Summary for Policymakers: The Economic and Social Dimensions of Climate Change -IPCC Working Group III

Contents

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1. Introduction

Working Group III of the Intergovernmental Panel on Climate Change (IPCC) was restructured in November 1992 and charged with conducting "technical assessments of the socioeconomics of impacts, adaptation and mitigation of climate change over both the short and long term and at the regional and global levels". Working Group III responded to this charge by further stipulating in its work plan that it would place the socioeconomic perspectives in the context of sustainable development and, in accordance with the UN Framework Convention on Climate Change (UNFCCC), provide comprehensive treatment of both mitigation and adaptation options while covering all economic sectors and all relevant sources of greenhouse gases and sinks.

This report assesses a large part of the existing literature on the socioeconomics of climate change and identifies areas in which a consensus has emerged on key issues and areas where differences exist[1]. The chapters have been arranged so that they cover several key issues. First, frameworks for socioeconomic assessment of costs and benefits of action and inaction are described. Particular attention is given to the applicability of costbenefit analysis, the incorporation of equity and social considerations, and consideration of intergenerational equity issues. Second, the economic and social benefits of limiting greenhouse gas emissions and enhancing sinks are reviewed. Third, the economic, social and environmental costs of mitigating greenhouse gas emissions are assessed. Next, generic mitigation and adaptation response options are reviewed, methods for assessing the costs and effectiveness of different response options are summarized, and integrated assessment techniques are discussed. Finally, the report provides an economic assessment of policy instruments to combat climate change.

In accordance with the approved work plan, this assessment of the socioeconomic literature related to climate change focuses on economic studies; material from other social sciences is found mostly in the chapter on equity and social considerations. The report is an assessment of the state of knowledge - what we know and do not know - and not a prescription for policy implementation. Countries can use the information in this report to help take decisions they believe are most appropriate for their specific circumstances.

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2. Scope of the assessment

Climate change presents the decision maker with a set of formidable complications: a considerable number of remaining uncertainties (which are inherent in the complexity of the problem), the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, wide regional variation in causes and effects, the irreducibly global scope of the problem, and the need to consider multiple greenhouse gases and aerosols. Yet another complication arises from the fact that effective protection of the climate system requires global cooperation.

Still, a number of insights that may be useful to policymakers can be drawn from the literature:

- Analyses indicate that a prudent way to deal with climate change is through a portfolio of actions aimed at mitigation, adaptation and improvement of knowledge. The appropriate portfolio will differ for each country. The challenge is not to find the best policy today for the next 100 years, but to select a prudent strategy and to adjust it over time in the light of new information.
- Earlier mitigation action may increase flexibility in moving toward stabilization of atmospheric concentrations of greenhouse gases (UN Framework Convention on Climate Change, Article 2). The choice of abatement paths involves balancing the economic risks of rapid abatement now (that premature capital stock retirement will later be proved unnecessary) against the corresponding risk of delay (that more rapid reduction will then be required, necessitating premature retirement of future capital stock).
- The literature indicates that significant "noregrets" [2] opportunities are available in most countries and that the
  risk of aggregate net damage due to climate change, consideration of risk aversion, and application of the precautionary principle provide rationales for action beyond no regrets.
- The value of better information about climate change processes and impacts and society's responses to them is likely to be great. In particular, the literature accords high value to information about climate sensitivity to greenhouse gases and aerosols, climate change damage functions, and variables such as determinants of economic growth and rates of energy efficiency improvements. Better information about the costs and benefits of mitigation and adaptation measures and how they might change in coming decades also has a high value.
- Analysis of economic and social issues related to climate change, especially in developing countries where little work of this nature has been carried out, is a high priority for research. More generally, research is needed on integrated assessment and analysis of decisionmaking related to climate change. Further, research advancing the economic understanding of non-linearities and new theories of economic growth is also needed. Research and development related to energy efficiency technologies and nonfossil energy options also offer high potential value. In addition, there is also a need for research on the development of sustainable consumption patterns.

A portfolio of possible actions that policymakers could consider, in accordance with applicable international agreements, to implement lowcost and/or costeffective measures to reduce emissions of greenhouse gases and adapt to climate change can include:

- Implementing energy efficiency measures, including the removal of institutional barriers to energy efficiency improvements;
- Phasing out existing distortionary policies and practices that increase greenhouse gas emissions, such as some subsidies and regulations, noninternalization of environmental costs and distortions in transport pricing;
- Implementing costeffective fuel switching measures from more to less carbonintensive fuels and to carbonfree fuels such as renewables;
- Implementing measures to enhance sinks or reservoirs of greenhouse gases, such as improving forest management and land use practices;
- Implementing measures and developing new techniques for reducing methane, nitrous oxide and other greenhouse gas emissions;
- Encouraging forms of international cooperation to limit greenhouse gas emissions, such as implementing coordinated carbon/energy taxes, activities implemented jointly and tradable quotas;

- Promoting the development and implementation of national and international energy efficiency standards;
- Promoting voluntary actions to reduce greenhouse gas emissions;
- Promoting education and training, implementing information and advisory measures for sustainable development and consumption patterns that will facilitate climate change mitigation and adaptation;
- Planning and implementing measures to adapt to the consequences of climate change;
- Undertaking research aimed at better understanding of the causes and impacts of climate change and facilitating more effective adaptation to it;
- Conducting technological research aimed at minimizing emissions of greenhouse gases from continued use of fossil fuels and developing commercial nonfossil energy sources;
- Developing improved institutional mechanisms, such as improved insurance arrangements, to share the risks of damages due to climate change.
- Contribution of economics
- Estimates of the costs and benefits of stabilizing greenhouse gas concentrations are sensitive, inter alia, to the ultimate target concentration, the emissions path toward this level, the discount rate, and assumptions concerning the costs and availability of technologies and practices.
- Despite its widespread use in economic policy evaluation, Gross Domestic Product is widely recognized to be an imperfect measure of society's wellbeing, largely because it fails to account for degradation of the environment and natural systems. Other methodologies exist that try to take these nonmarket values and social and ecological sustainability into account. Such methodologies would provide a more complete indication of how climate change might affect society's wellbeing.
- Given the interrelated nature of the global economic system, attempts to mitigate climate change through actions in one region or sector may have offsetting economic effects that risk increasing the emissions of other regions and sectors (socalled leakages). These emission leakages can be lessened through coordinated actions of groups of countries.
- The literature suggests that flexible, costeffective policies relying on economic incentives and instruments, as well as coordinated instruments, can considerably reduce mitigation or adaptation costs or increase the costeffectiveness of emission reduction measures.

Equity considerations

In considering equity principles and issues related to greenhouse gas emissions, it is important for policy consideration to take into account in particular Articles 3, 4.2a and 11.2 of the UN Framework Convention on Climate Change, Principle 2 of the Rio Declaration and general principles of international law.

Scientific analyses cannot prescribe how equity should be applied in implementing the UN Framework Convention on Climate Change, but analysis can clarify the implications of alternative choices and their ethical basis.

- Developing countries require support for institutional and endogenous capacity building, so that they may effectively participate in climate change decisionmaking.
- It is important that both efficiency and equity concerns be considered during the analysis of mitigation and adaptation measures. For the purposes of analysis, it is possible to separate efficiency from equity. This analytical separation presupposes that (and is valid, for policy purposes, only if) effective institutions exist or can be created for appropriate redistribution of climate change costs. It may be worthwhile to conduct analyses of the equity implications of particular measures for achieving efficiency, including their social considerations and impacts.

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3. Decisionmaking frameworks for addressing Climate Change

Since climate change is a global issue, comprehensive analyses of mitigation, adaptation and research measures are needed to identify the most efficient and appropriate strategy to address climate change. International decision-making related to climate change, as established by the UNFCCC, is a collective process in which a variety of concerns such as equity, ecological protection, economics, ethics and poverty-related issues, are of special significance for present and future generations. Treatments of decision-making under uncertainty, risk aversion, technology development and diffusion processes, and distributional considerations are at present relatively poorly developed in international environmental economics, and especially in the climate change literature.

Decision-making related to climate change must take into account the unique characteristics of the "problem": large uncertainties (scientific and economic), possible non-linearities and irreversibilities, asymmetric distribution of impacts geographically and temporally, the very long time horizon, and the global nature of climate change with the associated potential for free riding. Beyond scientific uncertainties (discussed in the volume on the science of climate change of the IPCC Second Assessment Report (SAR)) and impact uncertainties (the volume on the scientifictechnical analyses of impacts, adaptations and mitigation of climate change of the IPCC Second Assessment Report (SAR)), socioeconomic uncertainties relate to estimates of how these changes will affect human society (including direct economic and broader welfare impacts) and to the socioeconomic implications of emission abatement.

The other dimension that magnifies uncertainties and complicates decisionmaking is geographical: climate change is a global problem encompassing an incredibly diverse mix of human societies, with differing histories, circumstances and capabilities. Many developing countries are in relatively hot climates, depend more heavily on agriculture, and have less well developed infrastructure and social structures; thus, they may suffer more than average, perhaps much more. In developed countries, there may also be large climate change impacts.

The literature also emphasizes that delaying responses is itself a decision involving costs. Some studies suggest that the cost of delay is small; others emphasize that the costs could include imposition of risks on all parties (particularly the most vulnerable), greater utilization of limited atmospheric capacity and potential deferral of desirable technical development. No consensus is reflected in the literature.

The global nature of the problem - necessitating collective action by sovereign states - and the large differences in the circumstances of different parties raise consequential as well as procedural issues. Consequential issues relate to outcomes while procedural issues relate to how decisions are made. In relation to climate change, the existence of an agreed legal framework involves a collective process within a negotiated framework (the UNFCCC). Accordingly, decisionmaking can be considered within three different categories of frameworks, each with different implications and with distinct foci: global optimization (trying to find the globally optimal result), procedural decisionmaking (establishing and refining rules of procedure) and collective decisionmaking (dealing with distributional issues and processes involving the interaction of numerous independent decision makers).

Application of the literature on decisionmaking to climate change provides elements that can be used in building collective and/or marketoriented strategies for sharing risks and realizing mutual benefits. It suggests that actions be sequential (temporally distributed), that countries implement a portfolio of mitigation, adaptation and research measures, and that they adjust this portfolio continuously in response to new knowledge. The potential for transfers of financial resources and technology to developing countries may be considered as a part of any comprehensive analytical framework.

Elements of a marketrelated strategy concern insurance and markets for risk. Pooling risk does not change the risk, but it can improve economic efficiency and welfare. Although insurance capable of sharing climate change risks on a global basis currently does not exist, one of the important potential gains from cooperating in a collective framework, such as the UN Framework Convention on Climate Change, is that of risk sharing. Creating an insurance system to cover the risks of climate change is difficult[3] and the international community has not yet established such sophisticated instruments. This, however, does not preclude future international action to establish insurance markets sufficient for some international needs.

4. Equity and social considerations

Equity considerations are an important aspect of climate change policy and of the Convention. In common language equity means "the quality of being impartial" or "something that is fair and just". The UNFCCC, including the references to equity and equitable in Articles 3.1, 4.2.a and 11.2, provides the context for efforts to apply equity in meeting the purposes and the objective of the Convention. International law, including relevant decisions of the International Court of Justice, may also provide guidance.

A variety of ethical principles, including the importance of meeting people's basic needs, may be relevant to addressing climate change, but the application to relations among states of principles originally developed to guide individual behaviour is complex and not straightforward. Climate change policies should not aggravate existing disparities between one region and another nor attempt to redress all equity issues.

Equity involves procedural as well as consequential issues. Procedural issues relate to how decisions are made while consequential issues relate to outcomes. To be effective and to promote cooperation, agreements must be regarded as legitimate, and equity is an important element in gaining legitimacy.

Procedural equity encompasses process and participation issues. It requires that all parties be able to participate effectively in international negotiations related to climate change. Appropriate measures to enable developing country parties to participate effectively in negotiations increase the prospects for achieving effective, lasting and equitable agreements on how best to address the threat of climate change. Concern about equity and social impacts points to the need to build endogenous capabilities and strengthen institutional capacities, particularly in developing countries, to make and implement collective decisions in a legitimate and equitable manner.

Consequential equity has two components: the distribution of the costs of damages or adaptation and of measures to mitigate climate change. Because countries differ substantially in vulnerability, wealth, capacity, resource endowments and other factors listed below, the costs of the damages, adaptation and mitigation may be borne inequitably, unless the distribution of these costs is addressed explicitly.

Climate change is likely to impose costs on future generations and on regions where damages occur, including regions with low greenhouse gas emissions. Climate change impacts will be distributed unevenly.

The Convention recognizes in Article 3.1 the principle of common but differentiated responsibilities and respective capabilities. Actions beyond "noregrets" measures impose costs on the present generation. Mitigation policies unavoidably raise issues about how to share the costs. The initial emission limitation intentions of Annex I parties represent an agreed collective first step of those parties in addressing climate change.

Equity arguments can support a variety of proposals to distribute mitigation costs. Most of them seem to cluster around two main approaches: equal per capita emission allocations and allocations based on incremental departures from national baseline emissions (current or projected). Some proposals combine these approaches in an effort to incorporate equity concerns not addressed by relying exclusively on one or the other approach. The IPCC can clarify scientifically the implications of different approaches and proposals, but the choice of particular proposals is a policy judgment.

There are substantial variations both among developed and developing countries that are relevant to the application of equity principles to mitigation. These include variations in historical and cumulative emissions, current total and per capita emissions, emission intensities and economic output, and factors such as wealth, energy structures and resource endowments. The literature is weak on the equity implications of these variations both among developed and developing countries.

In addition, the implications of climate change for developing countries are different from those for developed countries. The former often have different urgent priorities, weaker institutions, and are generally more vulnerable to climate change. However, it is likely that developing countries' share of emissions will grow further to meet their social and developmental needs. Greenhouse gas emissions are likely to become increasingly global, even whilst substantial per capita disparities are likely to remain.

It is important that both efficiency and equity concerns should be considered during the analysis of mitigation and adaptation measures. It may be worthwhile to conduct analyses of the equity implications of particular measures for achieving efficiency, including their social considerations and impacts.

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5. Intertemporal equity and discounting

Climate policy, like many other policy issues, raises particular questions of equity among generations, because future generations are not able to influence directly the policies being chosen today that could affect their wellbeing and because it might not be possible to compensate future generations for consequent reductions in their wellbeing.

Sustainable development is one approach to intergenerational equity. Sustainable development meets "the needs of the present without compromising the ability of future generations to meet their own needs".[4] A consensus exists among economists that this does not imply that future generations should inherit a world with at least as much of every resource. Nevertheless, sustainable development would require that use of exhaustible natural resources and environmental degradation are appropriately offset - for example, by an increase in productive assets sufficient to enable future generations to obtain at least the same standard of living as those alive today. There are different views in the literature on the extent to which infrastructure and knowledge, on the one hand, and natural resources, such as a healthy environment, on the other hand, are substitutes. This is crucial to applying these concepts. Some analysts stress that there are exhaustible resources that are unique and cannot be substituted for. Others believe that current generations can compensate future generations for decreases in the quality or quantity of environmental resources by increases in other resources.

Discounting is the principal analytical tool economists use to compare economic effects that occur at different points in time. The choice of discount rate is of crucial technical importance for analyses of climate change policy, because the time horizon is extremely long, and mitigation costs tend to come much earlier than the benefits of avoided damages. The higher the discount rate, the less future benefits and the more current costs matter in the analysis.

Selection of a social discount rate is also a question of values since it inherently relates the costs of present measures, to possible damages suffered by future generations if no action is taken.[5] How best to choose a discount rate is, and will likely remain, an unresolved question in economics. Partly as a consequence, different discount rates are used in different countries. Analysts typically conduct sensitivity studies using various discount rates. It should also be recognized that the social discount rate presupposes that all effects are transformed to their equivalent in consumption. This makes it difficult to apply to those nonmarket impacts of climate change which for ethical reasons might not be, or for practical reasons cannot be, converted into consumption units.

The literature on the appropriate social discount rate for climate change analysis can be grouped into two broad categories. One approach discounts consumption by different generations using the "social rate of time preference," which is the sum of the rate of "pure time preference" (impatience) and the rate of increase of welfare derived from higher per capita incomes in the future. Depending upon the values taken for the different parameters, the discount rate tends to fall between 0.5% and 3.0% per year on a global basis - using this approach. However, wide variations in regional discount rates exist, but these may still be consistent with a particular global average.

The second approach to the discount rate considers market returns to investment, which range between 3% and 6% in real terms for longterm, riskfree public investments. Conceptually, funds could be invested in projects that earn such returns, with the proceeds being used to increase the consumption for future generations.

The choice of the social discount rate for public investment projects is a matter of policy preference but has a major impact on the economic evaluation of climate change actions.[6] For example, in today's dollars, $1,000 of damage 100 years from now would be valued at $370 using a 1% discount rate (near the low end of the range for the first approach) but would be valued at $7.60 using a 5% discount rate (near the upper end of the range for the second approach). However, in cost-effectiveness analyses of policies over short time horizons, the impact of using different discount rates is much smaller. In all areas analysts should specify the discount rate(s) they use to facilitate comparison and aggregation of results.

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6. Applicability of cost and benefit assessments

Many factors need to be taken into account in the evaluation of projects and public policy issues related to climate change, including the analysis of possible costs and benefits. Although costs and benefits cannot all be measured in monetary terms, various techniques exist which offer a useful framework for organizing information about the consequences of alternative actions for addressing climate change.

The family of analytical techniques for examining economic environmental policies and decisions includes traditional project level costbenefit analysis, costeffectiveness analysis, multicriteria analysis and decision analysis. Traditional costbenefit analysis attempts to compare all costs and benefits expressed in terms of a common monetary unit. Costeffectiveness analysis seeks to find the lowest-cost option to achieve an objective specified using other criteria. Multicriteria analysis is designed to deal with problems where some benefits and/or costs are measured in nonmonetary units. Decision analysis focuses specifically on making decisions under uncertainty.

In principle, this group of techniques can contribute to improving public policy decisions concerning the desirable extent of actions to mitigate global climate change, the timing of such actions and the methods to be employed.

Traditional costbenefit analysis is based on the concept that the level of emission control at each point in time is determined such that marginal costs equal marginal benefits. However, both costs and benefits may be hard, sometimes impossible, to assess. This may be due to large uncertainties, possible catastrophes with very small probabilities, or simply because there is no available consistent methodology for monetizing the effects. In some of these cases, it may be possible to apply multicriteria analysis. This provides policymakers with a broader set of information, including evaluation of relevant costs and benefits, estimated within a common framework.

Practical application of traditional costbenefit analysis to the problem of climate change is therefore difficult because of the global, regional and intergenerational nature of the problem. Estimates of the costs of mitigation options also vary widely. Furthermore, estimates of potential physical damages due to climate change also vary widely. In addition, confidence in monetary estimates for important consequences (especially nonmarket consequences) is low. These uncertainties, and the resolution of uncertainty over time, may be decisive for the choice of strategies to combat climate change. The objective of decision analysis is to deal with such problems. Furthermore, for some categories of ecological, cultural and human health impacts, widely accepted economic concepts of value are not available. To the extent that some impacts and measures cannot be valued in monetary terms, economists augment the traditional costbenefit analysis approach with such techniques as multicriteria analysis, permitting some quantitative expression of the tradeoffs to be made. These techniques do not resolve questions involving equity - for example, determining who should bear the costs. However, they provide important information on the incidence of damage, mitigation, and adaptation costs and on where costeffective action might be taken.

Despite their many imperfections, these techniques provide a valuable framework for identifying essential questions that policymakers must face when dealing with climate change, namely:

- By how much should emissions of greenhouse gases be reduced?

- When should emissions be reduced?
- How should emissions be reduced?

These analytical techniques assist decision makers in comparing the consequences of alternative actions, including that of no action, on a quantitative basis - and can certainly make a contribution to resolution of these questions.

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7. The social costs of anthropogenic climate change: Damages of increased greenhouse gas emissions

The literature on the subject in this section is controversial and mainly based on research done on developed countries, often extrapolated to developing countries. There is no consensus about how to value statistical lives or how to aggregate statistical lives across countries.[7] Monetary valuation should not obscure the human consequences of anthropogenic climate change damages, because the value of life has meaning beyond monetary valuation. It should be noted that the Rio Declaration and Agenda 21 call for human beings to remain at the centre of sustainable development. The approach taken to this valuation might affect the scale of damage reduction strategies. It may be noted that, in virtually all of the literature discussed in this section, the developing country statistical lives have not been equally valued at the developed country value, nor are other damages in developing countries equally valued at the developed country value. Because national circumstances, including opportunity costs, differ, economists sometimes evaluate certain kinds of impacts differently amongst countries.

The benefits of limiting greenhouse gas emissions and enhancing sinks are: (a) the climate change damages avoided; and (b) the secondary benefits associated with the relevant policies. Secondary benefits include reductions in other pollutants jointly produced with greenhouse gases and the conservation of biological diversity. Net climate change damages include both market and nonmarket impacts as far as they can be quantified at present and, in some cases, adaptation costs. Damages are expressed in net terms to account for the fact that there are some beneficial impacts of global warming as well, which are, however, dominated by the damage costs. Nonmarket impacts, such as human health, risk of human mortality and damage to ecosystems, form an important component of available estimates of the social costs of climate change. The literature on monetary valuation of such nonmarket effects reflects a number of divergent views and approaches. The estimates of nonmarket damages, however, are highly speculative and not comprehensive.

Nonmarket damage estimates are a source of major uncertainty in assessing the implications of global climate change for human welfare. While some regard monetary valuation of such impacts as essential to sound decisionmaking, others reject monetary valuation of some impacts, such as risk of human mortality, on ethical grounds. Additionally, there is a danger that entire unique cultures may be obliterated. This is not something that can be considered in monetary terms, but becomes a question of loss of human diversity, for which we have no indicators to measure economic value.

The assessed literature contains only a few estimates of the monetized damages associated with doubled CO2 equivalent concentration scenarios. These estimates are aggregated to a global scale and illustrate the potential impacts of climate change under selected scenarios. Aggregating individual monetized damages to obtain total social welfare impacts implies difficult decisions about equity amongst countries. Global estimates are based upon an aggregation of monetary damages across countries (damages which are themselves implicit aggregations across individuals) that reflects intercountry differences in wealth and income - this fundamentally influences the monetary valuation of damages. Taking income differences as given implies that an equivalent impact in two countries (such as an equal increase in human mortality) would receive very different weights in the calculations of global damages.

To enable choices between different ways of promoting human welfare to be made on a consistent basis, economists have for many years sought to express a wide range of human and environmental impacts in terms of monetary equivalents, using various techniques. The most commonly used of those techniques is an approach based on the observed willingness to pay for various nonmarket benefits.[8] This is the approach that has been taken in most of the assessed literature.

Human life is an element outside the market and societies may want to preserve it in an equal way. An approach that includes equal valuation of impacts on human life wherever they occur may yield different global aggregate estimates than those reported below. For example, equalizing the value of a statistical life at a global average could leave total global damage unchanged but would increase markedly the share of these damages borne by the developing world. Equalizing the value at the level typical in developed countries would increase monetized damages several times, and would further increase the share of the developing countries in the total damage estimate.

Other aggregation methods can be used to adjust for differences in the wealth or incomes of countries in calculations of monetary damages. Because estimates of monetary damage tend to be a higher percentage of national GDP for lowincome countries than for highincome countries, aggregation schemes that adjust for wealth or income effects are expected to yield higher estimates of global damages than those presented in this report.

The assessed literature quantifying total damages from 23^{o}C warming provides a wide range of point estimates for damages, given the presumed change in atmospheric greenhouse gas concentrations. The aggregate estimates tend to be a few per cent of world GDP, with, in general, considerably higher estimates of damage to developing countries as a share of their GDP. The aggregate estimates are subject to considerable uncertainty, but the range of uncertainty cannot be gauged from the literature. The range of estimates cannot be interpreted as a confidence interval, given the widely differing assumptions and methodologies in the studies. As noted above, aggregation is likely to mask even greater uncertainties about damage components.

Regional or sectoral approaches to estimating the consequences of climate change include a much wider range of estimates of the net economic effects. For some areas, damages are estimated to be significantly greater and could negatively affect economic development. For others, climate change is estimated to increase economic production and present opportunities for economic development. For countries generally having a diversified, industrial economy and an educated and flexible labour force, the limited set of published estimates of damages are of the order one to a few per cent of GDP. For countries generally having a specialized and natural resourcebased economy (e.g., heavily emphasizing agriculture or forestry), and a poorly developed and landtied labour force, estimates of damages from the few studies available are several times larger. Small islands and lowlying coastal areas are particularly vulnerable. Damages from possible largescale catastrophes, such as major changes in ocean circulation, are not reflected in these estimates. There is little agreement across studies about the exact magnitude of each category of damages or relative ranking of the damage categories.[9] Climate changes of this magnitude are not expected to be realized for several decades, and damages in the interim could be smaller. Damages over a longer period of time might be greater.[10]

IPCC does not endorse any particular range of values for the marginal damage of CO2 emissions, but published estimates range between $5 and $125 (1990 U.S.) per tonne of carbon emitted now. This range of estimates does not represent the full range of uncertainty. The estimates are also based on models that remain simplistic and are limited representations of the actual climate processes in being and are based on earlier IPCC scientific reports. The wide range of damage estimates reflects variations in model scenarios, discount rates and other assumptions. It must be emphasized that the social cost estimates have a wide range of uncertainty because of limited knowledge of impacts, uncertain future technological and socioeconomic developments, and the possibility of catastrophic events or surprises.

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8. Generic assessment of response strategies

A wide range of technologies and practices is available for mitigating emissions of carbon dioxide, methane, nitrous oxide and other greenhouse gases. There are also many adaptation measures available for responding to the impacts of climate change. All these technologies, practices and measures have financial and environmental costs as well as benefits. This section surveys the range of options currently available or discussed in the literature. The optimal mix of response options will vary by country and over time as local conditions and costs change.

A review of CO2 mitigation options suggests that:

- A large potential for costeffective energy conservation and efficiency improvements in energy supply and energy use exists in many sectors. These options offer economic and environmental benefits in addition to reducing emissions of greenhouse gases. Various of these options can be deployed rapidly due to small unit size, modular design characteristics and low lifetime costs.

The options for CO2 mitigation in energy use include alternative methods and efficiency improvements, among others in the construction, residential, commercial, agriculture and industry sectors. Not all costeffective strategies are based on new technology; some may rely on improved information dissemination and public education, managerial strategies, pricing policies and institutional reforms.

- Estimates of the technical potential for switching to less carbonintensive fuels vary regionally and with the type of measure and the economic availability of reserves of fossil and alternative fuels. These estimates also have to take account of potential methane emissions from leakage of natural gas during production and distribution.
- Renewable energy technologies (e.g., solar, hydroelectric, wind, traditional and modern biomass, and ocean thermal energy conversion) have achieved different levels of technical development, economic maturity and commercial readiness. The potential of these energy sources is not fully realized. Cost estimates for these technologies are sensitive to sitespecific characteristics, resource variability and the form of final energy delivered. These cost estimates vary widely.
- Nuclear energy[11] is a technology that has been deployed for several decades in many countries. However, a number of factors have slowed the expansion of nuclear power, including: (a) wary public perceptions resulting from nuclear accidents, (b) not yet fully resolved issues concerning reactor safety, proliferation of fissile material, powerplant decommissioning and longterm disposal of nuclear waste, as well as, in some instances, lowerthananticipated levels of demand for electricity. Regulatory and siting difficulties have increased construction lead times, leading to higher capital costs for this option in some countries. If these issues, including inter alia the social, political and environmental aspects mentioned above, can be resolved, nuclear energy has the potential to increase its present share in worldwide energy production.
- CO2 capture and disposal may be ultimately limited for technical and environmental reasons, because not all forms of disposal ensure prevention of carbon reentering the atmosphere.
- Forestry options, in some circumstances, offer large potential, modest costs, low risk and other benefits. Further, the potential modern use of biomass as a source of fuels and electricity could become attractive. Halting or slowing deforestation and increasing reforestation through increased silvicultural productivity and sustainable management programmes that increase agricultural productivity, the expansion of forest reserves and promotion of ecotourism are among the costeffective options for slowing the atmospheric buildup of CO2. Forestry programmes raise important equity considerations.[12]

There is also a wide range of available technologies and practices for reducing emissions of methane from such sources as natural gas systems, coal mines, waste dumps and farms. However, the issue of reduction of emissions related to food supply may imply tradeoffs with rates of food production. These tradeoffs must be carefully assessed, as they may affect the provision of basic needs in some countries, particularly in developing countries.

Most nitrous oxide emissions come from diffuse sources related to agriculture and forestry. These emissions are difficult to reduce rapidly. Industrial emissions of nitrous oxide and halogenated compounds tend to be concentrated in a few key sectors and tend to be easier to control. Measures to limit such emissions may be attractive for many countries.

The slow implementation of many of the technologically attractive and costeffective options listed above has many possible explanations, with both actual and perceived costs being a major factor. Among other factors, capital availability, information gaps, institutional obstacles and market imperfections affect the rate of diffusion for these technologies. Identifying the reasons specific to a particular country is a precondition to devising sound and efficient policies to encourage their broader adoption.

Education and training as well as information and advisory measures are important aspects of various response options.

Many of the emissionreducing technologies and practices described above also provide other benefits to society. These additional benefits include improved air quality, better protection of surface and underground waters, enhanced animal productivity, reduced risk of explosions and fire, and improved use of energy resources.

Many options are also available for adapting to the impacts of climate change and thus reducing the damages to national economies and natural ecosystems. Adaptive options are available in many sectors, ranging from agriculture and energy to health, coastal zone management, offshore fisheries and recreation. Some of these provide enhanced ability to cope with the current impacts of climate variability. However, possible tradeoffs between implementation of mitigation and adaptation measures are important to consider in future research. A summary of sectoral options for adaptation is presented in the volume on the scientifictechnical analyses of impacts, adaptations and mitigation of climate change of the IPCC Second Assessment Report (SAR).

The optimal response strategy for each country will depend on the special circumstances and conditions which that country must face. Nonetheless, many recent studies and empirical observations suggest that some of the most costeffective options can be most successfully implemented on a joint or cooperative basis among nations.

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9. Costs of response options

It must be emphasized that the text in this section is an assessment of the technical literature and does not make recommendations on policy matters. The available literature is primarily from developed countries.

Cost concepts

From the perspective of this section on assessing mitigation or adaptation costs, what matters is the net cost (total cost less secondary benefits and costs). These net costs exclude the social costs of climate change, which are discussed in Section 7 above. The assessed literature yields a very wide range of estimates of the costs of response options. The wide range largely reflects significant differences in assumptions about the efficiency of energy and other markets, and about the ability of government institutions to address perceived market failures or imperfections.

Measures to reduce greenhouse gas emissions may yield additional economic impacts (for example, through technological externalities associated with fostering research and development programmes) and/or environmental impacts (such as reduced emissions of acid rain and urban smog precursors). Studies suggest that the secondary environmental benefits may be substantial but are likely to differ from country to country.

Specific results

Estimates of the cost of greenhouse gas emission reduction depend critically upon assumptions about the levels of energy efficiency improvements in the baseline scenario (that is, in the absence of climate policy) and upon a wide range of factors such as consumption patterns, resource and technology availability, the desired level and timing of abatement, and the choice of policy instruments.

Policymakers should not place too much confidence in the specific numerical results from any one analysis. For example, mitigation cost analyses reveal the costs of mitigation relative to a given baseline, but neither the baseline nor the intervention scenarios should be interpreted as representing likely future conditions. The focus should be on the general insights regarding the underlying determinants of costs.

The costs of stabilizing atmospheric concentrations of greenhouse gases at levels and within a time-frame that will prevent dangerous anthropogenic interference with the climate system (the ultimate objective of the UNFCCC) will be critically dependent on the choice of emission timepath. The cost of the abatement programme will be influenced by the rate of capital replacement, the discount rate, and the effect of research and development.

Failure to adopt policies as early as possible to encourage efficient replacement investments at the end of the economic life of a plant and equipment (i.e., at the point of capital stock turnover) imposes an economic cost to society. Implementing emission reductions at rates that can be absorbed in the course of normal stock turnover is likely to be cheaper than enforcing premature retirement now.

The choice of abatement paths thus involves balancing the economic risks of rapid abatement now (that premature capital stock retirement will later be proved unnecessary) against the corresponding risk of delay (that more rapid reduction will then be required, necessitating premature retirement of future capital stock).

Appropriate longrun signals are required to allow producers and consumers to adapt costeffectively to constraints on greenhouse gas emissions and to encourage research and development. Benefits associated with the implementation of any "noregret" policies will offset, at least in part, the costs of a full portfolio of mitigation measures. This will also increase the time available to learn about climate risks and to bring new technologies into the marketplace.

Despite significant differences in views, there is agreement that energy efficiency gains of perhaps 10-30% above baseline trends over the next two to three decades can be realized at negative to zero net cost. (Negative net cost means an economic benefit.) With longer time horizons, which allow a more complete turnover of capital stocks, and which give research and development and market transformation policies a chance to impact multiple replacement cycles, this potential is much higher. The magnitude of such "noregret" potentials depends upon the existence of substantial market or institutional imperfections that prevent costeffective emission reduction measures from occurring. The key question is then the extent to which such imperfections and barriers can be removed cost-effectively by policy initiatives such as efficiency standards, incentives, removal of subsidies, information programmes and funding of technology transfer.

Progress has been made in a number of countries in costeffectively reducing imperfections and institutional barriers in markets through policy instruments based on voluntary agreements, energy efficiency incentives, product efficiency standards and energy efficiency procurement programmes involving manufacturers, as well as utility regulatory reforms. Where empirical evaluations have been made, many have found the benefitcost ratio of increasing energy efficiency to be favourable, suggesting the practical feasibility of realizing "noregret" potentials at negative net cost. More information is needed on similar and improved programmes in a wider range of countries.

Infrastructure decisions are critical in determining longterm emissions and abatement costs because they can enhance or restrict the number and type of future options. Infrastructure decisions determine development patterns in transportation, urban settlement and landuse, and influence energy system development and deforestation patterns. This issue is of particular importance to developing countries and many economies in transition where major infrastructure decisions will be made in the near term.

If a carbon or carbonenergy tax is used as a policy instrument for reducing emissions, the taxes could raise substantial revenues, and how the revenues are distributed could dramatically affect the cost of mitigation. If the revenues are distributed by reducing distortionary taxes in the existing system, they will help reduce the excess burden of the existing tax system, potentially yielding an additional economic benefit (double dividend). For example, those European studies which are more optimistic regarding the potential for tax recycling show lower and, in some instances, slightly negative costs.

Conversely, inefficient recycling of the tax revenues could increase costs. For example, if the tax revenues are used to finance government programmes that yield a lower return than the private sector investments foregone because of the tax, then overall costs will increase.

There are large differences in the costs of reducing greenhouse gas emissions among countries because of their state of economic development, infrastructure choices and natural resource base. This indicates that international cooperation could significantly reduce the global cost of reducing emissions. Research suggests that, in principle, substantial savings would be possible if emissions are reduced where it is cheapest to do so. In practice, this requires international mechanisms ensuring appropriate capital flows and technology transfers between countries. Conversely, a failure to achieve international cooperation could compromise unilateral attempts by a country or a group of countries to limit greenhouse gas emissions. However, estimates of so called leakage effects vary so widely that they provide little guidance to policymakers.

There has been more analysis to date of emission reduction potentials and costs for developed countries than for other parts of the world. Moreover, many existing models are not wellsuited to study economies in transition or economies of developing countries. Much work is needed to develop and apply models for use outside developed countries (for example, to represent more explicitly market imperfections, institutional barriers, and traditional and informal economic sectors). In addition, the discussion below and the bulk of the underlying report deal with costs of response options at the national or regional level in terms of effect on GDP. Further analysis is required concerning effects of response options on employment, inflation, trade competitiveness and other public issues.

A large number of studies using both topdown and bottomup approaches (see Box 1 for definitions) were reviewed. Estimates of the costs of limiting fossil fuel carbon dioxide emissions (expressed as carbon) vary widely and depend upon choice of methodologies, underlying assumptions, emission scenarios, policy instruments, reporting year and other criteria. For specific results of individual studies, see the volume on economic and social dimenstions of climate change of the IPCC Second Assessment Report (SAR).

OECD countries. Although it is difficult to generalize, topdown analyses suggest that the costs of substantial reductions below 1990 levels could be as high as several per cent of GDP. In the specific case of stabilizing emissions at 1990 levels, most studies estimate that annual costs in the range of B0.5% of GDP (equivalent to a gain of about $60 billion in total for OECD countries at today's GDP levels) to 2% of GDP (equivalent to a loss of about $240 billion) could be reached over the next several decades. However, studies also show that appropriate timing of abatement measures and the availability of lowcost alternatives may substantially reduce the size of the overall bill.

Bottomup studies are more optimistic about the potential for low or negative cost emission reductions, and the capacity to implement that potential. Such studies show that the costs of reducing emissions by 20% in developed countries within two to three decades are negligible to negative. Other bottomup studies suggest that there exists a potential for absolute reductions in excess of 50% in the longer term, without increasing, and perhaps even reducing, total energy system costs.

The results of topdown and bottomup analyses differ because of such factors as higher estimates of noregrets potential and technological progress, and earlier saturation in energy services per unit GDP. In the most favourable assessments, savings of 1020% in the total cost of energy services can be achieved.

Economies in transition. The potential for costeffective reductions in energy use is apt to be considerable, but the realizable potential will depend upon what economic and technological development path is chosen, as well as the availability of capital to pursue different paths. A critical issue is the future of structural changes in these countries that are apt to change dramatically the level of baseline emissions and the emission reduction costs.

Developing countries. Analyses suggest that there may be substantial lowcost fossil fuel carbon dioxide emission reduction opportunities for developing countries. Development pathways that increase energy efficiency, promote alternative energy technologies, reduce deforestation, and enhance agricultural productivity and biomass energy production can be economically beneficial. To embark upon this pathway may require significant international cooperation and financial and technology transfers. However, these are likely to be insufficient to offset rapidly increasing emissions baselines, associated with increased economic growth and overall welfare. Stabilization of carbon dioxide emissions is likely to be costly.

It should be noted that analyses of costs to economies in transition and developing countries typically neglect the general equilibrium effects of unilateral actions taken by developed countries. These effects may be either positive or negative and their magnitude is difficult to quantify.

It should also be noted that estimates of costs or benefits of the order of a few per cent of GDP may represent small differences in GDP growth rates, but are nevertheless substantial in absolute terms.

Preservation and augmentation of carbon sinks offer a substantial and often costeffective component of a greenhouse gas mitigation strategy. Studies suggest that as much as 1530% of 1990 global energyrelated emissions could be offset by carbon sequestration in forests for a period of 50100 years. The costs of carbon sequestration, which are competitive with source control options, may differ among regions of the world.

Control of emissions of other greenhouse gases, especially methane and nitrous oxide, can provide significant costeffective opportunities in some countries. About 10% of anthropogenic methane emissions could be reduced at negative or low cost using available mitigation options for such methane sources as natural gas systems, waste management and agriculture.

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10. Integrated assessment

Integrated assessment models combine knowledge from a wide range of disciplines to provide insights that would not be observed through traditional disciplinary research. They are used to explore possible states of human and natural systems, analyze key questions related to policy formulation and help set research priorities. Integration helps coordinate assumptions from different disciplines and allows feedbacks and interactions absent from individual disciplines to be analyzed. However, the results of such analyses are no better than the information drawn from the underlying economic, atmospheric and biological sciences. Integrated assessment models are limited both by the underlying knowledge base upon which they draw and by the relatively limited experiential base.

Most current integrated assessment models do not reflect the specific social and economic dynamics of the developing and transition economies well; for example, none of the existing models addresses most market imperfections, institutional barriers, or the operation of the informal sector in these countries. This can lead to biases in global assessments when mitigation options and impacts on developing or transition economies are valued as if their economies operated like those in the developed countries.

While relatively new, integrated assessment models of climate change have evolved rapidly. Integrated assessment models tend to fall into two categories: policy evaluation and policy optimization models. Policy evaluation models are rich in physical detail and have been used to analyze the potential for deforestation as a consequence of interactions between demographics, agricultural productivity and economic growth, and the relationship between climate change and the extent of potentially malarial regions. Policy optimization models optimize over key variables (e.g., emission rates, carbon taxes) to achieve formulated policy goals (e.g., cost minimization or welfare optimization).

Key uncertainties in current integrated assessments include the sensitivity of the climate system to changes in greenhouse gas concentrations, the specification and valuation of impacts where there are no markets, changes in national and regional demographics, the choice of discount rates, and assumptions regarding the cost, availability and diffusion of technologies.

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11. An economic assessment of policy instruments to combat climate change

Governments may have different sets of criteria for assessing international as well as domestic greenhouse policy instruments. Among these criteria are efficiency and costeffectiveness, effectiveness in achieving stated environmental targets, distributional (including intergenerational) equity, flexibility in the face of new knowledge, understandability to the general public, and consistency with national priorities, policies, institutions and traditions. The choice of instruments may also partly reflect a desire on the part of governments to achieve other objectives, such as sustainable economic development, meeting social development goals and fiscal targets, or influencing pollution levels that are indirectly related to greenhouse gas emissions. A further concern of governments may lie with the effect of policies on competitiveness.

The world economy and indeed some individual national economies suffer from a number of price distortions which increase greenhouse gas emissions, such as some agricultural and fuel subsidies and distortions in transport pricing. A number of studies of this issue indicate that global emission reductions of 418%, together with increases in real incomes, are possible from phasing out fuel subsidies. For the most part, reducing such distortions could lower emissions and increase economic efficiency. However, subsidies are often introduced and price distortions maintained for social and distributional reasons, and they may be difficult to remove.

Policy instruments may be identified at two different levels: those that might be used by a group of countries and those that might be used by individual nations unilaterally or to achieve compliance with a multilateral agreement.

A group[13] of countries may choose from policy measures and instruments including encouragement of voluntary actions and further research, tradable quotas, joint implementation (specifically activities implemented jointly under the pilot phase[14]), harmonized domestic carbon taxes, international carbon taxes, nontradable quotas and various international standards. If the group did not include all major greenhouse gas emitters, then there might be a tendency for fossil fuel use to increase in countries not participating in this group. This outcome might reduce the international competitiveness of some industries in participating countries as well as the environmental effectiveness of the countries' efforts.

At both the international and national levels, the economic literature indicates that instruments that provide economic incentives, such as taxes and tradable quotas/permits, are likely to be more cost-effective than other approaches. Uniform standards among groups of countries participating in an international agreement are likely to be difficult to achieve. However, for one group of countries there has been agreement on the application of some uniform standards.

At the international level, all of the potentially efficient marketbased instruments could be examined during the course of future negotiations. A tradable quota system has the disadvantage of making the marginal cost of emissions uncertain, while a carbon tax (and related instruments) has the disadvantage of leaving the effect on the level at which emissions are controlled uncertain. The weight given to the importance of reducing these different types of uncertainty would be one crucial factor in further evaluating these alternative instruments. Because of the lack of appropriate scientific knowledge, there would remain a high degree of uncertainty about the results of limiting emissions at specific levels. The adoption of either a tradable quota scheme or international taxes would have implications for the international distribution of wealth. The distributional consequences would be the subject of negotiation. To insure the practicability of such instruments, there is a need for additional studies on the possible design of tradable quotas and harmonized taxes and on the institutional framework in which they might operate.

Individual countries that seek to implement mitigation policies can choose from among a large set of potential policies and instruments, including carbon taxes, tradable permits, deposit refund systems (and related instruments) and subsidies, as well as technology standards, performance standards, product bans, direct government investment and voluntary agreements. Public education on the sustainable use of resources could play an important part in modifying consumption patterns and other human behaviour. The choice of measures at the domestic level may reflect objectives other than costeffectiveness, such as meeting fiscal targets. Revenue from carbon taxes or auctioned tradable permits could be used to replace existing distortionary taxes. The choice of instruments may also reflect other environmental objectives, such as reducing nongreenhouse pollution emissions, or increasing forest cover, or other concerns such as specific impacts on particular regions or communities.

Box 1. TopDown and BottomUp Models

Topdown models are aggregate models of the entire macroeconomy that draw on analysis of historical trends and relationships to predict the largescale interactions between the sectors of the economy, especially the interactions between the energy sector and the rest of the economy. Topdown models typically incorporate relatively little detail on energy consumption and technological change, compared with bottomup models.

In contrast, bottomup models incorporate detailed studies of the engineering costs of a wide range of available and forecast technologies, and describe energy consumption in great detail. However, compared with topdown models, they typically incorporate relatively little detail on nonenergy consumer behaviour and interactions with other sectors of the economy.

This simple characterization of topdown and bottomup models is increasingly misleading as more recent versions of each approach have tended to provide greater detail in the aspects that were less developed in the past. As a result of this convergence in model structure, model results are tending to converge, and the remaining differences reflect differences in assumptions about how rapidly and effectively market institutions adopt costeffective new technologies or can be induced to adopt them by policy interventions.

Many existing models are not well suited to study economies in transition or those of developing countries. More work is needed to develop the appropriate methodologies, data and models and to build the local institutional capacity to undertake analyses.

Footnotes:

[1] The UN Framework Convention on Climate Change defines "climate change" as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The question as to whether such changes are potential or can already be identified is analyzed in the volume on the science of climate change of the IPCC Second Assessment Report (SAR).
[2] "No regrets" measures are those whose benefits, such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their cost to society, excluding the benefits of climate change mitigation. They are sometimes known as "measures worth doing anyway".
[3] Without knowing the extent of potential impacts, the ability of private markets to insure against losses associated with climate change is unknown.
[4] A related (somewhat stronger) concept is that each generation is entitled to inherit a planet and cultural resource base at least as good as that of previous generations.
[5] A social discount rate is a discount rate appropriate for use by governments in the evaluation of public policy.
[6] Despite the differences in the value of the discount rate, policies developed on the basis of the two approaches may lead to similar results.
[7] The value of a statistical life is defined as the value people assign to a change in the risk of death among the population.
[8] The concept of willingness to pay is indicative, based on expressed desires, available resources and information of a human being's preferences at a certain moment in time. The values may change over time. Also, other concepts (such as willingness to accept compensation for damage) have been advanced, but not yet widely applied, in the literature, and the interpretation and application of willingness to pay and other concepts to the climate problem may evolve.

[9] Due to time lags between findings in the natural sciences, their use in determination of potential physical and biological impacts, and subsequent incorporation into economic analyses of climate change, the estimates of climate change damage are based mainly on the scientific results from the 1990 and 1992 IPCC reports.

[10] See the volume on the science of climate change and the volume on the scientifictechnical analyses of impacts, adaptations and mitigation of climate change of the IPCC Second Assessment Report (SAR).

[11] For more information on the technical aspects of nuclear power, see the volume on the scientific-technical analyses of impacts, adaptations and mitigation of climate change of the IPCC Second Assessment Report (SAR).

[12] These are addressed in Section 4 above and in the volume on economic and social dimensions of climate change of the IPCC Second Assessment Report (SAR).

[13] The group could contain only a few, quite a number, or even all countries.

[14] See decision 5/CP.1 of the first Conference of the Parties (COP1) to the UNFCCC.