

IAMs and Developing Countries

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REPRESENTATION OF DEVELOPING COUNTRY FEATURES IN INTEGRATED ASSESSMENT MODELS*

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ABSTRACT

Full scale integrated assessment models (IAMs) include representations of sources of greenhouse gas (GHG) emissions, changes in atmospheric composition of GHGs, climate change induced by GHGs, and finally the impacts of climate change. Of these, the processes represented in two categories of the models, GHG emissions and climate change impacts, can be significantly different across countries or regions. Modeling of the processes within these categories to appropriately reflect the underlying socio-economic and institutional structures, and available data, is important to obtain realistic estimates of the country-specific and global costs of reducing emissions and impacts. This paper illustrates that better data and appropriate models are needed in order to improve the estimation of the economic potential for reducing emissions from developing countries. Most IAMs evaluate carbon-tax and tradable-permit policies to mitigate climate change. The policies evaluated by IAMs need to be broadened to include energy and land-use sector institutional reforms, which are already being considered. In many cases, the reform policies are much more implementable, have the potential to bring about significantly larger emissions reduction in the near term, and have other national benefits than what might be achieved through carbon taxes and tradable permits. Climate change policymakers need to focus on ways to achieve these institutional changes rather than on smaller technical efficiency gains. Modelers need to incorporate such changes explicitly in their framework in order to examine the impacts of realistic policies on the costs of reducing emissions and damages.

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1. Introduction

The analysis of climate change requires a wide array of disciplines to work together. Analysts from diverse backgrounds ranging from various physical to social sciences have come together under the auspices of the Intergovernmental Panel on Climate Change over the last seven years to devise reasoned and well informed policies to stabilize climatic change. The IPCC summary notes that a balance of evidence suggests a discernible human influence on global climate and, that in the absence of mitigation policies or significant technological advances, concentrations of GHGs and aerosols are expected to grow (IPCC, 1996). Despite the improved data and analytical methods, our understanding of the effects of human influence on climate change and its likely geographic and temporal impacts is limited. With this in mind, it is imperative to better understand the uncertainties that plague the projections of climate change impacts.

Integrated assessment modeling offers alternative ways to simulate an integrated representation of the full climate system, from emissions to impacts. The goal of such integrated analysis is to discern the socioeconomic and physical consequences of mitigation and adaptation policies to reduce net emissions, and adapt to a changing climate. Given our limited knowledge, such integrated analysis will also reveal the sources of major uncertainties in the projected impacts of policies. A recent article (Nordhaus and Popp,

1997), for instance, notes that the most important uncertain variables are the damages of climate change and the costs of reducing greenhouse gas emissions. Resolving the uncertainties in these two variables would contribute 75% of the value of improved knowledge.

For the developing and transition countries, the US Country Studies Program has supported 55 country studies on estimating the costs of reducing GHG emissions (Dixon, et al., 1996) and the vulnerability and potential of each country for adaptation to a double CO₂ scenario (Sathaye, Dixon, Rosenzweig, 1997). In addition, the Global Environment Facility is supporting two projects, one through the United Nations Development Programme and another through the United Nations Environment Programme. One purpose of these projects is to estimate the costs of mitigation in energy, forestry and other sectors in twelve Asian, two Latin American, two African and two East European countries. Other bilateral activities are underway as well. Taken together, these studies will considerably enhance our knowledge about the damages of climate change and the costs of reducing emissions.

In this paper, we draw on the data, information and knowledge gained from these and earlier mitigation studies to discuss the features of developing countries whose understanding and representation in IAMs would be crucial to improved estimation of impacts and costs, and to reduced uncertainty in their estimates. We discuss (1) current IAMs, (2) distinguishing features of developing countries, (3) state-of-the-art in the modeling of costs and damages in developing and transition countries, (4) issues to consider in designing IAMs, and finally (5) desirable IAM attributes for representing developing countries.

2. Country-specific Features of Integrated Assessment Models:

Full-scale integrated assessment models (IAMs) categorize the system of events from emissions to impacts into four major categories. One way to categorize these events is depicted in Figure 1 (Bruce, Lee and Haites, 1996):

- emissions
- atmospheric composition
- climate and sea level
- impacts

The emissions of greenhouse gases are caused by human activity in energy, agriculture and forest sectors, which are composed of both man-made and natural systems. Energy production primarily leads to release of carbon dioxide and fugitive methane emissions, forest sector burning releases primarily carbon dioxide and methane, and agricultural systems are largely responsible for the release of methane from paddy fields and livestock, and, to a smaller extent, nitrous oxide. The emissions of carbon dioxide from human activities and natural sources increases its concentration in the atmosphere depending on the extent to which oceans and terrestrial sinks remove the gas. Other GHGs do not have these sinks and their concentration depends on their reactions with other elements in the atmosphere. Climate and sea level depend on the concentration of GHGs and their interactions with oceans, which act as enormous heat sinks. Finally, the changes in climate and sea level have impacts on various human and natural systems, as shown in Figure 1. Each IAM simulates the processes within these four categories at more or less level of detail depending on the modelers' interests and the data and information available to them.

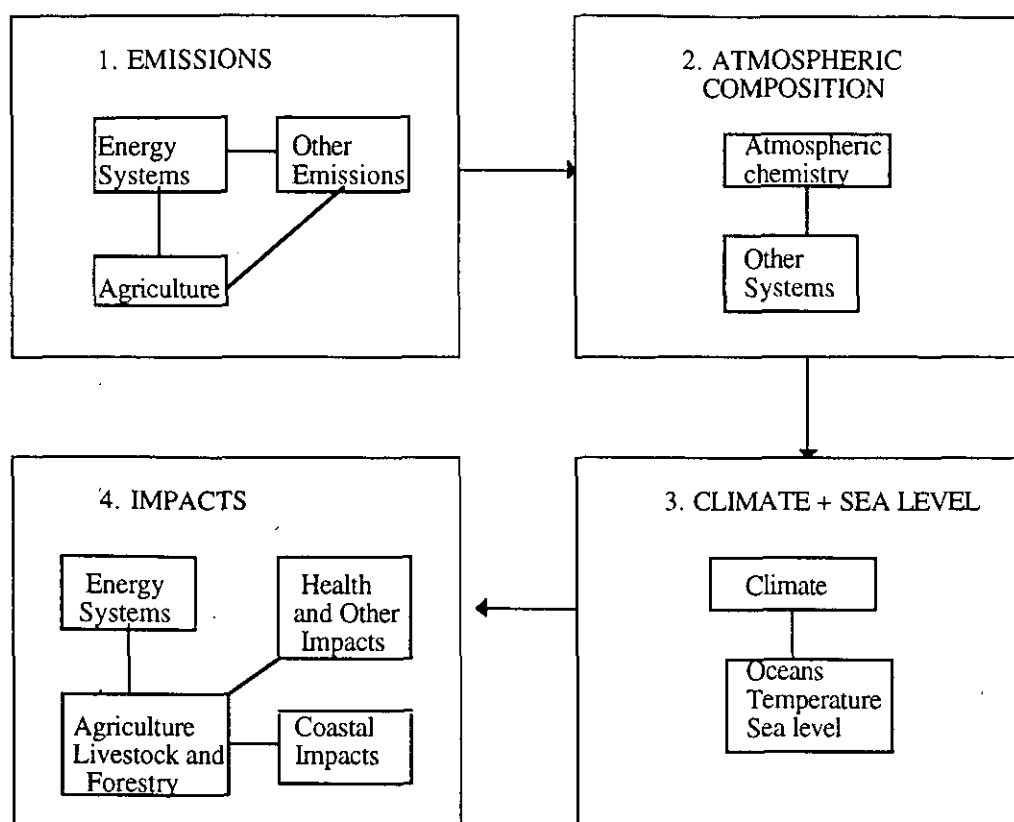


Figure 1: End - to - End Characterization of IAMs

For our purposes, the main point of interest is to identify the categories and systems where interactions differ across countries, particularly between developing and industrialized ones. Category 1 deals with emissions of GHGs, and Category 4 with the impacts on natural and man-made systems. In these two categories, there is potential for significant differences among countries. Energy systems are country-specific both because the types of fuels used vary by country, and regions within a country, but also because the types of uses vary by the socio-economic systems in place. Similarly, land use patterns, which reflect the geographic distribution of forestry, agriculture and other related sectors, are dictated by the natural resources of the country, and their exploitation is a function of its socio-economic systems.

The other two categories are largely global in nature, where regional or country-specific interactions are not as important. Atmospheric composition is not a function of any particular country, although the associated concentration of local air pollutants does vary across countries and cities and needs to be addressed separately. Likewise, the interaction between oceans and climate is global in nature, although the impacts of sea-level rise and temperature increases need to be considered on a country-specific basis, and these are dealt with in Category 4.

3. Integrated Assessment Models

The IPCC Working Group (WG) III report (Bruce, Lee and Haites, 1996) suggests two broad classes of IAMs: policy *optimization* models and policy *evaluation* models. Optimization models optimize key policy control variables, such as carbon emissions control rates or carbon taxes. Evaluation models project the physical and socio-economic consequences of policies. There were about a dozen models of each type listed in the IPCC, WG III report. Optimization models balance the marginal costs of controlling GHG emissions and adapting to damages that may be caused by climate change. The models generally provide information on the damage that climate change might cause globally; they do not disaggregate the impacts by countries. Evaluation models are rich in physical detail on the impacts of climate change on various market and non-market sectors by countries or regions, but do not put economic values on these impacts.

The cost-benefit analysis in optimization models results in a tradeoff between substantial abatement costs early in the horizon and avoidance of potentially large damages later in the horizon. The rate used to discount future damages plays a crucial role in determining the costs that nations should bear to avoid emissions. The time path of emissions reduction is an important determinant of the cost of meeting an atmospheric GHG concentration target. More abatement later is to be preferred if the discount rate is low and because later abatement permits capital stock to adapt to a less-carbon-intensive economy. On the other hand, early abatement may induce further cost reductions, will not lock economies onto carbon-intensive development paths, and inertia may increase later costs of abatement.

IPCC WG III cites five major challenges facing integrated assessment modelers: (1) representing dominant policies and processes in the developing countries, (2) addressing low probability but potentially catastrophic events, (3) representing and valuing the impacts of climate change, (4) integrating multiple models and data from diverse disciplines, and (5) improving the relevance of models to policymakers. The report notes that models contain rich detail on the 24 countries of the OECD and a poor representation of the 140 developing countries. It notes that land use, land tenure and population growth are three key determinants that are poorly modeled in the IAMs, and that much of the land-use data for the IAMs are derived from one or two international data bases. But, in addition to these, there are several other variables and policies where IAMs fail to adequately recognize the particular features of developing countries. As Gaskins and Weyant, 1993, note, higher levels of geographical aggregation result in higher estimates of both costs of damage mitigation of climate change as well as levels of emissions.

4. Distinguishing features of developing countries

It is important to note at the outset that the developing countries are not a monolithic group with common fuel use patterns, socio-economic structures, land use and tenure, etc. The diversity in this group of countries is far larger than in the 24 countries of the OECD. Not all the generalizations implied in the discussion below apply to a particular country, but one or more of the features should be characteristic of a developing country.

Population growth rates are generally high in the developing countries, with urban growth rates almost double those in the rural sector. Household formation is taking place faster, and thus the household size is typically falling in these countries. Urban lifestyles, including food habits, are steadily drifting away from the traditional rural ones and mimicking those of the industrialized countries. The high population growth rates are falling across much of the developing world, except in some countries in Africa and the Middle East.

The implication being that the urban/rural and age-wise population distribution in the developing world of the future may be similar to that in the industrialized world today. In the interim period, which may last several decades, the developing world will have very different population distribution from the industrialized one.

Economic growth rates vary across countries and over time, but the Asian ones are growing much faster than other developing economies. The structure of these economies includes oil-exporting countries, those with highly developed and complex industries, and largely rural and traditional economies. In large countries, all these features may be present simultaneously. Most countries have complex government regulations applied to energy-intensive industry, forestry and agriculture. Both price and quantity controls may be present with prices varying by fuel type, and sometimes set differently for each type of industry. A government may directly or indirectly own, control or guide portions of various economic sectors. As a consequence, the functioning of these economies may be far from a neoclassical paradigm.

Rapid growth of energy consumption, particularly that of electricity and petroleum products, is a common feature in most developing countries. The rapid growth causes scarcity of capital for electricity generation and foreign exchange for oil-importing developing countries. In the energy demand sector, urban fuel use patterns are radically different from their rural counterparts. Modern fuel use is steadily increasing and biofuel use is now confined to the poorer urban households, whereas in the rural areas biomass use is still dominant. The end-uses tend to be very different in rural areas, where cooking and lighting are the primary energy uses. In the productive sectors, the end-uses are similar to those in the industrialized countries, although the proportion of energy use for agriculture in some countries is high. Energy supply is accomplished through much the same technologies, which are specific to a fuel type, in most of the world. What distinguishes these in the developing world, is their vintage, and their low efficiency and poorer exploitation. These are caused both by the lack of capital for new plants and by the overall inefficiency of the system as a whole. Technological change in end-use and supply sectors may be constrained by a lack of capital and by price and quantity controls on production processes and imports of products.

The economies of developing countries (DC) are transforming towards a market system, whereby the level of control exercised by the government on economic output and various factor inputs is diminishing. The speed of this change varies across developing countries, but it is conceivable that the modern sector of these economies will be no different than their Industrialized Country (IC) counterpart in a few years time. The more traditional sector, particularly that dealing with land-use, is likely to remain outside the formal markets for some time to come. The economic transition will be a period of faster technological improvements as domestic and multinational companies with modern more energy-efficient technologies set up joint ventures, licensing agreements, larger and more modern manufacturing plants, and/or sell goods directly to DC consumers. The transition path will be crucial, however, since many IAMs show that the cost of cumulative emissions reduction will be a function of the time path of reduction.

In the land-use dominated sectors, land tenure and demarcation for particular uses, and the governments desire and ability to control land-use patterns, are fundamental to reducing carbon emissions. Land-use measures and policies have contributed to deforestation, which is widespread in the tropics. Paddy fields are mostly found in Asia, and the number of cattle is also large on this continent. Understanding methane emissions from paddy fields and livestock poses different challenges since the emissions factors from these sources are still being researched.

5. Energy-Sector Mitigation Models Used in the Developing Countries

The methods used to study mitigation options in the energy sector are commonly classified as bottom-up and top-down types. These methods form the core by which the cost of reducing emissions from the energy sector are analyzed. Bottom-up models make a highly disaggregated representation of energy use and have a detailed technological specification. Top-down models analyze aggregate economic behavior. Table 1 shows various bottom-up and top-down models that are currently being used in developing countries for mitigation analysis (Sathaye and Meyers, 1995).

Table 1: Examples of Analytical Tools Used in Developing Countries for Mitigation Assessment

Topic	Analytical Tools
Energy Sector	
Accounting Models	LEAP, STAIR
Optimization Models	MARKAL, ETO
Iterative Equilibrium Models	ENPEP
Decision Analysis Framework	Analytical Hierarchy Process (AHP)
Non-Energy Sectors	
Forestry	COPATH, COMAP
Agriculture	EPIC, CENTURY
Rangelands	CENTURY
Top-down Models	LBL-CGE, MIMIC, MARKAL-MACRO

The aggregation level aside, the other distinguishing feature relates to the endogenization of economic effects. In bottom-up approaches, macroeconomic data enter exogenously. Top-down models include feedback between the energy system and the other economic sectors, and also with the macroeconomic performance of economy. Bottom-up models pay greater attention to energy details from the end-use side, but lack the endogenization of economic behavior associated with top-down models.

Most top-down models consider economic sectors at highly aggregated levels and presume the economy to be in equilibrium as a result of optimal decisions taken by consumers, producers and the government. These models overlook specific technological opportunities identified by bottom-up models, but they provide greater insights into the impacts of economic policy interventions, like taxes or subsidies, which cause market distortions.

Most bottom-up and top-down models simulate the energy-economy of a country with assumptions which ignore the complex institutional structures within a country that make an energy-economy function. As a result, bottom-up models tend to be optimistic about future GHG abatement opportunities and identify numerous "no regrets" and low cost energy efficiency options. The optimism of bottom-up models reflects the perspective that the present technology mix does not minimize the cost of providing energy services. In the case of developing countries, bottom-up models suggest enormous "no regrets" opportunities through energy efficiency improvements and fuel switching. For example, a study of the cost of reducing carbon emissions in India concluded that, in the Low Carbon scenario, the cost of providing energy services in 2025 could be reduced by 13% while simultaneously reducing carbon emissions by 32% (Sathaye, Monahan, and Sanstad, 1996). But this theoretically predicted potential is unattainable in practice as a result of numerous social, economic and

legal barriers, the removal of which would require significant reform of the energy sector. The abatement costs derived from bottom-up studies often ignore the implementation costs, including the costs of overcoming the barriers to achieving energy efficiency.

The "pessimism" of the top-down models originates from the assumption that the present technology mix results from efficient behavior by consumers and firms under prevailing economic conditions. The application of top-down models to developing countries suffers from unrealistic assumptions about the existence of "free markets". Two models, one for Venezuela (Mongia and Sathaye, 1995) and another for Nigeria (Oladosu, 1996), have tried to break this mold. The models are "structuralist" CGE models as opposed to more "neo-classical" constructs which emphasize macro-behavioral functions. Structuralist models can reflect underlying features which are specially apt for developing economies. Structural factors include control of the means of production by distinct types of actors (private sector, state or transnational capital), the functioning of financial intermediaries, degree of concentration of markets, etc. How prices and production equilibrate is determined by a model's causal structure, and secondarily by substitution response. Thus these models explicitly account for structural features such as oil production quotas, administered prices of fuels and electricity, and the cost plus nature of the refinery sector. The Nigeria model concludes, for example, that price reforms and taxation of carbon emitting product can reduce emissions at a cost to the economy, while energy efficiency options achieve emissions reduction while growing the economy. The combination of both price reforms (20% general tax on the use of petroleum products) and energy efficiency (20% improvement in efficiency of petroleum product use) is more effective than either approach alone to reduce emissions by 2.3% and achieve higher economic growth by 0.9%.

None of the IAMs discussed in the IPCC Working Group III report utilize the "structural" approach to modeling of the economic systems of developing countries. The optimization models noted in the IPCC report do not have country-specific representation, and thus are not able to distinguish between developing countries and industrialized countries. The current representation of country-specific socio-economic systems is thus very weak and needs to be strengthened. At least two efforts are underway in this regard. One study being conducted at the Lawrence Berkeley Laboratory (LBL) will improve the representation of factor productivity in IAMs. In many of the IAMs, productivity improvements are input as an exogenous variable with little evidence to support the values of the assumed parameters. At LBL, we are establishing industry profiles and will econometrically estimate historical and future productivity improvements of India's energy-intensive industry. Another effort at Harvard University is aimed at establishing a better representation of China's economic growth with separate treatment of rural and urban sectors.

It should be noted that in the last several years progress in the development of global IAMs has proceeded rapidly, and a number of models have moved toward regional disaggregation (Sanstad and Greening, 1997). For example, the RICE model of Nordhaus and Yang, an extended version of Nordhaus' original DICE, includes a 10-region representation, while the MIT EPPA model includes 12 regions. Nonetheless, even in the current generation of models, developing and developed countries are distinguished primarily via parameterization rather than through structural differentiation. Thus, only those differences that can be measured through quite aggregate parameters are captured.

In addition, given their basic design in terms of the perfect competition paradigm, these models are best-suited to the analysis of economic policies, such as carbon taxes or tradable emissions permits, in fully developed economies. While they are of course applied to world and inter-regional policy analysis, their structure precludes the analysis of key

institutional factors that would substantially affect the introduction of large-scale carbon abatement in the developing world. Indeed, in the case of policies - such as regulatory reform and the divestiture of state enterprises - that might have considerable implications for a given country's emissions profile, the models are an imperfect analytical instrument.

6. Land-use Related Mitigation Models Used in the developing countries:

In the land-use sectors, bottom-up analytical methods have been used to estimate carbon and GHG flows. While there are several macro-models, particularly CGE ones, that have been used for assessing the impacts of agricultural policies, we are not aware of any that have been used explicitly for the evaluation of GHG flows. The COPATH model has been used for carbon accounting and scenarios, and COMAP has been developed for estimating the impacts of mitigation options in the forest sector. EPIC and CENTURY are plant/soil simulation models which may be used to simulate carbon cycling dynamics in agricultural and rangeland ecosystems.

The COMAP mitigation model is also structuralist in nature, in that it allows the user to input the particular species type, land-use and cost/benefit data in order to determine the cost of sequestering and conserving carbon. The model is appropriate for developing country applications where because of land tenure traditions, markets for the transfer of land do not function, or do so under tight constraints. This also means that most forest products, fuelwood, fruits, nuts, etc., are used locally without an operating market.

The physical processes are being represented in some of the policy-evaluation IAMs, although the socio-economic ones are not.

7. Issues to Consider in Formulating an IAM that is Specific to Developing Countries

There are several issues that plague the modeling of GHG emissions and impacts for developing countries. We discuss some of these issues below. An extensive discussion of these and other issues is in a companion paper in these proceedings by Morita, Shukla and Cameron.

Limited data: This is a perennial problem in the developing countries. Agencies to collect data exist for some standardized set of topics, such as population and demography, economic and financial statistics, energy supply, etc. As soon as one steps outside these bounds, as is necessary for climate change analysis, the agencies to collect such data do not exist, and the data collection and collation is occasional and sporadic. End-use energy data, forestry inventory by species, mitigation and adaptation costs are examples of such data. There is a need for a flexible IAM framework wherein the processes to be represented within each country would be tailored to the available data for that particular module.

Market-based, efficiency-oriented, neoclassical equilibrium models vs. developing countries' actual socioeconomic structures: We alluded to this issue in Section 5. The representation of the economic structure in most IAMs is market-based, efficiency-oriented in a neoclassical framework. Models that are structuralist and therefore which provide a more realistic representation of the DC economy have been constructed for Venezuela and Nigeria, and these yield reasonable results. Such models should form the basis for the representation of DC economies in future IAMs. Even these two models, however, ignore the informal markets in each country, in large part because data that have been collected on a systematic periodic basis are not available. The size of these markets varies across countries. In the relatively poorer countries, where rural agriculture dominates economic activity, not having them included would be a gross misrepresentation of the nation's economic activity. Not

representing this sectors would severely underestimate energy demand and associated emissions and lead to the formulation of unsustainable policies.

Given that this problem is not unique to IAMs, however, we should not burden the IAM modelers with the responsibility to create complex models that include informal markets. If desired, they could include informal markets in the IAMs in some relatively simple manner.

Differences in lifestyles: This particular issue is important in countries where the rural sector is large. While there are differences among industrialized and developing country cities, these differences are largely disappearing as two-income families dominate and cultural differences are overcome by a more job-oriented lifestyle, that is typical of an industrialized economy. Surveys of household energy use in about 20 developing-country cities clearly show that higher income households aren't that different from their counterparts in industrialized countries in terms of their lifestyles, fuel consumption and appliance ownership (Tyler, Sathaye and Goldman, 1994). Energy consumption in the residential and commercial sector is clearly influenced by lifestyles and the types of fuels that are consumed, which ought to be regionalized and captured separately for each region or country. However, energy use in the industrial sector can also be quite different depending on how industry is defined. Chinese industrial statistics, for instance, often include data related to housing and other services that the industry provides.

Developed countries technological assumptions vs. developing country ones: A key issue regarding the adoption of new technology is that in many larger developing countries energy-intensive manufacturing is controlled by government bureaucrats and the government owns over 50% of the company. As a result the technology adoption process is not driven by profit maximization principles. How to represent such a firm in a modeling framework is a difficult question since at least in the near term the technology adoption process will be ad-hoc and subject to many criteria -- employment, vested interests, union rules, etc. -- other than profits. We need detailed models to simulate the growth of energy/carbon-intensive industry and the many economic and non-economic factors that influence such growth.

Developing countries damage functions vs. developing countries value systems: Using damage functions for developed countries and applying them for developing countries will overstate the economic damage and understate the social and ecological damage that climate change might cause to a developing country. The problem is not unique to this topic. In the past modelers have used coefficients for developed-country technologies and applied these to developing countries. Further, in some models, the coefficients for one country have been used to represent the entire continent. Lack of data is one problem, but the bigger problem is the valuation of impacts (value of life for instance), which is an ethics question and can have many interpretations. The models should clearly be tested from the perspective of various definitions of the value of impacts.

Climate policy vs. developing country policy linkages and developed countries vs. developing countries policy-instruments: developing countries are generally inclined to use existing or ongoing policy changes to foster the reduction of GHG emissions. In the energy sector, the mitigation options reduce to two basic ones, improving energy efficiency and using less-carbon-intensive fuels. In either case, policy measures such as institutional reforms of the power sector, petroleum product rationalization, including reduced subsidies and taxes, privatization of the energy industry, removing government allocation of fuels are likely to bring about far significant reduction in GHG emissions than single-focus policies such as carbon taxes, which have been widely discussed in industrialized countries. Similarly, in the land-use sectors the bigger gains are to be achieved through forest conservation laws that

include an array of changes, rather than single decrees to reduce deforestation. The challenge to IA modelers is how such radical transformations may be captured in the model structures.

A related issue is the use of tradable permits as a basis for reducing emissions at a least cost across countries. As in the case within countries, near-term reductions are best achieved by modifying current international practices to include climate change considerations. For instance, it would not be impossible to require that all multilateral bank lending ensure that cost-effective energy-efficient equipment is procured in energy projects. Likewise, inter-country negotiations on energy issues may be required to emphasize sector reforms to promote energy efficiency and the use of renewables.

8. Desirable IAM Attributes for Improving the Representation of Developing Countries

Given the above discussion of issues, what should the framework for the first and fourth categories of an IAM look like? An IAM should have the following attributes:

1. Its economic basis should be "structuralist" so as to better represent developing country realities.
2. The structuralist basis should be amenable to change over time. As the country's economy evolves, it is conceivable that the model would move towards a free market representation.
3. The informal sector of the economy needs to be explicitly represented in the model.
4. The representation of technologies should also change over time and may depend on indigenous factors, such as size and R&D investment, and the access to imported technology.
5. To the extent data permit, urban and rural sectors should be separated in the model and informal markets should be explicitly recognized.
6. The policy choices that the model would evaluate should be allowed to change over time. Policy evaluations may begin with reducing subsidies and end with carbon taxes.
7. The model should be amenable to evaluating a package of policies rather than single-focus policies. These policies would be representative of the energy and land-use sector reforms that are ongoing in many developing countries.
8. The size and complexity of the model should be dictated by the data that are available for the developing country or group of countries. One may use parameter values derived from other countries if these are deemed to be robust enough, or the model is simply not sensitive to them.

Finally, it is important that developing country researchers be actively involved in the development of IAMs so that they (1) provide input to the modelers about the appropriate DC features that models need to capture, and (2) understand the implications of the policy analyses that might be conducted. Heretofore, all IAMs have been developed in industrialized countries, and DC researchers do not have easy access to these models. Even when models are available, these may be "black boxes" where DC researchers are asked to fill in data rather than being involved in the development of the model itself. This approach ensures consistency across countries in terms of the method that is used and permits easier evaluation of the results, but force-fitting data to the model may invalidate the results. What is needed is an open structure framework whereby developing country researchers can modify the processes that are represented within each module of the framework. This would permit greater transparency and a more accurate representation of the country-specific processes.

The processes would then have to be modeled outside the framework, and a range of approaches for each process would have to be developed.

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