Applications of Risk Assessment in the Development of Climate Change Adaptation Policy

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Abstract

The consequences of climate change will affect both natural systems and human populations. Adaptation policies that provide mitigation against these effects require the collaboration of natural and socio-economic sciences to assess future risks of climate change. Future impacts and the vulnerability of the impacted system are used to perform risk assessments allowing decision-makers to select optimal adaptation choices given available knowledge. Under climate change, however, future risk assessments are based on a number of possible climate scenarios. This multiplicity results in more than one assessment of risk with large uncertainty bounds. Present applications of risk assessment for climate change adaptation have taken two main approaches. The main difference between these approaches is in the presentation of the final risk either as cumulative probability distributions of threshold exceedance or as a number of risk assessments assigned to different plausible futures. Different adaptation scenarios or policies are then evaluated in terms of their effectiveness in reducing risk. This paper presents an analysis of applications of both approaches of risk assessment from recent literature for climatic effects such as sea-level rise. The analysis provides an evaluation of the strengths and weaknesses of present climate change risk assessment methods in terms of providing useful information to support decision-making at relevant spatial and temporal scales, and the ability of each method to direct policy-development by providing the best representation of future uncertainties given policy objectives. This analysis sheds light on the utility of climate change risk assessment methods as a function of information availability and policy scope, thereby providing the necessary factors that decision-makers should consider when a choosing an approach for adaptation policy development.

1. Introduction

The intensity of the changes to the earth's climate caused by anthropogenic emissions of greenhouse gases are expected to vary between different regions of the world. Climate change is expected to cause damage to both human and natural systems, thereby requiring adaptation planning to prevent or reduce the associated adverse effects. Providing decision-makers with climate change information relevant to policy and planning presents a challenge to researchers due to the large uncertainty associated with modeling future social and economic development, the associated climate reactions, and the resulting effects on human and natural systems. Handling this high uncertainty resulted in a number of policy development approaches that can be integrated, and used separately or concurrently to direct adaptation planning and policy development (Dessai and Hulme 2004). The basic idea behind these methods is to handle the high uncertainty associated with the projected impacts of climate change by increasing the robustness, resilience, and adaptive capacity of the analyzed system instead of focusing on a cost-benefit or risk analysis. Although these methods provide reasonable information and objectives for policy development, recent guidelines proposed by developed countries and international organizations reinforce the fact that a focused adaptation investment requires an assessment of risk. This fact is also clear in recent adaptation policy literature that indicates a move towards a risk-management approach because of its advantages in providing a representation of uncertainty and ease of integrating climate change with existing policies.

Despite the interest expressed by various governments in adapting to climate change, the high uncertainty associated with risk assessment and the perceived limited relevance of the produced information to policy applications limit investment in adaptation (Dessai 2005). Attempting to eliminate or reduce these limitations coupled with the move towards a risk-management approach motivated a number of risk assessments and a large number of risk related studies in recent literature. Understanding the strengths and weaknesses or risk assessments in guiding policy development and decision making requires an analysis of recent developments in the context of previous limitations. This paper assesses recent risk research and applications in terms of its effectiveness at directing policy and decision-making. For this purpose, information that is relevant to policy development is defined through the review of a number of workshop and survey studies identifying the requirements of decision-makers. This review is followed by an evaluation of developments of risk applications under each requirement and finally a discussion of the strengths and weaknesses of present risk assessment methods in directing policy development.

2. Current adaptation policies

Assessing the value of risk assessment information in guiding climate change adaptation policies starts with analyzing the motivations for performing risk assessments in the context of current adaptation strategies. Presently, adaptation strategies to climate change impacts are taking different directions in developed and developing countries. Developed countries, such as the United Kingdom, Norway and Canada, are attempting to integrate adaptation to climate change within regular planning and management of sector policies (water, agriculture and forestry, coastal defense, etc.). A main objective of this integration is to facilitate adaptation of climate sensitive sectors and prevent maladaptation due to existing policies or regulations within or outside the sector. Integration within the sector requires analyzing climate change impacts as a factor among other stressors acting on an environmental or social system, thus requiring a unified framework to analyze comparative risks. Furthermore, integrating climate change policies requires a method for handling the large uncertainties associated with climate change impact projections in a probabilistic framework. For these two reasons, developed countries are moving towards a risk-management approach in the development of adaptation policies. A recent example is presented in Yohe (2006), who points to the inadequacy of cost-benefit analysis for policy selection under high uncertainty, and recommends a risk-management approach that manages risk through selection from a portfolio of policies. This direction is further demonstrated by the next round of United Kingdom climate impacts scenarios, which "support[s] probabilistic projections and risk-based assessments" (Wilby et al. 2006).

On the other hand, adaptation programs such as the United Nations Development Program Adaptation Policy Framework (UNDP-APF) (Lim and Spanger-Siegfried 2005), which are targeted at developing countries, aim to establish specific adaptation projects or policies to motivate developing countries to perform vulnerability assessments, establish measures to reduce this vulnerability, and increase the adaptive capacity and resilience of communities to climatic impacts. More importantly, the urgent requirement for developing countries is to increase their present adaptive capacity. This is demonstrated by the UNDP-APF emphasis on establishing good policies and adaptive capacity to handle present climate variability risks before adapting to future climate change impacts. Under this situation, the current use of risk assessment methods in developing countries requires lower analysis complexity and limited use of future climate scenarios.

Beyond current climate change strategy directions, the application of adaptation measures is still in its early stages, with limited investment in adaptation (Dessai 2005). Reasons contributing to this "delay and inaction" (Dessai 2005) are high scientific uncertainty associated with projected climate change impacts and limited communication between scientists and decision-makers to convey the policy-relevant information. These reasons further affect cultural and socio-economical factors, such as risk perception, that play a role in building political interest in climate change adaptation. Clear scientific information can greatly motivate both society and policy makers to act and implement adaptation measures.

To overcome these obstacles, developed countries are focusing large efforts towards providing adequate scientific data to support climate change adaptation policies, to motivate decision-makers to participate in climate change science formation, and to raise awareness. For example, the United Kingdom Climate Impacts Program (UKCIP) and the United Kingdom Environmental Agency (EA) are providing the tools and regulations to help organizations and stakeholders include climate change risks in their planning and management practices (Dessai 2005). In addition, multiple European Union programs are directed towards improving future climate change impacts and risk projections, such as PRUDENCE (http://prudence.dmi.dk/), ENSEMBLES (http://www.ensembles-eu.org/) and CRANIUM (http://www.ncl.ac.uk/cranium/).

3. Climate change risk assessments

As explained in section 2, research into, and applications of, risk assessment for future climate change are mostly motivated by developed countries moving towards a risk-management approach to climate change adaptation. Consequently, risk and impact assessment studies in recent literature are mostly performed in developed countries through research and environmental institutions as part of a general objective of improving the climate change science to meet policy information needs. Examples of such studies include assessments performed in the United Kingdom (Hall et al. 2006; Holman et al. 2005; Wilby et al. 2006) and in the United States (Payne et al. 2004; Tanaka et al. 2006). Therefore, the following analysis focuses on risk and impact assessments for governments and institutions engaged in strengthening the adaptation of sectors that are sensitive to climate variability (e.g. agriculture, water resources, coastal defense) against future impacts of climate change. The objectives of this analysis are to 1) introduce risk assessment methods as defined by the UNDP-APF (Lim and Spanger-Siegfried 2005), 2) list the main limitations of present risk assessment methods according to decision-makers surveys and workshops, and 3) preview recent steps taken toward meeting these needs and improving estimates of climate impacts.

3.1. Risk assessment definition and methods

The UKCIP defines climate change risk assessment as “any impact assessment that includes consideration of the probability or uncertainty associated with the consequences of climate variability or climate change” (Willows and Connell 2003). Methods used to calculate climate change risk are classified according to the UNDP-APF as hazard-based and vulnerability-based methods. Hazard-based methods calculate the climate change risk for a given system as the probability of a certain climate hazard multiplied by the system’s vulnerability (a function of space and time). This method requires good knowledge of the analyzed system to set future climate hazards and associated vulnerability. Using different climate scenarios, the probability of the set hazard is calculated and risk is obtained by multiplying by the associated vulnerability. Vulnerability-based methods, on the other hand, define risk as the probability of exceeding one or more criteria of vulnerability. These criteria are set by stakeholders and represent the limits beyond which the system will suffer damages. The risk is then calculated by modeling the impacts of various climate scenarios on the analyzed system to construct cumulative distribution functions of vulnerability variables on which thresholds are applied. A large number of impact assessments have been performed recently, which are classified as risk assessments according to the UKCIP definition and represent a main step in calculating risk according to the UNDP-APF vulnerability-based method.

3.2. Climate change risk assessment structure

Recent climate change risk assessment studies have a common structure with differences mostly in the methods or models used to assess impact. The structure of assessment studies consists of four stages: (i) Using scenarios to represent future climate (mostly based on the latest IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic and Swart 2000) and modeling global climate response using

General Circulation Models (GCMs)), (ii) generating regional climate scenarios using downscaling methods, and (iii) simulating the impacts of future downscaled regional climate through process models, such as models that simulate river flow or catchments hydrology. Differences between studies are mostly limited to the number of emission scenarios, GCMs and downscaling methods used to represent the range of uncertainty in projected regional climate scenarios. On the contrary, the final step of estimating impacts show a higher level of diversity in the methods applied to estimate impacts, in the level of integration of different systems, and in the representation of the effect of future adaptation on estimated impacts.

3.3. Limitations and developments in risk and impact assessments

Three recent studies (Hanson et al. 2006; Morss et al. 2005; Power et al. 2005) provide an analysis of workshops and surveys held by stakeholder and decision-makers . Hanson et al. (2006), provide an analysis of the requirements of stakeholders in a number of sectors including agriculture, water, forestry and insurance. This analysis identified general and sector-specific requirements that can be classified from a risk analysis point of view into a number of main requirements, as presented in the following subsections. Morss et al. (2005) and Power et al. (2005) report on additional stakeholder studies. The major requirements of decision-makers and stakeholders in these studies can also be classified according to the topics presented in this section. One of the major concerns of decision-makers is having an assessment of possible impacts of climate change on a relevant sector with consistent uncertainty quantification. Managers in climate-sensitive sectors are also interested in transparency of methodology and the types of uncertainty analyzed, with the possibility of providing simple and computationally inexpensive tools through which they can conduct climate impacts analysis in support of management decisions (Holman et al. 2005).

3.3.1. Analysis at relevant spatial and temporal scales

Various downscaling techniques are available to obtain higher spatial and temporal resolutions of climate variables. These techniques include statistical downscaling methods, dynamical downscaling (Regional Circulation Models (RCMs)) or pattern scaling techniques(Lim and Spanger-Siegfried 2005; Mitchell 2003; Willows and Connell 2003). From a decision-making point of view, present downscaling techniques allow for more relevant risk assessment information, especially for managing sectors such as flooding control and agriculture, which require high spatial detail. However, downscaling expands the uncertainty associated with risk assessments and this type of uncertainty is not quantified beyond using a number of downscaling methods for comparison.

3.3.2. Improve uncertainty representation

The uncertainty associated with projected climate change risks for a given system has different types. These types are classified in Dessai and Hulme (2004) as epistemic, natural stochastic and human reflexive. Epistemic and natural stochastic uncertainties can be represented by probability distributions. Improving this representation depends on the availability of data, computational power and degree of knowledge. Epistemic uncertainty is mostly associated with the use of models such as simulating the climatic response to increased GHG concentrations using GCMs, downscaling climatic variables using different downscaling techniques and projecting climate effects using impact models. Human reflexive uncertainties are represented by scenarios. This includes future emissions of greenhouse gases, future socio-economical conditions and future adaptation to climate change. Better representation of this type of uncertainty requires larger number of scenarios. Wilby and Harris (2006) present a recent example of a probabilistic representation of the uncertainty associated with climate change impacts applied to low river flows. In this study, uncertainty of future GHG emissions was represented using two emission scenarios, and the epistemic uncertainties of GCMs, downscaling and impact model were represented using four GCMs, two downscaling techniques and two impact (hydrological) models. Finally, the natural stochastic uncertainty was represented using two sets of impact model parameters. Cumulative distribution functions of changes in the river's low flows were constructed using Monte Carlo analysis. Different weights were assigned to the GCMs according to their skill in reproducing important impact variables and to the hydrological models according to their adjusted correlation coefficients. Other components were given equal weights.

Currently, the representation of uncertainty for guiding decision-making faces a number of challenges. First, most studies quantify a limited number of the types of uncertainties listed above, and, even in the most comprehensive studies, certain simplifications had to be made to reduce the number of simulations. Second, providing a probabilistic representation of the uncertainty as presented in Wilby and Harris (2006) is not the norm in climate change risk and impact studies. Instead, the uncertainty in impact is usually presented as a number or risk assessments that reflect different models or scenarios (Hall et al. 2006). To further complicate the problem, other policy and decision-making requirements may increase uncertainty sources, thus reducing the ability to include all types of uncertainty. In such situations, it is important to include the uncertainty of the most important parameters affecting the final probability of climate hazard or risk. The choice of the level and type of detail included in a risk assessment should be driven both by scientific experts and by decision-makers, because more specific information is usually associated with higher uncertainty.

3.3.3. Integrating relevant natural and socio-economical systems and stressors

Climate change impacts do not occur in isolation of other environmental stressors that evolve with time and are mostly affected by climate. A main concern expressed by decision-makers in the reviewed studies was the ability to integrate climate change risks with other stressor risks normally considered in their decisions. Integration tries to simulate the cumulative effect of multiple stressors and interrelated systems to provide a more informative and realistic representation of possible impacts. Recent studies attempt to achieve these objectives by using scenarios (Hall et al. 2006; Holman et al. 2005) and/or models of related systems (Wilby et al. 2006).

3.3.4. Analysis of alternative adaptation policies

An important type of information needed by decision-makers is the effectiveness of specific policies in mitigating the impacts of climate change. Such analysis is usually performed by modeling the sector using different regional climate scenarios and different adaptation measures or policies (Hall et al. 2006; Tanaka et al. 2006). Two main points should be emphasized that recent literature is attempting to address. First, such analysis requires a high level of integration because possible changes will not affect the modeled system in isolation of all other stressors; therefore, in situations where the controlled parameter is highly sensitive to inputs from other systems (e.g. biodiversity) and results from a low level of integration, risk assessments should be handled with care. Second, present estimates and future projections of the impacted systems' resilience and adaptive capacity should be included when testing adaptation policies, although this is partly explored by using different socio-economical scenarios.

3.3.5. Communication with stakeholders

Communication with stakeholders and decision-makers is important in defining the risk assessment problem and promoting the use of climate change information. The type of information identified through stakeholders determines the appropriate risk analysis method and level of detail. The guidelines of both UKCIP and UNDP-APF recognize the importance of this requirement for shaping adaptation policy scope and methods, and determining critical thresholds. The recognition of the value of stakeholder involvement is also demonstrated in climate change impacts projects such as the Regional Climate Change Impact and Response Studies in East Anglia and North West England (RegIS) (Holman et al. 2005). Throughout this project, a high level of communication with stakeholders was maintained to shape and direct the scientific efforts in estimating climate change impacts on the analyzed regions and systems (e.g. Agriculture, biodiversity, coasts and floodplains and water resources).

4. Adaptation policy development

Recent studies discussed in the previous section demonstrate the ability of current risk assessment methods to provide relevant information to guide policy development. However, these studies also reveal a number of limitations that require further research and development. At present, risk assessments provide a framework to probabilistically represent the high uncertainty of future impacts. Furthermore, the flexibility in forming risk assessment analysis and the hierarchy of detail to analyze a problem provide the opportunity to formulate the risk analysis according to the requirements of decision-makers, available information, and technical capacity. From this perspective, present climate change risk assessment methods provide policy makers with comparisons of risks due to different stressors affecting a system, a quantification of the associated range of uncertainty, and the ability to use available information about the analyzed system through flexibility in formulating the impacts functions. Furthermore, present research is directed towards solving some of the scientific problems in representing future climate impacts on scales relevant to policy makers and in representing the associated uncertainty. Present research also shows a large effort from developed countries, such as the United Kingdom and the United States, to involve stakeholders to produce policy relevant information. Despite these large efforts and advancements in risk assessment methods, a number of limitations and difficulties remain, as presented in the following sections.

a) High level of uncertainty

The level of uncertainty in projected climate change risks is not expected to decrease in the short-term (Dessai 2005), and a number of factors further complicate this problem. First, meeting stakeholders' requirements of higher spatial resolution and more systems integration adds to the uncertainty associated with projected impacts. Second, short-term planning and management of climate-sensitive sectors requires examining the effects of climate change on time horizons of 5 to 20 years. At such small time scales, the effects of climate change are generally less important relative to other factors (Dessai 2005). Furthermore, the climate change signal is sometimes undetectable from the general natural variability of the climatic parameter (Prudhomme et al. 2003). Such conditions can be an obstacle to the implementation of adaptation policies in the near future, and may project a general perception that climate change risks are not an urgent risk to be accounted for. Taking into consideration extreme events (Willows and Connell 2003) and the possibility of surprises in the climate system can provide better motivation for, and more awareness of, the climate change problem. Third, the quantification of the true impact of climate change and its contributing factors depends on the ability to separate the climate change signal from other environmental and socio-economical factors affecting trends in climate variables or related events. This separation is important for understanding the processes affecting climate change and in improving risk perception. For example, Prudeholmme et al. (2003) explained that "there is evidence of an increase in the frequency and magnitude of high flow in the last 30–50 years in rivers in the UK, although those trends cannot be separated from those due to natural climate variability." They then explained that the problem is further complicated when examining fluvial flooding trends because of factors such as land use, reservoirs, drainage and flood alleviation schemes.

b) Stakeholder communication and management tools

One of the requirements that has received the most emphasis is the need for simple and fast tools to characterize risks associated with climate change. Such tools would allow decision makers to integrate climate change effects into their regular management practices in their respective fields. Morss et al. (2005), suggests an end-to-end approach of iterative communication between scientists and decision-makers to refine these tools and ensure their usability. Present risk research, however, does not show a strong move in this direction. An exception is the next stage of the RegIS project (Holman et al. 2005), which will focus on developing practical tools for decision-makers that provide a balance between scientific complexity and practical implementation.

c) Choice of policy development approach

Dessai and Hulme (2004) classify the approaches used in adaptation policy development as biophysical and socio-economical. Present risk-management approaches fall under the first type. The second type, however, is concerned with improving socio-economical conditions reflected in concepts such as adaptive capacity and resilience. Dessai and Hulme (2004) continue to note that more than one approach can be used to develop adaptation policies capable of handling large ranges of uncertainties. Strengths and weaknesses of current climate change risk assessment methods emphasize the need for including more that one approach in designing adaptation policy. More specifically, one of the present limitations of risk assessment applications is the lack of representation of the effect of the resilience of natural and social systems and their coping ranges on estimating the impacts of climatic hazards. Therefore, the importance of preserving or improving these characteristics in natural and social systems might be overlooked in policy development. Including a resilience objective in adaptation development will also provide more robustness in handling the large uncertainties associated with risk assessments. Other approaches, such as the robustness approach (Lempert et al. 2006), are advocated for designing policies that are capable of adapting to a wide range of possible impacts instead of adapting based on a particular probabilistic risk assessment. This approach can account for wide and unquantifiable uncertainties, such as future emission scenarios.

5. Conclusions

The value of risk assessment in the development of climate change adaptation policy is well recognized in current guidelines of developed countries and international organizations. Large developments have been accomplished through risk and impact assessment research to produce methods that are capable of providing information at spatial and temporal scales that are relevant to policy development, with a representation of the associated uncertainty. However, the ability to focus this research to produce risk assessment information that can be easily integrated into current policy and management practices presents a number of challenges. One main challenge is the ability to provide tools that both answer the policy or planning questions and reflect socio-economical as well as biophysical projections and impacts. Communication with stakeholders is a key requirement in the development of these tools to ensure usability and ease of integration. Another challenge is extending the present research to the anticipated problems associated with actual risk applications. This includes communicating various types of uncertainty to decision-makers and defining the risk problem through variables and indicators that reflect policy objectives and available information about the analyzed system. Recognition of these challenges is motivating ongoing research such as the RegIS project (Holman et al. 2005). However, more effort is required in this area to motivate adaptation to the effects of climate change.

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