Assessing vulnerability to climate change: The link between objectives and assessment

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The vulnerability of developing countries to potential impacts of climate change and the options for adaptation are rapidly emerging as central issues in the debate around policy responses to climate change. In order to prioritize, design and implement interventions to adapt to climate change, it is essential to adopt a coherent and consistent set of definitions and frameworks for examining vulnerability, adaptation and adaptive capacity. In practice, a variety of definitions of vulnerability and adaptation are found in the literature. This paper uses the base of literature from the context of the coastal impacts of climate change to draw some explicit linkages between the objectives of vulnerability and adaptation assessment and the definitions used in the analysis. We find that such a linkage is helpful for identifying the nature of assessment required, and the data and information necessary. The paper concludes with some thoughts regarding directions for research with regard to vulnerability and adaptation assessment.

Keywords: Climate change, coastal change, sea level rise, vulnerability assessment.

RECENT assessments, such as the Third Assessment Report of the IPCC (Intergovernmental Panel on Climate Change) indicate that developing countries are likely to be highly vulnerable to climate change, both due to the projected magnitude of the change and due to the lack of coping ability[1]. This coping ability or adaptive capacity depends on a variety of economic, social and technological factors such as infrastructure, access to and the distribution of resources and management capabilities. Developing countries, particularly the least developed countries, are generally poorest in this regard, and as a result, they have lesser capacity to adapt and are more vulnerable to climate change damages, just as they are more vulnerable to other stresses.

Climate change impacts become even more important as it becomes increasingly clear that we are already committed to a certain magnitude of change. Even very aggressive mitigation scenarios would, at best, lead to a stabilization of atmospheric CO_2 at around 550–650 ppmv, which is more than a doubling of pre-industrial levels. At the same time, there is increasing recognition of the link between the processes of adaptation, the creation of adaptive capacity and long-term social and economic development. While at first sight, developmental activities might be considered as enhancing capacity, it is possible that they might even lead to mal-adaptation. For example, there is rapid growth of human settlements in areas that have increased exposure to climate hazards, such as river floodplains or coastal zones. From the perspective of developing countries, therefore, issues of vulnerability and adaptation are central to a *research* agenda in climate change.

This paper is organized as follows. We begin by using the context of the coastal impacts of climate change to describe the evolution of impact assessment approaches and draw insights regarding methodological issues. Much of the recent evolution reflects a shift in approach from a somewhat mechanistic and deterministic view of impacts, as exemplified by the early ‘coloring book’ approach to a more dynamic, path-dependent view of the process in which human response through the process of adaptation is treated explicitly. A consequence of this shift is the increased salience of the concept of adaptive capacity. We then review the current set of vulnerability assessments from the point of identifying and designing adaptation interventions to identify the link between the objectives underlying the analysis and the operational definition of vulnerability. For this purpose, we describe vulnerability using a standard risk assessment and management framework, and find that vulnerability can be represented by a composite measure that can be assessed in varying levels of detail, with implications for data and information needs. The final section outlines a research agenda for vulnerability and adaptation assessment from a developing country perspective.

Insights from assessments of coastal impacts of climate change

Coastal zones were amongst the first regions or sectors for which assessments of climate change impacts were performed. In particular, sea level rise was considered as a ‘typical’ indicator of climate change, often due to the ease of visualization of consequences, as well as the relatively direct linkage between global warming and global mean sea level rise due to thermal expansion and glacial melt. As a result, there is an extensive base of literature that reflects the evolution of methodological as well as sub-

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stantive understanding of climate change impacts, vulnerability and adaptation.

In describing the evolution of sea level rise (SLR) impact assessments it is possible to identify a number of stages, marked by changes or improvements in methodology and substantive understanding. A characterization of these stages is useful for identifying research needs and provides guidance for future assessments. Such a characterization is also useful in bringing out the linkage between the results and products of the assessment and the working definition of vulnerability.

Chen, Schneider and Titus, among others, are credited with the first generation of quantified assessments of SLR impacts[2–4]. In this first generation of assessments, simple SLR models were used yielding relatively high estimates of global mean sea level change (1–3 m by 2100) with no regional differentiation. The main impacts considered were those resulting from inundation, and the general approach to assessing impacts was similar to that of a 'coloring book' – where scenarios for sea level change are overlaid on contour maps to determine area inundated, and consequent economic loss. A similar approach was adopted in early studies of SLR impacts in India[5]. This approach is depicted in Figure 1. These assessments heightened the early concern regarding climate change by producing fairly large values for the economic impacts of SLR.

In the next few years, SLR impact assessment became more sophisticated, with growing contributions from economists, coastal specialists and modellers. Assessments were also conducted for many developing countries in addition to refinements of studies of developed country impacts[6–11]. This second generation work was characterized by the recognition that: (i) many developed countries either had coastal protection infrastructure already in place or had the wherewithal to put it in place; and (ii) that early estimates of future sea level rise were too high – these estimates were revised downwards to about one-third of the earlier estimates. For developed countries, the second generation work emphasized protection costs[12,13], but these investments in protection were often cost-effective and led to generally lower damage estimates.

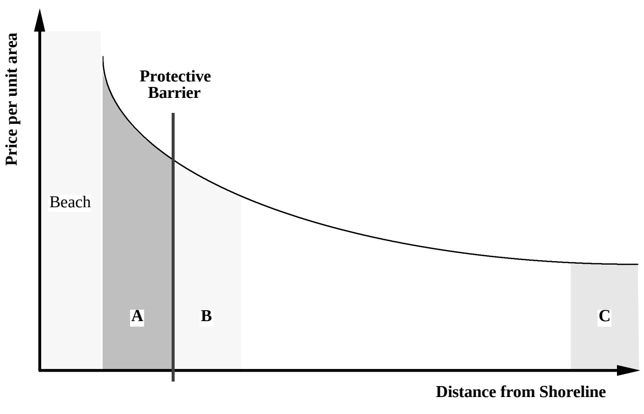

Figure 1. The 'coloring book' approach to SLR impact estimation. **Explanation:** In first generation impact assessments, the loss due to sea level rise was estimated to be the sum of areas A and B. In second generation impact assessments, the estimates for sea level rise were lowered (effect not shown) and the area lost in developed countries was corrected to include the effect of protective barriers – only area A was considered lost. In third generation impact assessments, adaptation was thought to be smooth and costless and while the 'physical' losses due to SLR occurred in A, adaptation and landward migration of the coastal development led to economic losses being equal to C.

Third generation work in sea level rise impacts extended this approach to developing countries[14,15] and also attempted to include non-structural responses to coastal change such as planned retreat and coastal zone management policies such as zoning. Thus, the third generation assessments sought to build greater policy realism by noting that in developed countries planned adaptation to SLR was not only possible, but quite likely. This had implications for estimation of economic loss, for example, as illustrated in Figure 1, if smooth and costless adaptation is possible, the actual economic value associated with the loss of land due to inundation would be that of an equivalent interior parcel of land which does not enjoy any excess value associated with proximity to the shoreline. This work led to a further reduction in damage estimates for developed countries. Much of the literature in this stage was reflected in the Second Assessment Report of the IPCC. It is instructive to note that both the second and third generation of sea level rise impact assessments still rely on the basic coloring book approach, although with some modifications to allow for protection and retreat. In India, TERI[16] made an attempt to include a more sophisticated treatment of economics within the existing framework.

The current, fourth generation work in SLR impacts[17–20], which appears in the IPCC Third Assessment Report reflects further improvements in the substantive and methodological domains. Substantively, there is

- Recognition of regional and local variations in sea level that in some locations can dominate the global or eustatic signal. As a result, projections for SLR need to account for local processes affecting sea level such as subsidence, uplift or continental rebound.
- Recognition of spatial inhomogeneity in sea level rise associated with global warming. The thermal expansion component of eustatic sea level rise is a dynamic quantity and in a transient scenario varies by location[17,20].
- Recognition of the interaction between sea level and storm surge. Realistic and accurate assessments of SLR impacts need to consider the joint effect of secular trends in sea level and storm regimes.

It is important to note that similar considerations of regional heterogeneity and the combined effect of secular changes and extreme events are important for most climate variables and impact sectors.

Table 1. Assessments of SLR impacts on US for doubled CO_2 ($\$10^9$)

	First generation	Second generation	Third generation	Fourth generation
SLR range (m)	1–3 m	0.3–1 m	0.2–0.8 m	0.2–0.8 m
United States	300	140–240	30–50	20–?

As an example, Table 1 describes the evolution in estimates of SLR impacts for the US. In the first generation assessments, high SLR estimates were combined with no adaptation or protection measures. In the second generation, SLR estimates were lower and protection was considered. The third generation assessments include adaptation. The fourth generation assessments explore extreme events and their interactions with secular trends; regional heterogeneity in SLR; and the limits to, and feasibility of adaptation. It is possible that while damage estimates were lowered significantly in the second and third generation assessments, the next generation estimates may not follow this trend. Another point of concern is that it does not appear that relevant information to support these more sophisticated assessments is available for most of the world, and more important, existing programmes to support such research may not be emphasizing the relevant research directions.

The interaction between storms and sea level is important not only in terms of the physical impacts, but also in terms of human responses that modulate the socio-economic impacts. For many locations, sea level change may have a greater impact by modifying storm damage, than by directly causing inundation or erosion[20]. As an example of the interaction, consider the specifics of two physical processes leading to impacts:

- The process of erosion is often modelled by the Bruun rule and treated as a continuous process. In reality, however, it is an episodic process often triggered by wave attack during storms. Increased sea level serves to enhance the effect of wave attack and leads to greater erosion. Consequently, a straightforward application of the Bruun rule might underestimate the actual erosion that might take place for a particular sea level rise scenario.
- Increase in local sea level produces greater wave attack and flooding, thus amplifying the impact of a particular storm. Viewed another way, a storm of a particular severity may happen more often. It is interesting to note that the 'coloring book' approach does not include a specific impact from storms and this mode of damage due to SLR is not represented.

Consequently, in the absence of any response, the damages associated with sea level rise are likely to be higher when considered together with a particular storm regime than in isolation.

Response to sea level rise (and climate change in general) may be regarded as a matter of detection of change, formation of expectations about future change, and development of appropriate protection or adaptation measures. In many cases climate change is easy to detect, though difficult to attribute. However, formation of future expectations is driven by the formation of subjective beliefs regarding future outcomes. There is an extensive literature that demonstrates the errors and biases associated with this subjective judgment, and as a result, formation of expectations is often subject to grave error. The low frequency of extreme events makes it difficult to know with confidence if the storm frequency and intensity have changed. For example, a climate change skeptic may consider a string of storms as unlikely realizations from a stationary process. A climate change believer may consider even one occurrence of a severe storm as evidence of a changing storm regime. The responses would be different, and impacts from subsequent sea level rise and extreme events would also be different. In neither case is it likely that the appropriate response is realized at the right time. As a result, even purposive adaptation may or may not lead to the desired outcome in terms of reducing vulnerability to climate change. Finally, it is important to recognize that in many developing countries, even if accurate expectations regarding future outcomes could be formed, the actual creation of adaptive capacity could be limited due to institutional, resource or a variety of other constraints.

It is important that further research explicitly addresses the interactions between extremes and secular trends; the role of on-going development patterns to alter future impacts, and the learning process by which individuals, organizations and nations form expectations regarding climate change and formulate and implement responses. A more realistic next generation SLR impact assessment might include:

- A more realistic depiction of processes of coastal change
- A behaviourally realistic representation of the options facing individuals and societies and the way in which they would be exercised
- The effect of external dynamics shaping the development of coastal communities and their activities, and
- A modelling approach that addresses the issue of path dependency.

The next section explores further implications of the assessments of SLR impacts with regard to the measurement and analysis of vulnerability.

Interpreting vulnerability definitions and objectives

The assessments of coastal impacts of climate change described in the previous section have been used to draw in-

Table 2. VA questions, decision contexts and objectives

Question	Decision context	Objective
What are the physical impacts of sea level rise?	Input to preliminary impact assessment	Identifying data needs and organizing data
What are the market and non-market losses associated with sea level rise?	Input to international negotiations	Countries have to provide estimates of abatement costs and climate damages
What is the optimal response to sea level rise?	Input to formulation of adaptation policies	Determining the reduction in damages with responses
Which research strategy will have the largest value of information?	Input to research prioritization	Determining the value of reducing key uncertainties through research
Which region should be selected for protection first?	Input to policy prioritization	Allocating resources efficiently towards responses to sea level rise

sights regarding the vulnerability of coastal regions, including efforts to compare regional and sectoral vulnerability. A detailed examination of these studies suggests that they often differ in their definitions of vulnerability. In addition, they often appear to be motivated by different objectives. This observation is significant because different vulnerability measures have different data and analysis needs, and consequently different cost and information burdens. In order to obtain an effective VA study design and to improve the interpretation of the results, it is important to clearly delineate the link between VA objectives and the working definition of vulnerability.

Vulnerability objectives

The desire to guide and prioritize policy action often serves as the objective for performing VA. However, this objective is often not spelt out clearly, nor are its implications considered. For example, the IPCC Response Strategies Working Group commissioned a number of country-level case studies of vulnerability[21]. For these studies, vulnerability was defined as 'the ability to cope with the consequences of sea level rise and other coastal impacts of climate change'[21]. This definition eventually led to the one in use today, which is that vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Such a definition encompasses both the impacts of sea level change *and* the abilities of the country or region to respond to it. These are often quite separate issues, for example, although the physical impacts of sea level change on the Ganges and the Mississippi deltas might be similar, there are significant differences in the economic and social consequences and in the set of possible responses. While there are a variety of possible responses to sea level change, including structural options (such as bulkheads, sea-walls, dikes and beach replenishment) and non-structural options (such as set-backs, zoning and insurance), the costs and legal/regulatory implications of implementing these options are quite different and are region/country-dependent.

Apart from the objective of guiding policy action, it is quite likely that the results from VA studies will play an important role in the on-going international negotiations concerning the climate convention. In this setting, however, the VA results are likely to be used by individual countries to support their estimates of the benefits and costs associated with climate change, which not only is a different objective, but one that has different implications as regards the extent of data and information required for the assessment. While discussing the objectives of VA, it is also important to identify the actors whose objectives are being considered. For example, individual researchers, the IPCC, individual countries and local and regional coastal zone managers are all likely to have different objectives.

Table 2 is a first attempt at sorting through the variety of questions to which VA might provide answers, what the VA results might be used for, and the objectives behind these questions. A clear identification of the objective behind VA and the question that is being asked needs to precede the definition of vulnerability in the analysis. It is possible to use a risk assessment and management framework to obtain the appropriate definition of vulnerability corresponding to a particular objective underlying the assessment.

Defining vulnerability

In the most general sense, we can regard vulnerability as some measure of the impact of a hazard on human socio-economic systems, which suggests that we ought to explore vulnerability in the context of a framework where the hazard process can be represented, and its impacts and relationship to the characteristics of the system can be modelled. Such a general framework[22] for risk assessment and mitigation is illustrated in Figure 2. In this frame-

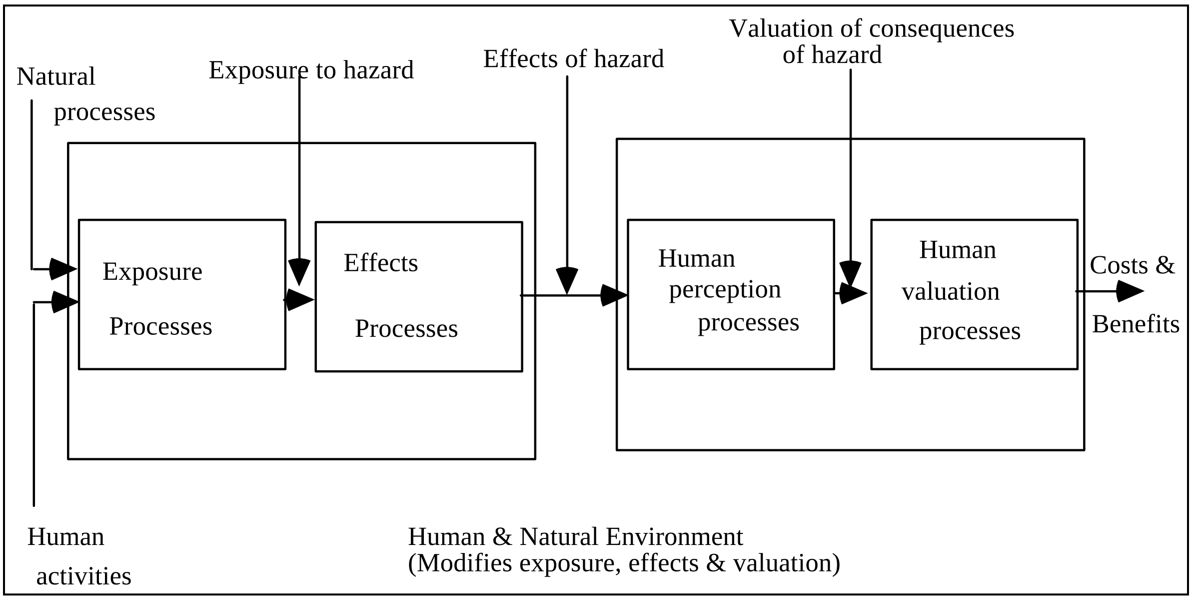

Figure 2. Exposure-effects framework[22].

Table 3. Exposure-effects framework in the context of coastal change

Process	Coastal change equivalence
Exposure	Sea level rise, change in sediment budget, change in storm statistics
Effects	Change in beach width, altered structural damage from extreme events, intrusion of salt water into a coastal aquifer. Conditioned on local geomorphology, sediment budgets and other physical characteristics
Perception and valuation	Changes in recreational benefits, property loss from extreme events, or an increase in water supply costs. These costs and benefits are conditioned on the resources at risk (amount and character of built property, population), on the existing regulatory and financial context such as availability of flood insurance, and on mitigative and adaptive policy actions

work, human economic systems are *exposed* to the possibility of change in a number of natural processes. *Effects* processes represent the changes in the human systems that can result from the changes in the natural processes. These effects are conditioned on local physical and economic factors that determine the degree of exposure. A set of *perception* and *valuation* processes determine the costs and benefits associated with the changes represented by the effects processes. Again, local legal, financial and regulatory structures serve to modify the perception and evaluation of the effects. Table 3 describes the translation of these concepts in the context of coastal change.

The risk assessment framework (Figure 2) provides a convenient route to define vulnerability in terms of the point in the framework where the impacts from the hazards are assessed. As we shall see, these definitions are also closely related to the VA questions and objectives listed in Table 2. Thus, vulnerability can be defined as:

1. The *degree of exposure* – a measure of the possible hazards to human economic systems. For example, a range of future relative sea level changes outcomes.
2. The *degree of effects* – a measure of the physical impacts caused by the hazards. For example, changes in beach width or a shift in the flood-frequency statistics for a coastal location.
3. The *degree of loss* – a measure of the change in benefits from economic goods and services caused by the hazard with respect to a base-case, do-nothing situation.
4. The *degree of least loss* – a measure of the change in benefits from economic goods and services caused by the hazard corresponding to the situation where the optimal policy response is adopted.
5. The *opportunity cost of inaction* – the difference between the loss for a do-nothing situation and a situation where the optimal policy response is considered.

Each successive definition of vulnerability in the list above includes the information and analysis requirements of the earlier definitions, together with additional inputs. For example, definition 1 requires only the specification of climate change scenarios, while definition 2 requires in addition, local information such as geomorphology and

Table 4. Qualitative relationships between the vulnerabilities for regions A and B

Case	Definition 1 (exposure)	Definition 2 (effects)	Definition 3 (loss)	Definition 4 (least loss)	Definition 5
Case 1	A ~ B	A ~ B	A > B	A > B	A < B
Case 2	A ~ B	A ~ B	A > B	A < B	A > B

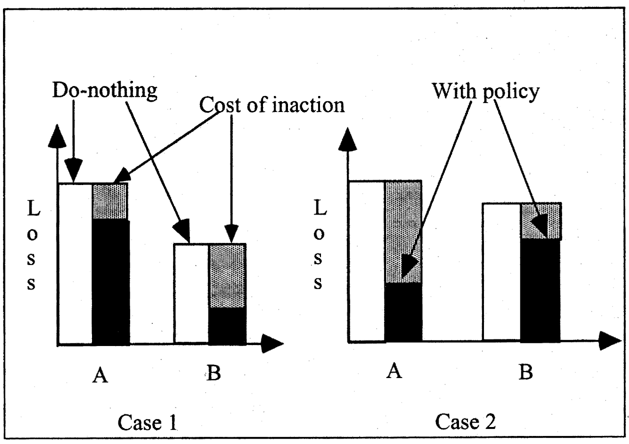

Figure 3. Loss due to sea level change for regions A and B and with and without policy responses.

sediment budgets. Definition 3 requires additional information about socio-economic characteristics such as the extent and value of property at risk from flood damage, and population density, while definitions 4 and 5 require the specification of policy options to respond to sea level change. Thus, the information requirements for a full characterization of vulnerability (as in the last definition) are quite significant, and can exceed the resources that many developing countries may be willing to commit to VA. While a number of imaginative solutions to the problems of information acquisition have been suggested, such as areal video mapping and remote sensing[23], these solutions may not be adequate for all situations.

Most impact and vulnerability studies to date have focused on definitions 1 and 2. Studies by Gornitz and co-workers provide a good example of how these definitions may be operationalized and automated using the appropriate data[24,25]. Other studies have used the coastal vulnerability index developed by Gornitz *et al*. for assessment in regions such as South Africa[26].

Vulnerability definitions in practice

In practice, the use of different vulnerability definitions is likely to lead to different conclusions. The difference between definitions 3, 4 and 5 and the dependence on the policy responses to sea level change can be described using the following hypothetical example illustrated in Figure 3. The figure plots the loss associated with two coastal regions A and B, the former assumed to be more developed than the latter, but sharing similar physical characteristics, and with and without policy responses.

Definitions 1 and 2 suggest that since A and B share similar physical characteristics, both have comparable vulnerability to sea level change. However, for the other definitions, the relative ranking is sensitive to the policy options and the possible reductions in loss that can result from the optimal policy choice. Two possible cases are illustrated. In case 1, although region A is more vulnerable in terms of the loss and net loss, the reduction in loss that is obtained by responding to sea level is much greater in region B than in A and thus there is a greater opportunity cost associated with doing nothing in region B than in A. Consequently, policy action based only on definitions 3 and 4 would lead to an inefficient situation. The situation in case 2 provides a contrasting picture, in that definitions 3 and 5 provide a similar ranking, while on the basis of net loss region B is more vulnerable. The relationship between the vulnerabilities for A and B, for the two cases and different definitions is summarized in Table 4.

Link between objectives and definitions

The link between the VA questions and objectives in Table 2 and the five vulnerability definitions is apparent from the risk assessment framework, in that the framework lays out the different elements of the problem. For example, in order to perform a preliminary impact assessment, it is sufficient to work with definitions 1 and 2 as they capture the degree of impacts. However, in order to determine the most efficient allocation of resources for abatement activities between regions, it is necessary to use definition 5, where there is an explicit comparison between the reductions in loss corresponding to the optimal policy for the different regions. Similar arguments can be used to match all the VA objectives in Table 2 to appropriate definitions. This matching is described in Table 5. Given that VA requires the commitment of substantial resources, it seems reasonable that the assessment be structured in a systematic fashion, proceeding from the objectives to vulnerability definitions.

Towards a research agenda

The previous sections have reviewed the current state of assessments of vulnerability, using examples from the coastal impacts of climate change. A number of methodological and substantive issues need to be addressed for

Table 5. Vulnerability objectives and definitions

Objective	Definition
Identifying data needs and organizing data	1 and 2 – degree of exposure and effects
Providing estimates of abatement costs and climate damages	3 – degree of loss
Determining the reduction in damages with responses	4 – degree of least loss
Determining the value of reducing key uncertainties through research	4 – degree of least loss, with uncertainty analysis
Allocating resources efficiently towards responses to sea level rise	5 – opportunity cost of inaction

further progress in understanding vulnerability and adaptive capacity. These are summarized below.

The unit of analysis

Most studies focus on the individual or the household as the unit of analysis with regard to the assessment and evaluation of impacts. When exploring vulnerability and adaptive capacity it is perhaps necessary to consider other units of analysis at different scales, for example, communities or other social and economic aggregations, as the formulation, implementation and success of a response is determined by such groups, rather than the individual or the household.

Multiple stresses and their interaction

The example of the interaction between storms and sea level rise has been discussed earlier. Such interactions are the norm rather than the exception in regional or sectoral contexts. For example, temperature extremes often play an important role in modulating the health outcomes associated with air pollution.

Valuation issues

Most estimates of the impacts of climate change value economic loss in terms of market goods and services. This approach may not capture the reality of the context in developing countries. For example, in many cases, damage to built property during tropical cyclones is not very relevant. First, the loss of output from the agricultural land may be more important, secondly, much of the stock of wealth may not be captured in the built structure, and finally, there may not be adequate market-based price information for the property.

Assessment methodology – top-down vs bottom-up approaches

Impact assessment studies have usually followed either top-down or bottom-up approaches. The former stresses consistency and comprehensiveness, while the latter emphasizes process realism and accuracy. However, a key requirement is the ability to compare and relate results from both approaches. For example, aggregation and scaling is a real concern due to heterogeneity in the physical, social and response processes.

It should be noted that this selection of issues is not exhaustive, but reflects the author's perception regarding their importance in the developing country context.

Policy issues and conclusions

In most discussions of climate change, climate policy has commonly been used to refer to mitigation policy. While mitigation is certainly important, developing countries have no obligations for mitigation under the UN Framework Convention on Climate Change. For these countries, issues of vulnerability and adaptive capacity are perhaps more germane, and it is therefore important to examine adaptation policy as a key element of overall climate policy. It is here that we often run into the first road-block of differing jurisdictions. In many countries, and India is no exception, climate policy often lies within the jurisdiction of the Environment Ministry, as the issue is framed in terms of response to an environmental problem. On the other hand, adaptation is linked to core developmental issues, whether with regard to infrastructure or institutions or sectors such as water resources, agriculture or health. These sectors are generally the responsibility of different agencies and ministries within the government. Therefore, perhaps one of the first steps to increase the visibility of climate policy would be to frame the issue of climate policy in terms of developmental priorities and policies.

The assessment of vulnerability in the context of extreme climate events and historical climate variability is another important avenue for engaging the policy community. A focus on climate variability automatically brings to the fore the way in which socio-economic systems become vulnerable to climate hazards. At the same time, this analysis provides insights that are relevant immediately, as we have to deal with extreme climate events well before the full range of consequences of mean changes in the climate state become apparent. Also, response to extreme climate events is often within the jurisdiction of state and local governments. As a result, this focus allows one to engage policy-makers that are typically not a part of the global climate policy process.

Finally, improved understanding of vulnerability and adaptive capacity is essential for identifying and realizing the full benefits of developmental projects, and in ensuring that such projects, particularly infrastructure projects, do not lead to maladaptation with regard to future climate change.

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