs; Foreign Exchange Requirements: The costs of importing crude petroleum, its products and natural gas; Investment: The funds invested in the energy sector in a particular year. These funds are used to construct energy supply facilities and to improve energy efficiency.

[10]For details of engineering processes of oil supply options, see R. Bhatia, *Planning for Petroleum and Fertilizer Industries: A Programming Model for India*, Oxford University Press, New Delhi/New York, 1983. For those of coal options, see N. Mongia, 'A process analysis of strip mining in coal industry for central Indian region', PhD thesis, University of Delhi, 1989.

[11]Pachauri, Suri and Gupta, *op cit*, Ref 1.

[12]Energy Policy Division, Planning Commission, Government of India, *An Analysis of Energy Requirements in the Transport Sector in India – the MEDEE's Approach*, New Delhi, December 1989; Energy Policy Division, Planning Commission, Government of India, *Energy Demand in the Commercial, Services, Industrial and Agricultural Sectors in India – the MEDEE's Approach*, New Delhi, June 1990.

[13]CO_2 emissions were estimated for each of the energy-using activities, as well as for electricity generation. The values used were calculated in terms of the carbon content of CO_2. The following coefficients were used: 1 tonne of carbon per 1 tonne of oil equivalent (toe) for coal; 0.82 tonnes of carbon per 1 toe for oil; 0.58 tonnes of carbon per 1 toe for gas.

[14]Government of India, Ministry of Finance, Economic Division, *Economic Survey, 1989–90*, Delhi, 1990.

[15]Private sector investment would help to reduce government outlay, but it would not change the proportion of GDP required for energy investment.

[16]J. Sathaye, *Sectoral Oil Transitions and Sustainable Use*, Proceedings of the Seminar on The Role of Petroleum in Sustainable Development, Penang, Malaysia, PETRAD, Norway, 7–11 January 1991.

[17]The Global Environment Facility is a pilot programme providing grants and low-interest loans to developing countries to help them carry out programmes to relieve pressure on global ecosystems. The Facility is a cooperative venture among national governments, the World Bank, the United Nations Development Programme and the United Nations Environment Programme.