Greenhouse Gas Models and Abatement Costs for Developing Nations: Critical Assessment

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Abstract

Numerous GHG policy studies are reported for developing countries. Most use demand driven bottom-up models. Reported abatement costs vary significantly across countries for identical options. This can cause policy conflicts such as for GEF financing schemes. Top-down macroeconomic studies for developing countries are scant. Model structure assumes dynamics akin to developed market economies. Transitional dynamics of developing countries like underdeveloped markets and informal activities are inadequately modelled. Policy analysis is thus restricted to market oriented alternatives, while more relevant bifurcation scenarios along alternate development patterns are ignored. Alterations in model structure and policy analysis are proposed for representing the realities of developing nations.

Key Words:
Greenhouse Gas (GHG) Policy Models, GHG Abatement Cost, GHG Modelling for Developing Countries

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GHG Models and Abatement Costs for Developing Nations

Introduction

Increasing accumulation of greenhouse gases (GHG) in the atmosphere is expected to lead to undesirable changes in the global climate. Abatement of GHG is a global effort. At the UN Conference on Environment and Development in Rio de Janeiro in June 1992, the framework convention on climate change was signed by 152 countries. The framework convention aims to achieve *stabilization of atmospheric greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system* (UNEP\WMO, 1992). To begin with, the target of returning to the 1990 emission levels by 2000 AD was acknowledged by the developed nations. There is no such agreement for the developing countries. Starting form a very low base, the future emissions from developing countries are set to grow rapidly. Realistic analysis of GHG abatement policies in the developing countries and their participation in the global GHG regime is essential for realizing the aims of the framework convention.

Global GHG emission studies have a recent history. Most initial studies originated from the developed nations. The analysis and results of these studies therefore pertained mainly to the developed country situation. Early studies followed engineering type bottom-up perspective and methodology and relied on exogenous specification of economic inputs. These models did not endogenize important macroeconomic effects such as energy price feedbacks, revenue recycling, economic growth, trade and the evaluation of policy measures like carbon or energy taxes. A problem with the present bottom-up studies is that the reported GHG abatement costs vary significantly for identical options across nations. This can cause policy conflicts for GEF type financing which uses the incremental cost as the financial criteria a technology or a project. Top-down macroeconomic models, which are more recent, represent the world dynamics as an image of the market based economies of the west. Top-down studies for developing countries are scant. Present top-down models the developing country realities like the underdeveloped markets, vast informal sector, predominant government monopolies, restrictive trade regulations and multifarious barriers to competition are not adequately modelled. This distorts the policy prescriptions for the developing nations.

This paper gives a comparative analysis of greenhouse gas abatement cost studies for developing nations. Notable among these are the GHG abatement cost studies sponsored by the United Nations Environment Programme (UNEP). Seven out of ten UNEP sponsored studies are for the developing countries. These studies are important as they have direct UNEP support and hence are expected to provide the guidelines for the future global GHG policy studies. Comparative analysis of the seven UNEP country studies is therefore presented in detail. Most of these studies use bottom-up methodology. Various top-down model application for the developing nations are then reviewed. Finally, the modifications in modelling methodology and policy analysis are recommended for strengthening future GHG policy studies in developing nations.

Bottom-up and Top-down Models

Typology of greenhouse gas models has originated from the energy field. Models are commonly classified as bottom-up and top-down types. The term "top" and "bottom" refer to the level of aggregation in the model. Bottom-up models make highly disaggregated representation of the economy and detailed technological specification. Top-down models analyze aggregate economic behaviour. Apart from the aggregation level, the other distinguishing feature relates to the endogenization of economic effects. Top-down models include feedbacks between energy system and the other economic sectors and also with the macroeconomic performance of the economy. Bottom-up models pay greater attention to energy details from the end-use side. Top-down models therefore offer greater endogenization of economic behaviour.

Bottom-up models are demand driven and provide disaggregated analysis of technical options. Top-down models consider economic sectors at highly aggregated levels and presume the economy to be in equilibrium resulting from optimal decisions taken by consumers, producers and the government. These models overlook specific technological opportunities such as those identified by the bottom-up models. They provide greater insights into the impacts of economic policy interventions, such as for example taxes or subsidies, which cause market distortions. The model dichotomy also reflect two different paradigms. Bottom-up models subscribe to the optimistic "engineering paradigm" as opposed to the "top-down" models which reflect the pessimism of the "economic paradigm" (Grubb et al, 1993).

Bottom-up models are optimistic about the future GHG abatement opportunities and identify numerous abatement options such as "no regret" and low cost energy efficiency options. Optimism of bottom-up models originates from the engineering perspective that believes that the efficiency gap exist, i.e. the present technology mix does not minimize the cost of providing the energy service. The pessimism of the top-down models originates from the assumption that the present technology mix results from the efficient behaviour by consumer and firms under the prevailing economic conditions. In case of developing countries, bottom-up models suggest enormous "no regret" opportunities through energy efficiency improvements. But this theoretically predicted potential is unattainable in practice due to numerous social, economic and legal barriers to the penetration of efficient technologies. Application of top-down models to developing countries suffers from unrealistic assumptions about the existence of developed market conditions. Within these limitations, the top-down studies provide good insights into the impacts of economic policy interventions on future GHG emission trajectories and gross domestic product (GDP) of the nations or regional blocks.

Methodology of UNEP Sponsored GHG Abatement Cost Studies

Ten country studies were carried out under the UNEP Greenhouse Gas Abatement Costing Studies Project (UNEP Collaborating Centre on Energy and Environment, 1993). Seven, out of these ten, are for the developing countries. Methodology followed by the studies are summarized in Table 1. Evidently the research teams in most UNEP sponsored studies in developing nations have used bottom-up models. In most cases, the macroeconomic data is used exogenously for preparing alternate scenarios under which the bottom-up model runs are taken. Linear Programming (LP) based optimization models are used for studies in Brazil (MARKAL-Like Model) and India (TEESE model, an adaptation of the Brookhaven's BEEAM Model). Both models minimize the total discounted cost of energy system. In Brazilian model, technological representation is made in detail and the abatement cost for major technology options are identified. Indian study on the other hand reports only the long run marginal cost of abatement. Traditional biomass fuels are considered explicitly in the Indian model. Both models suffer from the limitations of the demand-side LP type optimization framework- mainly the static coefficients, exogenous specification of prices, insensitivity to price induced input substitutions and ignorance of supply limitations such as the limited availability of finance for supporting the presumed development trajectory. The model dynamics being specified from the demand-side, also suffer from supply-side inconsistency.

Egyptian study is the only one which used the top-down approach, besides also using the bottom-up approach. The bottom-up approach has detailed specification of energy technologies and resource options. The study gives abatement cost curve including the implementation costs which are usually missed in bottom-up studies. Abatement cost curves show a considerable negative cost potential. The bottom-up scenario constructing does consider the traditional biomass fuels. The top-down approach uses the macroeconomic Energy-Economy Model. Energy conservation measures are included in the top-down approach besides new "back-stops". Top-down model used ten year planning horizon up to the year 2002. For a 40% emission reduction scenario, the welfare and GDP increased. This is not surprising considering the fact that the major investment was diverted for energy conservation. Results of bottom-up and top-down models do match. This is so since the top-down modelling analysis is done for a short time horizon. The model therefore chooses less capital intensive options, such as energy conservation, which are identical to those recommended by bottom-up studies. If a longer planning horizon is used, then the model has greater freedom of choices. The recommended measures by the two modelling approaches may then differ. Macroeconomic analysis should therefore be considered for a longer planning horizon, especially since the abatement is needed for extended future. The Egyptian top-down model lacks adequate representation of the traditional sector dynamics. The approach of the Egyptian study is however worth considering for improving methodology of the future policy studies. The improved modelling and policy framework should explicitly include the developing country realities such as those in the informal and traditional sectors.

Senegal and Venezuela country studies use the LEAP model, an accounting type bottom-up model which facilitates detailed energy and environment scenario specification. Senegal study also uses separate ad-hoc models for traditional sector activities- mainly biomass use, savannah burning, land clearing for agriculture and rice cultivation. Both studies give abatement costs for the various technological options. However, the limitation of the accounting approach of LEAP is evident in both studies where all important variables are specified exogenously as parameters in future scenarios. Although such a framework has the merit of allowing the policy makers to construct and test numerous policy scenarios, the approach fails to provide the insights into the economic dynamics and their impact on the policy scenarios. The results from the model are therefore as good as the experts would have specified them to be through various parameters. Supply-side consistency of the model is again weak and will be as good as the insights of the experts specifying the parameters or the other macroeconomic models used for generating the parameters. Main strength of both studies is the detailed specification of energy and environment options. But the main deficiency is the weak specification of the economic dynamics.

Thailand country study uses accounting methodology supported by ad-hoc models for specifying some future scenario parameters like the model for projecting the future electricity demand. The study arrives at CO_2 abatement cost curve for various abatement options treated independently under presumed macro and micro economic conditions. Zimbabwe study is essentially an energy study with no representation of economic relations. No model is used. CO_2 abatement cost curve is developed for demand and supply side energy options.

Some Observations on Modelling Methodology

Energy and GHG abatement studies in developing countries have continued to rely on the bottom-up approach and models. This is so despite the fact that the UNEP Phase Two Study guidelines unambiguously suggest use of top-down macroeconomic approach in conjunction with the bottom-up models (UNEP Collaborating Centre on Energy and Environment, 1992). The discomfort of the researchers to use macroeconomic models for developing country studies is attributed to reasons like the unavailability of the type of data needed by top-down models, unfamiliarity with the use of equilibrium models, excessive non-market influences over the prices, excessive government involvement and restricted entry into crucial sectors such as energy and infrastructure and persistent disequilibrium in the markets.

Although the above reasons are important, the main cause for the discomfort in using the market type macroeconomic models has been the shortcoming of the present models which treat the developing country dynamics as a caricature of the market oriented economic functioning of advanced industrialized nations. The macroeconomic relationships tend to miss the influence of excessive but unreported economic activities of informal and traditional sectors of developing country. Besides, the models disregard the distortions caused by non-monetized economic activities like firewood collection and use (which incidentally has bearing on GHG emissions and deforestation), weak market institutions, persistent market disequilibrium (energy and labour markets often being the most out of kilter), coexistence of numerous production functions for the same commodity (for example a crop produced under modern irrigated agriculture sector with use of fertilizers and mechanized equipments versus the same crop produced in the traditional sector where farmers depend on rain water and do little investment in the inputs) and the limited choices made available to the consumers. The policy scenarios in macroeconomic models rely excessively on the market based interventions, disregarding the fact that in the transitional process that the developing economies are in, the non-market interventions such as building institutions, local technology development and employment generation, government participation in production and distribution and selected entry restrictions in certain sectors might have to be tolerated or even designed for some time in future.

Despite these limitations, the top-down models can provide insights into the macroeconomic aspects overlooked by the bottom-up models. As most bottom-up models are driven by exogenous demand-side parameters, mainly sectoral growth rates, their projections often tend to be too optimistic to be achieved by the internal savings in the economy (even including the inflow of foreign financial investment). Results from long horizon models are very sensitive to the growth rates. Macroeconomic models have the merit of maintaining the demand and supply side consistencies and are therefore important for validating the bottom-up model projections, besides analyzing the various economic policies such as taxes and subsidies, revenue recycling, international trade, allocations for research and development and "back stop" technologies. Not equipped with the top-down models, most developing country studies give only cursory treatment to these important policy options. Learning from the strengths and weaknesses of the existing developed country models, climate change study analysts need to evolve and use top-down models with adequate representation of developing country dynamics.

Abatement Costs and Recommended Response Measures

UNEP Sponsored abatement cost studies follow two main abatement scenarios. Abatement Scenario I targets 25% reduction and Scenario II targets 50% reduction in emission in the long run (Year 2020 to

2030) over the business as usual reference scenario. Abatement achievement from the studies however vary from the scenario targets mainly due to the infeasibility of achieving large abatement within the existing constraints. Table 2 summarizes the abatement achieved in different countries. The modelling methodology used also influences the achievement of targets. For instance the Indian study uses the LP based optimization model which runs into infeasibility problem for higher abatement scenario. In cases of Thailand, Venezuela and Zimbabwe, the higher abatement targets are not achieved since only limited abatement options are considered.

A summary of abatement measures and costs from developing country studies sponsored by UNEP are given in Table 3. Costs are reported only for a few high potential measures. Cost here refer to the "incremental" abatement cost of a project or a technology intervention (King, 1993). It is evident from Table 3 that the abatement costs vary considerably for different measures within a country and also for a similar type of measure across the countries. The variation can be attributed both to the differences in the economic structure and energy use pattern in different countries as well to the differences in the study methodology across countries. The studies which emphasized the energy conservation report numerous negative cost options on the demand side efficiency improvement. Supply side energy options turn out to be quite expensive and the renewable energy options are found to be even more expensive. Infrastructural options like change in transport mode are the most expensive.

The disturbing aspect of the variation in the cost is that in India and Venezuela, the energy conservation options have positive incremental abatement costs whereas in Egypt and Thailand the cost for similar energy conservation options are negative. The Indian study (Phase Two) reports the long run marginal abatement cost to be an extremely high, $ 2163 per Ton of Carbon (TC). The high number in fact only reflects the shadow cost of the tight abatement constraint. Rather than using this number, the LP model could have provided better insights through an analysis done by relaxing the model framework, such as for example by adding more options for technology, resource and trade or by relaxing some constraints. On the other hand the Zimbabwe study reports very high negative cost of $ 1123 per TC for "Zero Tillage" option. The GHG emission abatement in this accrues from stopping the agriculture which results in saving of energy used by tractors in commercial farms. The option ignores other economic costs to the nation of stopping the commercial agriculture. More attention is required to develop viable and consistent abatement options.

Due to wide variations, the abatement costs such as those reported in the UNEP studies, have limited utility in international policy formulation- such as decisions on financing through Global Environment Facility (GEF) the incremental cost of implementing GHG abatement project in a developing nation. For meaningful, harmonious and optimal financing, it is essential to use uniform methodology, data and policy framework for GHG abatement costing studies across countries. Although the straight jacket standardization of the models is not possible, it is necessary to use consistent methodology, perspective and policy scenarios across nations to achieve meaningful comparison of results. Most developing nation studies use bottom-up approach which consider the costs of options in isolation. The abatement costs derived from these studies often miss the implementation costs, including the costs of overcoming the barriers to achieving economic efficiency. Results of the bottom-up studies for the developing country need to be validated for the macroeconomic consistency. This can be done through the top-down models in conjunction with the bottom-up models .

Top-Down GHG Abatement Studies for Developing Countries

Top-down GHG emission abatement studies are mostly focused on the developed nations. Some studies that report analysis for developing countries are reviewed briefly. Coverage of studies is not exhaustive, however the issues raised and critique of the models is pertinent in general. CO_2 emission from major developing nations (Sathaye J and Ketoff A, 1991) can be expected to increase two fold between the years 1985 and 2025 under the low emission scenario which assumes energy technologies in developing nations to be similar in the year 2025 to those in industrialized nations in the year 1985. Under the business-as-usual, the increase in emission for the same period is 2.7 times. The projections in the study are made using the bottom-up approach. The supply balance of energy resources is then checked exogenously to ensure feasibility of resource availability and consistency of price assumptions. Like other bottom-up studies, most abatement measures identified relate to energy conservation and rest to fuel switching. Study methodology is based on disaggregated sectoral specifications and international comparison of estimated activity levels in conjunction with the income distribution. The energy and emission projection methodology used is robust. However, the study ignores the economic aspects of abatement measures. Brief reviews of some top-down GHG emission modelling studies with developing country analysis is given below.

OECD's GREEN Model

The OECD study[1] using the top-down macroeconomic GREEN model analyzes the impact of removal of subsidies in two major developing nations, namely China and India. The *Distortion Removal* scenario assumes phasing out of subsidies on the sale prices of coal and gas by the year 2010 and for oil by 2000. Under *No-Distortion Removal* scenario, the energy subsidies observed in the base year (1985) are assumed to remain throughout the entire period up to the terminal year 2050. The percent subsidy in the year 1985, respectively for China and India, is taken as under- coal: 55 and 41.5; oil: 1.7 and 41.7; and gas: 11.2 and 50.1. Various backstop technologies are introduced in the model from the year 2010 at different price tags assumed exogenously.

Under the *No-distortion Removal* scenario, carbon emission in both China and India increases nearly by fourteen times between the years 1985 and 2050. Energy consumption in both countries also increases by similar magnitude. The large increase in future energy consumption and carbon emission are attributable to the fact that in both India and China, future energy supply is dominated by coal under this scenario. Contribution of coal in total energy in China and India in the year 2050 works out to be a whopping 88 percent and 90 percent respectively. Combined share of China and India in the global carbon emission increases from 24 percent in the year 1985 to 38 percent in 2050. Due to low cost of subsidized coal, use of backstop synthetic fuels is limited to just 4.4 percent and 3 percent of total energy consumption respectively in China and India, compared to 16 percent in OECD region in the year 2050.

Under *Distortion Removal* scenario, the energy consumption and emission in China and India respectively reduce to nearly forty percent and sixty percent of that for the *No-distortion Removal* scenario in the year 2050. Combined share of China and India combined share in energy consumption and carbon emission under *Distortion Removal* Scenario is nearly a quarter of the global totals. The reductions are achieved due to higher energy efficiency and use of backstops promoted due to higher market prices of carbon based fuels. Evidently, the removal of energy subsidies has a major impact on reducing energy consumption and abatement of carbon emissions.

Global 2100 Model

A study using the top-down Global 2100 Model (Manne A.S and Richles R.G, 1991) reports the impact of rising energy costs on carbon emissions from five geopolitical groupings. There are two developing countries groups, namely China and Rest of the World (ROW) which include most developing countries. Base year of the study is 1990 and the terminal horizon is up to the year 2100. Under the business-as-usual (BAU) scenario, China's carbon emission increases from 0.63 billion tons in 1990 to 5.9 billion tons in 2100. China's share in global carbon emissions increases from 11 percent to 22 percent over the same period and the share of the ROW changes from 18 percent to 35 percent.

The study considers various carbon emission abatement scenarios. In one scenario, the emission from the industrialized countries is assumed to be reduced by 20 percent of 1990 emissions and emission from China and ROW is limited to twice their 1990 levels by the year 2020 and then maintained at that level. The global emission increases by 15 percent of 1990 global level by 2030 and then is maintained. China's GDP loss for this scenario over the BAU, is over ten percent in the later half of the twenty first century. The corresponding losses for ROW and OECD are respectively 5 percent and 1 to 2 percent. China thus becomes heavily affected by this policy regime mainly since China's fossil fuel base is dominated by coal. To bring the China's GDP loss in line with that of the ROW, the carbon limit for China has to be relaxed to four times the 1990 emission level. In this case, the global emission increases by 37 percent over 1990 level. To reduce the global emission by 20 percent of the 1990 level, keeping the emissions from China and ROW at twice their 1990 levels, the industrialized countries will have to reduce their emission level by 70 percent of their 1990 emission. To achieve the global emission reduction by 20 percent of 1990 level, applying equal per capita quota rights, China has to maintain its emissions to around 150 percent and ROW to around 230 percent of their 1990 emission. Under this scenario, industrialized countries will have to reduce their emission to 30 percent of their 1990 level.

A Comparative Study of Six Top-Down Models

A study of six top-down models (Dean A and Hoeller P, 1992) compares the impact of carbon constraint on regional carbon taxes and GDP losses. The models considered are: Carbon Rights Trade Model of Rutherford (CRTM); Edmonds-Reilly Model (ERM); the OECD model (GREEN); an econometrically estimated partial equilibrium model of International Energy Agency (IEA); Global 2100 model of Manne-Richels (MR); and the Whalley-Wigle model (WW). The study standardizes the analysis from the models in two key ways; i) specifying a few key economic assumptions for BAU scenario of unconstrained carbon emission growth, and ii) specifying a set of common simulations for reducing carbon emissions. The study divides the world into five regions similar to the Global 2100 model. The regional division relevant for the developing country analysis is China. The results from WW model, which is a static general equilibrium model, are not compared with others as it does not give dynamic path. Besides BAU, two scenarios reported are: Scenario I) Reduction in the rate of growth of emissions in each region by 2 percent per annum, and Scenario II) Stabilisation of emissions at 1990 levels in each region. Table 4 summarizes the percent growth rate of carbon emission for BAU scenario and GDP losses for China and the World for the two scenarios.

As is evident from Table 4, for all models, the GDP losses in China are very large for the stabilization scenario. This is because the emission growth in BAU is much higher for China compared to the world and hence for stabilization China will require greater emission reduction over the BAU. In Scenario I

(2% reduction), absolute cuts in emissions will be required in the industrialized countries, while a low growth in emissions is allowed for China. Hence the %GDP losses for China are lower than those for the world in scenario I. Although, the rest of the world (ROW) figures are not reported due to its heterogeneous nature, the paper indicates that the GDP losses are very high for ROW too in both the scenarios. The figures for China and the ROW are both representative of the developing countries. As in most bottom-up studies, the main abatement options recommended by the top-down models are the energy efficiency improvement and fuel switching to low carbon intensive fuels.

OPEC Model: Dynamics of Non-Commercial Energy

A study by researchers from OPEC secretariat (Walker I.O and Birol F, 1992) uses a top-down macroeconomic model to investigate the impacts of OECD type carbon tax on developing countries. A merit of the study is that it explicitly considers the non-commercial energy (NCE) and analyzes the impact of income and price levels on consumption of NCE. Initial and terminal years of the study are 1990 and 2010 respectively. The study consider two scenarios besides the BAU scenario. The *Stabilization* scenario imposes carbon tax on OECD consumers to stabilize CO_2 emissions by the year 2000, at 1990 level, with a compensatory reduction in other direct and indirect taxes. The *Strategic Response* scenario assumes that the crude price is allowed to adjust upward due to lack of capacity expansion and thereby shifting the burden of CO_2 abatement from OECD to all energy consumers.

The perspective of the study, the model and scenarios is that of the oil producers. For *Stabilization* and *Strategic Response* cases respectively, the energy consumption in developing nations grow at an annual rate of 2.9 and 2.6 percent respectively, instead of 5 percent assumed in the base case. Similarly the GDP growth for non-OPEC developing nations for the two cases work out to be 4.5 and 4.4 percent respectively compared to 4.5 percent for the BAU case. The econometric analysis for the non-commercial energy suggests that the income elasticity of NCE shares is negative, meaning that the consumers shift from NCE to commercial energy as income rises. But more importantly, the study also reports the inverse behaviour of non-commercial and commercial energy demand in response to the price changes, i.e. switching from commercial to NCE in case of price hikes. Both these results point to the obvious and what is well-known in the developing nations, and yet most often forgotten or ignored in the top-down models. Based on the above findings, the study correctly concludes by agreeing with Grubb (Grubb M, 1989) that:
"a serious potential problem with focusing on fossil carbon is that in the absence of effective controls of deforestation, it would create incentives to deplete forest for energy use. Cutting forests for energy use is much more damaging than burning equivalent fossil fuels, because wood emits much more carbon per unit of energy, and because of many other aspects of deforestation".

Critique of Top-down Model Applications for Developing Countries

Top-down models are economically consistent in balancing the demand and supply sides. The endogenous determination of prices and behavioural approach (instead of the optimization approach followed by some bottom-up models) makes the top-down models powerful tools for macroeconomic policy analysis. But, top-down models are market driven and assume existence of future markets, perfect information, competitive economic dynamics on the demand and the supply side, and optimizing behaviour of producers, consumers and the government. Most of these conditions are at best weakly valid in the developing nations. Major problems in representing the developing nation situation with top-down models are the unavailability of data from the vast informal and traditional sectors which account for a significant proportion of employment, land use and biomass energy use; persistent disequilibrium in factor and product markets; barriers to competition on the supply side due to predominance of government monopoly in energy and infrastructure sectors.

While the results of the GREEN study are striking in terms of the magnitude of impact of energy subsidies on the carbon emission, several methodological and data issues need to be clarified before accepting the results. Reliable Indian data suggests that the extent of subsidy in 1985 assumed in GREEN is too high. For instance the Coal subsidy in 1990 in India, reported as a difference between the average pithead price and the production cost, was only 7.8 percent (Centre for Monitoring Indian Economy, 1991). This is evident from Table 5 which shows the average production cost and the average pit-head cost of coal in India over a decade. Compared to the international prices, after accounting for the freight, the prices in India are comparable for oil distillates.

Accounting the subsidy as the difference of price with costs of production plus freight still shows subsidy figures assumed in GREEN model to be too high. But the accounting issues apart, it must be understood that the economic costs of production in India (and so is the case in most developing nations) also include the vast distortions and inefficiencies due to the fact that the costs are not achieved under competitive conditions (assumed by market equilibrium models like GREEN) since all three fuels are produced by the government monopoly firms operated by bureaucracy and sustained by systematic barrier to entry for others. Due to the supply shortages, there also exists an informal market for these fuels where higher prices prevail. Besides, the disequilibrium in the market is evident for instance from the fact that at the current market prices, seven million consumers await the liquid petroleum gas registration and their demand is expected to remain unfulfilled for decades due to the supply side entry barriers.

Conclusion of the study that China and India will increasingly rely on coal proves what the model designed to prove. Even in no-distortion removal scenario, coal will remain a major energy source for these countries. The result is a function of model assumptions on oil prices, backstop synthetic fuel prices, advancements in renewable technologies, penetration of nuclear technology and also the recycling regime for revenues by the government, all of which need close scrutiny. Most importantly, the future energy consumptions in developing nations shall be a function of penetration of efficient demand side technologies, changes in consumer behaviour and specific bifurcation (Hourcade J.C, 1993) policies for infrastructure investments; all of which are poorly modelled or analyzed at present. For developing nations these policies are more crucial than the price motivated modifications alone.

As top-down models show, the stringent abatement targets can lead to significant GDP losses in developing nations and that the coal, as with the GREEN study, will dominate the future energy mix of China. The study takes advantage of the basic strengths of the top-down approach to give interesting analysis of abatement scenarios which will be crucial for deciding policies on global carbon target allocations. However, the crucial scenario options for the developing nations, such as those mentioned above, are not considered in Global 2100, and hence the GDP losses for developing nations might be over assessed. Same comment is also applicable for the scenarios constructed for the comparative study of six models.

To understand fully the impact of macroeconomic policies in developing nations, the models should include the representation of traditional sector dynamics and monopolistic control by the government in major energy and infrastructure sectors, which is significant both in China and India. For instance the market models based on formal sector representation suggest that the removal of kerosene subsidy in India will reduce energy use and GHG emissions. Exactly opposite response appear if the traditional sector dynamics are represented in the model as anticipated from the results of the OPEC study for non-commercial energy use in developing countries.

The increase in price of kerosene, a fuel used by low income and rural households for cooking and lighting, moves the poor rural consumers to switch to firewood for cooking. To supply same end use energy, firewood is nearly twelve time energy inefficient. The deforestation danger due to excessive firewood demand potentially adds more to the carbon stock and in addition contributes to other ecological damage. The price of firewood does not rise in reality since in the traditional sector this is not a traded commodity. Due to tremendous excess supply in the labour market, the price signal for firewood does not appear in energy market. Besides, there are no competitive choices on energy market for the rural consumers as the restricted monopoly supply is mainly allocated through non-market quotas to the urban and industrial consumers. Under the circumstance, kerosene subsidy appears as the credit for stopping negative environmental externality rather than the energy subsidy assumed by formal sector oriented market based models.

Macroeconomic models based on market dynamics need to modify their framework to represent appropriately the developing country dynamics. This will require modifications in the modelling methodology. Some important aspects to be considered for adapting the top-down models for the developing country analysis are:

1. Consumer preferences and production systems are in transition and hence the elasticities from revealed consumer and producer behaviour will have to be adjusted,

2. Non-commercial energy sources, essentially traditional biomass, should be explicitly represented in the model as this has crucial influence on both the future energy flows and GHG emissions,

3. Macroeconomic accounting should include the informal and traditional sector transactions which are usually not included in the national account statistics. In terms of traditional sector energy use, the accounting of unpaid work of the household labour for biomass energy collection is crucial for evaluating the fuel substitution and energy technology penetration policies in the traditional sector. Evaluation of unpaid work shall also provide correction for the sizeable disequilibrium in labour market,

4. Some crucial sector are in disequilibrium at present and may remain so for a reasonable future. For instance the electric power sector in India remains in perpetual disequilibrium with nearly 18 percent shortage in peak electric power (Tata Energy Research Institute, 1994, pp. 94),

5. Assumptions regarding future technology trajectory require special attention in the case for developing countries. Crucial issues here pertain to understanding the transition of the traditional manufacturing into modern industries and the subsistence agriculture into modern agriculture. Recently many developing countries are in the process of restructuring their economies with market oriented reforms. While this is makes the top-down models more relevant, these changes signify a strategic shift *or alternatively a discontinuity in the policy regime. The inputs derived from the past data, such as the elasticities, tax and subsidy levels and saving rates should be appropriately reevaluated.*

Conclusions and Discussion

GHG emission abatement studies in developing nations mainly use the bottom-up approach. The estimates of abatement costs for developing nations, for example those reported in the seven UNEP sponsored studies, vary widely. The reported costs therefore have limited utility in international policy formulation and also for implementation programs such as the GEF financing schemes. Use of incremental cost for the global policy requires, at the least, an application of uniform methodology across the nations. At present, the country studies use too diverse methodologies which also vary widely in terms of the aggregation details, endogenization of economic effects, data assumptions and behavioural assumptions.

In addition to the uniform application, the developing country studies also need strengthening in terms of methodology, data and policy framework. Although, a straight jacket standardization of the models is not possible, it is essential to use consistent methodology, perspective and policy scenarios in different nations to achieve meaningful comparison of results. Most developing nation studies use only the bottom-up approach with optimistic demand side options. The abatement costs derived from these studies are lower as they often miss the implementation costs, including the costs of overcoming the barriers to achieving economic efficiency. On the other hand, the top-down studies have tended to ignore the strong non-market dynamics in the developing nations. There is therefore a need to develop and use both the bottom-up and top-down models, keeping in view the specific transitional conditions in the developing countries.

In developing nations, the traditional and informal sectors account for overwhelming proportion of agriculture and land use activities, employment and household energy consumption. Activities in these sectors; such as the traditional biomass use, deforestation, rice cultivation, animal husbandry; account for significant GHG emissions. Transitional dynamics in the developing nations is essentially a process that transforms the traditional activities into modern activities through myriad of simultaneous processes such as monetization, market development, technology penetration, institution building and education. Representation of these dynamics shall require basic changes in the present modelling perspective. This will require a big shift in the global policy studies where the developing country analysis is just piggy-backed over the studies which are primarily oriented to the market economies of the west and are designed primarily for analysing policy responses of the developed country.

Future GHG policy studies for the developing countries can be strengthened by:

1. *representing the traditional and informal sector- mainly the phenomenon related to transitional dynamics such as learning processes, institution building, enhanced competition among producers and wider consumer choices,*

2. *identifying the barriers to energy efficient technologies (since these account for most of the negative or low cost options in developing nations),*

3. *integrating policies such as for industrial location and local air quality issues within the GHG*

emission studies,

4. *analyzing bifurcation policies such as promoting specific modes of transport (road versus rail and water), irrigation (big dams versus small decentralized dams; surface irrigation versus ground water irrigation); and fuel (coal versus gas; washing coal versus using unwashed coal),*

5. *analyzing the impacts of alternate policies related to international trade and technology transfer,*

6. *incorporating in the top-down studies the policies on employment, land-use (like modern biomass production and afforestation) and infrastructure investments for the entire economy and separately for the traditional sector; and assessing GDP and welfare loss in the long-run from achieving GHG emission abatement targets over the business as usual,*

7. *developing a consistent data base for important economic and GHG related activities in numerous developing countries,*

8. *evolving meaningful and comparable policy scenarios and consistent methodology (this is essential for using the results of the policy studies to arrive at global agreement on policies for individual nations).*

Most GHG policy studies at present emphasize the efficiency issues alone. Explicit consideration of equity issues in the GHG policy studies will make these more effective as well as acceptable from the developing country perspective. Policy scenarios for GHG abatement need to be based on a broader perspective of sustainable development rather than the economic efficiency alone. The policies evaluation should use multiple criteria which reflect the social and political concerns besides the economic factors. Effects of the policies on the weaker sections of the developing nations, such as the tribal population and women, should be considered separately so as to integrate the multifarious global efforts aimed at improving the conditions of these sections. This suggestion is made since the developing nations have a strong dual character. Its formal and modern sector is closer to industrialized north in its economic dynamics and consumption behaviour, where as the traditional sector is a world apart and is the real south of south. The impact of the policies on this latter sector is essential to be segregated in any policy analysis since it involves the most numerous population of the world, the population which is yet to enjoy the benefits of the present world development, and therefore deserves not be penalized for its associated problems like GHG emissions, global warming and climate change. On the contrary, justice demands that they be assisted in adaptation to the impacts of climate change so as to minimize the welfare losses resulting from the specific GHG abatement policies.

Climate change is a global problem. The findings of the present studies indicate that under business-as-usual, the developing nations' contribution to GHG emissions will surpass that from the developed world in few decades. GHG abatement policies for developing countries therefore has crucial role in ultimately bringing the future emission within the target levels that are necessary to ensure the realization of the aim of the framework convention of *stabilization of atmospheric greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference at with the climate system*. Success of a global policy regime depends critically on the widest acceptability of underlying principles and implementability of specific policy options. The policy models therefore need to emphasize political and social consideration, like the equity issues in distribution of global emission quotas among nations and within the nations among the different income groups or regions based on their specific emission rates. For models to become more realistic tools for developing countries, it is crucial to make explicit representation of informal and traditional sector dynamics. The global convention on climate change will come in force in next few years. It is therefore important that the global climate change studies come out with meaningful methodologies, measurements and policy recommendations which are widely agreeable, acceptable and implementable.

References

Centre for Monitoring Indian Economy. (1991), *Current Energy Scene in India*, Bombay, October 1991.

Dean A and Hoeller P.(1992), *"Costs of Reducing CO_2 Emissions: Evidence from Six Global Models*", OECD Economic Studies No. 19, Winter 1992.

Grubb M. (1989), *"The Greenhouse Effect: Negotiating Targets*", London: Royal Institute of International Affairs, UK.

Grubb M., J. Edmonds, P. ten Brink and M. Morrison. (1993), *"The Costs of Limiting Fossil-Fuel CO_2 Emissions: A Survey and Analysis"*, Annual Review of Energy and the Environment, 18, pp. 397-478.

Hourcade J.C. (1993), "*Modelling Long-run Scenarios: Methodology Lessons from a Prospective Study on a Low CO_2 Intensity Country"*, Energy Policy, 21(3), pp. 309-325.

King K. (1993), "*The Incremental Costs of Global Environmental Benefits"*, Working Paper 5, Washington D.C.: Global Environment Facility.

Manne A.S and Richels R.G. (1991), *"Global CO_2 Emission Reductions- the Impacts of Rising Energy Costs"*, The Energy Journal, 12(1), pp. 87-107.

Sathaye J and Ketoff A. (1991), *"CO_2 Emissions from Major Developing Countries: Better Understanding the Role of Energy in the Long Term"*, The Energy Journal, 12(1), pp. 161-196

Tata Energy Research Institute. (1994), "*TERI Energy Data Directory and Yearbook*", New Delhi.

UNEP Collaborating Centre on Energy and Environment. (1992), *"UNEP Greenhouse Gas Abatement Costing Studies: Analysis of Abatement Costing Issues and Preparation of a Methodology to Undertake National Greenhouse Gas Abatement Costing Studies- Phase Two Guidelines*", Working Paper, Denmark: RISO National Laboratory, September.

UNEP Collaborating Centre on Energy and Environment. (1993), "*UNEP Greenhouse Gas Abatement Costing Studies: Analysis of Abatement Costing Issues and Preparation of a Methodology to Undertake National Greenhouse Gas Abatement Costing Studies* (*Phase Two, Part 2, Country Summaries*)", Denmark: RISO National Laboratory.

UNEP\WMO. (1992), "*United Nations Framework Convention on Climate- Text*", Geneva: UNEP\WMO Unit on Climate Change.

Walker I.O and Birol F. (1992), "*Analysing the Cost of an OPEC Environmental Tax to the Developing Countries*", Energy Policy, 20(6), pp. 559-567

Footnotes

1. We thank Dr. Peter Sturm, head of the OECD's Resource Allocation Division, for providing the draft study paper discussing the distortion (energy subsidy) removal scenarios.

List of Captions

List of Tables

Table 1: Models Used in UNEP Sponsored Studies for Developing Countries

	Country	Model Used
1	**Brazil**	MARKAL (Like) Model of Optimization of Energy System (Static Model, Bottom-up Approach)
2	**Egypt**	Bottom-up: no model (only framework); Top-down: Energy Economy Model
3	**India**	LP-Optimization Model (TEESE); Bottom-up analysis
4	**Senegal**	LEAP (Simulation); a Model for Biomass; and an Ad-Hoc Model for land clearing, Savannah burning and rice cultivation (All models follow bottom-up approach)
5	**Thailand**	Ad-Hoc Models for overall analysis coupled with use of specific sectoral models such as for energy demand projections; bottom-up approach
6	**Venezuela**	LEAP (Bottom-up approach); no top-down model but exogenous macroeconomic scenarios are analyzed with LEAP.
7	**Zimbabwe**	No Model; Energy demand and supply options are independently considered for preparing the abatement cost curve
Source: UNEP Collaborating Centre on Energy and Environment. (1993).		

Table 2: Abatement Achieved for Different Countries

Country	Abatement Scenario I		Abatement Scenario II	
	Medium Term	Long Term	Medium Term	Long Term
Brazil	13% (2010)	25% (2025)	25% (2010)	50% (2025)
Egypt	-	25% (2020)	-	50% (2020)
India	12.5%(2010)	23%*(2020)	25% (2010)	-
Senegal	14% (2005)	25% (2020)	26% (2005)	50% (2020)
Thailand	-	16%+(2030)	-	29%+(2030)
Venezuela	-	25% (2025)	-	27% (2025)
Zimbabwe	-	-	21%++(2010)	39%++(2030)

* For India, higher CO_2 reduction in the Year 2020 gave infeasible solutions
\+ For Thailand, model obtained abatements of 16% and 29% by 2030, as against the targeted 25% and 50%
++ For Zimbabwe, abatements obtained were 21% by 2010 and 39% by 2030 as against the targeted 25% and 50%

Source: UNEP Collaborating Centre on Energy and Environment. (1993).

Table 3 : Abatement Cost and Selected Measures

Country	Selected Measures Recommended For high CO_2 Reduction	Long Term Abatement Cost*** (US$/TC)
Brazil	1) Electricity conservation	- 255
	2) Solar energy*	82
	3) Fuelwood & Charcoal	89
	4) Ethanol, bagasse cogeneration	107
Egypt	1) Fuel switching in households	- 77
	2) Efficient industrial equipment	- 44
	3) Maintenance & process control	- 42
	4) Efficient transport technology options	- 42
	5) Fuel switching in industry (solar for natural gas)	- 33
	6) Electricity generation (natural gas, renewable & nuclear*)	- 4
	7) Efficient stoves	7

India[**]	1) Increase in energy efficiency in power (coal washing, T&D)	34
	2) Increase in energy efficiency of equipments in industry	33
	3) Increase in energy efficiency in rail transport	221
	4) Increase in energy efficiency in agriculture (pumpset)	101
	5) Increase in energy efficiency in households (biomass stoves)	14
	6) Fuel switching in industry	20
	7) Electricity from renewable (hydro, biomass)	40
	8) Biogas plants	348
	9) Afforestation	27
Senegal	1) Prepone hydro-power implementation	- 243
	2) Agricultural intensification	- 33
	3) Energy conservation in industry	- 5
	4) Improved wood stoves	1
	5) LPG - charcoal substitution[*]	2
	6) Reforestation for biomass needs[*]	3

Table 3 : Abatement Cost and Selected Measures (Continued)

Country	Selected Measures Recommended For high CO_2 Reduction	Long Term Abatement Cost (US$/TC)
Thailand	1) Efficient electric motors in industry	- 57
	2) Efficient air-conditioners	-133
	3) Electronic Ballast	-100
	4) CFL (commercial)	- 52
	5) CFL (residential)	-31
	6) Highly efficient gasoline car	72
	7) Nuclearization of power sector*	338
Venezuela	1) High reduction of flaring/venting of natural gas	7
	2) High reduction of methane leaks from natural gas distribution	11
	3) Reduce energy consumption of boilers, furnaces and motors	95
	4) Reduce energy consumption of gasoline/diesel vehicles	110
	5) Energy saving in households	367
Zimbabwe	1) Zero Tillage (No use of Tractors in commercial farms)	- 1124
	2) Efficient boilers & tobacco barn	- 75
	3) Efficient motors	30
	4) Hydroelectricity	45
	5) Biogas for domestic use	45
	6) Afforestation	105
	7) Efficient furnaces	599
	8) Central PV electricity plants	1348

* These options do not occur for medium CO_2 reduction

** Options for India are from UNEP Phase One study; Phase Two study for India recommends options like fuel substitution in households, use of animal power in agriculture, shift to diesel rail, etc. The long term marginal abatement cost (1989) reported is Rs. 35096 /TC (US $2163 /TC)

*** Abatement cost for India and Senegal are respectively for years 1989 and 1988. For other countries costs are for 1990. Exchange rate used is the annual average for the reference year: Senegal(1988): US $1 = CFA 298; Thailand(1990): US $1 = Baht 25.6; Zimbabwe(1990): US $1 = Z$2.5

Source:

1. Tata Energy Research Institute (1993), *UNEP Greenhouse Gas Abatement Costing Studies: India Country Study*, Phase One, New Delhi, India, April.

2. UNEP Collaborating Centre on Energy and Environment. (1993).

Table 4 : Carbon Emission and GDP Losses for China and the World

Model*	% Av. Annual Carbon Emission Growth		% GDP Loss in Year 2100 over Business-as-Usual (BAU)				Major Policy Option for Carbon Emission Abatement
	BAU Scenario		Scenario I		Scenario II		
	World	China	World	China	World	China	
CRTM	1.6	2.5	4.0	3.5	3.5	5.0	-
ERM	1.2	2.5	7.0	6.0	4.5	13.0	Fuel substitution
GREEN	2.0	3.8	3.6	1.5	3.0	5.5	Energy conservation
IEA	2.0	3.2	-	-	-	-	Energy conservation
MR	1.7	2.2	5.2	5.0	4.5	5.0	Fuel substitution

* Terminal Year for ERM, GREEN and IEA models are 2095, 2050 & 2005 respectively, and Year 2100 for other two models

Table 5: Coal Price, Cost of Production and Subsidy in India

Year (April-March)	Average Pithead Price (Rs./Ton)	Cost of Production* (Rs./Ton)	Percent Subsidy
1980-81	101.08	123.12	17.9
1981-82	128.02	134.40	4.7
1982-83	145.90	152.02	4.0
1983-84	145.90	183.69	20.6
1984-85	183.00	190.63	4.0
1985-86	210.00	213.63	1.7
1986-87	210.00	221.54	5.2
1987-88	219.00	236.07	7.2
1988-89	219.00	244.35	10.4
1989-90	249.00	264.69	5.9
1990-91	249.00	269.82	7.7

* Cost of Production comprises Salaries (47%), Administrative Expenses (4%), Stores (14%), Power (7%), Transport (3%), Depreciation (10%), Interest (8%) and Other Expenses (7%). The proportions in brackets are for the year 1986-87.

Sources:

1. Current Energy Scene in India, Centre for Monitoring Indian Economy, October, 1991
2. Current Energy Scene in India, Centre for Monitoring Indian Economy, May, 1987