Mitigation and Adaptation Cost Assessment
Concepts, Methods and Appropriate Use

Mitigation and Adaptation Cost Assessment: Concepts, Methods and Appropriate Use.

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Preface

At the plenary session in September 1996 the Intergovernmental Panel on Climate Change (IPCC) decided to establish a number of activities (special reports, workshops, scoping papers, etc.) in the period between the finalisation of the Second Assessment and the commencement of the next full assessment process.

One of these activities was a workshop on “Mitigation and Adaptation Cost Assessment, Concepts, Methods and Appropriate Use” co-sponsored by IPCC, the Danish Government, Risø National Laboratory, UNEP, ADB and GTZ.

This workshop was held at Risø from 16 to 18 June 1997 and hosted by the UNEP Collaborating Centre on Energy and Environment. As part of the workshop preparations a writing team had been established to prepare a concept paper on the workshop topic. The preparation of the paper has been co-ordinated by the UNEP Collaborating Centre on Energy and Environment and the Lawrence Berkeley National Laboratory with Dr. J. Christensen (UCCEE), Dr. K. Halsnæs (UCCEE) and Dr. J. Sathaye (LBNL) as the convening authors. The final editing of the paper has been done by David Francis, Cassandra Brooke and Kirsten Halsnæs.

The first draft of the paper was presented at the workshop, which recommended that the paper be published following a full IPCC scientific review. The present paper has therefore been reviewed by the IPCC experts and is updated according to the suggestions supplied by more than 200 experts.

The Subsidiary Body for Scientific and Technological Advice under the Climate Convention (SBSTA) has given priority to activities aimed at developing mitigation methodologies, including methods for estimating costs. In this regard, it has strongly endorsed the work programme of UNEP, which was submitted to SBSTA. The present concept paper constitutes one product under this UNEP/Risø work programme.

The convenors would like to thank the lead authors and contributors to the paper for the time and effort they have put into its preparation (authors are listed for the individual chapters). The valuable contribution from workshop participants (see Annex A) in reviewing and discussing the first draft of the paper is also acknowledged along with other internal reviews. A special thanks to Cassandra Brooke for organising the workshop and a substantial editing effort in preparing the present report.

Finally the convenors would like to thank the institutions and organisations that have contributed financially to the preparation of the paper and the organisation of the workshop. These include the Danish Ministry of Foreign Affairs, the Danish Environment Protection Agency, Risø National Laboratory, the Asian Development Bank, the United Nations Environment Programme, German Technical Co-operation (GTZ), Environment Canada and the UK Department of Environment, Transport and the Regions.

Foreword

Klaus Töpfer
Executive Director, United Nations Environment Programme

The United Nations Environment Programme (UNEP) supports the implementation of the Framework Convention on Climate Change (FCCC) through a large number of activities. Historically UNEP has been instrumental in getting climate change issues on the international political agenda. Through the establishment of and continued support to the Intergovernmental Panel on Climate Change (IPCC), UNEP has made a strong contribution to clarifying key issues in climate science and in the areas of vulnerability, adaptation and mitigation.

Specific programmes on economic aspects of climate change and mitigation have been undertaken for more than 5 years, including development of guidelines for national and regional mitigation analysis. The programmes have included testing and application of the guidelines in a large number of national studies. In addition, UNEP has for a number of years been working more broadly on environmental economics issues.

With the report - *Mitigation and Adaptation Cost Assessment* - *Concepts, Methods and Appropriate Use* - UNEP makes a timely contribution to clarification of key economic concepts relevant to the FCCC and the Kyoto Protocol, such as cost-efficiency and incremental cost. These concepts are crucial elements of the Kyoto Protocol flexibility mechanisms – Joint Implementation, the Clean Development Mechanism, and Emissions Trading.

The report is one important output of the UNEP work programme on methodologies, which was strongly supported by the Subsidiary Body for Scientific and Technical Advice (SBSTA) in June 1997. It provides an excellent example of collaboration between key institutions and bodies involved in climate change. The report has been prepared by an international group of experts in close co-operation with the IPCC, including a joint workshop and a full IPCC technical review. Activities have mainly been sponsored by the Danish Government with additional contributions from Canada, Germany and the Asian Development Bank. As a leading international Centre of Excellence on technical and economic issues relating to climate change the UNEP Collaborating Centre on Energy and Environment has been instrumental in the entire process of developing the report.

As an economist I naturally have a special interest in the topics covered by the report and believe it provides an extremely timely contribution to the international debate on climate change. I fully expect that *Mitigation and Adaptation Cost Assessment – Concepts, Methods and Appropriate Use* will become a basic reference, whether for policy makers and negotiators, for practitioners of cost analysis, mitigation, and adaptation assessment, and for the scientific community at large.

Nairobi, Kenya
October 1998

Foreword

Ogunlade R. Davidson and Bert Metz

Co-Chairs, Working Group III, Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) has started developing the Third Assessment Report (TAR) on Climate Change. This report will focus primarily on the development, sustainability and equity concerns of climate change, while recognizing the varied local and regional specificities in the world. The Third Working Group will concentrate on the technical, economic and social aspects of mitigating climate change, while interacting very closely with Working Group II, which will focus on adaptation to climate change. In undertaking this task, Working Group III will need to tackle many complex concepts and methods relating to the analysis of mitigation to climate change. One such concept is the issue of cost assessment in mitigating or adapting in the climate change regime. Expert meetings and special workshops on these complex concepts provide IPCC with the opportunity for experts to not only discuss these concepts and develop operational definitions, but also to identify areas for more work and attention. This report, *Mitigation and Adaptation Cost Assessment: Concepts, Methods and Appropriate Use,* was the result of the UNEP programme on methodologies which was initiated in cooperation with IPCC and endorsed by the Subsidiary Body for Scientific and Technical Advice (SBSTA) of the United Nations Convention on Climate Change.

The present report on mitigation and adaptation costs addresses the complex issue of identifying synergies and tradeoffs between national priorities and mitigation policies, an issue that requires the integration of various disciplines so as to provide a comprehensive overview of future development trends, available technologies and economic policies. Further, the report suggests a new conceptual framework for treating the social aspects in assessing mitigation and adaptation costs in climate change studies. The impacts of certain sustainability indicators such as employment and poverty reduction on mitigation costing are also discussed in the report.

Among the topics to be considered by over 120 distinguished international experts, who will be assisted with contributions by an equal number of other experts in Working Group III of the TAR, are the elements of costing methodologies at both the micro and macro levels. Special effort will be made to include the impacts of such parameters as income, equity, poverty, employment and trade. Hence, the contents of this report are highly relevant to the authors of the Third Working Group in the development of the TAR.

The report contains a chapter on Special Issues and Problems Related to Cost Assessment for Developing Countries. This chapter will provide valuable background in the further development of these concepts in the TAR because it is an area that has not received due attention in previous work.

The publication of this report is very timely as authors of all the working groups of IPCC are due to start developing the TAR.

Chapter 1

Introduction

by

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This report defines and clarifies cost concepts for use in the field of climate change. The extent and depth of discussion of costs in the Second Assessment Report (SAR) of the Intergovernmental Panel on Climate Change varied among the many chapters of the Working Group reports. The variations made it difficult to provide an indication of the costs of reducing carbon emissions from the energy, forestry and agriculture, and other sectors in a consistent and comparable manner. The specific purposes of this report therefore are to (1) define, explain and discuss the relevant cost concepts and their limitations, (2) establish correspondence across sectors, (3) explain frequently used terminology, and (4) illustrate the applicability of these cost concepts in the formulation of national climate change policies and programs.

The report has been developed for practitioners in the field of climate change including climate change negotiators, technical experts from varied disciplines, policy-makers, and other interested groups. The substantive material from the eight chapters of the report is summarized below.

1.1 Cost Analysis Principles

In spite of the vast literature on the costs of reducing emissions from greenhouse gases (GHGs) and adapting to climate change, there is very little discussion of the conceptual and theoretical issues involved. The basis for the estimation of mitigation and adaptation costs should be the *economic opportunity cost of a product or activity*. To estimate this, price and other data from market transactions are needed, but these data are not enough. One also needs information on the distortions in market prices so that corrections can be made. The process of making such corrections is called shadow pricing and methods for estimating shadow prices are discussed. The other correction is to account for external effects, both positive and negative. Again methods for doing so are available and can be applied to the estimation of the costs of GHG mitigation and adaptation. Together the two corrections provide an estimate of the *social costs* of GHG mitigation. Both these corrections to market prices are important, but in most studies of GHG mitigation and adaptation they have not been undertaken, or have been only partially undertaken.

Although the most important policy tool in GHG policy making is the estimation of the *social costs*, policy-makers are also interested in the financial costs. These should therefore also be provided, and should be based on an accurate reporting of the financial flows generated by the project.

An overall framework in which climate change mitigation and adaptation costs have previously been measured may be considered at three levels (macroeconomic, sectoral and project). A review of existing literature in the field reveals considerable inconsistencies of methodology and a lack of coherence between the different levels of analysis. An ‘ideal’ framework for such cost assessment, and a discussion of the specific problems that arise in each type of assessment (macro, sectoral and project) is presented. It is clear that models at each level serve a different purpose in climate change policy. While macroeconomic models are useful in designing policies to combat climate change, sectoral and project levels of analysis are more useful in designing detailed measures to mitigate and adapt to climate change.

There are several issues that arise across **all assessments**, beginning with the definition of baseline. Baselines are critical in the whole exercise of cost estimation and evaluation. Here the choice should be based on expected policies, not optimal policies, and should be as consistent as possible between different levels of analysis. Given the major uncertainties about future development, however, it is recommended that multiple baselines be used, giving a range of estimates to the policy-maker. This will also provide some appreciation of the uncertainty that surrounds these estimates. The other issues are: valuation of indirect costs and benefits; choice of discount rates; integrating adaptation and mitigation costs; and selection criteria for evaluating different programs when results are available from cost assessments at different levels of aggregation.

The valuation of indirect costs and benefits can proceed, at least in the first instance, by taking the results of existing studies, of which there are now many. These will provide information on how the choices can be affected by the move from financial costs to social costs. The choice of the discount rate remains an unresolved question but again the use of more than one rate allows the policy-maker to see the sensitivity of the results to this parameter.

The methods of designing the optimal adaptation programme are based on a comparison of the damages avoided with the costs of adaptation and will be largely independent of the selected mitigation programme, which responds to a target reduction in GHG emissions. The use of *social cost* is as important here as it is for mitigation costs. The two need to be integrated, however, in the macroeconomic studies, where their fiscal and macroeconomic implications can be studied.

Several writers have noted that there is a serious divide between the estimated costs and the actual costs likely to be incurred in implementing a particular GHG programme. Such implementation costs cannot all be easily included in the formal cost assessments but are nevertheless very important in the selection of policies. Where they can be included in the main analysis this should be done, but where they cannot be a separate report should be made of these implementation 'issues'.

In this context, it is important to note that the selection of policies for GHG adaptation and mitigation will not merely depend on such costs (although these should be one of the most important factors). They will also depend on the impacts of the programmes in terms of financial costs, the impacts on income distribution and the uncertainty of the impacts, amongst other things. The difficulties that arise in making changes to established institutional practices and market arrangements will also be important. The 'costs' associated with such changes cannot be measured in monetary terms, or can only partly be measured in such terms. The nature of these constraints on implementing mitigation programmes and how they might best be reported is considered also.

Reporting of the different dimensions of 'cost' for a project or a programme of climate change deserves attention. There is some merit in providing simple charts of marginal cost, but there is also a need to provide information on other dimensions. From these a selection of the appropriate strategy will be made. Ultimately the selection is a political one. However, the analyst is responsible for presenting the information in a clear and coherent manner. In this regard there may be some scope for the use of multi-criteria analysis.

1.1.1 Special Issues and Problems Related to Cost Assessment for Developing Countries

Most present mitigation cost studies have been conducted on the basis of models and approaches originally designed for the market-based economies of industrialized countries. A simplified application of the methodologies to developing countries can lead to inaccurate projections of greenhouse gas emissions and their mitigation potential. Their application in a developing country context poses special problems relating to data, sectoral coverage, and assumptions about markets, behaviors, and policy instruments. The particularly vexing implementation issues, including institutional and human capacity aspects, of developing countries are not captured in the studies. There is, therefore a need for further development of methodologies and approaches that reflect the specific characteristics of climate change mitigation policies in developing countries.

The diversity of developing countries means that each economy may follow a different growth path depending on its unique socioeconomic conditions, resource endowment, and government policies. Considerable uncertainty exists about how these factors and their long-run impact on economic activity may evolve over the next century. This uncertainty serves as a rationale for the use of multiple baselines; each corresponding to a particular expectation of the future pattern of development and economic growth.

As noted above in the section on Cost Analysis Principles, cost is never the only consideration in choosing among alternative measures for climate mitigation and adaptation. In developing countries, other factors can dominate decision-making more so than in industrialized countries. Other factors such as the equitable distribution of benefits, taking into consideration impacts on those that are particularly vulnerable to climate change, the associated benefit of reduced air pollution, and other environmental impacts need to be considered in an integrated manner in analyzing policies and programs to combat climate change.

The large informal sector and poorly established property rights can create significant barriers to the introduction of advanced technologies and for the implementation of climate change mitigation policies in developing countries. It is suggested that a modified approach be developed and applied to costing studies of developing countries with particular attention given to the following:

- Inclusion of alternative development pathways in projecting future baselines
- Consideration of market transformation processes in capital and labour markets in macro-economic assessment, and the inclusion of non-energy sectors such as land-use change
- Explicit representation of traditional energy sources, such as biomass, in climate change modeling
- Inclusion of transactions in the informal and traditional sectors in national macroeconomic statistics
- Transparent consideration of the full costs of removing market barriers

1.1.2 Mitigation Assessment in Energy, Forestry and Agriculture Sectors

The assessment of GHG emissions and carbon sequestration in energy and the two land-use sectors should follow similar analytical steps that are shown below:

- Construction of a baseline, including a socioeconomic scenario and sectoral activity projections
- Identification of mitigation options
- Assessment of mitigation potential and costs of the options
- Construction of mitigation scenarios that integrate combinations of mitigation options
- Assessment of policy measures and their potential for implementation

The specific coverage of the steps may vary across studies, depending on the availability of data, modeling tools, and existing human capacity for sectoral assessment.

Optimization and simulation are the two main modeling approaches in the energy sector, and these yield cost estimates that are not necessarily comparable, and require reconciliation. The major cost concepts used in the energy sector include the use of cost curves which illustrate the economically attractive technology options for reducing greenhouse gas emissions. Methodological approaches and input assumptions for energy demand and supply projections also differ, and these affect the comparability of energy sector studies. Finally, implementation challenges affect the choice of options in the energy sector. The potential barriers and policies to remove them are discussed in the report.

The discussion of the forestry and agriculture sectors outlines the specific cost and benefit components relevant to these sectors, and explains the way carbon accounting and cost assessment can be conducted for different types of mitigation activities. The carbon accounting is different and more complicated than for the energy sector, because carbon is stored in vegetation, detritus, forest soils and wood products over different timeframes. A methodology for assessing this carbon sequestration is supplied. The section also provides an overview of methodological approaches and models applied to the assessment at project and sectoral level, and reviews costing studies for developing countries. It is finally concluded that there is a need for further methodological development in relation to mitigation assessment for forestry and agriculture in order to reflect economic impacts at sectoral level and to understand specific policy issues for developing countries.

1.1.3 Adaptation Costs Framework and Methods

The report describes a framework for defining adaptation to climate change that considers several important dimensions. First, it differentiates between: (i) adaptation that economic agents would undertake, on their own, to avoid (or benefit from) the impacts of climate change in the absence of government policies or programs to adapt to climate change, and (ii) actions that governments undertake to adapt to climate change. Second, it includes adaptation measures that are structural in nature, such as dams and sea walls, as well as behavioral adjustments. Finally, it includes activities to improve and disseminate information about the way climate is changing.

The report also presents a framework for estimating and comparing adaptation and mitigation benefits and costs. The framework is consistent with traditional approaches as presented in a number of recent studies about the economic value of the effects of climate change in specific sectors of developed country economies. This means that sector models that have been used to estimate the imposed costs of climate change can also be used to estimate adaptation benefits and costs. This is achieved by comparing the benefits and costs of a new scenario, which includes adaptation to an altered climate, to those of a Base Case climate scenario.

The application of this framework needs to be conducted at the global level to ensure that the resulting balance of actions is globally optimal. This stems from the fact that mitigation projects provide benefits that are in the nature of a global public good, while the benefits of adaptation actions represent either private goods, in the case of autonomous adaptation, or regional or national public goods in the case of adaptation strategies

The definition of adaptation and the framework for estimating adaptation benefits, costs and net benefits is based on optimising behaviour by individual economic agents - consumers, producers and factor owners. As such, it is a normative framework, similar to that employed by many governments and international funding agencies to evaluate alternative investments. But normative in relation to what? Optimising behaviour depends on the objectives being pursued by economic agents and governments.

This definition of optimal adaptation (and mitigation) is based largely on the concept of economic efficiency. This normative framework describes how rational economic agents will respond to climate change in a perfectly competitive economy, and provides a proscription for governments to take actions to remove various forms of “market failure”, including the global externality created by GHG pollution. However, the concept of perfectly competitive markets is rarely found in reality. Moreover, rational behaviour is also an illusive concept because both governments and individuals often have objectives other than welfare maximisation. This means that the definition of “optimal” adaptation and mitigation will need to be tailored to the objectives and structure of different economies.

1.1.4 Macro-economic Cost Assessment

A macroeconomic cost assessment seeks to estimate the net overall cost of a mitigation or adaptation action after taking all of the indirect effects into account. Various sectors of the economy are interrelated, both directly, through purchases of goods and services, and indirectly, through mechanisms such as changes in government spending or borrowing. Thus mitigation and adaptation actions induce costs and benefits in various sectors of the economy which cause the net overall cost to differ from the direct cost of the measure.

The macroeconomic cost of a mitigation or adaptation action is estimated by comparing the performance of a national or the global economy under the assumption that the action is not implemented and the performance of the same economy assuming the action is implemented. The comparison must be framed correctly for the question being analysed. If the question is the cost of meeting a proposed commitment then a base case with no mitigation actions is appropriate. If the focus is on alternative policies for meeting a commitment, then the base case should reflect the commitment.

A model or models should be selected for the analysis on the basis of their suitability for the task and their ability to provide the information desired by policy makers. Each model has strengths and weaknesses for particular applications. To answer the questions of concern to policy makers it may be necessary to use more than one model. Unfortunately, the number of models available for a particular country is often quite small, so the reality is usually a choice from among a limited number of imperfect options.

The scale and the specific nature of the proposed mitigation or adaptation action affects the macroeconomic cost. The purpose of a macroeconomic cost assessment is precisely to understand how costs vary with the nature and magnitude of the proposed action. But the estimated costs also depend significantly on the assumptions embedded in the model(s) and those adopted for the analysis. Assumptions that are particularly important include the:

- Rate of economic growth in the base case
- Rate and nature of technical change
- Arrangements for revenue recycling
- Adjustments for changes to the performance of the economy relative to its potential output
- Policies adopted by other countries.

1.2 Cross-sectoral and Long-term Cost Issues

Measures to mitigate emissions of GHGs and their impacts on natural and human-made systems involve a number of long-term and cross-sectoral issues. Whereas mitigation projects in the energy sector mostly consist of activities and policies which reduce GHG emissions through energy efficiency improvements and/or switching to less-carbon-intensive fuels, in land-use sectors mitigation projects entail both emission reduction through measures such as forest preservation and substitution of fossil fuels with biofuels, as well as measures to sequester carbon in vegetation, soils, and biomass-based products.

Analysis of mitigation and adaptation measures in the energy and land use sectors reveals an array of cost concepts which originate from the nature and functioning of these sectors in the economy. The impacts of these measures can not fully be adjudicated through the market mechanisms largely due to the interactions with other sectors. This compels us to examine the related issues of cost representation in various measures, prices of inputs and outputs, externalities, capital market imperfections, income distribution and infrastructural costs.

Implementation of mitigation and adaptation policies has long-term ramifications due to the competition for resources by various socio-economic activities and due to the long-term nature of damage associated with climate change. Analysis of these policies requires a thorough understanding of critical issues like the timing of emission reduction, rate and impact of technological change, and discounting of values of inputs (costs) and outputs, including reduction of damages associated with climate change.

The timing of emissions reduction is crucial to policy makers because excessive allocation of resources to these measures in the early stages will draw resources away from competing sectors, while inadequate allocation may lead to unacceptable levels of damages. Factors which tend to point to an economic preference for deferred abatement include capital stock considerations, greater removal of atmospheric carbon, possibilities of rapid technological change, and the discounting of future values.

The speed with which climate-friendly technologies diffuse through economics is one factor that will decide whether extraordinary resources need to be allocated for reducing emissions. Higher economic growth could lead to faster capital stock turnover, and rapid penetration of energy-efficient and/or affordable climate-friendly technologies will affect the necessary abatement levels. The choice of an appropriate discount rate is crucial since a high discount rate can cause the present value of costs incurred over decades or that of impacts occurring far into the future seem negligible.

These issues are discussed and suggestions are presented on how to adequately cover them in analyzing climate mitigation policies and projects.

1.3 Cost Concepts in Climate Policies and Strategies

Political decision making relating to the issue of climate change takes place at different levels of aggregation: globally in the convention negotiation context, regionally (as in the European Union, where countries make joint action decisions), and nationally where all countries are required to develop strategies for meeting their obligations under the Framework Convention on Climate Change (FCCC). Within countries, meanwhile, analysis and decision making are typically carried out at the national and local levels.

In most cases, decisions will be based on a number of criteria and concerns. Economic analysis can make important contributions. However, it is important for both national and international discussions and policy-making processes that the different economic concepts be understood and applied in a manner consistent with their theoretical and practical limitations. This naturally applies also to concepts from disciplines other than economics.

Actions taken to mitigate or to adapt to climate change will generally divert resources from alternative uses. Within the general analytical framework, the purpose of the cost assessment is therefore to translate the effects of climate change action into comparable quantitative units that reflect the impacts on society's welfare. In this way the national cost assessment ideally should become an integrated part of a broader national decision framework for climate change mitigation, given the variety and importance of non-economic factors that will inevitably play a role at every stage of policy formulation. Since all potential impacts cannot possibly be analyzed, choices must be made as to what should be studied. To make such a selection, any of a variety of other decision-making criteria could, consciously or subconsciously, be utilized.

It is worth spelling out some of these other decision-making criteria. Equity is one that receives a good deal of emphasis. However, it is important to recognize that there is not one universal interpretation (let alone application) of the term. With respect to climate change mitigation, equity arguments can be used to support prescriptions for “polluter pays,” “ability to pay.” “meeting basic needs,” and other operational rules. Views will differ on the most desirable distribution of costs and benefits. Another decision-making criterion is risk. Some decision-makers are highly risk-averse, while others are risk-neutral, and still others are risk-loving. Given these differences, the criterion of risk can also yield a wide range of prescriptions.

Factors other than economic costs and benefits will therefore be important in determining the national decision framework for climate change mitigation. Nevertheless, it is also worth noting that decisions may not be made as rationally as has been suggested here. There is a strong process element, which means that climate policies will evolve over time as part of a process involving a number of iterations. Given the various pressures placed upon decision-makers, from both within and outside government, it stands to reason that different pressures will be felt at different times, and not always for expected reasons. Again, the message is simply that the policy-making process will inevitably use a range of criteria to make and implement decisions and that not all of these actions will necessarily be predictable at the outset.

In the FCCC negotiation context and in other international fora, there has been significant discussion of national and international regulatory and economic instruments that could be used to implement agreed emission reduction targets. The purpose of this section is to examine a few of these key instruments, especially in the light of the Kyoto Protocol, which in Article 2 calls for the implementation of appropriate policy instruments, including emission trading and joint implementation.

The report will illustrate how economic concepts and well as non-economic concepts can make a contribution to ensuring that society's overall response is as positive as possible. Separate discussions are made on regulatory approaches and market instruments such as emission taxes, tradeable permit systems and joint implementation projects.

This report is intended to be used for understanding cost concepts and their appropriate applications. It can also serve as a basis for the development of guidelines for the estimation of costs, but in its current form it does not contain material that can be used for the latter purpose. The paper focuses primarily on results and examples from the energy and forestry sectors and on macroeconomic analysis. However, it does not provide a comprehensive review of results. A review of results reported in the literature can be found in the 1995 IPCC Second Assessment Report (IPCC, 1996).

Reference

IPCC, 1996: *Climate Change 1995: Economic and Social Dimensions.* Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Chapter 2

Cost Analysis Principles[1]

by

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[1] This chapter was revised after the Workshop on Mitigation and Adaptation Costs Assessment: Concepts, Methods and Appropriate Use, held at Risø, Denmark, June 9–11, 1997, and in the light of comments received from several peer reviewers to an earlier draft. We thank the participants of the workshop and the reviewers for their comments. The final responsibility remains, however, with the authors. The authors acknowledge the financial support for this work provided by the UK Government (Department of Environment, Transport and the Regions)

2.1 Introduction

2.1.1 Background

This chapter presents a conceptual framework for estimating the costs of mitigating and adapting to climate change. In spite of the availability of a vast literature on the costs of adapting to climate change and reducing emissions from greenhouse gases, there has been very little discussion of the conceptual and theoretical issues involved. Since much of the work has been done by non-economists, and since well-known economic principles of cost assessment have not previously been used in this area, there is a need to lay out the key issues in a clear and non-technical manner. Although the whole of this report is dedicated to that task, this chapter is particularly important in ensuring that the key definitions and concepts are presented in a clear and consistent manner.

2.1.2 Structure of the Chapter

The following section (Section 2.2) presents an outline of cost concepts and how they should be understood in the context of estimating mitigation and adaptation costs. Some of this may seem unnecessarily simple and didactic, but laying out the different definitions of cost, and describing how they apply in the climate change context is both important and helpful, especially to non-economists. Section 2.3 presents the overall framework in which climate change mitigation and adaptation costs have previously been measured. This has been done at three levels (macroeconomic, sectoral, and project), and has been used to evaluate a variety of policies and investments. A review of existing literature in the field reveals considerable inconsistencies of methodology and a lack of coherence between the different levels of analysis. The section describes what an “ideal” framework for such cost assessment would look like, and includes a discussion of the specific problems that arise in each type of assessment (macro, sectoral, and project). This is followed by a discussion of the issues that arise across all assessments, beginning with the definition of baseline, which has a whole section to itself (Section 2.4). Other key issues are discussed in Section 2.5. These include valuation of indirect costs and benefits, choice of discount rates, integration of adaptation and mitigation costs, and selection criteria for evaluating different programmes when results are available from cost assessments at different levels of aggregation. Section 2.6 discusses the problems arising in the implementation of the kinds of programmes for which the costs have been estimated. The workshop in June 1997 which discussed earlier versions of this paper noted that there was a serious divide between estimated costs and the actual costs likely to be incurred in implementing the programme. Such implementation costs cannot be easily included in the formal cost assessments but are nevertheless very important in the selection of policies. Where they can be included in the main analysis, this should be done, but where they cannot be a separate report should be made of these implementation issues. Section 2.6 also discusses how the different dimensions of cost should be reported for a project or a programme that addresses climate change. Finally, Section 2.7 makes some recommendations and concludes the report.

Wherever possible technical jargon has been avoided. Where it has been essential to define terms, as non-technical an approach as possible has been used. In all cases examples are given from the climate change literature.

2.2 Concepts of Cost for Climate Change

2.2.1 General Conceptual Issues

The word cost is widely used in everyday language and has a number of meanings and applications. This makes its use in a precise context all the more difficult, as people bring strong preconceptions to their understanding of the term. In addition, different cost concepts may be relevant to different decision makers and different purposes. Many of these concepts are also related to each other in a variety of ways.This section examines the concept of cost as it is used in the economic literature and differentiates among the various types of costs that must be considered in cost analysis.

2.2.2 Economic Opportunity Cost or Economic Cost

The key idea behind an economic cost of something (call it *X*) is the value of the scarce resources that have been used in producing *X*. That, in turn, is measured in terms of the value of the next best thing that could have been produced with the same resources, and is called the *economic opportunity cost*[2] (because it represents the value of a forgone opportunity to use the resources for something else)**.** This notion of cost may differ greatly from the common notion of cost. For example, take the cost of sequestering carbon by growing trees on a tract of public land. In estimating the costs of such a programme, what do we take as the cost of the land? In some cases no "cost" is attached, because the land is not rented out and no money actually flows from the project implementor to the owner (the state in this case). This, however, is incorrect in economic terms. The cost of the land is to be measured in terms of the value of the output that would have been received from that land had it not been used for forestry. The output could be a market good or service (e.g., agricultural output), a non-market good or service (e.g., recreational use), or a combination of both.

Resource use also incurs financial flows. In the same example, the government may have leased the land to a farmer, who keeps livestock on it. If it is used for forestry, the government may demand no payment from the forestry authority. In that situation the opportunity cost might be interpreted as a loss of revenue to the government. Although that is an opportunity cost to the government, it is incorrect to take it as the *economic opportunity cost.* The reason is that the price of the original lease may not be equal to the opportunity cost of that land. Even assuming that livestock grazing is the highest value use to which the land can be put, the value of the land is actually equal to the *net income* from livestock grazing after all expenses have been deducted.[3] If, as is often the case, the land is leased for much less than that, the opportunity cost will not be equal to the financial flow to the government[4].

The key points to note with regard to opportunity cost are the following:

a) There exists an *economic opportunity cost* for the use of a particular resource, provided this use hinders an alternative use.
b) There may be an *economic opportunity cost* to the use of a resource, even if there are no financial flows associated with that use.
c) If there are any financial flows, the *economic opportunity cost* may or may not be equal to the value of those flows.

In designing mitigation and adaptation programmes, decision makers are interested in minimizing the *economic opportunity cost* of the programme. *Economic opportunity cost* is sometimes called just the *economic cost* and is closely related to *social cost.* It is also related to the concept of *shadow price,* both of which are discussed below. Policymakers will, however, also be interested in the *financial costs* of a programme, because these costs may well determine what can, in fact, be implemented. Hence, both *economic opportunity cost* and *financial cost* are relevant. Financial costs are also discussed below.

2.2.3 Average, Marginal, and Total Costs

The terms *average, marginal,* and *total costs* are frequently used. The *total cost* of a programme is simply all items of cost added together. The *average cost* is defined as the total cost divided by the number of units of the item whose cost is being assessed. With greenhouse gases, for example, it would be the *total cost* of a programme, divided by the physical quantity of emissions avoided. By contrast, the *marginal cost* is the cost of avoiding the last unit of the emission. Marginal cost can also be defined as the rate of change of total cost with respect to the level of control. In all of the above cases, a problem arises when there is more than one objective whose cost is being assessed, or when the cost figures relate to more than one objective. This gives rise to *joint costs* which are discussed below.

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[2] The modified term *economic opportunity cost* is used here because there is a distinction between such a cost measured in terms of the true scarcity value of the economic activities forgone and the opportunity cost measured, for example, in terms of the financial value of the activities forgone. The text provides examples of this distinction.

[3] How such expenses are deducted is discussed in greater detail later in this chapter.

[4] It can be shown that, under competitive markets with no taxes, costs based on market prices will be equal to the economic opportunity costs. This is important in the estimation of opportunity costs from market data.

In terms of valuation, all three types of cost are relevant. Programmes with given emission reduction targets are evaluated in terms of minimizing *total costs*, but decisions about the level of mitigation or adaptation to be undertaken will need to consider *marginal costs* (see Section 2.3). *Average costs* are relevant when comparing mitigation programmes with different levels of greenhouse gas reduction. Examples of all three are given in this chapter.

2.2.4 Incremental Cost

The term *incremental cost* is used by the Global Environment Facility (GEF), which provides financial support for climate change programmes. *Incremental cost* is defined as the additional cost a country incurs when undertaking a climate mitigation project, compared with the economic cost of the activity that could have been substituted for the project[5]. In order to estimate such a cost it is necessary to know the economic costs the country would incur in the absence of the programme or, in other words, to define the *baseline.* There may be a difference in incremental cost as estimated by the country and as estimated by an international body such as the GEF. Differences may arise because of the way that costs are perceived – an *economic opportunity cost* for one group is not necessarily a cost for another.

A full discussion of incremental costs can be found in GEF (1996) or Gowen (1996). For the purposes of this report, it must be recognized that *incremental cost* is a distinct cost concept, although it is related to *marginal cost*[6]. As an example, consider a programme that results in reductions in greenhouse gases through upgrading of gas pipelines. The cost to the country of the programme is $50 million, but there are direct benefits, in terms of reduced gas leakage of $25 million. Hence the net cost of the project is $25 million. What is the incremental cost? This depends on what measures the country would have undertaken in the absence of its climate change obligations. Without having to reduce greenhouse gas emissions, it could have implemented a less ambitious project with net costs of $10 million instead. The incremental cost would then be $15 million.

From a country's point of view there is, therefore, a distinction between the cost of the project (total or marginal) and the incremental cost. Both concepts are relevant for decision-making purposes. The selection of projects to achieve a certain target reduction should be based on minimizing the incremental cost as defined above. The total costs of the project are, however, relevant for determining its financing and may be instrumental in deciding which projects can in fact be implemented.[7]

2.2.5 External Cost, Private Cost, and Social Cost

The term *external cost* is used to define the costs arising from any human activity that is not accounted for by the agent causing the externality. For example, emissions of particulate pollution from a power station may affect the health of people in its vicinity, but this effect is not considered in private decision making and there is no market for such impacts. Hence such a phenomenon is referred to as an externality, and the costs it imposes are referred to as the *external* costs. These external costs are distinct from the costs that the emitters of the particulates do take into account when determining their outputs, costs such as the prices of fuel, labour, transportation, and energy. Categories of costs influencing an individual's decision making are referred to as *private costs*. The total cost to society is made up of both the *external cost* and the *private cost* and together they are defined as *social cost.*[8]

Social Cost = External Cost + Private Cost

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[5] This is the definition adopted by the Framework Convention on Climate Change (FCCC). The FCCC distinguishes between *agreed full costs* and *agreed full incremental costs*. The former indicates that that all cost elements are to be covered but there is uncertainty about costs and parties have to agree on underlying assumptions. The term incremental costs reflects the fact that only the incremental costs measured in relation to a baseline case are to be covered.

[6] Gowen (1996) warns of the danger in confusing marginal and incremental cost in the estimation of greenhouse gas reductions.

[7] The *incremental cost* notion is quite close to the cost-benefit rule for the evaluation of a project or programme, in which one compares the cost with the project and without the project. The difference between the two represents the true cost of the project.

[8] Where the pricing of commercial goods is such that it includes both the private cost and the external cost (i.e., it is based on social cost), it is referred to as *full cost pricing*.

To estimate mitigation and adaptation costs, it is necessary to work with social costs. Often, however, data will only be available on the private cost. In these situations a correction has to be made for the missing costs. Methods for doing so are discussed briefly below. For further material on external costs the reader is referred to Baumol and Oates (1988), and Cornes and Sandler (1996).

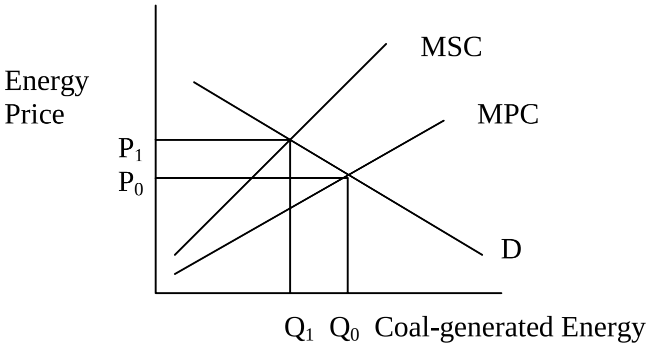

Figure 2.1. Relationship between external, private and social costs

The relationship between these different cost concepts is illustrated in Figure 2.1. The market equilibrium for energy occurs where marginal private costs (MPC) are equal to demand (D), resulting in a clearing price of P_0 and consumption of Q_0. The marginal social cost (MSC) function, however, lies above the MPC function due to the existence of externalities, and, thereby, external costs. The extent of those costs is measured by the vertical distance $P_1 - P_0$. If these external costs are accounted for, the new clearing price will be P_1, and the consumption of Q_1 will be correspondingly lower. This is considered to be the *socially optimal* equilibrium.

Following on from the above example, the burning of fossil fuels (which, *inter alia*, is associated with private costs and benefits) is also associated with distinct external costs, of which global warming is one. If greenhouse gases are abated by reducing fossil energy use, not only are the social costs of global warming reduced but other direct external costs associated with the use of that energy (such as damage to health, forests, and ecosystems) are reduced as well. This results in additional external benefits, known as *secondary benefits* (see Ekins, 1996). There are also other important secondary benefits related to mitigation strategies such as forestry projects, where the conservation of biodiversity may yield significant value (see Janssen, 1997).

2.2.6 The Time Dimension in Costs

When a project or programme is undertaken, costs will be incurred at various points in time. In evaluating such programmes we must take account of all such costs, and not just those incurred in the present time period, or even during the lifetime of the project. For example, a nuclear power project will have costs of safe disposal of radioactive waste long after the plant has been decommissioned.

There are various concepts of total cost that reflect the time dimension. A principal one is the *present value cost* of a project. This is the sum of all costs over all time periods, with future costs discounted. For a project that has costs C_i in period i the present value cost of the project is:

$$\sum_{i=0}^{i=T} C_i (1+r)^{-i}$$

Where the project has costs incurred over T years, and where the annual rate of discount is r. Discussion of discount rates is to be found in Chapter 7. Such a cost can also be referred to as the *lifecycle cost* of the project, where the lifecycle is defined as the full period over which the project has impacts and incurs costs.

2.2.7 Joint Costs

Many projects undertaken as part of a climate change programme will have secondary objectives. Alternatively, projects undertaken for reasons other than climate change may also have the effect of reducing greenhouse gases.

In terms of defining costs these secondary outcomes can pose a problem. If a project is undertaken primarily for the purposes of reducing greenhouse gases, and if it has other impacts, then it is most convenient to treat any costs or benefits relating to those impacts as *secondary costs* or *benefits* for the greenhouse gas project. For example, if a greenhouse gas limitation project consists of measures to increase energy efficiency in transport, some of the costs will be associated with the purchase of more energy efficient vehicles, which in turn will provide benefits for the operators of the vehicles. The cost to the greenhouse gas project should then be the total cost of the whole project, less any secondary costs and benefits received by the operators.

In cases where the activity is largely carried out for its own sake, only a very small component may be associated with greenhouse gas mitigation. Take a gas pipeline project of $2 billion. Normal design would result in a given level of gas losses. If, however, the project is designed so that greenhouse gas losses are further reduced, the cost may rise to $2.2 billion. In such a case the cost of the greenhouse gas project is best treated as the incremental cost of $200 million and appraised accordingly.

The decision whether to treat the associated activities or the greenhouse gas project as secondary has to be taken on a judgmental basis. If the project is likely to have taken place regardless of its climate change implications or if it could be justified on the basis of purely non–greenhouse gas benefits alone, the greenhouse gas emission reduction could be regarded as secondary.

2.2.8 Shadow Prices

The preceding discussion concluded that the proper cost to consider in greenhouse gas projects is one based on *economic opportunity cost*. Where markets operate competitively and efficiently, the prices will reflect the opportunity costs and can be used to estimate the correct costs. In many instances, however, this will not be the case, and some correction will need to be made. The corrected market price, which should be equal to the *economic opportunity cost* of the resource, is called the *shadow price*. For example, if a project uses labour that is paid a wage of $20 a day but the *economic opportunity cost* of that labour is only $12, the *shadow price* of labour is $12. Adjustments to market prices to obtain shadow prices will be needed when

a) there are distortionary taxes and subsidies, so market prices deviate from economic opportunity costs
b) there are monopolies and other market imperfections making the market price higher or lower than the shadow price.

The simplest way to correct for such distortions, *where the resources are tradable,* is to take the international prices of the resources. Assuming well-functioning markets and no significant externalities, these prices have been shown to be “optimal.” If a good is exported, for example, the export price can be taken, or where it is imported the import price can be taken. These prices should then be corrected for taxes and subsidies (i.e., the former should be deducted and the latter added).

However, given the inequities in trading relations between many nations in the international trading system and the reliance of some nations on a limited number of exports, the use of shadow prices based on international prices may not adequately reflect the value of those resources to that nation. Appropriate mechanisms are therefore needed to enable indigenous valuations to be reflected in decisions concerning the allocation of resources.

Where the good is not traded, the shadow price should be calculated on the basis of the cost of producing the good, with the inputs being valued at their economic opportunity cost. A method for doing this has been developed by Little and Mirrlees (1974), Ray (1984), and Squire and van der Tak (1975) and subsequently used by researchers to estimate shadow prices in a number of developing countries.

When applying this framework to a project (e.g., wind-powered irrigation for increased agricultural yields), three important shadow prices are typically required. They are the prices of capital, labour, and foreign exchange. For these, detailed analysis of the relevant sectors is required, and a discussion of the methods is beyond the scope of this report. The analyst carrying out a greenhouse gas estimation is advised to obtain the relevant values from economists who have worked on the sectors concerned. The World Bank and other bodies involved with GEF projects appraise projects in most developing countries and have a set of values that are used; these can be accessed from their databases (as can the shadow prices for many inputs and outputs).

The framework of shadow prices has also been used to address the fact that policymakers place different valuations on costs borne by different sections of society. There is a view in the economics literature that income transfers to the poor are worth more than transfers to the rich because the same increment in income for each will have a considerably greater impact on the welfare of the poor. Consequently, projects should take account of "relative" income effects (Ray, 1984; Ng, Yew-Kwang , 1987). In order to do this, it is first necessary to know which parties bear the costs and which ones receive the benefits. Second, it is necessary to have weights that can be applied to these costs and benefits. Both exercises are problematic; data on the income levels and other characteristics of gainers and losers are not easy to come by and will require additional information which may not be available. The weights applied are, of course, value judgements. They estimate, for example, the value of a gain of one dollar to someone whose present income is Y_i relative to someone whose income is equal to the average for that country or region $\overline{Y}$.

Economic theory has developed a method of weighting the benefits and costs according to who is affected. This is based on converting changes in income into changes in welfare and assuming that an addition to the welfare of a lower income person is worth more than the same addition to that of a richer person.

More specifically, a special form can be taken for the social welfare function. One that has been commonly adopted is that of Atkinson (1970). He assumes that social welfare is given by the function

$$W = \sum_{i=1}^{N} \frac{AY_i^{1-\varepsilon}}{1-\varepsilon}$$

where:

W is the social welfare function
Y_i is the income of individual i
ε is the elasticity of social marginal utility of income or inequality aversion parameter
A is a constant

The social marginal utility of income is defined as

$$\frac{\partial W}{\partial Y_i} = AY_i^{-\varepsilon}$$

Taking per capita national income $\overline{Y}$ as the numeraire and giving it a value of one, we have

$$\frac{\partial W}{\partial Y_i} = A\overline{Y}_i^{-\varepsilon} = 1$$

and

$$\frac{\partial W}{\partial Y_i} = SMU_i = \left[\frac{\bar{Y}}{Y_i}\right]^{\varepsilon}$$

where SMU_i is the social marginal utility of a small amount of income going to group i relative to income going to a person with the average *per capita income*. The values of SMU_i are in fact the weights to be attached to costs and benefits to group i relative to average costs and benefits.

In order to apply the method, estimates of $\bar{Y}$ and ε are required. The literature gives estimates of the inequality aversion parameter (ε) that lie in the range of 1–2 (Stern, 1977; Murty *et al*. 1992). A value of 1 would be implied if (a) policymakers decided to value environmental damages to all individuals at the value associated with the average-income individual, and (b) the "income elasticity" of environmental damage with respect to income was 1. This approach has some appeal when governments are unwilling to attach higher costs for environmental damages to the rich than to the poor. Estimates of $\bar{Y}$ can be obtained from national or regional income data for the country or region concerned.

To take a simple example, consider the case of India, where in 1995–1996 the average annual income was Rs9300. What would the project cost to a person with an income level of Rs3000 (about 30% of the average)? If the value of the inequality aversion parameter is assumed to be 1, then the "cost" entered into the accounts for that person would be (9300/3000), which is 3.1. Similar weights can be constructed for different values of inequality aversion and for any country in which greenhouse gas limitation costs are being estimated and applied in any analysis.

The decision of whether or not to use income weights remains, however, a problematic one. Many decision makers prefer to look at the distributional effects separately from the cost efficiency issues. Others prefer an integrated approach such as that presented above. In the latter case, income weights can be applied, based on the method outlined above.

2.2.9 Financial Costs

An important component of each project or programme is the financial cost involved and the implications it has for the government budget. Consequently, a financial analysis will be required for any mitigation/adaptation programme for greenhouse gas limitation. Financial analyses will differ from economic analyses in the evaluation of projects and programmes in the following respects:

a) Financial analysis considers net returns to equity capital or to a private group, whereas economic analysis considers the net returns to society as a whole.
b) Financial costs indicate an incentive to adopt a project, whereas economic costs determine whether a project can be justified on the basis of economic efficiency.
c) Loans and interest payments are considered as costs in a financial assessment and as transfers in an economic assessment.
d) The rate of discount is considered as the marginal cost of money in financial analysis and as the opportunity cost or social time preference rate in economic analysis.
e) Financial costs include unadjusted taxes and subsidies.
f) Financial costs ignore all external effects.
g) Income distribution is considered in financial analysis but not in economic analysis.

2.2.10 Conclusions

A clear understanding of the terms and their role in the analysis is critical to the correct and consistent estimation of the costs of mitigation and adaptation to climate change. The main points to note are:

a) The key cost concept in evaluating mitigation/adaptation programmes, despite its rather theoretical and abstract nature, is the *economic opportunity cost*. This may not be equal to the financial flows arising from the programmes.
b) To estimate the *economic opportunity cost* of a programme it is necessary to adjust the data received from market transactions. One set of adjustments involves the addition of any *external costs* that arise.
c) A second set of adjustments is needed to correct for distortions in market prices. Such distortions include government taxes and subsidies, non-clearing markets (where supply and demand are not equated), and various forms of imperfect competition.
d) The full set of corrections described above can provide an estimate of the *social cost* of the programme. In order to compare programmes, it is necessary to calculate such costs with and without the programme. The difference is called the *incremental cost.*
e) In addition to the analysis based on the social cost as defined above, policymakers will be interested in the *financial costs*. Hence it is important that these also be estimated carefully and presented alongside the *incremental costs*.

2.3 A Framework for the Estimation of Mitigation and Adaptation Costs[9]

2.3.1 Background

This section looks at the different levels of analysis for greenhouse gas mitigation and adaptation and discusses the best method of ensuring consistency between the different levels of estimation and analysis. Table 2.1 describes the main ways in which different studies of greenhouse gas mitigation and adaptation are conducted.

The highest level of analysis is the national or international macroeconomic study. Such studies (also referred to as “top-down” studies) look at different policies for reducing greenhouse gas emissions and compare the impacts of these policies with a scenario in which the policies have not been implemented. Examples of such studies are Barker *et al*. (1994) and Ekins (1994) for the UK, Jorgensen and Wilcoxen (1993), Nordhaus and Popp (1997) for the US, and Capros *et al*. (1996) for the EU. Details of the use of such models are discussed in Chapter 9. IPCC (1996) cites more than two hundred such studies. The analysis is conducted using sophisticated models of the economy that incorporate the linkages between the different sectors and allow for the responses of supply and baseline demand in different markets to changes in prices, taxes, and other control parameters.

The analysis at the macroeconomic level provides the policymaker with information on the likely impacts of different policies. These impacts are measured in terms of changes to parameters such as the rate of growth of GDP, the level of *per capita* GDP, employment, and the trade balance. In almost all cases such an analysis does not include the costs of adaptation to climate change. The models may or may not specify a target reduction in emissions (see Chapter 5).

The economic assessment is usually carried out at the national level, but in some models the issues have been addressed at the regional level (e.g., for the EU, see above) or even globally. The wider framework for looking at policies allows us to examine the effects of different policies in different countries (e.g., by comparing a carbon tax introduced in one country unilaterally with a carbon tax introduced worldwide).

The next level of analysis is the sectoral level and is usually conducted for the energy sector, but it may also be carried out for forestry and other sectors that can contribute to greenhouse gas emission limitation. Some models may work with subsectors, such as the electricity supply industry and transport. Studies of the sectoral level are often based on a very detailed data collection where linkages between sectors are generally not taken into account. The aim is to identify investments and policy changes that will limit greenhouse gas emissions in a cost-effective manner.

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[9] The cost concepts developed in this section are also discussed in Chapter 8 of IPCC, 1996 (Section 8.2.2). In this section we elaborate on that earlier discussion and focus it more towards the practical task of estimating the mitigation and adaptation costs in specific studies.

Examples of major studies of this type are Edmonds and Reilly (1985, energy sector), Joule (1991, energy sector), ADB (1993, energy sector), and Dixon *et al.* (1991, forestry). The analyst looks at a range of options and selects those that will achieve a given reduction in emissions at least net present value (NPV) cost. These options are sometimes classified in terms of *technical potential*, *economic potential,* and *market potential*.

Technical potential options are those that, given current technology, could be adopted. Economic potential options are those technical options that could be implemented in a cost-effective way[10] in the absence of market barriers but may need market reforms to be realizable. Market potential options are those economic potential options that could be achieved under current market conditions, assuming no new policies and measures.

As with the macro-level analysis, a baseline has to be defined, but now this baseline will represent only a subset of the variables considered in the macroeconomic baseline. As with the macroeconomic level, there are no major studies where the analysis includes policies for mitigation *and* adaptation. In general, adaptation policies do not apply to the same sectors as the ones for which mitigation impacts are estimated, so it is not surprising that the integration of the two sets of costs is not carried out at this level.

From the sectoral analysis, specific projects will have been identified as those that can achieve the greenhouse gas targets at least cost. A further stage looks at the projects in greater detail, including design features, and estimates the costs as well as the greenhouse gas reductions achieved at a more refined level. At this level, issues of financial cost will play a prominent role in determining the choice of projects and could be as important as the economic costs.

2.3.2 The Ideal Method of Estimating Greenhouse Gas Mitigation and Adaptation Costs

Ideally the analyses should be consistent between levels and should provide a coherent information set to the policymaker. To achieve this objective, the analyses should be structured as follows.

a) The macroeconomic analysis should be based on greenhouse gas mitigation targets *and* adaptation programmes and should look at the implications of meeting such targets and implementing such programmes with different macroeconomic policy instruments. These include economic instruments such as carbon taxes, government spending on adaptation, increases in energy prices, and incentives for energy efficiency. The “without policy” option will provide a baseline for the economy as a whole and will include predicted emissions for the period of the analysis.
b) The sectoral analysis should follow from the macroeconomic analysis, which will have identified broad policy variables for all sectors. Sectoral policies and investment programmes should be consistent with the broader macroeconomic analysis. As an example of how sectoral cost estimation is influenced by the macroeconomic policies, consider energy efficiency programmes, the costs of which are dependent on prevailing tax regimes. With higher energy taxes, certain measures will automatically be adopted by the private sector. It would be incorrect if the sectoral analysis did not take account of such adoptions or did not include them in the selected programme.
c) The project level analysis must only include projects that are part of the solution thrown up by the sectoral analysis. Although the costs that emerge from a more detailed investigation may be different from the estimates of the higher level analysis, the overall set of projects should be in the sectoral plan. Likewise, the baseline emissions for the project evaluation have to be consistent with those for the sectoral evaluation.

2.3.3 Macroeconomic Analysis

The macroeconomic models are discussed in greater detail in Chapter 6. The main issues associated with such models and their use in the analysis of greenhouse gas costs are the following:

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[10] Cost-effective options are defined as ones using a technology or measure to deliver a good or service at equal or lower cost than current practice allows.

a) measurement of costs using GDP
b) baseline selection
c) modelling of macroeconomic impacts
d) selection of adaptation programme
e) treatment of double dividend and multiple objectives
f) interpretation of the results of the macroeconomic analysis in combination with the results of lower levels of analysis

a) Measurement of costs using GDP. Macroeconomic models use changes in GDP as a measure of the economic cost. There is a difficulty here in that GDP, unlike economic opportunity costs, is not a correct measure of welfare. The reasons why GDP changes may not reflect changes in welfare are primarily the presence of non-market benefits and costs. So, for example, a policy that reduces GDP but improves air quality will have a measured loss in GDP terms but could have a net welfare gain when account is taken of the benefits of the improved environment. The same applies to changes in income distribution, or poverty, since these will affect welfare but will not be picked up in the crude macroeconomic measures of GDP change. For these reasons the macroeconomic analysis can only provide a partial picture of the impacts of climate change measures.

b) Baseline selection. Issues related to the baseline are discussed in some detail in Section 2.4. It should be noted that the baseline in many macroeconomic models will generally be rather crude as far as emissions are concerned, given the higher level of aggregation of these models. In most cases these are not checked for consistency with the more disaggregated sectoral models. This is due to the fact that the work is frequently done by different researchers who do not communicate on the setting of the baseline. Ideally the baseline assumptions for the macroeconomic evolution of the economy should be made by the macroeconomic analysts and these afterwards should be linked to disaggregated sectoral projections of emission sources and sinks.

c) The modelling of macroeconomic impacts. There are many approaches to the modelling of macroeconomic impacts and these make different assumptions about how the economy operates and, in particular, how efficient it is at clearing markets, especially the labour market. The costs of containing greenhouse gases will in large part depend on which kind of model is taken and on the assumed values for key parameters. In particular, since greenhouse gas models have long horizons (often more than 20 years) the rates of technological change will be crucial in determining the costs. IPCC (1996) provides ample evidence that results can vary a great deal from one model to another. We should also emphasize that even if agreement could be reached on the underlying model to be used, differences would arise because many of the parameters on which the answers depend are not ones for which we have adequate empirical estimates. Modelling is further discussed in Chapter 6.

d) Selection of adaptation programme. No macroeconomic analysis known to the authors includes increased expenditures for adaptation in its macroeconomic projections. As noted below, these will be determined by global emissions, not the emissions of the country itself. However, whatever level is chosen will have an impact on the macroeconomic performance of the economy. Thus, work needs to be done to include adaptation costs in the existing models.

e) Treatment of double dividend and multiple objectives. Some macroeconomic models have looked at the issue of climate change by imposing carbon taxes to encourage the reduction of greenhouse gases. In such models the issue of what is done with the revenues arises. If the revenue is used to reduce other taxes or is recycled in some other way, the overall impacts will not be indifferent to the method of recycling. Much is made in some studies of a possible “double dividend,” in that reducing the more distortionary taxes can increase economic efficiency and provide economic gains in addition to reductions in environmental impacts. The view taken here is that the modelling of policy instruments for climate change should not confuse the issue by seeking multiple objectives. If a carbon tax is introduced, the costs of achieving a given target reduction in emissions should be based on a series of realistic scenarios that could be adopted for revenue recycling and the potential impacts assessed. This ties in with baseline definitions, as discussed below. The models that have looked at double dividend issues have focused on the concept of tax recycling where the revenues gained from the carbon tax are used to offset payroll taxes, corporate taxes and even reduce public expenditure deficits. This requires several complex tax reforms, which may be very difficult to implement.

f) Interpretation of the results of the macroeconomic analysis in combination with the results of lower levels of analysis. The results of macroeconomic models are presented in terms of changes in GDP. This is, of course, not the same as the economic cost, which was defined in Section 2.2. GDP is an aggregate measure of the value of goods and services and is based largely on market transactions. It does not include damages to the environment or other external costs and benefits. A major secondary benefit of greenhouse gas mitigation is the reduction of emissions of pollutants such as particulates and sulphur dioxide, which is not captured in GDP changes. Furthermore, to the extent that resources in the economy are not efficiently employed, market prices will deviate from economic opportunity costs and the GDP measure will be flawed. At present it is not possible to work comprehensively with *green GDP* concepts which, in principle, correct for externalities, but much is hoped for the future. Hence, it is important to note that the GDP measure can only provide one guide to policy. It cannot be the basis of the detailed mitigation or adaptation plan, which must be drawn from a careful estimation of the costs in the disaggregated sectoral models.

Table 2.1. Framework of models for estimating adaptation and mitigation costs

LEVEL	BASELINE	OBJECTIVES	OPTIONS	METHOD	OUTPUTS	COST ISSUES
MACRO	Macro level estimates of greenhouse gas emissions.	National or global targets for emissions. How are reductions measured? Cumulative vs. final year?	Macroeconomic plus sectoral policies. Define set of options as set S1.	CGE models Macroeconomic models	Cumulative costs relating to sectors and projects identified	Discounting Relation to lower levels of assessment Modelling of macroeconomic impacts. Treatment of double dividend and multiple objectives.
SECTORAL	Projects at sectoral level (e.g., energy, forestry)	Targets for sectoral reductions in emissions	Sectoral investment programs and policies. Define set of options as S2 ⇒ S2δ S1. Policies include adaptation and mitigation	Integrated sectoral models for mitigation and for adaptation. Combining the two sets of models.	Least-cost NPV including secondary costs and benefits.	Discounting Treatment of indirect costs and benefits. Treatment of joint costs. Treatment of no-regrets options.
PROJECT	Disaggregation of sectoral policies	Implementation of specific policies/ investment programmes.	Issues of design of detailed programmes and policies. Define set of options as S3 ⇒ S3δ S2δ S1. Both adaptation and mitigation policies and investments to be covered.	Extended project appraisal methods.	Net costs of options in NPV terms, including secondary costs and benefits.	Discounting. Definition and use of shadow prices, including for capital. Joint costs. Economic costs. Financial costs. Treatment of external costs.

2.3.4 Sectoral Analysis

The sectoral or “bottom-up” models are discussed in greater detail in Chapters 4 and 5. The selection of the mitigation options that will form the basis of the analysis has to be wide enough to include all those that could be implemented, *given* the current institutional and market arrangements and *given* the way these arrangements are likely to evolve. Using the terms discussed above, the options from which the selection of mitigation strategies is made should not be the technical potential options but the economic potential options.

In addition to some of the points raised above, the main issues arising at the sectoral level are:

a) selection of the baseline
b) treatment of no-regrets policies
c) estimation of economic opportunity costs
d) treatment of joint costs

a) Selection of the baseline. In sectoral analysis the baseline is more precisely defined, but, as was stated in Section 2.4, it is highly sensitive to the assumptions made about the future development of the economy and the sector. It will also be sensitive to policy changes that are assumed to take place in the future.

b) Treatment of no-regrets policies. Many sectoral analyses conclude that there are options that will reduce greenhouse gas emissions and have lower costs than the baseline. Such options are referred to as no-regrets options. No-regrets options may actually exist at every level, but their benefits may not accrue at each level simultaneously. However, if such options exist, why are they not already being implemented? There are often perfectly good reasons for the failure to adopt such policies, such as institutional barriers or an inefficient capital market. But the key point to note is that these barriers are not going to disappear of their own accord. If we wish to implement the so-called no-regrets policies, we should allow for the costs of removing these barriers. One way the estimates could be modified is by including costs such as those of institutional reform and capacity building into the analysis This has until now only to a limited extent been done in sectoral or bottom-up analyses.

Another is to place a shadow price on the resources that are scarce and that act as an impediment to the adoption of no-regrets policies. Prime among these is capital, which should have a shadow price greater than one in many developing countries. Overall, the need to take account of such “hidden” costs is very important to a realistic appraisal of the different projects and policies. It is a grave mistake to assume that certain projects and policies can be implemented without incurring significant institutional and transitional costs relating to changing practices and customs. This is a sadly neglected area of cost estimation and needs a lot more work. It is discussed further in Sections 2.4.2 and 6.3.1.

c) Estimation of economic opportunity costs. Estimation of the economic opportunity costs is necessary for establishing both the baseline and the selected policy scenario. Section 2.2 discussed the issues in some detail; these will not be repeated here. The main point to note is that in each case there is an attempt to measure the social costs. This will require estimation of the key external costs and benefits as well as the adjustment of market prices for deviations from economic opportunity costs. Again, with few exceptions, the sectoral analyses that have been carried out to date have not done this. Where the options selected involve changes in market institutions (i.e., they are part of the economic potential but not the market potential), the additional costs of making these changes *must* be included in the cost assessment.

d) Treatment of joint costs. Section 2.2 raised the point that many programmes involve secondary benefits and costs. The least-cost strategy for greenhouse gas limitation should allow for such secondary effects; either by netting them out of the main -greenhouse gas–related programmes or by analysing any greenhouse gas changes resulting from actions that have been taken for other reasons. One approach to computing the cost-effectiveness of pollutants with joint costs is to add all the reductions together, with or without any form of weighting.Alternatively, one can compute the cost per tonne reduced for each pollutant separately.

2.3.5 Project Analysis

The main issues at the project level relate to the estimation of external costs, the estimation of shadow prices, and the treatment of joint costs/multiple objectives. These issues are discussed in detail in Sections 2.2 and 2.6

2.4 Baseline Scenarios

2.4.1 Definitions

Any cost estimate is a function of the underlying *baseline scenario*, also referred to as the *reference scenario*. A baseline scenario reflects those actions expected to be taken at the global, national, regional, or sectoral level in the absence of any intervention with respect to the climate change issue and does not include assumptions concerning the effect of climate change on costs. The baseline scenario incorporates forecasts of economic growth and structural and technological change (for both consumption and production technologies). On the basis of these variables, an estimate of future greenhouse gas emissions is made. The underlying assumption is that no specific actions are taken to reduce emissions or enhance carbon sinks over the given period.

The magnitude of the costs of mitigation or adaptation to climate change is critically dependent on assumptions about future economic development and structural change in the economy. For example, the higher the underlying economic growth assumed in the baseline, the greater the estimated costs of mitigation or adaptation will be. Similarly, the greater the shift to low energy sectors (e.g., services), because of structural change, the higher the estimated costs of *further* emission reductions. Because we cannot make firm predictions about such shifts, many commentators have suggested working with multiple baselines (see below).

2.4.2 Issues Arising in Short- to Medium-Term Baseline Scenarios[1]

As already noted, baseline use will depend on the kind of analysis being undertaken. For macroeconomic models it will be more approximate about emissions but more detailed about economic variables such as growth rates, investment, and taxes. Bottom-up models, on the other hand, will give more accurate (or at least more detailed) information on emissions, but will keep information on the overall economic performance as background to the emissions scenario. Similarly, there will be a difference between scenarios built to determine actions over the short to medium period and those needed for longer-term mitigation plans. This section discusses the problems to be addressed in the short- to medium-term scenarios. These arise, primarily, from differing views in three general areas:

- the efficiency of energy markets and hence the size of no-regrets potentials induced by switching to cheaper alternative technologies
- the degree of distortion due to pre-existing fiscal systems
- the influence of labour market distortions

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[1] Sections 2.4.2 and 2.4.3 draw heavily on the discussion given by Hourcade and Robinson (1996), which, in turn, is a condensed and reworked version of Chapter 8 of the Working Group III volume of the Second Assessment Report of the IPCC (IPCC, 1996).

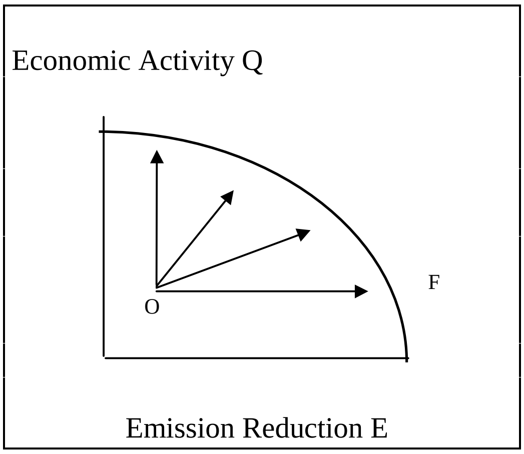

Figure 2.2. Trade-offs between emission reduction and economic activity (Hourcade and Robinson, 1996)

The no-regrets concept is illustrated in Figure 2.2. The figure depicts the production frontier (F) of an economy, showing the trade-off between economic activity (Q) and emissions reduction (E). Each point on the curve shows the maximum level of emission reduction for a given level of economic activity.

For the preparation of cost assessments, the crucial factor is where the baseline scenario is located with respect to this curve. If the chosen baseline scenario assumes the economy to be located on the frontier, then there is a direct trade-off between economic activity and emission reduction. Increased emission reduction moves the economy along the frontier to the right. Economic activity is reduced and the costs of adaptation or mitigation increase. In this case, no-regrets measures cannot be implemented. If the economy is below the frontier, at a point such as O, the potential for no-regrets actions exists and there are various options available to realize them. *Theoretically*, emissions can be reduced without hindering economic growth (i.e., without increasing overall costs), and their reduction may even enhance economic activity. In reality, however, realizing this potential will incur costs of the kind discussed in the previous section and will be dependent on political commitment and the availability of cost-efficient strategies.

The baseline chosen will reflect the efficiency of the economy. Unfortunately, this matter is rather difficult to assess in its own right, and its assessment is complicated by the fact that the frontier itself is not static (since it is most likely to expand outwards over time through technological innovation). The economic debate is, therefore, as much about the location and characteristics of the baseline scenarios as it is about the comparative costs and implications of the various *interventionist* policy scenarios.

The other market and government distortions mentioned above (labour markets and fiscal inefficiencies) will have a similar effect to that of no-regrets policies. If it is assumed that they can be removed, the economy can move closer to its efficiency frontier and reductions can be made in emissions without incurring real costs in terms of reduced economic activity elsewhere in the economy. Such an assumption cannot, and should not, be made simply on the grounds that economists or other policy analysts have identified such opportunities. The assumption should only be made if it is part of the policy framework; otherwise, it will create false expectations about the costs of mitigating greenhouse gases[2].

In conclusion, therefore, the construction of the baseline is a complex and difficult matter. Whilst the differences in estimates arising through the use of different modelling approaches have become more reconciled in recent years (IPCC, 1996), those arising from the use of different baselines remain. It is therefore important that studies carefully report assumptions about the location of the baseline relative to the

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[2] Multiple baselines are now considered in a number of studies. One baseline takes for example policy as unchanged, and the other assumes policy will change in a direction that is based on past trends and present declarations. In the energy sector, for example, mitigation guidelines distinguish between several types of baseline scenarios, including business-as-usual, (where no specific, non–price-induced greenhouse gas reduction actions are taken) and minimal energy efficiency (where some measures to improve the efficiency of resource use are voluntarily adopted). See UNEP (1994) or Sathaye and Meyers (1995).

economy-emissions frontier in order to provide the necessary background information to understand differences in cost estimates.

2.4.3 Long-Term Projections and Multiple Baselines

The preceding discussion is mainly applicable to the assessment of climate change costs over the short to medium term. Over the long term, the focus changes, with more emphasis being placed on the structural content of the baseline scenario and its predictability. The chosen baseline still has the power to affect mitigation cost estimates and the resulting energy policies in a fundamental way, but for different reasons. According to comparative studies,[3] long-run greenhouse gas emissions appear to be strongly related to underlying development patterns. The main determinants are:

- population
- technological patterns
- income and consumption patterns
- policy decisions and their timing and enforcement
- geographical distribution of activities
- structural change within industry
- trade patterns and international specialization

These factors can be incorporated to some extent in existing climate change models that analyse policy over the short term or medium term. In the long term, however, it is less acceptable to assume that historical trends in the determinants of development patterns will continue to unfold at the same pace and in the same direction. For example, developing countries could leapfrog over the most energy intensive (and environmentally damaging) stages of industrialization.

The difficulty in predicting the evolution of development patterns over the long term stems, in part, from a lack of knowledge about the dynamic linkages between technical choices and consumption patterns and, in turn, how these interact with economic signals and policies. Technology and consumption patterns are both endogenous, their direction essentially determined by political decisions. There are also many general uncertainties, particularly of a political and social nature. Indeed, the whole methodology of constructing scenarios is in itself a complicated and controversial procedure. The inevitable result is that subjective judgement is required about how such qualitative factors might influence the variables in the model. This subjective factor clearly has an influence on the resulting cost estimates and indeed tends to decrease the value of costs assessments in the long run.

These considerations strongly suggest the need to work with several alternative baseline scenarios that are characterized by different assumptions about, for instance, development patterns and innovation. This approach allows the mitigation or adaptation assessments to create an impression of the costs associated with very different development paths. Indeed, the range of emission levels associated with alternative baseline scenarios could well be greater than the difference between a certain baseline and the corresponding active policy case! The majority of work on climate change has focused only on the construction of a single baseline scenario (no active policy) and then compared this with several interventionist policy cases.

In reality, such an approach can only provide a partial insight into the costs of climate change. Despite the large disparities in cost estimates likely to arise through the use of multiple baselines, they do allow the future to be framed in a much wider analytical perspective. The use of a number of different development patterns is of particular importance for developing countries. Since the major part of their infrastructure and energy systems is yet to be built, the spectrum for future development is wider than in industrialized countries and this variety of future development trends should be reflected in baseline scenarios for developing countries (IPCC, 1966, Chapter 8).

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[3] Martin (1992) and Darmstadter *et al*. (1977)

2.4.4 Tools for the Construction of Baseline Scenarios

Much of the data for the construction of national baseline scenarios can be obtained from official economic and environmental development programmes and sector-specific planning documents. Once projections have been made from the data, they need to be evaluated with regard to consistency, *realism,* and policy implications. Following that it is necessary to make an assessment of macroeconomic development trends (in the absence of climate change policy) that are connected to the major greenhouse gas emitting sectors identified under the anticipated development path or paths. The aim of this macro assessment is to identify key national economic priority areas and the implications for future greenhouse gas emissions and policy options (UNEP, 1996).

The availability of macroeconomic plans and formalized models for developing countries is generally limited. The available data will typically project from five to ten years, limiting macro analysis to the short term. More medium-term analysis must focus on the main factors connected to future greenhouse gas emissions. This suggests that the baseline scenarios need to include a broader evaluation of short-term economic development policies, especially in sectors where climate change mitigation projects might be integrated. Valuable inputs in such broad assessments include:

- national development plans and economic statistical reviews
- formalized macro models (Input-Output, Computable General Equilibrium)
- national sector plans for the energy system
- detailed project assessments carried out in relation to general aid programmes
- sector-specific models (e.g., energy, agriculture, transportation, forestry)
- detailed site-specific assessments of land use activities
- implementation studies for specific technical options, including Demand-Side Management (DSM) and Integrated Resource Planning (IRP)
- broader implementation studies for the financial sector

Data limitations will mean that it is inevitable for longer-term projections to be more aggregated than those for the short to medium term. For developing countries, the focus should be on the main future trends in population, sectoral economic growth, the transition from the informal to the formal economy, infrastructure investments, and natural resource management.

2.5 Other Issues Arising in Cost Estimation

2.5.1 Valuation of Indirect Costs and Benefits

The need to include the indirect costs and benefits of mitigation programmes as well as of the baselines was emphasized in the previous section, together with the main procedures for doing so. Again it should be noted that in most studies these costs and benefits have not been included, nor has allowance been made for the fact that many market prices are distorted and give an incorrect estimate of the true social costs of the programmes.

Methods for the valuation of such costs and benefits exist, and indeed estimates exist for many of the relevant impacts. For a discussion of the methods, the reader is referred to ADB (1996) or Winpenny (1995). For estimates of external costs relevant to energy, see CEC (1995) and Pearce (1996). For shadow pricing, close collaboration with local project economists is suggested, since they have estimates that can be applied to the mitigation cost exercises. The time is appropriate, therefore, for the greenhouse gas cost estimates to be extended in these directions wherever sufficient data are available. It should be stressed, however, that monetary estimates of climate change damages are still highly contentious, not only because of uncertainty about certain parameter values but also because many commentators feel that numerical estimates tend to conceal the difficult ethical implications of various actions[4].

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[4] The literature in this area is very large, but work by Azar (1997), Schneider (1997), and Spash (1996) stresses various aspects along these lines.

2.5.2 Choice of Discount Rates

The debate on discount rates is a long-standing one. As the IPCC (1996) report notes, there are two approaches to discounting: an *ethical* approach based on what rates of discount should be applied and a *descriptive* approach based on what rates of discount people actually apply in their day-to-day decisions. The former leads to relatively low rates of discount (around 3% in real terms[5]) and the latter to relatively higher rates (in some cases very high rates). The arguments for either approach are unlikely to be resolved, given that they have been going on since well before climate change was even an issue. Normally, the costs are calculated for more than one rate to provide the policymaker with some guidance on how sensitive the results are to the choice of discount rate. The sensitivity is certainly there; at high rates energy projects with long gestation periods become unattractive compared to those with a shorter period.

In addition to discounting future costs and benefits as shown in Section 2.2, there is the further issue of whether or not future emission reductions or carbon sequestration should be discounted when compared to present reductions. The justification for discounting them is that future reductions are worth less than present reductions in terms of reduced impacts. The choice of the appropriate rate, however, remains an unresolved issue and, again, taking a range of plausible values is the only solution. A recent survey of discount rates applied to carbon flows reveals values ranging from 0 to 10 % (Boscolo *et al.*, 1998). Some studies do not apply a discount rate but simply take the average amount of carbon stored over the project lifetime (referred to as flow summation) or amount of carbon stored per year (flow summation divided by the number of years). Both these methods are inferior to applying a discount rate to allow for the greater benefit of present sequestration over future sequestration.

Issues relating to discount rates are discussed further in Chapter 7. One point perhaps that should be noted relates to the use of low discount rates for appraising greenhouse gas programmes in developing countries, where capital is scarce and market rates of discount are very high. This low real rate for mitigation programmes can be justified on the ethical grounds mentioned above. The scarcity of capital, however, can be dealt with by having a shadow price for capital that is greater than 1.

2.5.3 Integrating Mitigation and Adaptation Costs

Most of the work on climate change has focused on mitigation costs and relatively little has been done on adaptation costs. Adaptation costs are costs arising from measures to reduce the impacts of climate change. They include such responses as the building of sea defences, the relocation of vulnerable groups of people, and changes in cropping patterns.

Adaptation may be autonomous (i.e., apart from public policy) or strategy-specific and will depend on what *global* emissions of greenhouse gases are anticipated. The greater the level of emissions over the next 20–30 years, the more important it will be to take measures to protect the public against the consequences of global warming. In principle, the level of adaptation chosen should be such that the present value of the marginal costs of actions undertaken is equal to the marginal value of the reduced impacts resulting from the actions. In practice, such calculations are exceedingly difficult to make, because the results of adaptation measures are very difficult to quantify in monetary terms, Doing so requires, as a start, an estimate of the damages associated with climate change. As is well recognized, such estimates are extremely uncertain. After that, the effects of adaptation measures in reducing climate change impacts have to be calculated. These, too, are difficult to quantify and uncertain. Much of the case for adaptation has to be based on risk aversion to possible future impacts. Finally, as with mitigation programmes, adaptation policy will also depend on the macroeconomic situation, which will determine the resources available for adaptation and the macroeconomic costs of diverting them from other activities.

What is clear, however, is that mitigation and adaptation decisions are, to a large extent independent of each other. A country that is committed to an emission target will have to meet it regardless of what adaptation is undertaken. The one way in which adaptation and mitigation options can influence each other is through their effects on the macroeconomic projections. For example, a high level of adaptation costs may imply

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[5] The real rate of discount is calculated by dividing the market rate by the rate of inflation. Thus, if a market has a discount rate of 12% and inflation is 8%, the real rate is 1.12/1.08 = 1.037 or 3.7%.

lower economic growth. Since these macroeconomic projections will be relevant to the selection of the adaptation policies and programmes, some of the tools that are used to assess mitigation options should also be used to assess the adaptation options. Preferably, the macroeconomic models should be run with the adaptation options included.

2.5.4 Selection Criteria for Evaluating Different Programmes

The selection criteria for the macro models are complex. Although one is interested in changes in GDP and/or welfare, that is not the only relevant factor. Other macroeconomic impacts, such as the government's fiscal position, trade, and redistribution are also important. The uncertainty of the impacts of different programmes is also noteworthy and may vary from programme to programme. It is extremely difficult to collapse all these factors into one single indicator of the rating of a programme, but attempts have been made using multicriteria or multiattribute analysis (MCA). This procedure weights the changes in the different indicators and arrives at a single value for ranking the project. It is described further in Section 2.6.3. We are not aware of any macro models having been evaluated in this way, but it is not impossible to do so. The main benefit of carrying out such an exercise is indirect: to see what weights would have been needed for a particular ranking to emerge or for a programme that is best in terms of GDP not to be the best in an overall sense. Other than that, the important thing is to present all the relevant information to the policymakers and let them make a decision that, ultimately, is a political one[6].

For programmes that estimate the cost of achieving a certain reduction in greenhouse gases, the main criterion is normally the net present value cost per tonne of greenhouse gas removed. If the cost in period i is C_i and the reduction in emissions in period i relative to the baseline is E_i, then the appropriate criterion is

$$\frac{\sum_{i=0}^{i=T} C_i (1+r)^{-i}}{\sum_{i=0}^{i=T} E_i (1+d)^{-i}}$$

where r is the rate of discount for costs and d is the rate of discount for emissions (usually but not always taken to be the same as r). It is rare, however, for programmes to be evaluated in this way. Frequently annual emissions are compared with levelized costs. Levelized costs are the fixed annual costs that have the same present value as the actual cost stream. Using such costs is not as accurate as using the above formula but is reasonable if it can be assumed that annual emission reductions are relatively constant. If a project has a present value cost of NPV and a life of T years, then the levelized cost is given by LC, where

$$LC = NPV \frac{r}{1-(1+r)^{-T}}$$

In addition to looking at the costs per tonne, analysts will also be interested in the financial costs of the programmes. They may also be interested in other aspects of the programmes, such as their impact on poverty, inequality, and the level of uncertainty involved. This chapter has not looked at such impacts directly, in the sense that no attempts have been made to incorporate them into the cost analysis.[7] It is probably best, if such considerations arise, that they be evaluated *alongside* the cost estimate, using the multicriteria approach described above, which will be needed anyway to resolve any differences that may arise as a result of ranking projects by their economic cost as opposed to their financial cost. The benefit of multicriteria analysis here, as in the case of the macro models, is that it shows what weights are needed to justify one policy or programme over another.

Thus far, the recommendation has been to use MCA for the different macroeconomic indicators of the programmes and *separately* for the microeconomic indicators. Although it is possible to use a combined

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[6] See Gregory *et al.* (1992).

[7] The exception is the treatment of inequality (see Section 2.2.8). As noted in that section, it may be unacceptable to convert inequality concerns into costs through shadow prices. If it is not acceptable, a multicriteria approach will be needed.

MCA for all cost indicators, this practice is not recommended. The issues involved in each type of analysis are different, and it is not easy to see how meaningful relative weights for micro and macro indicators can be derived.

Finally, the adaptation costs must be evaluated in terms of the net benefits, for example, in terms of the gains from reducing climate change impacts such as sea level rise and damage to agriculture. Such net benefits will make up one dimension of the "information pack" needed by the policymaker, who will also need to know the macroeconomic effects of the policies, the distributional impacts, and any uncertainties that may arise. All these factors may be important for the final decision.

2.5.5 Treatment of Uncertainty

A thread that runs through much of the discussion so far is that of uncertainty. The whole exercise of estimating mitigation costs is confounded by imprecise information about baselines and the direct and indirect costs of mitigation measures. It is critical that such uncertainties be recognized and conveyed to the policymakers in the best manner possible.

As has been noted, uncertainty about baselines is best dealt with by taking more than one baseline and reporting cost estimates for multiple baselines. Hence, costs will not be given as single values but as ranges based on the full set of plausible baselines.

Cost uncertainties can be divided into those related to direct costs and those related to indirect costs. Direct cost figures are more certain than the indirect ones, but there remains some imprecision, especially about the amount of carbon reduced and about the rate at which costs of technology will change over time. As with baselines, a scenario approach is recommended, with estimates prepared for low, middle, and high values.

Uncertainty about the indirect costs has been noted in Section 2.5.1. Summarizing the results of the different sectoral models will often not be very helpful because the range of results is extremely wide. Instead, the results of a wide range of analytical models should be reviewed. What is critical is to identify the main parameters that cause the variations in the macroeconomic results and bring these to the attention of the policymaker.

Overall, uncertainty is at the heart of the problem of mitigation and adaptation cost estimation. It has to be recognized and reported. Otherwise, the analysis could be extremely misleading to anyone responsible for formulating policy.

2.6 Issues Arising in the Implementation of Programmes and the Reporting of Cost Assessment Results

2.6.1 General Issues Arising in the Implementation of Climate Change Mitigation Programmes

Many aspects of implementation are not fully covered in conventional cost analyses. Considerable work needs to be done to quantify the institutional and other costs of programmes, so that the reported figures are a better representation of the true costs that will be incurred if the programmes are actually implemented. This section discusses the issues of implementation and the associated costs further.

Several economic and technical studies suggest that there is a large potential for climate change mitigation with no cost or very low cost. This potential results from energy efficiency improvements relating to end-use savings as well as from the introduction of more efficient supply technologies. There is also a potential for introducing new advanced renewable technologies like wind turbines, biomass combustion, photovoltaics, and solar-thermal power plants. The big remaining issue is, then, how such policies can be implemented.

The implementation of cost-effective mitigation options should be considered in the specific context where the policy is pursued. In particular, the following conditions for implementation need to be considered:

- market prices of inputs and outputs demanded or substituted
- financial market conditions
- institutional and human capacities
- information requirements market size and opportunities for technology gain and learning
- economic incentives needed (grants, subsidies, taxes)

Only some of these implementation conditions can be included in the formal cost assessment carried out for individual mitigation options. It will generally be more complicated to design implementation programmes involving many individual actors (e.g., a DSM program) than those involving centralized project planning (e.g., large-scale power sector changes). In this context it is important to distinguish between marginal and non-marginal projects, since the latter may well induce significant price effects.

Implementation policies can be separated into policies that can be described as small, marginal efforts that create an incentive for changing specific behaviour or introducing new technologies and more general policy efforts, like economic instruments or general educational programmes, that work by changing general market conditions and the capabilities of the actors.

Whether an implementation policy is marginal or general depends on general market conditions as well as on the whole design of policy instruments targeted towards climate change mitigation. Given a general environment in which energy and financial markets are efficient, competitive, and have little government intervention, and where the institutional context is perceived as favourable for climate change mitigation programmes, the implementation policies need only take the form of information programmes, energy auditing, and specific regulatory efforts. On the other hand, if energy prices are heavily subsidized and financial markets are very limited, the implementation policy may require general price reforms, specific grants, and other institutional changes.

Implementation policies of the marginal sort can be integrated relatively easily into project- or sector-level mitigation assessment. Implementation assessment will include the costs of different kinds of programmes for information, training, institution-strengthening, and the introduction of technical standards. The most difficult part of such an assessment relates to the behaviour of the target groups. A detailed amount of information is needed on the behaviour of specific actors, including households and private companies, in order to design the most effective policy options.

It is difficult to integrate general implementation policies like price changes into specific project and sector assessments. In a DSM programme in the commercial lighting sector, for example, implementation costs would include information and training programmes, institutional capacity building, financial costs, and sometimes also “costs” of changing market conditions (prices and taxes). The costs of general changes in market prices and tax systems can only be assessed at the economy-wide level. The introduction of energy or carbon taxes or removal of subsidies can cause significant structural effects that again will change energy demand and technology choice. Thus, the proper full analysis of the implementation costs will necessitate an economy-wide analysis involving, for example, the use of computable general equilibrium models and intersectoral macroeconomic models. These have been discussed in Section 2.3.3, and the difficulties and limitations of their policy usefulness have been noted there.

To a limited extent, such feedbacks can be integrated in a project- or sector-level mitigation cost assessment by the use of shadow prices. These shadow prices reflect underlying social valuations of the use of different goods and services by different agents. By estimating them in a suitable manner, some of the implementation costs, such as changes in government income or expenditure or the higher value of foreign exchange, can be captured in the cost analysis. (See Section 2.1 for a discussion of shadow prices.) It should be recognized, however, that implementation costs that have been assessed using shadow prices will not pick up factors such as quantitative or physical constraints on the use and allocation of some resources, particularly financial ones.

A framework for assessing implementation costs will then include: costs of project or policy design, institutional and human capacity costs (management and training), information costs, and monitoring costs. The costs of the resources involved should, in each case, be based on economic opportunity costs.

2.6.2 Incentives and Mechanisms for Implementing Climate Change Mitigation Policies

Climate change mitigation projects may often be proposed in sectors where major investment activities are taking place. An example is the energy sector in developing countries, where capital investments are expected to average nearly $300 billion per year over the period 1990–2020 (GEF/STAP, 1996b). International aid programmes, including support of incremental costs by the Global Environment Facility, will be small compared with these total energy investments, and it is therefore important to integrate climate change mitigation objectives as far as possible into the general investment policy.

Such an integration can take several different forms, including:

- specific programmes to support the development (including efficiency improvements, cost reductions, and market creation) of renewable energy technologies and other technologies with low carbon emissions
- bilateral financing mechanisms, such as joint implementation
- carbon offset systems, where a market is created for the exchange of emission permits

The idea of such mechanisms is to create attractive market conditions that will give private investors incentives to be involved in climate change mitigation projects. A number of international studies have discussed the potential and specific design of such strategies (GEF/STAP, 1996a; IPCC , 1996a; Reddy *et al.,* 1997).

It has been argued that the incremental cost concepts as defined by the FCCC can be used as an integrated part of such mechanisms, where international bodies such as the GEF, or national governments, support the creation of private sector incentives, either by funding incremental costs or by establishing conditions for bilateral project collaboration.

In one example of such mechanisms outlined by the GEF, it was assumed that the costs and efficiency of advanced renewable energy technologies such as wind turbines, biomass, photovoltaics, and solar thermal power would follow a so-called learning curve, where the marginal production costs would be brought down to the cost of conventional technologies with a certain implementation scale as a result of innovation (GEF/STAP, 1996b). Financial support would therefore be needed to support the implementation of the first generation of plants that could bring costs down. Subsequently, the technologies would be competitive on a regular market basis.

Market-based climate change mitigation instruments like joint implementation (JI) and carbon offsets focus, in a similar way, on the creation of conditions under which the private sector can mobilize capital. This will often be in conjunction with various kinds of government support systems, such as incremental cost compensation or other financial arrangements, legal support, and monitoring systems. JI projects, however, will only tend to be an incentive to investors if credits can be either sold or used to offset a domestic policy instrument such as a carbon tax or permit system (see Michaelowa, 1996).

Climate change mitigation policies based on the market or private sector, as described above, have a cost perspective that is somewhat different from the social cost concept described in the main part of this paper. The latter focuses on assessing resources involved in specific policy alternatives in order to evaluate their cost-effectiveness, while in the case of the market incentives one needs to consider the framework and conditions for different actors in order to establish a decentralized decision on policy implementation. Although the social costs will still be relevant for the analysis of such cases, it will be necessary to pay more attention to the indirect costs as described above. Some of these are not easily quantified in monetary terms. Others can only be assessed at the economy-wide level, and appropriate models will be needed for doing that.

2.6.3 Reporting of Cost Assessment Results

The cost and other impacts of implementing specific climate change mitigation options can be reported in several alternative formats, each reflecting different study assumptions and policy objectives. Some of the key aspects to report are: costs and other impacts of implementing climate change mitigation policies, time aspects, and uncertainties involved in scenario development and study design. The following section, based on current international practice, will critically assess how these different aspects can be reported.

Key policy impacts. National climate change mitigation studies are in most cases structured around identifying least-cost greenhouse gas emission reduction policies. These policies, however, have a number of important impacts in addition to those that are traditionally reflected in a cost assessment. These impacts include:

- employment
- income distribution
- foreign exchange
- financial requirements
- joint environmental products
- institutional and human capacity aspects
- reliability and robustness of strategies (reliability, risk, flexibility)
- market creation
- linkage to specific domestic technology suppliers
- technology innovation

These impacts have a multi-dimensional nature, and it is therefore difficult to define reporting formats that integrate the different dimensions. Some of the impacts such as employment, income distribution, foreign exchange, and financial requirements can be reported in monetary terms and/or in other quantities, such as number of persons employed. Other impacts, such as joint environmental products, can also be assessed partly in monetary values and partly using physical indicators and qualitative values. The most complicated impacts to report alongside cost results are probably those relating to institutional and human capacity considerations and those relating to technology and market creation. These, however, can be key national criteria for policy design. A number of different formats for reporting climate change mitigation study results are presented in the following paragraphs.

Cost-effectiveness of policy option. Most studies report the costs of meeting climate change mitigation potentials as one of the major policy design indicators. A very common framework for reporting utilizes the so-called greenhouse gas emission-reduction cost curves (IPCC, 1996, Chapters 8 and 9; UNEP, 1994). The idea of cost curves is to represent the marginal costs of greenhouse gas emission reduction in merit order. The costs as well as the greenhouse gas emission reduction can be measured in different units. Costs can be represented as net present values or levelized costs and can be assessed at project or sector level. In a similar way, greenhouse gas emission reductions can be represented as annual average flows or time-dependent values.

Cost curves can be constructed step-wise or as envelope curves. The step-wise procedure is based on assessments of specific projects or policies. Each step of the cost curve represents the marginal costs of implementing the options considered. Envelope cost curves are the least-cost combination of points on separate curves, each indicating an integrated set of sectoral policies. The two different cost curves are illustrated in Figures 2.3 and 2.4.

The obvious strength of the cost curve format is that it presents decision makers with a simplified overview of the cost-effectiveness of different options, telling them how the costs for a fixed point in time change with increasing greenhouse gas emission-reduction targets. Used alone, however, this overview can result in an overemphasis on the monetary cost aspects in the decision process.

The costs reported in the cost curves are, as already noted, only one important decision parameter. Impacts that are measured in monetary values can be integrated in the cost curve format, but until now few studies have integrated a monetary assessment of impacts outside the traditional market boundaries. The cost curves should therefore primarily be used as *one* of the key inputs for selecting policies to undergo a more comprehensive impact assessment.

Cost curve results are very dependent on a number of critical assumptions including baseline definitions, technology assumptions, and behavioural assumptions. This implies that cost curve results cannot be used directly to compare the cost-effectiveness of options across countries but should rather be used as a tool for ranking the cost-effectiveness of different options, given specific national study assumptions. International study reviews have, in fact, concluded that the ranking of specific subcategories of technical options in cost curves seems to be reasonably comparable across countries (IPCC, 1996, Chapter 9).

The development of costs over time. A number of important time issues are involved in assessing the costs of climate change mitigation. If income, measured in the conventional fashion, rises over time and the stock of natural resources does not increase, environmental wealth will become more scarce and its value will appreciate. Other things being equal, mitigation costs will decrease over time if they quantify greenhouse gases in monetary terms. A further issue is how the availability and efficiency of technical climate change mitigation options are expected to increase over time. Similarly, the potential for integrating technical options with capital turnover and new investment will increase with time and needs to be taken into account.

These different temporal aspects can be integrated in energy system models and other tools used for sectoral mitigation cost assessment, but the temporal aspects of strategies can be difficult to illustrate in cost curve representations. Figures 2.5, 2.6, and 2.7 illustrate various temporal aspects of mitigation costs.

The cost curve shown in Figure 2.5 is a snapshot of costs measured on an annual basis in relation to one specific reporting year. Here the costs are defined as levelized cost, and the greenhouse gas emission reductions are annual reductions (eventually transformed to “levelized” values). The options included in the establishment of the snapshot cost curve have been evaluated over the full lifetime of the options, and the curve is therefore a kind of frozen picture of the options in that specific year. It should be stressed that the upward concave shape of the curve is somewhat idealized and speculative with respect to the evolution of costs.

The temporal aspects of climate change mitigation costs can be illustrated as in Figure 2.6, where two snapshot cost curves for greenhouse gas emission reduction are shown for different reporting years. Here the two cost curves can be constructed to show the costs of meeting specific reduction targets at different points in time. In this example, the costs of reductions are assumed to decrease over time as a consequence of technological development and expanded possibilities for matching new investments and regular capital turnover. Again, the curves should be regarded as hypothetical.

Lastly, the cost curve illustrated in Figure 2.7 shows the development over time of meeting one specific emission-reduction target (in this example, stabilization of emissions at base year 1990). The costs in this figure are shown to be increasing over time because the absolute greenhouse gas emission reduction required to meet base year stabilization is expected to increase. However, alternative cost variations, such as a function that decreases over time, could be possible and would be dependent on rates of technical innovation and societal adjustments.

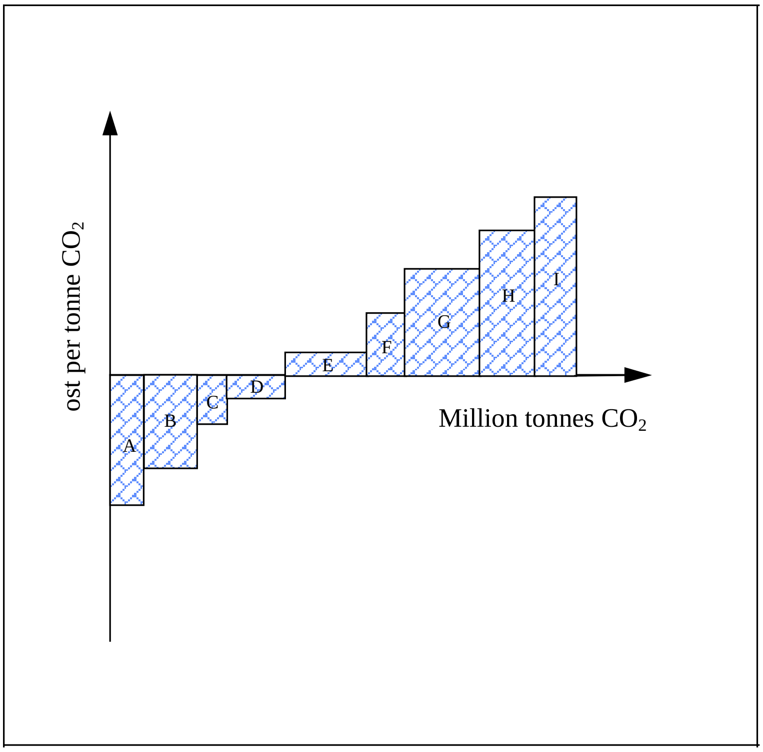


Figure 2.3. Stepwise cost curve

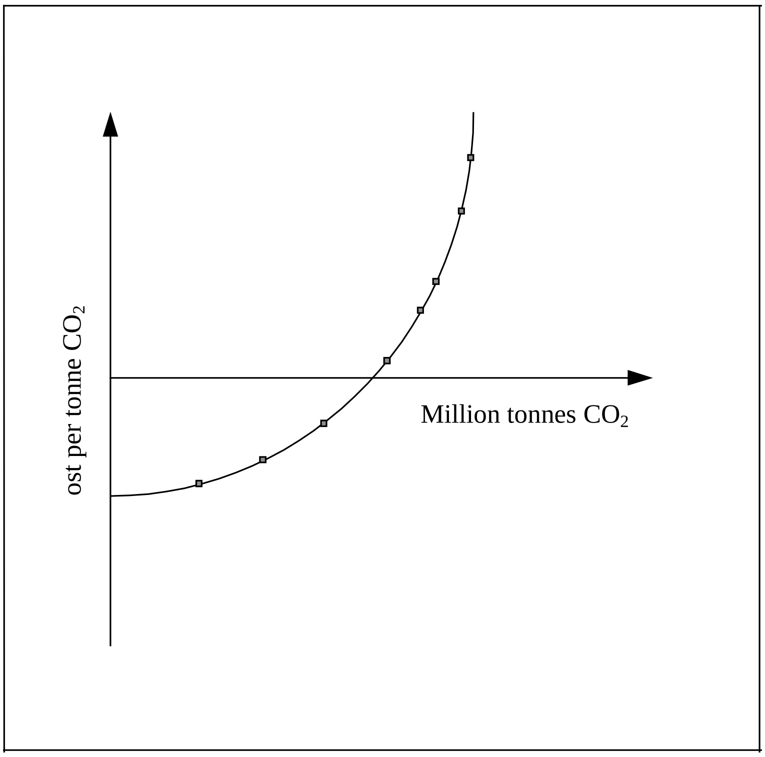


Figure 2.4. Envelope cost curve

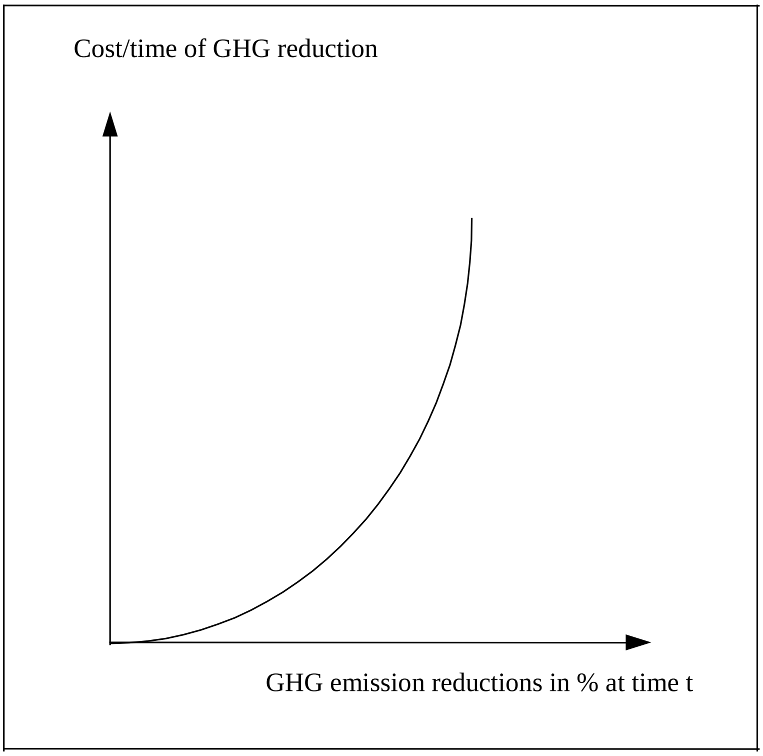


Figure 2.5. Snap-shot Cost Curve

In many cases it will be reasonable to assume that efficiency and technology costs develop with the scale of adoption of technology. This can be explained in the framework of so-called technology-learning. According to this framework, the efficiency of the technology is improved as a consequence of experience gained in the implementation phase. These efficiency improvements are explained by feedbacks from test configurations, maintenance skills, institutional capacity building, and creation of industrial collaboration.

Technology learning should be distinguished from traditional economy-of-scale effects, where the economically optimal implementation scale is relatively large, as in the case of conventional power plants and infrastructure projects.

Expected technology learning effects have been a key argument behind the operational funding criteria of the Global Environment Facility. A GEF strategy paper (GEF/STAP, 1996a and 1996b) argues that the marginal costs over time of a number of advanced renewable energy technologies (e.g., wind turbines, biomass, photovoltaics, and solar thermal-electric technologies) can be brought down to the level of conventional technologies, if GEF subsidizes the implementation in the initial phase. The cost principles behind this approach are illustrated in a technology learning curve, illustrated in Figure 2.8. A similar format can be used to illustrate the costs of a specific technology innovation process seen from a national perspective.

Reporting the implications of major study assumptions. The costs and greenhouse gas emission-reduction potential of a specific policy are dependent on a number of economic and technical assumptions in the baseline and the mitigation scenario that interact in a very complicated way. The magnitude of the climate change mitigation potential is related to the greenhouse gas emission intensity of the baseline scenario as well as to the assumptions about available technologies and policy instruments. The options considered in the mitigation case will vary with the development of the economic structure and general technological development. This is valid for both highly aggregated scenarios and individual options, where penetration rates and efficiency parameters will change over time. Figure 2.9 shows some major scenario assumptions.

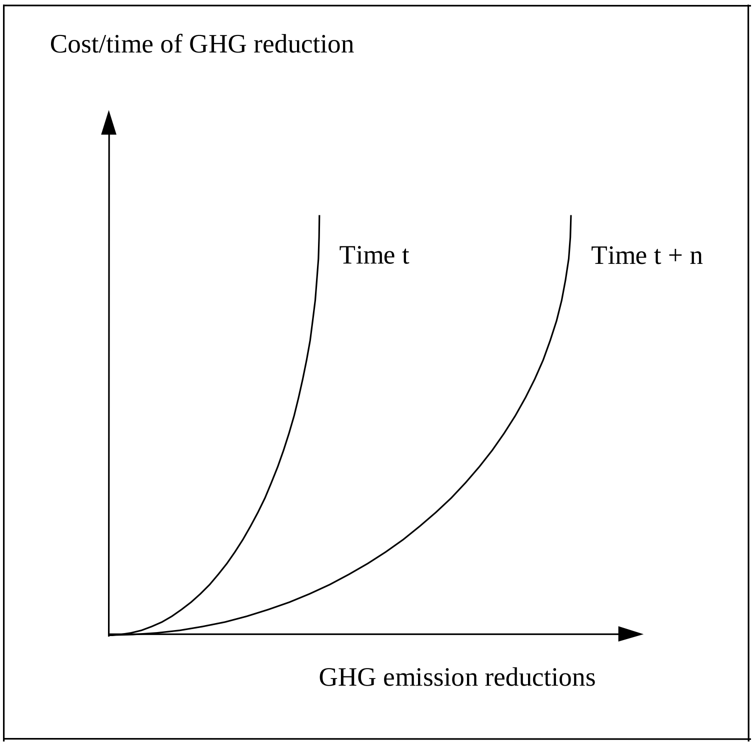


Figure 2.6. Temporal aspects of mitigation costs

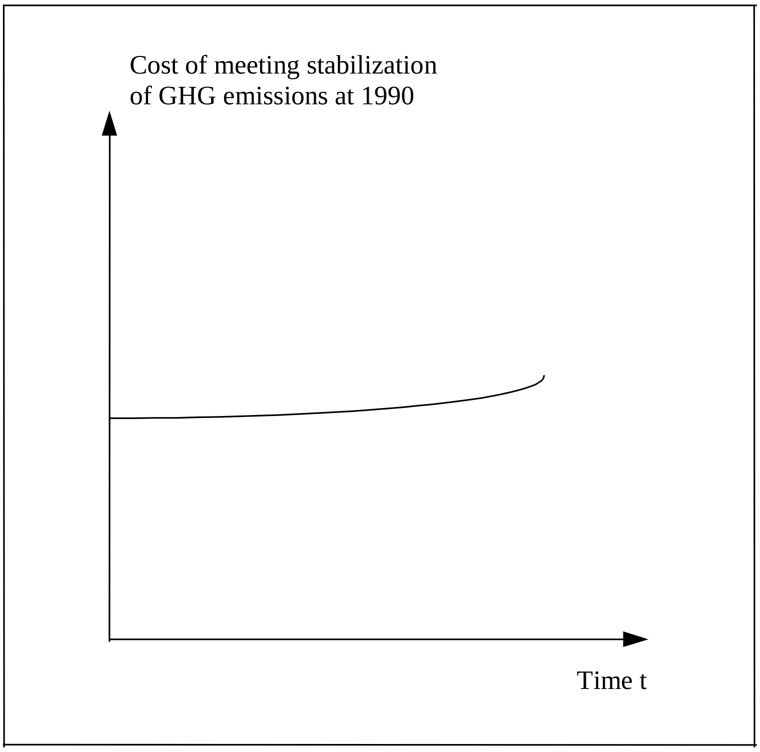
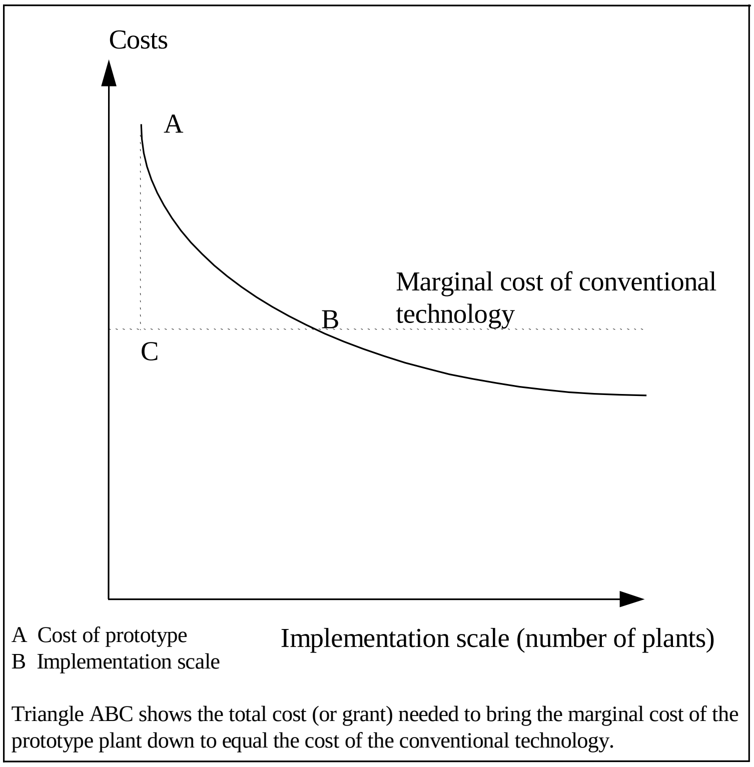


Figure 2.7. Cost of emission target over time



A Cost of prototype
B Implementation scale

Triangle ABC shows the total cost (or grant) needed to bring the marginal cost of the prototype plant down to equal the cost of the conventional technology.

Figure 2.8. Technology learning curve

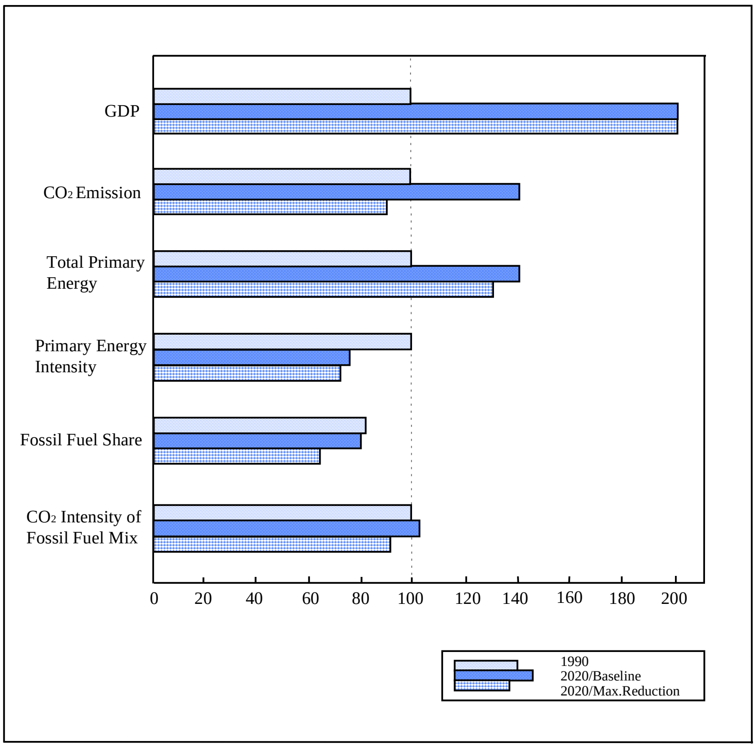


Figure 2.9. Scenario indicators – maximum reduction vs. baseline

Figure 2.9 illustrates the major policy options applied in one specific study. The CO_2 reduction is achieved with an unchanged GDP in the scenario end year, 2020. It can be seen that the primary CO_2 reduction is due to a reduced fossil fuel share of primary energy consumption and also to the reduced CO_2 intensity of the remaining fossil fuels.

Multiple decision criteria. The different kinds of cost curves mentioned above all focus in a relatively narrow way on the cost of eliminating a unit of greenhouse gas emission as the main decision criterion. In practice, however, national decisions, as outlined above, will consider a large number of impacts. There exist a number of different methodologies for the integrated assessment of several impacts. The best-known of these is probably multiattribute, or multicriteria, analysis (Keeney and Raiffa, 1993).

The basic idea of multiattribute analysis is to base decisions upon several objectives. The focus is on identifying decision criteria specified in attributes and weights in order to measure and evaluate trade-offs between different criteria. The attributes represent costs and other impacts of climate change mitigation options, and the weights are the values given to the individual impacts. Weights can then either be monetary values (e.g., prices) or other weights decided by the decision maker(s). Table 2.2 gives an example of how impacts of climate change mitigation projects can be reported. In practice, more criteria will be required, but the table shows the way the information can be presented.

This method was discussed in Section 2.5.4, where it was recommended for use in evaluating the different impacts of a programme or project that cannot be collapsed into a single measure such as cost. There are problems with determining weights, but the use of the method allows exploration of different weights to see how robust particular choices are to variations in weights within a reasonable span. It is repeated here, as it is a key aspect of the final analysis and reporting of results.

Table 2.2. Reporting of climate change mitigation impacts

Impact Indicator	Greenhouse Gas Reduction / Unit Cost	SO_2 Emission Change / Unit Cost	Employment / Unit Cost
Project 1			
Project 2			
Project 3			

2.7 Conclusions

This chapter has looked at the conceptual issues arising in the estimation of the costs of adaptation and mitigation. The basis of this estimation is the *economic opportunity cost*. To estimate this, price and other data from market transactions are needed, but these data are not enough. One also needs information on the distortions in market prices so that corrections can be made. The process of making such corrections is called shadow pricing, and methods for estimating shadow prices have been discussed. The other correction is to account for external effects, both positive and negative. Again methods for doing so are available and can be applied to the estimation of the costs of greenhouse gas mitigation and adaptation. Together the two corrections lead to an estimation of the *social costs* of greenhouse gas mitigation. Both these corrections to market prices may be important, but in most studies of greenhouse gas mitigation and adaptation they have not been undertaken or have been only partially undertaken. There is, furthermore, the possibility of valuing different costs differently, depending on the income status of the person on whom the cost is being imposed. A method for making such income value judgements has been presented in this paper, although it is acknowledged that not all policymakers will wish to formalize the assessment of the income effects in this fashion.

Although the authors believe that estimates of *social costs* are the most important policy tool, policymakers are also interested in the financial costs. These should therefore be provided also and should be based on an accurate reporting of the financial flows generated by the project.

In analysing and evaluating costs, modellers work at three levels: the macroeconomic level, the sectoral level, and the project level. Macroeconomic models are useful in designing policies to combat climate change, whereas the sectoral and project levels of analysis are more useful in designing detailed measures to mitigate and adapt to climate change.

There are several issues that arise in the evaluation of costs. These are the determination of the baseline, the valuation of the indirect costs and benefits, the choice of discount rates, the integration of adaptation and mitigation costs, and the selection of criteria for ranking different mitigation/adaptation programmes.

Baselines are critical in the whole exercise of cost estimation and evaluation. Here the choice should be based on expected policies, not optimal policies, and should be as consistent as possible between different levels of analysis. Given the major uncertainties that exist about future development, however, it is recommended that multiple baselines be used, giving a range of estimates to the policymaker. This will also provide some appreciation of the uncertainty that surrounds these estimates.

The valuation of indirect costs and benefits can proceed, at least in the first instance, by taking the results of existing studies, of which there are now many. These will provide information on how the choices can be affected by the move from financial costs to social costs.

The choice of the discount rate remains an unresolved question, but again the use of more than one rate allows the policymaker to see the sensitivity of the results to this parameter.

The methods of designing the optimal adaptation programme are based on comparing the damages avoided to the costs of adaptation and will be largely independent of the selected mitigation programme, which responds to a target reduction in greenhouse gas emissions. The use of *social cost* is as important here as it is for mitigation costs. The two need to be integrated, however, in the macroeconomic studies, where the fiscal and macroeconomic implications of both can be studied.

Although this chapter has focused on social costs, the selection of policies for greenhouse gas adaptation and mitigation will not merely depend on such costs (although these should be one of the most important factors). They will also depend on the impacts of the programmes in terms of financial costs, the impacts on income distribution, and the uncertainty of the impacts, amongst other things. The difficulties that arise in making changes to established institutional practices and market arrangements will also be important. The costs associated with such changes cannot be measured in monetary terms or can only partly be measured in such terms. We have discussed the nature of these constraints on implementing mitigation programmes and how they might best be reported.

Finally, we have looked at how the overall impacts of a mitigation programme might be reported. There is some merit in providing simple charts of marginal cost, but there is also a need to provide information on other dimensions. From these a selection of the appropriate strategy will be made. Ultimately the selection is a political one. However, the analyst is responsible for presenting the information in a clear and coherent manner. In this regard, there may be some scope for the use of multicriteria analysis.

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Chapter 3

Special Issues and Problems Related to Cost Assessment for Developing Countries

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3.1 Distinctive Features of Developing Countries

Developing Countries (DCs) include a wide variety of states with distinct differences in terms of their economic, political, social, and technological levels of development. At one end of the spectrum there are the Least Developing Countries (LDCs), which have very little basic infrastructure, while at the other there are the Newly Industrialized Countries (NICs), which have a structure closer to that of the industrialized countries. Many others lie between these two extremes. Almost all DCs have a relatively low level of greenhouse gas emissions per capita at present, but large countries like India, China, and Brazil will soon become very important in terms of their contribution to total global emissions, and it is therefore important to understand how these countries might participate in globally cost-effective policies.

Mitigation costs in a country depend critically on underlying technological and socioeconomic conditions. Studies that assess these costs make assumptions about current and future socioeconomic development patterns and the potential for implementing climate change mitigation policies. Developing countries exhibit a number of specific complexities that are of major importance to costing studies. Data is limited, exchange processes are constrained, markets are incomplete, and there exist a number of broader social development issues, such as the living conditions of the poor, gender issues, and institutional capacity needs, that are potentially important for future greenhouse gas emission rates. Some of these difficulties are particularly predominant in relation to land use sectors but can also be important in relation to the energy sector and transportation. These latter sectors, however, have received more attention over a longer time span in modelling and other studies and consequently more experience has been gained in treating developing country issues in these areas than in the land use sector.

The methodology of most present mitigation cost studies has been developed on the basis of models and approaches originally designed for the market-based economies of the industrialized countries. The application of these methodologies in a developing country context typically poses special problems relating to data, sectoral coverage, activity projections, and assumptions about markets, behaviours, and policy instruments. A simplified application of these methodologies to developing countries can lead to a number of inaccuracies in mitigation studies because of difficulties such as the following:

- Major greenhouse gas emission sources and drivers for future emissions can be overlooked. This consideration is especially relevant to the land use sectors.
- Mitigation studies may focus on specific technical options that are not consistent with the national macroeconomic policy context and broader social and environmental policy priorities.
- The technical potential of specific options, such as electricity-saving measures, may be overestimated because consumer behaviour and power market failures are not captured.
- Implementation issues, including institutional and human capacity aspects and local market development, may not be represented.
- The impacts of using different policy instruments cannot be assessed because studies do not include any information on national tax systems, sectoral regulation policies, and various technology promotion programmes.

There is, therefore, a need for further development of methodologies and approaches that reflect the specific characteristics of climate change mitigation policies in developing countries. This section introduces a number of distinct features for developing countries that are of importance for costing studies and concludes with a number of suggestions for the expansion of studies and methodology development.

3.2 Alternative Development Paths

Economic development in developing countries may follow different paths in different countries. A country’s development path will depend upon socioeconomic conditions, resource endowment, and government policies. Considerable uncertainty exists about how these conditions may evolve over the next century. The uncertainty concerning the prediction of the long-run development trajectory is even greater. This uncertainty introduces the possibility of multiple baselines, each corresponding to a particular expectation of the future development pattern. Each development pattern may exhibit a unique emissions trajectory. For instance, a rapidly growing economy can develop through qualitatively varied compositions of the capital stock and energy patterns. A nation following development policies that emphasize greater investments in infrastructure such as efficient rail transport, renewable energy technologies, and energy efficiency improvements would exhibit a low emissions trajectory. On the other hand, a nation with substantial coal resources, scarce capital, and a low level of trade can get pushed towards a development path with high emissions.

Mitigation costs for different development patterns may vary substantially. Since long-term development patterns are uncertain, a mitigation policy analysis should use a probability distribution of mitigation costs rather than a single mitigation cost. A probability distribution of mitigation costs will correspond to the probability of occurrence of alternative development patterns and the mitigation costs associated with each. Multiple baselines also complicate the assessment of the level of mitigation, since each development pattern follows a different emissions path. Estimates of the mitigation cost and quantum of mitigation derived from a "most likely scenario," which most often represents the conventional "business-as-usual" view of the future, are grossly misleading, because such a scenario can narrow the potential for introducing more sustainable technologies in the future and in this way fails to capture the diversity of development possibilities.

Assessing the mitigation costs and quantum of mitigation for developing countries will require a modelling approach in which alternative development paths and multiple base cases are considered (IPCC, 1996, Chapter 8). It is not very helpful to use the common approach that automatically assumes that developing countries will follow the past development paths of industrialized countries. The significant transformations that have recently occurred in the international economy and energy markets highlight the limitations of such an analogy, both in space and time. The GDP structure and its physical basis in developing countries have to be considered specifically. Among the important aspects that should be integrated in the scenario development are the changes in economic structure and relative prices emerging from structural adjustment programmes and other macroeconomic policies that many countries currently are undertaking. Another crucial issue, following that, will be the development in developing countries of energy-intensive and heavily polluting industrial activities, such as steel and aluminium production. As the recent shift of heavy industries from the North towards developing countries reaches its end, long-term economic output could come from services and other less energy-intensive activities.

Moreover, technological choices both in production and consumption can substantially decrease the energy demand/GDP elasticities. The preservation of a certain cultural diversity in opposition to the trend towards a global homogenization of lifestyles would also favour less energy intensive housing, transportation, leisure, and consumption patterns, at least in some cases. A possible example would be to avoid low urban population density coupled with long daily car trips to work and large shopping centres.

Finally, because the spatial distribution of the population and economic activities is still not settled in developing countries, there still remains an opportunity to adopt urban/regional planning and industrial policies directed towards strengthening small and medium cities and rural development, thus reducing the extent of rural exodus and the degree of demographic concentration in large cities. In this connection, it should be noted that the large amount of natural resources available in developing countries could be tapped through the use of modern technology, which would also facilitate the emergence of more decentralized development patterns. The opportunities provided by biotechnology, for example, could contribute to this kind of development. Turning to the energy supply side, more decentralized societies would also facilitate the adoption of renewable energy sources, such as biomass, solar, wind, and hydro power.

These examples show that developing countries could adopt anticipative strategies that would avoid in the long term some of the problems faced today by industrial societies. Energy demand/GDP elasticities in industrialized countries at first increased with successive stages of industrialization, accelerating during the 1950s and 1960s. Since then they have sharply decreased as a result of a variety of factors, such as the relative growth of services as a proportion of GDP and technical progress induced by higher oil prices and energy conservation efforts, among others (see Martin, 1988; Darmstadter *et al*, 1978). Developing countries could follow a path leading directly to less energy intensive development patterns in the long run and avoiding a large increase of energy/GDP intensities in the short and medium terms (the so-called "tunnel effect"; see Berrah, 1983).

The above-mentioned possibilities for following alternative development patterns highlight the technical feasibility of low carbon futures in the South that are compatible with national objectives. On the other hand, the barriers to more sustainable development in the South can hardly be underestimated. These include financial constraints, cultural behaviours (in industrialized as well as in developing countries), and a lack of appropriate institutional building. Any abatement cost assessment must therefore rely on the implicit assumptions taken in baseline or mitigation scenarios about the probability of removing these barriers.

3.3 Broadening the National Decision-Making Framework

Although cost is a key component of the decision about which policies to select, it is not the only consideration. Other factors will enter the decision, such as the impacts of policies on different social groups in society, particularly those that are vulnerable, the benefits of greenhouse gas limitation in other spheres such as reduced air pollution, and the impacts of the policies on broader concerns such as sustainability. In developing countries these other factors are even more important than in the industrialized countries. Greenhouse gas limitation does not have as high a priority relative to other goals, such as poverty reduction or employment, as it does in the wealthier countries. Indeed, one can argue that the major focus of policy will be development, poverty alleviation. and other similar objectives, and that greenhouse gas limitation will be an *addendum* to a programme designed to meet those needs. Taking account of the greenhouse gas component may change the detailed design of a policy or programme, but it is unlikely to be the main issue that determines the policy.

Markandya (1998) has developed a framework for expanding mitigation cost analyses by including assessments of other impacts of climate change mitigation projects, such as employment, income distribution, environmental changes, and sustainability indicators. This involves combining monetary cost and benefit estimates with physical indicators and qualitative information, including the impacts of projects on vulnerable groups, impacts on the environment more generally, and impacts on sustainability in a wider sense. Markandya also offers some advice on how these different dimensions can be brought together in a decision-making framework.

The expanded framework has been applied to three case studies: a biogas plant in Tanzania, a reforestation project in Russia, and a demand-side management programme in Thailand. The results generally indicate that it makes an important difference in valuation and priorities when a broader range of social impacts is integrated into the analysis. In the case of the Tanzanian biogas plant,[1] a purely financial cost analysis of the project arrived at a cost around 15$ per tonne of CO_2 while a broader social cost assessment changed the CO_2 reduction costs to a negative quantity. The reason for this difference is primarily that the project has a number of important local social impacts, like employment for unskilled workers, a reduction of time spent on fuel collection, health benefits from replacing fuel wood for domestic use, income transfers to low income families, and the establishment of sustainable energy patterns.

Many of these broader social and environmental impacts of implementing climate change mitigation policies in developing countries are relevant to the design of sustainable national policies that permit local governments and various other stakeholders to combine local priorities with global policy goals on climate change. It should, however, be recognized that the information presently available on environmental impacts is limited, and priority should be given to the establishment of more accurate country-specific data.

3.4 Addressing the Specific Characteristics of Markets and Other Exchange Processes in Developing Countries

Cost assessments of climate change are largely market oriented. The sources of greenhouse gases that are considered are predominantly represented in official economic and sectoral statistics, and the prices used for the valuation of resources are derived on a market basis. Such information, however, is inadequate for developing countries, where markets are incomplete, property rights are not well established, and a

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[1] The project assessment is based on a GEF project document for Tanzania in which it is assumed that a biogas plant using anaerobic digestion of industrial and municipal waste is substituting fossil fuels.

significant part of the exchange process belongs to the informal economic sector. The following subsections discuss the implications of these specific features for climate change studies.

3.4.1 Price Distortions

Major greenhouse gas emission sources in the energy and agriculture sectors are influenced by present subsidies, which are known to increase emissions substantially. Subsidy removal in the energy sector, if supported by improvements in managerial efficiency, could reduce emissions of CO_2 and other pollutants by up to 40% in developing countries, with very low or even negative costs (Anderson, 1994; Halsnæs, 1996). It should be recognized, however, that general macroeconomic policies, such as structural adjustment programmes, already include subsidy removal policies to a wide extent.

Since the 1980s some developing countries have embarked on different price reforms that have resulted in a significant drop in carbon emissions. Between 1990–1991 and 1995–1996 fossil fuel subsidies in 14 developing countries that accounted for 25% of global emissions declined by 45% – from US$60 billion to US$30 billion (Flavin and Dunn, 1997; Davidson, 1998).

The further success of such price reform policies in reducing greenhouse gas emissions depends critically on the responce from power utilities and the private sector, including enterprises and households. Efficiency improvements in energy consumption can be constrained by capital market imperfections and weak institutional capacity. There can also be a number of social and income distribution consequences that need to be considered if the policies are to be sustainable. It is therefore likely that price reform programmes will in practice be carried out through a more gradual development process, where adjustments and compensation programmes are part of policies to improve programme efficiency and establish sustainable market structures. Mitigation policies that include price reform options, therefore, should address these broader issues and, when appropriate, consider various tax revenue options and other compensation mechanisms.

3.4.2 Incomplete Markets

Most major markets in developing countries are characterized by supply constraints, with the labour market as an exception and with unskilled labour, in particular, in excess supply. Examples of such supply constraints are seen in the financial sector, in the power production sector, and in infrastructure development. This situation results from high transaction costs caused by weak market linkages, limited information, inadequate institutional setups, and policy distortions. In India, for instance, there is a 16% gap between electric power demand and supply during peak hours (CMIE, 1996). As a result, power shutdowns are frequent and cause enormous losses to production and welfare. Such market imperfections can make it difficult to establish reliable parameters such as the price elasticity of demand. Due to excess demand in energy markets, price increases enhance consumption as supply improves.

In many developing countries, commodity prices, including those of energy resources, are regulated and are not market-determined. The consequent market distortions have often not been adequately captured by models. There is, therefore, a need for applying some price-correcting rules to reflect social costs.

Traditional cost-benefit analysis uses shadow prices to correct for market distortions (see Section 2.2.8). Such a procedure is also consistent with the methods used in computable general equilibrium models. In both cases mitigation policies and related costs are assessed in relation to an “optimal resource allocation case,” where markets are in equilibrium and prices (and thereby cost) reflect resource scarcities. However, these conditions are far from present in these countries, and studies should therefore consider how a transformation to the optimal resource allocation case can take place over a certain time frame. Although developing countries are presently undergoing market-oriented economic reforms, price distortions have only been partially and gradually remedied because of the high social costs associated with speedy reforms. In the wake of these changes, past price data do not remain representative of future trends. The complexities in modelling this process cannot be underestimated, and it should therefore be recognized that only part of the transformation can be captured.

Integration of market transformation processes in costing studies should include an assessment of barrier removal policies. Such policies will include efforts for strengthening the incentives for exchange (e.g., policies relating to prices, capital markets, international capital, and donor assistance), the introduction of new actors (e.g., policies relating to institutional and human capacity efforts), and attempts to reduce the risk of participating (e.g., policies relating to the legal framework, information, and the general policy context of market regulation). Some of these policies (such as barrier removal policies that address market prices, capital markets, and technology transfers) can be reflected in modelling studies, while other areas, like capacity building, should be addressed in a more qualitative way.

Another major source of error in price estimation is distortion in the currency market, which causes a substantial discrepancy between the market exchange rate and the purchasing power of the currency within the country. The purchasing power parity (PPP) of the currencies of developing countries is substantially higher than one (UNDP, 1997). Besides pricing distortions, government monopoly in the energy and infrastructure sectors in developing countries also manifests itself in a myriad of barriers to competition and in restrictions on international trade. This situation also distorts market responses and perpetuates disequilibrium. To avert estimation errors, crucial parameters like price elasticity of demand are often rescaled on the basis of their values for industrialized economies.

3.4.3 Non-market and Informal Economy

A large part of the economic activities in developing countries are not captured by key indicators or are not well documented. These activities make up the informal economy or, as it is also known, the popular economy.

The sectors where activities are systematically reported are generally referred to as the modern or formal economy. Meier, (1995) characterizes the informal sector by

- ease of entry
- reliance on indigenous resources
- family ownership of enterprises
- small scale of operation
- labour-intensive and adapted technology
- skills acquired outside the formal school system, and
- unregulated and competitive markets.

These characteristics of the informal sector are the obverse of those of the formal sector, which, according to Meier, is defined by

- difficulty of entry
- frequent reliance on overseas resources
- corporate ownership
- large scale of operation
- capital-intensive and often imported technology
- formally acquired skills, often imported, and
- protected markets (through tariffs, quotas, and trade licenses).

A number of important interrelationships and spillovers between the informal and the formal sector are relevant to climate change mitigation policies. An example is the potential for introducing advanced production technologies in the energy and agriculture sectors that will, on the one hand, use domestic resources (e.g., biomass) in a more sustainable way and, on the other, improve efficiency and create capacity in local companies and institutions. The impact of introducing policy instruments, such as carbon taxes or the removal of energy subsidies, also depends on potential substitutes for non-commercial wood fuels that might be unsustainable. Similarly, the penetration rate of advanced technologies can depend on the capacity of enterprises in both the formal and informal sectors to adapt and manage these technologies.

According to the 15th International Conference of Labour Statisticians (Young, 1994), held in January 1993 in Geneva, the so-called informal sector also includes all small businesses that are not registered companies or that do not have a comprehensive accountancy framework, whether they be household enterprises (with no permanent staff) or microenterprises (with permanent unregistered staff or with a small number of permanent staff). The informal economy is a growing structural phenomenon. In most developing countries, it is neither a detour, an after-effect of the traditional economy, nor a reaction against the modern economy. It is a component of social and economic systems with its own dynamics and logic. The relationship between the modern economy and the informal sector is based on the component elements they have in common. This implies that the formal and informal economies should be regarded as parts of a single entity in their economic and social situations rather than as a dichotomy.

Informal activities usually lie beyond the pale of official regulation or occur outside legally established institutions. These activities cause considerable reporting and measurement problems and can be difficult to integrate into national climate change regulation frameworks. This also causes difficulties in assessing the costs and the potential of mitigation and adaptation strategies.

A number of factors explain the existence and growth of the informal sector in developing countries (UN/DPCSD, 1996). The growth of population and hence of the labour force has been rapid, but despite increases in agricultural output, employment in agriculture has not increased significantly. Rather, it has been stagnant or falling. The pressure to create additional jobs outside agriculture has therefore been mounting. In recent years, some countries, particularly those committed to structural adjustment programmes, have sought to reduce budgetary expenditures by retrenching employment in the government service, and this has further contributed to the expansion of the informal sector. Structural factors such as sparse infrastructure and low levels of education also explain why certain activities remain in the informal sector.

3.4.4 Size of Informal Economy

The informal sector plays a very important role in developing countries, especially in those that are least developed. A survey that examined informal sector activities in the urban commercial sector in Africa concluded that this sector typically accounted for more than 50% of total urban commercial activity. In Senegal, the informal economy contributed 60% of the GDP in 1990. In Kenya, the urban informal and rural non-farm sector accounted for 30% and 13% respectively of all employment outside agriculture in 1985 (Livingstone, 1991). A UNDP/ILO survey (Charmes, 1995) estimated the contribution of the informal sector (excluding agriculture) to the GDP in Benin at 64.5% in 1985. The survey showed that the informal sector in Africa increased considerably between 1973 and 1993 and absorbed the unemployed at a time when the modern sector (public and private) was experiencing a progressive decline in capacity due to economic crises and structural adjustment. In the 1990s, the informal sector represented 40% to 80% of the working, non-farming population in Africa (Table 3.1). In the late 1980s, the informal sector share of the urban labour force in 11 Latin American countries ranged from 30.3% to 57.0% (Lubell, 1991) and employed 30 million people (Tokman, 1989).

Informal financial markets play a crucial role in the economies of developing countries. In Sri Lanka, for example, informal lending mechanisms provide significant credit to small enterprises and households (Sanderatne, 1989). In Cameroun, 70% of the adult population participates in informal financial associations, which in 1988 held money deposits equivalent to 54% of the country's total savings (Lubell, 1991). Informal credit accounts for one to two thirds of total credit in Bangladesh and China, about two fifths in India and Sri Lanka, and two thirds to three quarters in Malaysia, Nepal, Pakistan, and Thailand (Montiel *et al*., 1993). Informal finance dominates the credit submarkets, which cater to small, poor, and risky borrowers, and also competes with and complements formal finance in other submarkets (Ghate, 1992). The informal credit market is often linked to formal finance institutions through middlemen, who provide credit at interest rates lower case as high as 500% per annum (Hemmer and Mannel, 1989). A study of money lending in the informal credit market in Malawi observed interest rates as high as 5000% per annum (Bolnick, 1992). Observed rates in these informal markets are too high to be explained by the concepts of risk and transaction costs alone and point to a need for developing altogether different concepts for understanding and explaining the dynamics of the informal sector.

Table 3.1. Estimated percentage of informal workers compared to total non-farming active population (selected years).

	1975	1976	1977	1980	1982	1983	1984	1985	1986	1988	1989	1990	1991	1993
Morocco					59.9									
Algeria			21.8					25.4						
Tunisia	38.4			36.0							39.3			
Egypt		58.7							65.3					
Mauritania				69.4						75.3				
Senegal				76										
Mali		63.1									78.6			
Niger			62.9											
Burkina Faso								70						
Chad														74.2
Benin														92.8
Guinea							64.4						74.9	
Zaire						59.6								
Kenya												61.4		

Source: Charmes, 1995.

3.5 Land Relations and Land Use

Land use changes are significant sources of greenhouse gas emissions from developing countries. These changes – such as land degradation, deforestation, and land cover degradation – emerge from various land clearing activities, including oil exploitation and mining carried out by international companies, infrastructure development, agricultural practices, expansion of cropland, and unsustainable timber harvesting and fuelwood collection.

The economies of developing countries are significantly influenced by the traditional use of land, the dependence of a sizeable proportion of the population on the land for their livelihood, and the significant contribution of agriculture to GDP. Production under traditional land use is highly dependent on climate. In addition, climate change will have direct implications for practices such as shifting cultivation. Land use practices are vital determinants of the economic development of developing countries and have a significant bearing on mitigation costs. Since the evaluation of mitigation options related to land use (including reforestation, afforestation, and agroforestry) requires accurate and comprehensive cost data, studies must allocate time and resources to collect data that specifically reflect the national or regional policy context. Studies should also reflect the unique characteristics of land use relations in developing countries. These include (1) a non-existent land market, (2) small and fragmented land holdings, (3) the use of land for subsistence production, (4) communal land ownership, and (5) technological isolation.

3.5.1 Non-commercial Fuel Use

Non-commercial fuels, mainly biomass, are principal primary energy resources in most developing countries. Biomass is the world's fourth largest energy source. It provides 14% of the world's energy needs and 38% of energy in developing countries (Woods and Hall, 1994).

Most biomass in developing countries is home-grown or collected by family labour. The share of biomass fuels varies between regions (Ellis *et al.*, 1997). In Western Africa more than 70% of the total energy supply is provided by biomass, and in many countries in the region it accounts for more than 90% of household fuel use. In South Africa biomass represents only 10% of the total energy supply; however, more than 80% of rural households use biomass for cooking and heating purposes. In South Asia biomass is the primary component in most household energy use and will remain so for the foreseeable future. In China biomass accounts for about 20% of the total energy supply, but for more than 70% of “rural energy for living.” Finally, in Latin America biomass supplies about 20% of the total energy supply and between 30% and 90% of household energy use.

If used sustainably, biomass is carbon neutral.[2] Present biomass use, however, remains unsustainable and adds to the carbon flux. In 1989, for instance, the deforestation of 14 million hectares of land added 1.4 Gt of carbon to the atmosphere (Rosillo-Calle and Hall, 1992). Combustion of wood fuels adds 0.5 Pg of carbon annually (Houghton, 1996). Biomass burning is estimated to contribute 22 million tonnes of methane and 0.2 million tonnes of nitrous oxide per year (IPCC, 1996). Despite the role, importance, and prospects of biomass in the energy, environment, and development nexus, reliable and long-term statistics are lacking.

There are a number of social issues connected to traditional biomass use. The cost can be high for typically poor consumers, whether as cash payments by the urban poor[3] or as hours of effort spent by rural women and children gathering fuels. Leach (1997) notes that it is surprising how often surveys reveal the low priority given to such issues, even in villages where women spend tens of hours each week collecting fuel. If fuel is that scarce, other vital resources are usually scarce too, and the poor face many problems apart from energy that they would like to see resolved, such as the time burdens of fetching water, weeding crops, and herding animals, or poor access to schools, health care, and other basic services. Energy solutions, seen in that perspective, should fit into a very broad context of socioeconomic priorities and policies.

The use of traditional biomass fuels is not directly reflected in many economic studies, as fuel is collected by unpaid household labour and not traded. One estimate places the amount of labour time spent on biomass collection in India at 8 billion person days, which is equivalent to the full-time employment of 30 million persons or 11% of the total labour force (Mahadevia and Shukla, 1997). The implicit value of this non-traded biomass energy, based on a minimum labour wage, is 150 billion rupees or 4% of India’s GDP. Since biomass fuels are not transacted in the market, they are not adequately accounted for in national energy statistics, and their economic value is often ignored in national economic accounts. Correct estimation of mitigation options in developing countries requires an accurate representation of non-commercial energy sources in climate change mitigation models, and this is lacking in many present mitigation studies.

3.6 Issues Related to the Implementation of Advanced Technologies

3.6.1 Technological Progress

The technology profile of developing countries is characterized by great diversity and the coexistence of numerous vintages of equipment. Traditional technologies, which are sustained in rural and artisan operations, exist side by side with an increasing number of modern technologies. The representation of technological progress in developing countries is complicated by several factors. These include:

1. *a diverse technology mix*, engendered by the dual economy, extreme variation in incomes, and the present stock of inefficient technologies (that eventually penetrate to low-income households and the informal sector at the same time as new technologies are being introduced elsewhere)
2. *high technological inertia*, resulting from a shortage of capital and the existence of secondary technology markets, and
3. the *potential for rapid technological progress* in the short run through the transfer of advanced technologies.

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[2] A sustainable use requires that the biomass use does not result in any net decrease in land allocated for biomass (net deforestation). This condition is not fulfilled in many cases.

[3] The high prices paid by the urban population for biomass fuels are as a rule not earned by the rural population supplying the fuel. The rent is typically collected by local dealers who, through their access to transportation, can collect a high rent.

The evolution of technology in a country is closely related to its development path. Consequently, developing countries have the opportunity to avoid the high energy and carbon-intensive development path taken by industrialized nations. Many developing countries are set to make major investments in the coming decades. Technological choices such as rail infrastructure and renewable energy technologies can shift development to a low resource and emissions trajectory. The timing of technological decisions is therefore vital, as these decisions tend to lock economies onto a path with a specific resource consumption and emissions intensity.

Superior low–carbon emitting technologies can be available to developing countries in the future. The costs as well as the applicability of these technologies will depend on the outcome of research and development programmes, demonstration projects, and market development activities in both industrialized and developing countries. Early adoption of mitigation policies and of targeted technology development programmes in all parts of the world are now needed for cost-effective future abatement (Schneider and Goulder, 1997).

The challenge is to create the window of opportunity that will make it possible to leapfrog the developed countries towards sustainable practices. Present mitigation models based on market-oriented logic, however, fail to represent the endogenous processes that can propel the evolution of technological patterns towards widely different but sustainable development pathways. Although market dynamics ensure economically efficient choices, such considerations do not necessarily encourage anticipatory strategies that would orient development along alternative pathways that are superior according to criteria such as equity, implementability, and sustainability.

High economic growth in developing countries establishes a potential for rapid technology transition through replacement of old technology vintages by new stock (Perez and Soete, 1988). The combination of high growth and low past investment can be converted to an advantage by developing countries, which can leapfrog the developed nations in some technologies. For this to happen, technology transfer is essential, since most new technologies originate in industrialized nations.

Developing countries can circumvent the conventional high energy and carbon-intensive development path through investments in energy efficient and carbon-free technologies. Barriers to technology transfer include lack of finances, limited foreign exchange, weak infrastructure, low skills, high import tariffs, and trade restrictions. Technological leapfrogging through the window of opportunity does not eventuate automatically, however, and would require overcoming these barriers. Initiatives by industrialized nations and strong global policy support are vital in this respect. Technology transfer can alter the development path and emissions trajectory. In addition, transfer of efficient energy supply and demand technologies and advanced carbon-free energy technologies provides extra low-cost mitigation opportunities. Thus, technology transfer can change both the mitigation cost and the amount of mitigation.

3.6.2 Transition to Advanced Renewable Energy Technologies

Several international initiatives suggest that advanced renewable technologies like windturbines, photovoltaics, and advanced biomass technologies could be cost-effective mitigation options for developing countries (Anderson, 1994). It is expected that these technologies, which today are just slightly more costly that conventional fossil fuel technologies, will become competitive under normal market conditions if implemented over a time frame that makes it possible to take advantage of learning and economies of scale.

Moriera *et al.* (1997) emphasize the potential for transition to modern biomass fuels through the use of integrated biomass gasifier/gas turbine systems for power generation, the adoption of improved techniques for biomass harvesting, transportation, and storage, and the utilization of other techniques such as the gasification of rice husks and other crop residues, briquetting, and treatment of cellulosic materials. Such advanced biomass technologies could facilitate a sustainable utilization of domestic resources in which biomass resources would be integrated into the commercial economy and a capacity for the management of more advanced technologies would be established.

The implementation of advanced renewable energy technologies should be considered as an option to improve the efficiency and sustainability of traditional land use activities and as a substitute for the introduction of traditional fossil fuel combustion processes. An assessment of the mitigation potential and related costs of advanced biomass technologies, therefore, should be based on information about traditional energy consumption as well as information on fossil fuel alternatives.

Implementation programmes will meet a number of specific barriers that should be assessed in these studies. These include:

- general energy market distortions such as subsidies
- the existence of high initial capital costs that can be difficult to finance due to capital market imperfections
- lack of local companies that can undertake activities related to construction, maintenance, and supply of spare parts
- weak institutional capacity at both the local and national level for the planning and management of projects.

Studies for sub-Saharan Africa have assessed the technical potential for disseminating advanced biomass technologies and the implementation policies required (Karakezi, 1994). The results of these studies indicated a large discrepancy between the technical potential as such and the market potential that can be realized in the near future. Further implementation activities should give particular emphasis to:

- the establishment of energy systems that utilize both renewable and fossil fuel technologies
- the establishment of a network for the manufacturing, marketing, and servicing of the necessary technologies
- the training of users, maintenance personnel, and manufacturers.

In this way, advanced renewable energy technologies such as biomass options would not be stand-alone projects but rather integral parts in the development of a comprehensive energy system.

3.7 Suggestions for Improving Costing Studies for Developing Countries

3.7.1 Representation of Non-market Activities in Cost Analysis

Climate change studies of developing countries need strengthening in terms of the methodology, data, and policy frameworks that are used. Although a complete standardization of methods is not possible, it is essential to apply consistent methodologies, perspectives, and policy scenarios to different nations in order to achieve a meaningful comparison of results. Most studies of developing countries use bottom-up economic models (IPCC, 1996, Chapter 9; Shukla, 1995). These models have a tendency to assess relatively low mitigation costs in some cases if they compare new, efficient technologies with existing equipment in the countries. The reliability of these cost estimates depends on how well implementation costs are integrated into the models. Implementation costs should be understood here in a broad sense as including the costs of overcoming barriers to achieving economic efficiency as well as the costs of different policies and programmes for institutional development, capacity building, and upgrading regulations and legislation. Top-down studies, on the other hand, tend to ignore the strong non-market dynamics in developing nations. There exists a need to improve modelling methodology by incorporating the particular dynamics that govern conditions in developing countries.

In developing nations, the traditional and informal sectors account for an overwhelming proportion of agriculture and land use activities, employment, and household energy consumption. Activities in these sectors, such as non-commercial energy use, deforestation, rice cultivation, and animal husbandry account for significant greenhouse gas emissions. This reality requires a shift in global policy studies towards the use of economic models that are specifically focused on developing countries and that integrate a detailed sectoral representation of these activities.

It is suggested that a modified approach be developed and applied to costing studies in developing countries. In developing such an approach, attention should be given to the following areas:

- The analysis should include alternative development pathways representing different patterns of investment in infrastructure (e.g., road versus rail and water), irrigation (e.g., big dams versus small decentralized dams; surface irrigation versus ground water irrigation), fuel mix (e.g., coal versus gas; unclean coal vs. clean coal; renewable versus exhaustible energy sources), and employment and land use policies (e.g., modern biomass production and afforestation).
- Macroeconomic studies should consider market transformation processes in capital, labour, and power markets.
- The models should be expanded to include sectors responsible for major greenhouse gas emissions, particularly the land use sectors.
- Non-commercial energy sources, essentially traditional biomass, should be explicitly represented in the model as these sources have a crucial influence on both future energy flows and greenhouse gas emissions.
- Transactions in the informal and traditional sectors should be included in national economic statistics. The value of unpaid household labour for non-commercial energy collection is quite significant and needs to be explicitly considered in economic analyses. The value of non-commercial fuel is an important parameter when evaluating fuel substitution and energy technology penetration in the traditional sector.
- The costs of removing market barriers should be explicitly considered.

In addition to the neglect of the tradtional and informal sectors, perhaps the most important limitation of the models applied to developing countries is the very poor quality of data available. Many mitigation studies, costing models or methodologies often try to circumvent these data problems by using estimates from data that relate to different circumstances. It is preferable in such cases to use simplified approaches that provide insights into basic development drivers, structures, and trade-offs rather than to use standardized international models that duplicate data and assumptions from industrial countries. This latter approach makes it difficult to judge uncertainties and policy conclusions derived from the studies and can therefore create serious cost estimation errors and confusion.

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Chapter 4

Sectorial Assessment

by

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4.1 Introduction

This chapter outlines the main analytical concepts relating to mitigation assessment in the energy, forestry, and agriculture sectors. The issues relevant to each of these main sectors are comprehensively addressed in separate sections of the chapter.

The energy sector is the focus of the first half of the chapter (see Section 4.2) and is defined as including energy extraction, supply, and demand in all end-use sectors such as industry, transportation, agriculture, and households. Specific cost and carbon accounting concepts are defined in relation to the practical energy sector applications of mitigation assessment.

The forestry and agriculture sectors are defined as land use activities related to forestry, agricultural lands, rangelands and grasslands, wildlife sanctuaries, national parks, and built-up/urban areas. Cost assessment for these sectors is discussed in section 4.3.

For each sector, the main analytical steps of the assessment are explained, and there is a brief overview of models and tools. Finally a number of implications for policy and decision making are discussed.

4.2 The Energy Sector

4.2.1 System Boundaries

The energy sector includes production and consumption for the total energy system. The energy flows included are defined by a number of standard international statistical systems. One of the most commonly applied systems is the IEA standards, which include the following main categories:[1]

- production of primary fuels
- imports and exports
- transformation
- energy sector consumption
- distribution losses
- final consumption

Final consumption includes all energy end-use sectors such as industry, transport, agriculture and services, and non-energy use of energy sources. Thus, it should be noted that the energy sector assessment considers the full fuel chain from extraction to final transformation of net energy into useful energy. This implies that energy planning concepts such as Integrated Resource Planning and Demand-Side Management can be seen as subelements of energy sector assessment. It should also be recognized that the energy sector assessment should include commercial as well as non-commercial energy sources.

The main greenhouse gas emissions from the energy sector are carbon dioxide (CO_2) emissions from fossil fuel combustion and methane (CH_4) emissions from the production, transmission, and consumption of primary fuels. Table 4.1 gives an overview of energy sector greenhouse gas emission categories defined in accordance with the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1995).

Energy consumption can also imply a number of indirect greenhouse gas emissions, for example, CO_2 emissions from wood fuels in cases where the consumption is not substituted by regenerated biomass. Another example is methane emissions arising from hydro power plant establishment[2].

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[1] A number of international organizations have also developed standardized energy accounting systems. This includes, for example, SIEE/OLADE: Sistema de Informacion Economico-Energetico/Organización Latinoamericana de Energia (Economics and Energy Information System/Latin American Energy Organization).

[2] According to the IPCC/OECD methodology, CO_2 emissions from net deforestation and CO_2 and CH_4 emissions from hydro power plant establishment are counted as emissions related to changing land use and as zero emissions for the energy sector.

Table 4.1. Main greenhouse gas emissions from the energy sector

	CO_2	N_2O	CH_4
Coal mining			x
Oil and gas exploitation	x		x
Gas pipeline leakages			x
Fossil fuel combustion	x	x	x

There can be some overlap between assessments for the energy sector and those for other sectors, for example, in cases where the energy sector consumes biomass produced by agriculture and forestry. This means that an intersectoral consistency check on demand projections and resource availability must be carried out

4.2.1.1 Analytical Steps

The energy sector assessment should basically include the same analytical steps as specified in Chapter 2, "Cost Analysis Principles." These steps are:

1. Construction of a baseline scenario, including a socioeconomic scenario and energy demand and supply projections
2. Identification of mitigation options
3. Assessment of mitigation potential and costs of the options
4. Construction of mitigation scenarios that integrate multiple mitigation options
5. Assessment of policy implementation

The specific coverage of the steps will vary from study to study, depending on data availability, modelling tools, and existing capacity in energy sector assessment.

4.2.2 Assessment of Practical Applications of Cost Assessments

4.2.2.1 The Implication of Alternative Baseline Scenario Definitions for Mitigation Costs

Mitigation costs are assessed as the difference between running the baseline case and the mitigation case. Therefore, baseline scenario definitions have a direct impact on mitigation costs. Chapter 2 has outlined how the baseline scenario and related mitigation scenarios depend on forecasts of economic growth and structural and technological change. In energy sector studies there is a long tradition of conducting scenario analyses that are based on different assumptions regarding these parameters.

Chapter 2 emphasized that, in the short to medium term in particular, alternative baseline definitions reflect different views on the efficiency of energy markets and a number of macroeconomic policy assumptions regarding structural change, labour markets, and the fiscal system. In the longer term, a major assumption is technological change. In traditional energy sector terminology, expectations of efficient energy markets form the basis for defining so-called *least-cost* cases. By definition, such cases assume that all technologies with the lowest cost are eventually implemented. It should be emphasized that *least cost* can be defined according to a number of different principles. Least cost, for example, can be defined on the basis of social, economic, or private cost concepts as defined in Chapter 2. The baseline scenario, furthermore, can be constrained by specific environmental policy constraints, as acid emission controls or environmental externality costs, for example, can be an integral component of a social cost assessment as explained in Chapter 2.

Other energy sector scenario approaches focus, in particular, on assumptions about technological development in the energy sector. An example of such an approach is the *frozen efficiency scenario,* which assumes constant efficiency for all technologies and a constant technical structure of the supply system in the scenario period. Another is the *continuation of current trends scenario,* which assumes that technological development and supply system structure will follow current trends. These scenarios can be seen as sensitivity cases that can be used to illustrate the implications of major technological innovations[3].

It should be recognized that similar technical options can be assumed to be implemented either in the baseline scenario or in the mitigation scenario according to the above-mentioned baseline scenario approaches. A least-cost approach will, by definition, include no-regrets options, simply because they meet the defined economic efficiency criteria. This can imply, for example, in the case of end-use efficiency improvements in household electric appliances, that the baseline scenario according to a least-cost definition includes a given share of new, efficient appliances. Furthermore, the expansion of this factor in the mitigation scenario will require significant programme costs, premature scrapping of old appliances, or just a high incremental purchase price compared with less efficient appliances. A scenario using the frozen efficiency approach, on the other hand, would assume a high penetration of new efficient appliances in the mitigation case, with a low incremental cost compared with the baseline case. All else being equal, mitigation costs will typically be relatively high and the greenhouse gas reduction potential relatively low when the baseline scenario is defined according to the least-cost approach as opposed to the frozen efficiency or continuation of current trends approaches.

Baseline scenarios that do not meet a least-cost criterion can lead to the identification of a potential for so-called no-regrets mitigation options, which are mitigation options that have negative or zero incremental costs compared with the activity they substitute in the baseline case. 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. The existence of no-regrets options presumes that there are energy market imperfections or institutional barriers that can be overcome as part of a mitigation policy (IPCC, 1996, Chapter 8; Halsnæs *et. al.*, 1994; Halsnæs, 1996).

A large number of energy sector mitigation studies have identified a significant no-regrets potential (IPCC, 1996, Chapter 9). This is especially the case when the studies include a detailed assessment of current energy supply and demand systems and potential technical and economic efficiency improvements. Current energy systems often embody technologies that do not meet a least-cost criterion, a situation that can be explained by a large number of factors, such as inertia, institutional or organizational constraints, market imperfections, or human capacity limitations. Such technologies will, if compared with new, economically efficient, mitigation projects, provide a basis for the assessment of negative or very low mitigation costs. It is very important to remember, however, that all of the barriers that inhibited innovation in the first place need to be removed if the economically attractive mitigation options are to be implemented (UNEP, 1998). Therefore, no-regrets options are only valid in cases where the assessment addresses these broader implementation issues as far as possible.

Economic inefficiencies related to energy system technologies can also somehow be explained by the importance of non-economic decision factors that are not reflected in the formal cost assessment. In practice, institutional issues and broader cultural, social, environmental, and political priorities are important aspects of technology choice.

4.2.2.2 Energy Sector Approaches to Baseline Scenario Construction

The baseline scenario for the energy sector includes projections of future energy demand and supply. A number of different approaches and models can be used to establish these projections. Energy demand projections can be based on either macroeconomic activity projections (top-down), or detailed end-use technology models (bottom-up). Top-down and bottom-up models have traditionally differed in focus and specifications. While bottom-up models have particularly emphasized detailed technology representation, top-down models have rather focused on endogenization of behaviour and links to non-energy sectors. In recent years there has been a tendency for both bottom-up and top-down models to develop more detail in

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[3] A somewhat similar set of scenario concepts includes *the economic potential scenario, the technical energy-efficiency potential scenario, and the market potential scenario. The economic potential scenario,* by definition, includes all technological options that are assessed to be profitable to society, utilities, or private consumers. The *technical energy-efficiency potential scenario* assumes that the most efficient technologies known today attain a 100 % market penetration. The *economic energy-efficiency potential scenario* is constructed to reflect the expected market penetration rate over time for specific technologies (Swisher *et al.*, 1997).

areas that previously had been the domain of the other model category. The result of this recent development is that the results generated by the different models have been easier to explain and compare (IPCC, 1996, Chapter 8).

A main distinction in modelling approaches for developing baseline scenarios for the energy sector is to be made between optimization approaches and simulation approaches. Optimization approaches project future energy systems as the least-cost technology choice, given a specific objective function, which may include a number of environmental constraints in addition to cost criteria. This approach implicitly corresponds to using the least-cost approach for baseline scenario definition as outlined in Section 4.2.2.1 above. Simulation approaches project the characteristics of future energy systems on the basis of an assessment of actual behaviour (such as consumer preferences and risk attitudes) and the present configurations of the technical systems and human capacities involved. In this way, optimization approaches can be said to be prescriptive, whereas simulation models are descriptive. An extensive discussion of methodological approaches, modelling issues, and the consequences for mitigation cost assessment is presented in IPCC (1996, Chapters 8 and 9.

4.2.3 The Energy Sector Decision Framework

4.2.3.1 Specific Cost Concepts for Mitigation Assessment in the Energy Sector

In principle, the cost assessment related to energy sector mitigation projects should compare the costs and benefits of using resources for these activities with a baseline case. A full assessment of costs and benefits can be rather complicated, especially if it is to include direct costs as well as indirect costs (e.g., price changes, multiplier effects, and structural changes). The importance of assessing all indirect costs will vary from project to project, depending on the significance of the activity involved and the actual composition of the project cost components. The simple and general rule is always to focus on major project-specific costs and then eventually use more aggregate data on less important impacts.

Some energy sector projects are dominated by a few major cost components. Large-scale power production projects, for example, are in many cases dominated by technology costs and fuel costs. Other cost components are land rents and labour, but together these typically contribute less than 10% to the total costs. Similarly, end-use energy efficiency improvements are dominated by the cost of equipment and fuel savings. Efficiency improvements, however, involve a significant implementation cost, and a detailed assessment will be required in order to assess implementation programmes.

Other projects, such as bioenergy plantations, show great diversity in cost components. The projects demand equipment and seeds as well as land and labour, and the project cost assessment therefore involves a more specific evaluation of resource flows, as opposed to the more aggregate assessment for a large-scale power production project as described above.

4.2.3.2 System Boundaries for the Cost Assessment

Mitigation costs can be assessed at the project, sector, and macroeconomic levels. A sectoral mitigation cost assessment should try to establish consistency with project-level studies as well as with macroeconomic studies. The major links between the different levels of assessment are considered in Chapter 2.

The assessment at *project level* considers an individual project as if it were a stand-alone case. It is assumed that the costs and greenhouse gas reduction potential of the project are independent of other projects. The assessment at *sector level* considers a case in which a number of mitigation projects are implemented in one sector. The costs and greenhouse gas reductions of the projects can be interdependent. Macroeconomic development and other sectors are assumed to be exogenous. The final *macroeconomic* assessment considers the full socioeconomic impacts of implementing mitigation strategies in one or more sectors and includes the interactions between the different sectors of the economy.

A number of energy sector projects can be assumed to be stand-alone projects that will have only marginal economic impacts on production factors and final product markets. The baseline and mitigation scenarios in these cases can be assessed with similar prices. Examples of such marginal stand-alone projects include small-scale power production projects, electricity savings schemes, and industrial boiler efficiency programmes. Other projects, such as large infrastructure projects in the power sector or in the transportation sector, can have significant implications on input and output markets through the establishment of new industrial expansion areas and trade patterns. Similarly, the combined effect of many small energy projects can lead to significant indirect economic impacts that should be addressed in a sectoral or macroeconomic modelling framework.

Energy sector projects will in many cases have significant technical interdependencies that need to be integrated in the assessment. Technical interdependencies are taken to mean all the complicated technical interconnections in the energy systems themselves, as described in various formalized mathematical models. Specific technical interdependencies relate to the greenhouse gas emission reductions achieved by implementing certain technical mitigation options. Since greenhouse gas emissions are connected directly to the production, transmission, and combustion processes, such sources will henceforth be termed direct greenhouse gas emission sources. Final energy use, however, indirectly implies greenhouse gas emissions through its demand for supply from the direct greenhouse gas emission sources. In this way, the greenhouse gas emission reduction achieved by implementing many end-use efficiency improvements depends on the actual supply source, which again is an integrated part of the whole energy system.

An example of technical interdependencies can be seen when electricity savings and low carbon-intensive power production technologies are implemented simultaneously. The “greenhouse gas reduction value” of electricity savings depends on the carbon emissions of the substituted power production. If a mitigation scenario includes both electricity savings and low carbon-emitting power production technologies, the implicit greenhouse gas reduction value of the savings will be low compared with another scenario in which the savings are assessed as a stand-alone project or in relation to a power system with high greenhouse gas emissions. An accurate assessment of the greenhouse gas reduction achieved by energy sector strategies should therefore include the technical interdependencies, and this will require the use of some sort of formalized energy system modelling framework.

Technical interdependencies can also appear at the cross-sectoral level. One example is bioenergy, where the final greenhouse gas emission reduction achieved depends on the net decrease in biomass of the land used for biofuel production compared with alternative uses of the land in agriculture and forestry.

4.2.3.3 Special Issues Related to Energy Sector Assessment in Developing Countries

In developing countries, the energy sector is characterized by a number of distinctive features that can have an important influence on the outcome of cost assessments:

- The expected growth in GDP is large, especially in secondary production sectors, and will require future growth in energy supply systems and infrastructure.
- Energy prices are often undergoing change due to subsidy removal or organizational changes such as privatization of power production.
- Energy markets are in many cases constrained by the absence of effective demand and by supply constraints.
- Current end-use and combustion technologies are mostly inefficient.
- Leap-frogging strategies can generate rapid technological change.
- Implementation of cost-effective mitigation options needs to be supported by barrier removal policies targeted to create markets, increase the flexibility of supply systems and infrastructure, and develop institutional and human capacity.
- The relative abundance of land resources and unskilled labour makes the implementation of rural decentralized renewable energy projects, such as bio-energy plantations or biogas plants, attractive.

Energy sector investments in developing countries must be expected to be high in the coming years. The more prosperous countries, in particular, will attract investments from independent power producers and new financing sources. Future energy prices are likely to change as a consequence of deregulation and subsidy removal. Deregulation of the markets will, if successful, have a tendency to increase competition and production efficiency, outcomes which can imply decreasing prices. Removal of subsidies, on the other hand, will imply increasing prices. Taken as a whole, there can be significant impacts on the economic structure and income distribution. Futhermore, current liberalization policies, by creating expectations of high profit rates and fast capital turnover, could create a preference for electricity production with traditional fuels as opposed to hydro power or advanced renewable technologies. Baseline scenario projections must reflect these changes as far as possible, perhaps by constructing a number of alternative scenarios.

Cost components such as fossil fuels and advanced power production technologies will to a large extent be related to tradable goods. The implementation of projects that are dominated by such inputs will therefore require foreign exchange and capital availability. The costs of these resources depend on the respective opportunity costs. These opportunity costs can be assessed either in relation to national markets or to international aid conditions, depending on the actual supply source.

The assessment of energy efficiency options will typically consider appliance or equipment costs and implementation costs related to information programmes, institutional capacity building, and regulatory measures. Implementation costs are generally difficult to assess, and the only source of information will often be specific programme costs.

Other projects such as biogas plants or bioforestry projects demand land resources, unskilled labour, and small-scale technologies. Major resource components in the cost assessment will be land rents, labour, technology costs, and maintenance costs. The opportunity cost of some of these resources can sometimes be low. This is, for example, the case if the land demanded by a project could not be otherwise employed in high value-adding activities in agriculture or forestry. On the other hand, the opportunity costs can be high if the available land could instead be used to produce cash crops. In the case of such land resources. the social cost assessment should aim to include specific environmental benefits of the land (e.g., preservation of biodiversity).

4.2.3.4 Outline of the Major Cost Concepts used in Energy Sector Cost Curves

A number of mitigation cost concepts have been used in energy sector assessments. The main differences between the major concepts are outlined below.

Mitigation costs are always calculated as the difference between the costs of a baseline case and a mitigation case. The appropriate cost concept to report in cost curves is that of marginal reduction costs.

Some energy studies report mitigation costs as average reduction costs or as total reduction costs. Average and total costs are easy to derive from marginal reduction costs. The total costs are the accumulated marginal reduction costs up to a given emission reduction target, and average reduction costs follow directly from that as the total reduction costs divided by the total emission reduction.

Energy sector studies often differ with regard to the concepts used to compare the cost-effectiveness of different projects. Cost-effectiveness should in this context be understood as a measure of the result measured in terms of climate change mitigation that one gets out of spending one currency unit on a project or a strategy. Following that, cost-effectiveness can be measured as:

$$Costeff = \frac{C}{E}$$

where C represents the net cost of a given policy and E is the emission reduction achieved by the programme. Both C and E are flows that occur at given points in time, and these flows need to be transformed to comparable units using a discounting procedure. The most commonly used concepts that are used for such a transformation are net present values and levelized costs. These concepts provide similar project rankings, but cost assessments performed with the two different concepts are not directly comparable without a transformation. These two concepts are further outlined in Box 4.1 (UNEP, 1997).

Box 4.1. The NPV and Levelized Cost Concepts

Guidelines for project assessment use a number of different concepts to compare the cost-effectiveness of projects. The most frequently used concepts are net present value (NPV) and levelized cost. These concepts basically provide similar project rankings.

The NPV concept
The NPV concept can be used to determine the present value of net costs by discounting the stream of costs back to the beginning of the base year (t = 0).

$$NPVC = \sum_{t=0}^{T} \frac{C_t}{(1+i)^t}$$

The levelized cost concept
The levelized cost is a transformation of the NPVC using the formula

$$C_0 = NPVC \frac{i}{1-(1+i)^{-n}}$$

where n is the time horizon over which the investment is evaluated.

The transformation is limited to calculating the constant value C_0 in the period *n,* which is equivalent to the real cost flow C_0,.., C_T. This transformation is useful because it allows us to compare projects of different duration.The use of NPV and levelized costs as project-ranking criteria is valid, given a number of assumptions:

NPV
An investment I_1 is more favourable than an another investment I_2 if $NPVC_1/GHG\ reduction < NPVC_2/GHG\ reduction$. It should be noticed *here* that the use of NPVCs to compare the cost-efficiency of projects requires that some discounting criteria be applied to the annual greenhouse gas emission reductions. The NPVC/GHG ratio can be used to rank investments with different time horizons.

Levelized cost
An investment I_1 is more favourable than another investment I_2 if the levelized cost of I_1 is less than the levelized cost of I_2. The levelized cost should be calculated for similar investment lifetimes, with a terminal value included for long-term investments.

4.2.3.5 Cost Curve Construction Using Energy System Models

Most energy system models focus on the sectoral assessment level. The models typically include a full description of the energy demand and supply system, with demand forecasts and factor prices included as exogenous parameters. The models focus on technical interdependencies related to available fuels, power management, energy demand, and related greenhouse gas emissions.

Technical interdependencies in the energy system can be addressed in different ways, either by using advanced energy system models or by scenario analysis, where mitigation costs and greenhouse gas emission reductions are assessed for different “packages” of options.

One way of presenting mitigation scenario results for greenhouse gases is to use “emission reduction marginal cost curves.” These marginal cost curves can, in some cases, be created using only information about emission reductions and project outlays on individual projects. In other cases, the marginal cost curves should be constructed on the basis of integrated sectoral assessments.

The emission reduction marginal cost curve expresses the relationship between the minimum cost to society of reducing an additional tonne of greenhouse gas emissions and the corresponding level of emission reductions. Greenhouse gas emission reductions are defined as reductions in relation to the baseline.

The emission reduction targets can either be defined in relation to a base year (as, for example, 1990 emissions) or in relation to future baseline scenario emissions. Figure 4.1 shows these alternative definitions of emission reduction targets. Line A illustrates future baseline emissions, line C corresponds to the base year emission level, while line B represents a reduction scenario. Emission reductions in relation to the baseline scenario involve the comparison of line A and B, while reductions in relation to the base year involve the comparison of line B and C.

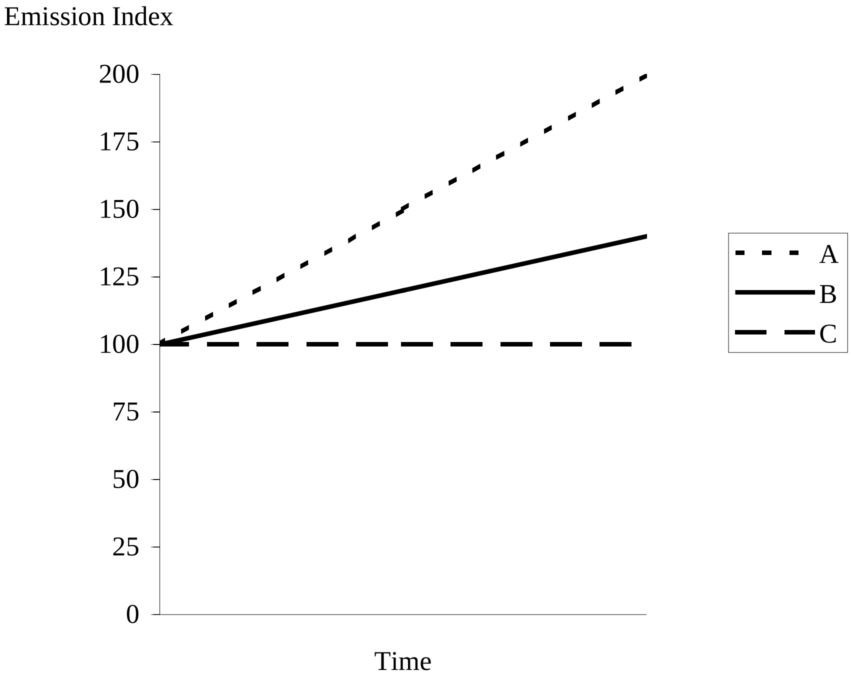

Figure 4.1. Greenhouse gas emission scenario cases

The UNEP Collaborating Centre on Energy and Environment has developed a methodological framework for climate change mitigation studies which has been tested in co-ordinated country study programmes for developing countries (UNEP 1998; UNEP 1994). The framework includes a common analytical structure for country studies, defines main economic and technical concepts and specifies a uniform format for reporting of national results in order to facilitate transparency across different countries and GHG emission sources and sinks. An example of the concepts defined in the UNEP framework is the cost curve format shown in Figures 4.2 and 4.3. The cost curve is a comparison of the marginal reduction cost for CO_2 reduction at a specific point in time where the costs of meeting a specific emission reduction target are depicted.

In the simplest case, where the marginal cost curves for greenhouse gas emission reductions are constructed on a project-by-project basis, from the bottom up, the marginal reduction costs (US$ per tonne of CO_2) are calculated as the difference between the cost of following the baseline scenario and the cost of following the mitigation scenario. A parallel cost assessment for these two scenarios can been done as follows:

$$MRC_t = \frac{CR_t^{'} - CR_t}{R_t - R_t^{'}}$$

where:

MRC_t is the marginal reduction costs in the year *t*.
R_t is the total CO_2 emissions in the year *t*.
$R_t^{'}$ is the total CO_2 emissions in the year *t* after the implementation of a given project.
CR_t is the total cost of a given scenario corresponding to the emission level R_t.
$CR_t^{'}$ is the total cost of a scenario corresponding to the emission level $R_t^{'}$.

The stepwise calculation of reduction cost is illustrated in Figure 4.2. The total reduction costs can then be calculated as the area below the marginal abatement cost curve.

Cost curve construction with an integrated energy system model will proceed from the first initial partial assessment of mitigation options and assess the consequences of introducing combinations of options using the following steps:

a) Ranking of possible mitigation options on a partial basis
b) Introduction of different baskets of mitigation options (chosen with a starting point in the preceding step), creating a large number of scenarios for possible greenhouse gas reductions and related costs
c) Choice of the lowest costs for a given greenhouse gas reduction, thus establishing an envelope curve for annual greenhouse gas emission reductions and related costs.

This approach aims to take into account all the interdependencies within the system as represented by the energy system model.

A probable result of the analysis is that a given greenhouse gas emission target can be fulfilled with several energy system solutions that, on the whole, are economically close. Such energy system solutions, however, may be quite different technically, for example, with regard to the dominant power production technology or the weighting of investments in demand or supply technologies. This introduces the possibility of other parallel criteria for project assessment, such as complementary environmental effects or other specific national priorities.

Figure 4.3 shows CO_2 reduction cost curves for the energy systems of six developing countries as estimated in the UNEP Greenhouse Gas Abatement Costing Studies (UNEP, 1994).

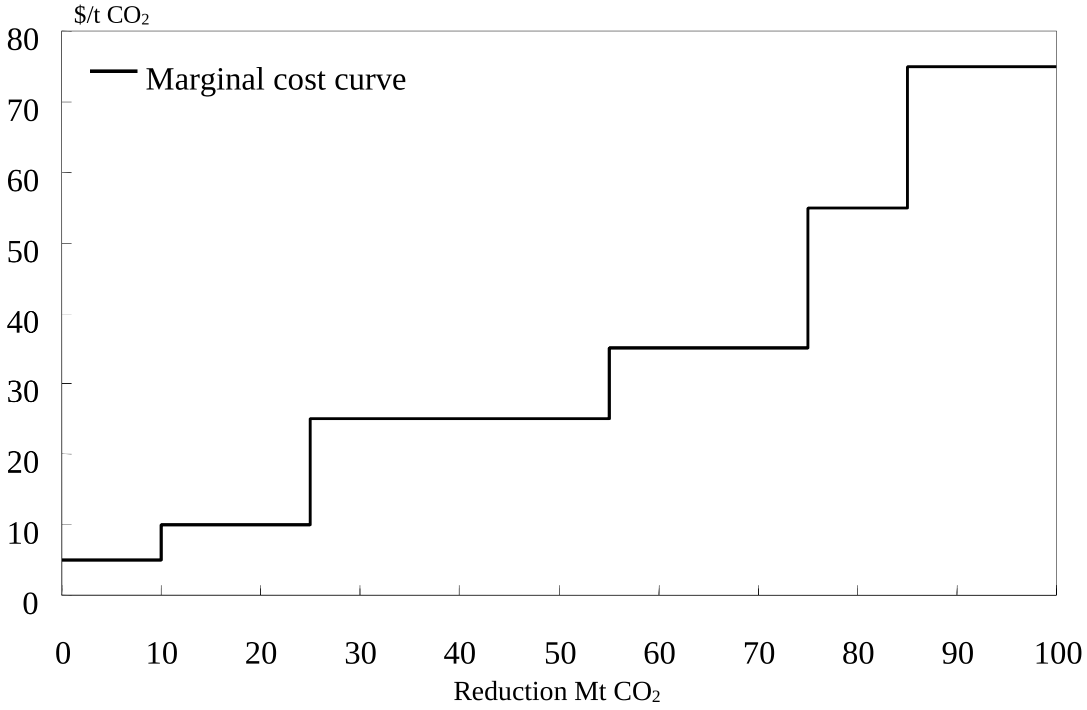

Figure 4.2. Marginal cost curves of greenhouse gas emission reduction.

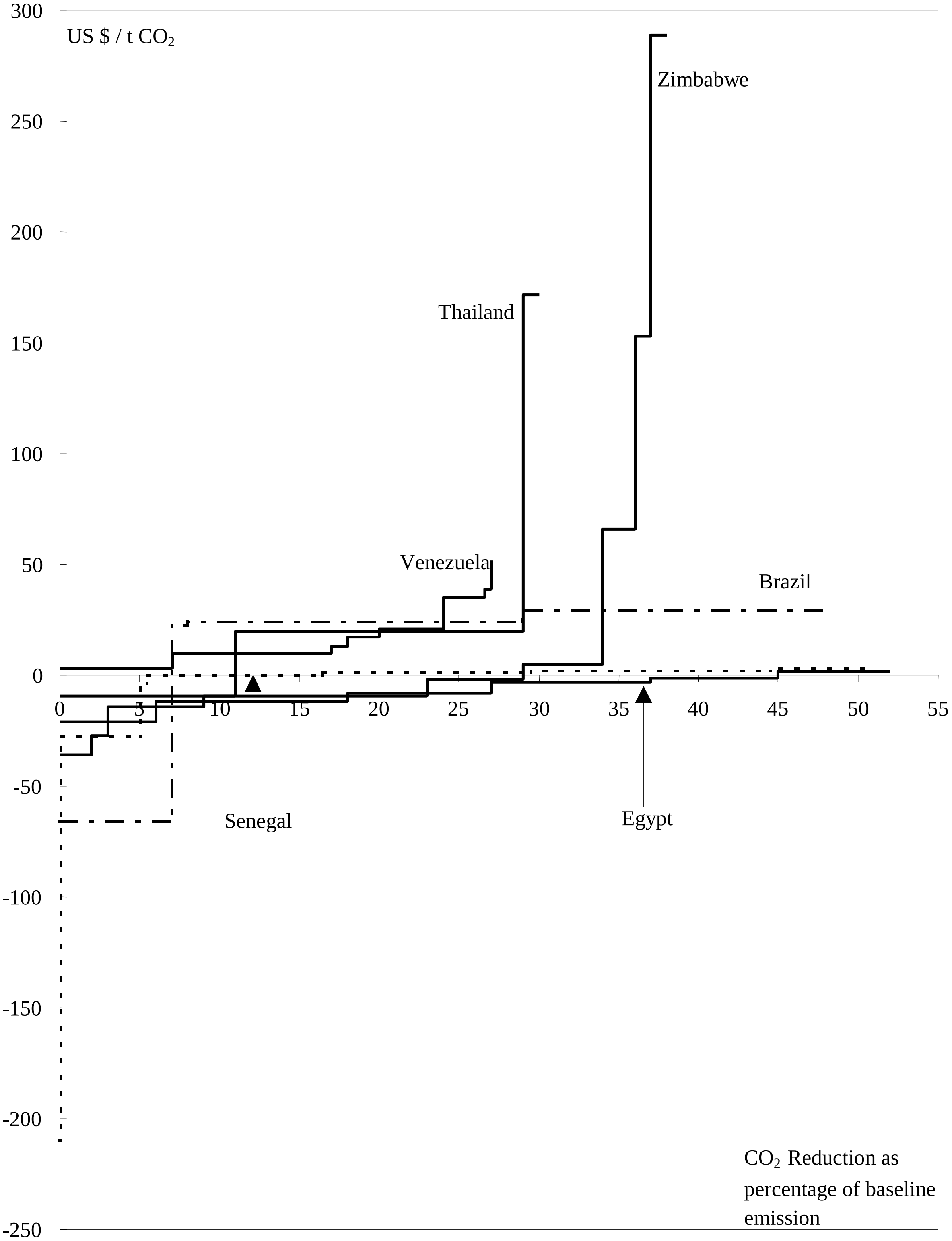

Figure 4.3. Marginal cost curves of greenhouse gas emission reduction for the energy systems of six developing countries (UNEP, 1994).

4.2.4 Mitigation Options

A very large number of energy technologies can in principle be assessed as part of a mitigation scenario, but only a more limited number of these options will be important in the specific national context. Data collection is very time-consuming, especially for developing countries, and a critical screening should therefore be carried out to select options that merit closer examination.

The following list shows possible economically attractive technology options for reducing greenhouse gas emissions in the energy sector. The list is not intended to be exhaustive, but shows some categories of options that will be relevant for inclusion in most country studies.

End-Use

Lighting:

- Commercial facilities: replacement of standard fluorescent tubes with lamps with electronic ballasts and reflectors
- Residential: replacement of incandescent bulbs with efficient fluorescent and compact bulbs

Motors:

- Use of high-efficiency motors and adjustable-speed drives in industrial facilities

Refrigeration:

- Residential: replacement of old home refrigerators (e.g., 1000+ kWh/yr in the USA) with new high efficiency models (e.g., as low as 300 kWh/yr in the USA)
- Commercial: replacement of standard compressors with high-efficiency compressors or multiplex compressors

Industrial Processes:

- Encouraging cogeneration for provision of electricity and process heat. Waste products from industrial processes (wood waste, bagasse, etc.) could also be usable for combustion in a cogeneration process.
- Industrial processes often have very high cost-effective energy efficiency potential, but their process-specific nature often precludes generic programs. Industrial audits are necessary to identify the most appropriate measures, and a financing mechanism should then perhaps be put in place to encourage actual equipment retrofits following audits.

Cooking:

- Use of improved woodstoves and other more efficient cooking devices
- Substitution of wood fuels in cookstoves in institutions such as rural schools, hospitals, and other centres

Water Heating:

- Replacement or reduction in use of electric resistance heating. Greater use of natural gas or simple solar systems. Heat pumps may be applicable in commercial and industrial facilities.

Space Heating:

- Refurbishing of district heating systems: improved controls, maintenance, metering
- Use of heat pumps

Space Conditioning:

- Many air-conditioning options are available, in particular district cooling in tropical countries.

Other appliances:

- Reduction of standby devices

Transportation

- Use of alternative fuels such as alcohol
- Efficiency improvements in vehicles
- Modal change in freight transport
- Modal change in public transportation
- Substitution of public transportation for private transportation
- Enhanced traffic management

Supply Side

- Combined-cycle natural gas and high-efficiency simple cycle gas turbine operations to replace coal- and oil-fired boilers for electricity generation
- Combined heat and power production systems
- Hydropower: large-scale systems have significant environmental impacts. Smaller-scale run-of-river systems may often be attractive.
- Wind power in places with favourable climate
- Small-scale photovoltaics can be competitive especially in remote areas with no grid access. In general, small-scale renewables in rural areas can be cost-effective and also reduce deforestation by reducing reliance on local biomass. Options include solar cooking stoves, biogas plants, small-scale wind systems, and small run-of-river hydro installations. Large-scale photovoltaics are not yet competitive against traditional generation in areas with a developed transmission grid.
- Biomass-based electric generation systems using agricultural wastes or forest plantations show significant potential, especially as gasification systems mature and allow biomass combustion in gas turbines.
- New coal-based electric generation such as integrated gasification combined cycle (IGCC) and pressurized fluidized bed combustion (PFBC) systems are both now well-demonstrated technologies that have been successful in significantly raising the efficiency of coal-based systems to total efficiencies of up to 45%.
- Fuel substitution
- Establishment of infrastructure: power transmission, natural gas pipelines
- Deployment of decentralized options for infrastructure development (photovoltaics, wind, photovoltaic/wind hybrid systems) and renewables for grid support and energy management. A distributed utility in which net metering and a form of performance-based ratemaking allow distributed generation, storage, and DSM to play an important role, could support the implementation of rural solutions.

4.2.5 Methodological Approaches

4.2.5.1 Energy Demand and Supply Projections

Several methods can be used in energy demand projections. A main distinction can be made between projections that are driven by aggregate macroeconomic activity forecasts and those that are based on detailed assessments of energy end-use and supply technologies. The following section explains the main differences between simplified versions of these two approaches.

Projections based on aggregate macroeconomic activity start with a link between economic development measured as total GDP or divided into various demand and production sectors and GHG emission sources and sinks. The activity forecast can be generated by macroeconometric models of various types or by simpler statistical surveys. In the simplest case, the relationship can be formulated as:

$$E = AY^{\alpha}P^{\beta}$$

where:

E is the energy demand
A is a (positive) constant (which, for example, can represent a technological trend factor)
Y is the income (total GDP or a vector of sectoral outputs)
P is the energy price
α is the energy-income elasticity (or a vector of sectoral elasticities); this elasticity is *positive*, implying that higher income entails higher energy demand.
β is the energy-price elasticity; this elasticity is *negative,* implying that higher energy prices entail reduced energy demand.

It should be recognized that this energy demand equation is based on a highly scematized functional relationship, but it illustrates how econometric estimates of historical trends can be used to establish a macroeconomic activity link to energy demand forecasts. Such an approach should be distinguished from behavioural relations, where energy demand is expressed as a function of prices, quantities, and substitutability.

This framework has its advantage in establishing a consistent relationship between macroeconomic activity and energy demand. The demand projections should preferably be divided into the main energy categories and demand sectors. In developing countries, however, it can be very difficult to obtain the appropriate statistical data for a time series that is long enough to make a valid econometric energy demand forecast. Many studies in these countries have therefore used some sort of generic international data to substitute for the lack of national data. Such an approach will, of course, decrease the quality of the forecasts.

Econometric energy demand forecasts are especially valid for short-term projections, because they basically project what will happen if existing historical trends continue in the future. Structural changes in energy demand or major technological changes are not reflected in the simplified representation of the demand forecast shown above. Such information, however, can be integrated into the assessment, for example, through the use of exogenous input on sectoral changes in energy demand. This limits the application of econometric forecasts in longer-term projections.

Some macroeconomic energy models include a so-called AEEI (Autonomous Energy Efficiency Improvement) parameter that reflects long-term technological changes, which are not induced by structural economic output changes or relative price changes. The AEEI parameter is exogenously determined, which, of course, is not a very satisfactory solution (for a further discussion of the methodological issues involved in the determination of this parameter, see Chapter 7). It is difficult to estimate the AEEI factor, and many studies have therefore used expert judgements in its determination. The AEEI value applied in macroeconomic energy models typically varies between 0.5% and 1.5% annually (EMF, 1993). As an alternative to the use of an exogenous AEEI factor, one can estimate a technological progress factor and include it in a production function.

An alternative energy demand projection methodology is the technology-driven end-use approach (Swisher *et al.* 1997). The end-use approach projects future energy demand as the product of two factors: the energy service level and the energy intensity. The energy service level is, as with econometric projections, related to economic output, income, and population projections. The energy services are then linked afterwards to detailed end-use technology data in order to project the quantity of energy that will be needed to satisfy a given energy service. The energy demand is calculated according to the following formula:

$$E = \sum_{i=1}^{n} Q_i \cdot I_i$$

where:

E is the energy demand
Q_i is the quantity of energy service *i*
I_i is the intensity of energy use for energy service *i*

The idea of the end-use methodology is that the various energy services and technologies represented by I_i can be considered separately, thus making it possible to assess the impact of introducing options relating to the different parameters. Lighting could be an example of such an energy service. The I_i would in this case be represented by the energy intensity of the light bulb, and the point would be to investigate the technical possibilities of keeping a constant energy service level whilst saving primary energy through efficiency improvements in lighting technology.

The energy service demand is, by nature, a rather detailed projection of energy requirements related to subcategories such as process heat, lighting, space heating, and air conditioning, The quantity of energy services Q_i can, for example, be projected on the basis of the following parameters (Swisher *et al.*, 1997):

- number of customers eligible for end use *i*.
- penetration of end-use service *i* (units/customer).
- magnitude or extent of use of end-use service *i* (e.g., number of hours in use).

The energy intensity parameter I_i is related to the end-use technologies and reflects the efficiency of these technologies. This efficiency level will change over time, based on the expected turnover rate of the existing stock of appliances.

The advantage of the end-use approach is that it can reflect developments in appliance technology. Future energy demand is primarily projected on the basis of today's known energy services and technologies, and the approach will therefore be most appropriate for the short to medium term. New energy service needs related to economic activity changes, or new future end-use technologies, can be difficult to forecast on the basis of the detailed technology information contained in end-use models. The best energy demand forecasting approach may therefore be a combination of the end-use and the econometric approach.

Supply system projections

The energy supply system includes power production technologies and heat production technologies. These technologies can be large centralized plants, or they can be decentralized in relation to specific production processes, heating and cooling systems, cooking devices, vehicles, and the like.

Supply projections can basically vary around the following parameters: fuel mix, technologies, and final energy forms (electricity/heating/cooling). Different supply scenarios can be constructed by varying these parameters.

The fuel mix can include both imported and domestic resources. In most cases supply technologies are linked directly to the fuel mix, but a number of variations are possible where different fuels can be used in the same combustion process or used following small technical modifications.

A major scenario parameter is the assumed technological development. This assumption relates to already implemented and traditional technologies as well as to technologies that would be cost-effective to implement in the future, given improved efficiency or decreased costs.

Changes in final energy demands in the form of substituting one energy form for another are closely linked to the detailed data on end-use technologies described in the section on energy demand forecasts.

Sensitivity analysis

It should be emphasized that energy forecasts for the long time frame considered in climate change mitigation studies will always be characterized by large uncertainties. It is therefore recommended that sensitivity analyses be conducted for the main scenario parameters and that multiple baseline scenarios be used, as recommended in Chapter 2.

4.2.5.2 Technology Data

One common difficulty in conducting climate change mitigation analyses is the shortage of data characterizing different technologies and their costs and performance. While it must be emphasized that nothing can truly substitute for local country-specific data, there are several data sources containing "generic data" that can provide a useful starting point for analyses. Some of these data sources are described below.

IIASA CO_2 Data Bank. The CO_2 Data Bank (CO2DB) was developed by the International Institute for Applied Systems Analysis (IIASA) in Austria. It contains approximately 1500 entries describing a wide range of technologies, including energy supply- and demand-side technologies, fuel extraction and conveyance, and passenger transportation.

IPCC Inventory of Technologies, Methods, and Practices for Reducing Emissions of Greenhouse Gases. The Intergovernmental Panel on Climate Change has produced this database as a technical appendix to the Climate Change 1995 Working Group II Second Assessment Report. The IPCC Inventory contains approximately 100 technologies, including energy supply, end-use, fuel extraction, and passenger transportation.

Environmental Management for Power Development (EM Model). The EM Model is a computer software package and database developed by the German aid agency GTZ, the Oeko-Institut, and the World Bank. The software contains generic data on a wide range of technologies and processes, including costs and detailed pollutant emissions.

CEC Energy Technology Status Report. The Energy Technology Status Report (ETSR), published by the California Energy Commission (CEC), is a multivolume document describing a very wide variety of supply-side and end-use energy technologies and processes, including coal, oil, and gas combustion, nuclear, geothermal, hydroelectric, biomass, municipal solid waste, cogeneration, wind, solar thermal, photovoltaics, ocean energy, fuel cells, storage systems, pollution control, water heating, space heating, space cooling, lighting, appliances, boilers, motors, load management, and transmission technologies. The coverage includes qualitative descriptions of the technologies, barriers to implementation, and quantitative economic analysis.

E Source. E Source is a membership-based commercial organization providing energy efficiency technology information to consulting firms, utilities, governments, and research institutions. E Source is perhaps the most complete source of end-use technology data and publishes, among other things, five comprehensive technology atlases (or “encyclopaedias”) covering lighting, drivepower, space cooling and air handling, space heating, and residential appliances. These five atlases are over 1700 pages in total length and include theory, design tips, and performance and cost information.

ACEEE. The American Council for an Energy-Efficient Economy (ACEEE) is a non-profit organization that publishes a variety of books and reports and organizes conferences related to energy efficiency. The ACEEE offers useful energy-efficiency design guidance through books and reports such as *Energy-Efficient Motor Systems*, *Financing Energy Conservation*, *Improving Energy Efficiency in Apartment Buildings,* and *Energy Efficiency and the Pulp and Paper Industry*.

EPRI TAG. The Electric Power Research Institute (EPRI) is a research organization jointly financed by U.S. investor-owned electric utilities. EPRI publishes a set of useful Technical Assessment Guides, commonly known as TAG. The TAG reports provide information on electric supply-side and demand-side technologies, assessment methods, and data.

DECADES. DECADES is a joint interagency project for creating and disseminating databases and methodologies for the comparative assessment of different energy sources. It was established in 1992 by nine international organizations: EU, ESCAP, IAEA, IIASA, IBRD, OECD/IEA, OPEC, UNIDO, and WMO. In addition to providing methodologies and a user-oriented interface, DECADES has made available the following five modular databases: Reference Technology, Country Specific, Vendor Specific, Toxicology, and Health and Environmental Impacts.

GREENTIE. A project of the IEA, GREENTIE provides some information about specific technologies but functions mainly as a directory of companies and organizations working with the various technologies.

IEA GREENHOUSE GAS R and D PROGRAMME is an international collaborative initiative for evaluating technologies for reducing greenhouse gas emissions. It uses a standardized system for the assessment of new and existing technologies. It also publishes regular newsletters and reports and organizes conferences.

4.2.5.3 Energy System Models

A large number of energy system models have been developed and applied to energy and environmental studies at the international and national level. Many of these models include standardized databases and optimization/or simulation programmes that can be applied to different national settings with relatively small changes. An overview of different energy system models that have been applied to mitigation costing studies in the energy sector is given by IPCC (1996), UNEP (1994), and Sathaye and Meyers (1995).

4.2.5.4 Comparability of Energy Sector Mitigation Studies

National and international mitigation studies for the energy sector have been carried out with a variety of models. In recent years, extensive scientific discussion has surrounded the review and comparison of results from these different modelling exercises (IPCC, 1996, Chapters 8 and 9). The models include technology assessment models, integrated energy system models, partial equilibrium models, macroeconomic models, and others. Despite differences in their focus and coverage, all of the models recognize a number of key input assumptions as being of major importance for the assessed mitigation potential and related costs.

The following identity shows, at the aggregate level, why energy baselines and mitigation assessments differ (Kaya, 1989):

The growth rate in CO_2 ≡ the GDP growth rate
minus the rate of decline of energy use per unit of output
minus the rate of decline of CO_2 emissions per unit of energy use

This identity can be developed further by adding extra arguments that reflect:

- the ratio of emissions to primary energy use
- the ratio of primary energy use to secondary energy use
- GDP per capita
- population growth rate
- structural changes in GDP

Energy models will, in most cases, include more detailed information than the parameters reflected in the Kaya identity. Energy consumption, for example, will be represented in an energy system model by detailed fuel and final energy subcategories. The growth of energy consumption will subsequently depend on the development in energy service demand and technological development of end-use and combustion technologies. The CO_2 intensity of energy consumption is likewise related to the detailed background information on the energy system. The three arguments of the Kaya identity are therefore primarily of interest as comparative aggregate statistical indicators of energy modelling output.

International reviews of mitigation costing studies for the energy sector have assessed the implication of key input assumptions on mitigation cost assessments (IPCC, 1996; Haites and Rose, 1996). Table 4.1 shows the implications of a number of key input assumptions.

Table 4.1. Input assumptions used in energy sector mitigation studies

Input assumptions	Meaning and relevance
Population	All else being equal, high growth will increase greenhouse gas emissions.
Economic growth	Increased economic growth increases energy-using activities and also leads to increased investment, which speeds the turnover of energy-using equipment.
Energy demand	
– structural change	Different sectors have different energy-intensities. Structural change will therefore have a major impact on overall energy use.
– technological change	This “energy-efficiency” variable influences the amount of primary energy needed to satisfy given energy services required by a given economic output.
Energy supply	
– technology availability and cost	Potential for fuel and technology substitution.
– backstop technology	The cost at which an infinite alternative supply of energy becomes available. Upper bound of cost estimates.
Price and income elasticities of energy demand	Relative change in energy demand due to change in price or income respectively. Higher elasticities cause larger changes in energy use.
Existing tax systems and tax recycling	Recycling of carbon taxes. Substitution of distortionary taxes decreases costs.
Implementation	
– instruments	Economic versus regulatory measures.
– barriers	Cost of overcoming barriers either in the form of transaction costs or improvements in markets (including capacity building and institutional reforms). Behavioural assumptions.

Source: IPCC (1996)

4.2.5.5 Assessment of Policy Implementation

The assumption is often made in traditional cost-benefit analyses, bottom-up studies, and sector studies that no specific activities, or very few, are necessary to promote policy implementation, despite the costs of the resources involved, such as production factors, technologies, final products, and overheads. To the extent that implementation costs are represented, they are limited to such items as planning activities, administration, information, training, monitoring, and the like.

Successful implementation of large-scale environmental projects or strategies such as climate change mitigation strategies will, however, typically involve costs that exceed administration and training costs. The existence of market imperfections, imperfect information, institutional failure, externalities, ill-defined and/or not well-enforced property rights, and other realities indicate that implementation is not a frictionless exchange process and that transaction costs can be significant (UNEP, 1998).

Specific measures can be taken, however, to remove or reduce barriers to implementation in order to realize the desired outcome of a given project or strategy. These additional measures can be termed *barrier removal policies.* Barrier removal policies are, as defined here, related to the *short- and medium-term reduction of transaction costs*. Their effects are not limited to the immediate project or strategy. Basically, barrier removal policies try to enhance the power of market forces and private incentives to implement projects. These policies can include a large number of different activities, including price incentives, information, and the establishment of an institutional framework for market competition and access (e.g., capital market structure and institutions).

It should be emphasized that different combinations of barrier removal policies can be suggested to implement projects or strategies, but the specific design and the cost of the different policies are dependent on the comprehensive barrier removal effort. This can be illustrated in the case of electricity-saving programs for private households. This policy can be implemented through information campaigns, through changes in technical standards, or through market instruments like taxes or subsidies, or, more realistically, through a combination of all these policies. The cost of an individual barrier removal policy must be expected to decrease if it is combined with other policies – price signals work better if households are well informed and the other way around. However, in practice, barrier removal policies may not be fully able to take advantage of such synergisms because other political or social considerations prevent the use of certain instruments. Furthermore, conflicts between the instruments used at the different levels is possible, or even likely. Box 4.1 provides examples of barrier removal policies targeted to reduce transaction costs in the energy sector.

Box 4.1. Examples of barrier removal policies

Barrier removal policies	Specific policy example
Market barriers	
Market creation, possibly with public sector involvement in the transition period	Temporary support to specific demonstration projects
Privatization, for example, through the establishment of well-defined property rights and their enforcement.	Bioenergy programmes entailing secure land use rights
Regulation of competition through introduction of more market actors.	Information campaigns; soft loans to developers of renewable technologies
Environmental taxes	Carbon taxes
Supporting efficiency in savings and investment decisions by deepening financial markets	Supporting financing mechanisms (e.g., GEF)
Launching technical standards to be met in a given time frame	Efficiency standards for electric appliances
Inflexibility and constraints of established technical systems	
Timing of infrastructure investments	Long-term planning of power production and transmission
Subsidization of capital turnover projects	Specific capital grants
Subsidized credit to support research, development, and learning processes	Demonstration and research programmes
Coordination and integration of specific climate change mitigation efforts in general investment policies	Information, capital subsidies (e.g., efficient industrial boilers)
Institutional barriers	
Establishment of monitoring and enforcement systems	Reporting systems
Establishment of institutions for the reduction of risks and/or risk pooling (notably capital market)	Offset market
Establishment of specific organizations to reduce uncertainty and transmit information	Energy auditing
Establishment of international mechanism for technology transfer	“Clean Development Mechanism”
Human capacity barriers	
Training and education activities	
Improvement of decision-making processes	
NGO involvement in specific areas	

The development of national policy strategies is further described in Chapter 8, “Appropriate Use of Cost Concepts.”

4.3 The Forestry and Agriculture Sector

4.3.1 The Forestry and Agriculture Sector Decision Framework

4.3.1.1 Specific Cost Components for Mitigation

The forestry assessment should consider the net cost and benefits of utilizing specific land areas for mitigation projects.

The main cost components are:

- land rents (land rent to be paid or opportunity cost of displaced activities such as agriculture)
- land conversion costs at the start of the programme, plus subsequent regeneration costs after harvesting
- establishment costs – costs of seeds or seedlings and other materials, labour cost, infrastructure costs
- maintenance and silvicultural costs
- harvesting cost
- overhead costs, including depreciation
- incentive costs – other payments, such as equipment loans or advanced harvest revenues
- loss of biodiversity

The corresponding benefits are:

- the value of wood products from thinning and harvest
- the shadow price of saved carbon and other greenhouse gases
- joint environmental benefits (biodiversity, reduced air pollution, watershed protection, etc.)
- recreation benefits.

In practice, it is difficult to assess all cost and benefit components, and many studies have therefore used simplified approaches in which only some of these components have been included. Land rents have been particularly difficult to assess, and some studies have therefore either excluded land rents or assumed that the wood products will eventually pay for the land rent. Future benefits of wood products have similarly been difficult to assess. Studies by Swisher and Masters (1991, cited in Makundi *et al.*) treat this problem by referring to the present value of future project costs as an "endowment." The endowment includes the initial cost of establishing the project plus the costs of silvicultural operations, management, extension services, protection, and monitoring the project's performance. For perpetual management of a given forest project, the benefits derived during the first rotation may be sufficient to cover the operation and management of future rotations.

The costs and benefits are to be measured against carbon savings. Carbon is stored in vegetation (mostly in tree stems, branches, and roots), detritus, forest soils, and wood products. The main sources of carbon flux include the decomposition of biomass after harvesting and clearing and the combustion and oxidation of wood.

The carbon fluxes of forestry and land-use projects differ depending on project type. Projects that reduce pressures on forested lands generate carbon benefits rapidly. In contrast, afforestation and reforestation projects sequester carbon over a long time horizon following the growth of the biomass. Future release and eventual substitution of released carbon depends on the use of the forested land and the biomass. The time path of carbon savings is thus non-constant.

This is different from the time path of carbon savings achieved by mitigation projects in the energy sector, where it often makes sense to assume relatively constant annual savings. Examples of such projects are energy efficiency improvements or the introduction of low carbon-intensive fuels.

4.3.1.2 System Boundaries

The assessment can be done at the project, sector, or macroeconomic level.

A project level assessment assumes that the activity is standing alone. The advantage of a project assessment is that it allows a very detailed accounting of resources and carbon savings for a specific activity. The project can therefore include detailed specifications of forest species, soils, and climatic conditions for a given land area.

A sector level assessment considers activities that are large enough to imply significant changes in sector output and demand markets. Supply costs as well as final product values can therefore vary. Thus, the main parameters to assess in a sectoral assessment are total carbon flows of the land, demand and supply of production inputs, and final product markets for domestic and tradable goods.

There will often be complex interrelationships between sectors. The energy sector, transportation, agriculture, and forestry are potentially in competition for available land, and agricultural crops, bioenergy, and wood products can both substitute and complement each other. System boundaries must be broad enough to include the flow of land and products between sectors and the "leakages" that occur directly or indirectly when production is displaced in another sector.

Macroeconomic assessment will include sectoral interrelationships and impacts on macroeconomic parameters such as employment, prices, the trade balance, and foreign exchange reserves. The appropriate assessment level (project, sector, or macroeconomic) depends on the scale of the activity and the expected economic feedbacks from project implementation.

A project level assessment can focus on direct cost assessment and carbon accounting for the project, compared with the baseline alternative. In its simplest form a mitigation scenario can then be constructed via the addition of individual project data, as long as significant technical or market interrelationships are not expected to eventuate from implementation of the strategy. This last condition holds in cases where the projects are relatively modest in scale. In some cases the effects of large individual projects or the collective impact of several projects will be sufficient to affect market prices or producer behaviour. In such cases a larger number of impacts must be assessed. These impacts include land prices, timber prices, competing land use, and combined policies (World Bank, 1997). This assessment should also consider possible leakages, where forest conversion activities simply are transferred from one area to another.

4.3.1.3 Main Mitigation Options for the Forestry Sector

Mitigation options for the forestry sector may be classified into two basic categories. One category involves expanding the pool of carbon in soils, vegetation, and wood products. The second involves maintaining both the existing pool of carbon in soils and vegetation and the proportion of forest products currently in use.

The options can be further classified into the following subcategories:

I. Reducing the rate of deforestation
  - Reducing the demand for fuelwood and agricultural products through substitution of “sustainable fuels” for wood fuels, increased fuel wood efficiency, increased agricultural productivity, forest protection and conservation, and other measures to reduce the conversion of forest to agricultural land
  - Preserving forested land as parks, wildlife reserves and refuges, and/or sustainable forestry areas

II. Increasing forested land (afforestation)
  - Plantations and community forestry

III. Increasing stocks of carbon in existing forests
  - Forest protection and conservation (vegetation and soil), timber standard improvement (hardwood control, precommercial thinning, fertilization, pest and disease protection, etc.)
  - Agroforestry. Increasing carbon in agricultural soils
  - Reforestation and rehabilitation of degraded forest lands through measures such as enhanced natural regeneration

IV. Increasing wood use and efficiency
  - Increasing efficiency of wood recovery; increasing the merchantable uses of wood
  - Substitution of timber for high energy materials in construction (e.g., concrete and steel)

V. Substituting wood and other biofuels for fossil fuels

VI. Agroforestry and multiple-use
  - Integrating trees into existing or modified agricultural land use patterns (windbreaks, shelterbelts, multiple-use species, live hedges, alley cropping, multilayer tree gardens)

VII. Urban forestry
  - Residential shade trees, roadside vegetation, demarcation trees. The primary greenhouse gas reduction benefit of urban forestry is reduced fossil fuel emissions resulting from reduced heating and cooling loads, rather than carbon sequestered in new biomass growth.

4.3.1.4 Main Mitigation Options for the Agricultural Sector

The mitigation options for the agricultural sector can be specified in the following subcategories:

I. Livestock methane: Enteric fermentation from livestock ruminants

- Improvement of nutrition through mechanical and chemical feed processing
- Improvement of nutrition through strategic supplementation
- Use of production-enhancing agents
- Improvement of production through genetic improvement of breeds
- Improvement of production efficiency through increased reproduction efficiency
- Disease control

II. Anaerobic fermentation (manure management)

- Use of digesters to recover methane from liquid- and slurry-based manure handling facilities
- Switching to non-liquid and non-slurry methods of manure handling

III. Reduction of methane emissions from rice paddies

- Reduction of raw organic material by switching to nitrogen fertilizer
- Reduction of period of time when crop is flooded
- Switching cultivars
- Reduction of cultivated area

IV. Reduction of nitrous oxide emissions

- Matching nitrogen supply and demand
- Closing the nitrogen cycle
- Use of new nitrogen application technologies and practices
- Improved tillage, irrigation, and drainage

V. Enhancement of soil carbon

- Use of conservation tillage
- Planting of cover crops

4.3.1.5 Carbon Accounting and Timing

Among the most difficult benefits to assess are those arising from saved carbon.

The benefits of reduced greenhouse gas emissions vary with the timing of the emission reduction, with the atmospheric greenhouse gas concentration at the time of the reduction, and with the total greenhouse gas concentrations more than 100 years after the emission reduction. There is much uncertainty surrounding these benefits, which are incompletely described. Many studies have therefore tried to avoid the use of shadow values of saved carbon by defining a simplified price proxy that can be used to compare the value of carbon savings occurring at different points in time.

IPCC identifies three different methodologies for carbon accounting that have been widely used in carbon sink mitigation analyses (IPCC, 1996, Chapter 8). The methodologies are the flow summation method, the average storage method, and the levelization/discounting method. The choice of accounting methodology has a major impact on carbon sequestration costs. This is illustrated in an example in Section 8.4 of the Working Group III contribution to the IPCC Second Assessment Report (IPCC, 1996).

The flow summation method simply accounts for the sum of the carbon storage increments (i.e., annual carbon fluxes) over the project cycle, regardless of the timing of these fluxes. This means that if all the biomass is harvested and released at the end of the project cycle, total storage is assumed to be zero. The average storage method uses the same basic accounting system as the carbon flow summation method; however, it goes a step further and measures the carbon storage as the average of the sum of all carbon fluxes over the project cycle. Thus, in contrast to the flow summation method, the average storage method would assign a positive carbon saving to a project in which all biomass was harvested and utilized at the end of the project cycle. The levelization/discounting method takes a different approach to the timing of carbon storage. It assumes that the timing of carbon storage is important, because the benefits of carbon storage may vary over time in relation to when a tonne of carbon is stored. To capture this effect, this approach involves discounting the carbon fluxes associated with a project over the project cycle and then annualizing the present value of the discounted carbon fluxes. When a constant, positive discount rate is used, more emphasis is placed on carbon stored early in the project cycle than on that stored in later years.

Discounting carbon flows is a proxy for estimating the shadow value of carbon, but it requires that certain assumptions be made about the relationship between carbon storage and the climate change damages avoided over time. Sathaye *et al.* (1993) suggest that the shadow value of reduced climate change (VC) should be determined as:

$$\text{VC} = \int_0^\infty P_c(t) e^{-rt} C_0 e^{-at}\, dt$$

where $P_c(t)$ is the shadow price of avoided carbon at time t, C_0 is a single year emission reduction, r is the discount rate and, a is the atmospheric decay rate of carbon dioxide.

The shadow price of avoided carbon $P_c(t)$ represents the damage function of climate change, estimates of which are subject to significant uncertainties. As a result, most discussions of the shadow price of carbon only cover the theoretical implications of different assumptions about this damage function.

If it is assumed that the emission reductions of a project, C_0, are small compared with the total atmospheric carbon stock, then $P_c(t)$ is constant for the project. The shadow price of avoided carbon $P_c(t)$ will probably vary over time as a function of the stock of atmospheric carbon. It is, however, difficult to determine that relationship, and for simplicity $P_c(t)$ will therefore be assumed to be constant. Given this assumption and assuming constant r and a, VC can be written as:

$$VC = P_c \frac{C_0}{r + a}$$

A project is worth pursuing if VC is equal to or greater than the costs of implementing the project. A cost-effectiveness analysis can therefore rank the projects on the criterion of VC versus costs. With the simplified assumption of a constant P_c, the ranking criterion is then reduced to a constant factor that converts future carbon emission reductions to a net present value.

It should be noted that projects will typically imply carbon reductions in multiple years. The total net present value of carbon emission reductions achieved in the total lifetime of the project (VCC) can, for discrete time steps, be calculated as:

$$VCC = \frac{P_c}{r + a} \sum_0^{Te} C_t / \left[(1 + r)^t\right]$$

where C_t is the quantity of carbon emissions at the time t, and Te is the time period where emission reductions occur.

The choice of carbon accounting method has important implications for the calculation of the cost-effectiveness of carbon storage in two fairly common cases: (1) when the annual carbon fluxes are uneven and, specifically, (2) when the emissions of carbon during the last period in the project cycle cancel out the undiscounted fluxes in all previous periods. When carbon flows are unequal, use of the levelization/discounting method will always produce a positive cost-effectiveness ratio, because the benefits of carbon storage in the denominator of this ratio will be positive, and the cost-effectiveness ratio will be different from the ratios derived by the other two methods. In case (2), the average storage method and the levelization/discounting method will return positive cost-effectiveness ratios; however, the cost-effectiveness of a project that is evaluated using the flow summation method will be undefined, since the benefits of carbon storage will be equal to zero. The effects of discounting carbon flows on cost-effectiveness ratios will be discussed further in Section 4.3.2.

4.3.2 Analytical Steps in Mitigation Cost Assessment for the Forestry Sector

The analysis of mitigation measures in the land use and forestry sector involves the following steps:

1. Compilation of an overview of the main sources and sinks and development of a baseline scenario
2. Identification of mitigation options
3. Assessment of mitigation potential and costs of the options
4. Construction of mitigation scenarios that integrate multiple mitigation options
5. Assessment of policy implementation

4.3.2.1 Overview of the Main Sources and Sinks and Development of Baseline Scenario

The purpose of this step is to establish a broad overview of main sources and sinks connected to land use activities and to develop a baseline scenario with an emphasis on areas where a more detailed examination should be carried out. The overview and baseline scenario can be established on the basis of specific sectoral development plans for agriculture, forestry, and other land use activities.

Key parameters to assess include:

- sectoral development policies, economic output, employment, exports, and capital demand
- land use
- general overview of present carbon flows and the likely future trends in these flows
- specific policy, implementation, and institutional issues related to the land use sectors

The baseline scenario is by definition a representation of expected land use development trends and forestry consumption patterns, given that no climate change policy is implemented in land use sectors. It involves describing existing land use distribution and the rate of conversion from one activity to another.

The baseline scenario should also specify assumptions for the main factors driving future land use, such as population growth, output of main products, production factor demand, and income growth. The baseline should include a detailed greenhouse gas emission inventory specified in detail for areas in which climate change mitigation projects and policies seem to be attractive.

The prediction of future land use changes is difficult because the controlling factors are numerous and in many cases poorly understood. Demographic changes, the interplay between rural and urban economies, and government policies and programmes all have significant effects. At specific locations unpredictable factors such as land ownership changes, social conflicts, development projects, crop failures, and fires frequently come into play. There are two basic approaches that can be used to predict future land use changes. One can try to model the processes (demographic, technological, and economic) that are thought to drive land use change, or one can extrapolate current trends into the future.

Many countries have already integrated far-reaching forestry plans into their official policies that will imply reduced greenhouse gas emissions for land use activities, but the implementation of these policies is often not assessed and specified in any detail. It can therefore be highly uncertain what will happen in a non-policy baseline case, and consequently it can be difficult to distinguish the potential mitigation activities and the incremental cost of implementing them.

4.3.2.2 Identification of Mitigation Options

Mitigation options will generally need to be identified in areas where the mitigation potential is seen to be significant and achievable. This step, therefore, involves a comparative assessment of the technical details of potential mitigation projects in the light of the broad overview of national sources and sinks established in the first study step. Potential policy obstacles to technically feasible projects in terms of adverse leakages or environmental effects should be included in the assessment.

Specific criteria for selecting forestry mitigation options may include conformity with existing forest management plans, issues of equity and joint benefits, feasibility and/or ease of implementation, and the ecological soundness of the option. The following are two examples of screening criteria (Sathaye and Meyers, 1995):

- Biophysical factors, which may include site characteristics (e.g., climate, soil, drainage, and altitude). For example, an option that would increase productivity through short rotation forestry in a dry area where irrigation was not possible could be screened out at this stage.
- Institutional factors, such as options that may infringe on the sovereignty of a country or might tend to cause political instability. For example, a measure that requires physical removal of large numbers of forest dwellers for resettlement may be politically infeasible and socially unwise. Another institutional issue relates to the possibility for establishing a mechanism for project implementation, control, and monitoring.

4.3.2.3 Assessment of Mitigation Potential and Costs of the Options

The next step involves estimating the carbon flows and stocks of the different mitigation options with reference to the baseline scenario. In the land use and forestry sector, this involves first identifying which baseline scenario activities will be displaced or affected by the mitigation options. In this step we must identify the impacts of the mitigation options on carbon flows and stocks in the economy and then calculate their magnitudes.

The easiest example to follow is that of an afforestation programme. In this case, it is assumed that the project supplants agricultural usage of the land. Such a programme will definitely affect carbon flows and stocks on the reforested land.

The assessment of carbon flows includes:

- biomass density and carbon content
- soil carbon end-use pools, wood products, and substituted end uses
- displaced fossil fuel emissions (cogeneration and bioenergy projects)
- CH_4 and N_2O emissions
- post-harvest residues

These carbon assessments can sometimes concentrate on technical projects, but there may be wider effects on carbon. For example, reducing the supply of land on which to grow food may result in an immediate increase in agricultural prices, which might, in turn, provide some incentive for forest land owners to harvest forests and convert the land to agriculture. This is an example of a static leakage. There may also be dynamic leakages. In this situation, dynamic leakages would occur if forest land owners expected future timber prices to fall when the trees from the afforested land were harvested. In that event, forest land owners who were not in the programme would have an incentive to harvest their forests earlier than they would otherwise and to reduce the intensity of management. Both types of activities would result in carbon leakages. Both the direct effects of mitigation programmes and the indirect effects of these programmes should therefore be estimated.

This step also involves estimating the net costs of the different mitigation options with reference to the baseline scenario. In the land use and forestry sector, one must know which baseline scenario activities will be displaced or affected by the mitigation options.

To facilitate cost comparison across options, their associated benefits should be assessed and subtracted to arrive at net mitigation costs. Such benefits can, for example, be timber or crops, fuelwood, tourism, or recreational values. In cases where they have a market value, this value should be subtracted from the cost. Mitigation projects, however, can also have additional benefits that are difficult to assess in monetary terms. Such benefits could, for example, include biodiversity, preservation of indigenous cultural values, and matters relating to long-term sustainability. Qualitative assessments of such values can be used to supplement monetarized costs and benefits.

Shadow prices should be used in cases where markets are significantly distorted (see Chapter 2 for a further explanation). This can, for example, be the case in centrally planned economies, where land and product prices may be determined by a government institution.

The costs and benefits should be assessed for the time period of the policies, and it is therefore necessary to apply discounting procedures to equalize financial flows occurring at different points in time. The costs and benefits can be transformed to either net present values or levelized values. See a further definition of these concepts in Chapter 2.

4.3.2.4 Construction of Mitigation Scenarios that Integrate Multiple Mitigation Options

The objective of this step is to calculate the cost-effectiveness of the different mitigation options and to integrate this information into mitigation cost curves.

This can be done in a variety of ways, but many of the issues associated with measuring and displaying incremental costs and cost-effectiveness in this sector are identical to those in the energy sector.

The traditional approach for calculating cost-effectiveness ratios for abatement cost curves involves dividing the present value of the incremental cost associated with an option by the change in the carbon stock achieved by the programme, or:

$$CER = \frac{PVC}{\sum_t E_t}$$

where *PVC* is the present value of the direct costs associated with the mitigation option and E_t is the emissions flow (flux) in period t. A net present value of the carbon fluxes, *PVE* can be calculated in similar way as *CER*.

For the approach that employs discounting, the *CER* is characterized by:

$$CER = \frac{PVC(r / (1 - (1 + r)^{-N})}{PVE(r / 1 - (1 + r)^{-N})}$$

The numerator is the annualized value of the incremental cost of the option. However, the denominator represents the annualized value of the emissions or carbon flow generated by the mitigation alternative (relative to the reference case, of course). Notice also that, in the case of a continuous emissions flow, the *CER* in the discounting case reduces to the ratio of the *PVC* to *PVE*, both of which are annualized. However, if the emissions flows are discontinuous, or if a different discount rate is used to discount costs and benefits, then the expression is conceptually the same but more difficult to express in algebraic terms. The point is that both benefits and costs are discounted from the point at which they occur back to a reference period. As previously indicated, this is done to account for the fact that a tonne of CO_2 emissions reduced (or stored) today may not have the same benefit as a tonne of CO_2 emissions reduced (or stored) at some other point in time.

4.3.3 Overview of Models and Studies

4.3.3.1 Tools for Project Assessment

The project assessment tools, like those for energy sector bottom-up models, are built around a parametric representation of individual mitigation options. The models are typically rich in detail about land and forest project-specific issues, while costs and benefits are treated in a more aggregate form. Market prices of final goods and production factors are typically exogenous or assumed to be constant, because the projects are assumed to be marginal. In this way the models focus on the supply side and have no representation of demand.

Many project assessment models include a consistent accounting system of the total available land in various categories. They calculate the carbon accounts on these lands over time and show how different types of mitigation options affect carbon flows and stocks.

The earliest types of project assessment tools were static. That is to say, they kept carbon accounts for a specific period of time, such as the rotation length of an even-aged forest, and calculated carbon flows on an average annual basis for that period. Annual tree growth over time and the associated carbon flows were not estimated. Perhaps the best known of these first-generation models is the one used by Moulton and Richards (1990) to estimate the costs of carbon sequestration programmes in the United States. Spread sheet models now in use are dynamic. They track the growth of trees over time and keep carbon accounts on an annual basis. More advanced models, such as COPATH (Makundi *et al.,* 1991), not only track carbon over time but also contain assumptions about biological processes and management which they build into the calculations for carbon balances.

The key advantages of project assessment tools are:

- They are relatively simple to construct and use.
- They can be organized around existing data.
- They are adaptable to different countries and land use systems.
- They can be used to generate carbon sequestration supply curves.
- The available models are widely applicable.
- The results they generate are transparent.
- All of the carbon flow, stock, and cost calculations can be made internally consistent because the format is so flexible.

The tools have a number of limitations that are especially important when larger mitigation activities or combined strategies are to be assessed. The major disadvantages are that the behaviour of landowners, land markets, and final product markets is not integrated, and it is therefore not possible to assess indirect economic impacts and the structural impacts of larger mitigation programmes. Furthermore, the missing demand representation makes it difficult to model the impacts of using economic instruments such as taxes and subsidies.

4.3.3.2 Sector Models

Sector models are, generally speaking, economic models that are used to simulate various kinds of economic activity in different product markets that are organized as a sector. For example, a model of the agricultural sector in a country would include markets for many different types of crops and livestock. Sector models can be either mathematical programming models or econometric models or a combination of the two. These models can represent market processes related to the production of goods and services in a sector (i.e., supply side only), or they can simulate *both* the production and consumption of goods and services in a sector (supply and demand sides are integrated). The sector models can be modified to include greenhouse gas mitigation activities and their costs. These models can then be used to estimate the benefits and costs of mitigating greenhouse gases in a given sector, taking “market forces” into account.

Supply-side models. The purpose of supply-side sector models is to generate supply curves for goods and services in that sector of the economy. These supply curves show how the minimum additional (i.e., marginal) cost of producing a good or service varies with the level of production. The models do not solve for market prices, although given an exogenous vector of prices, they can solve for the associated levels of output for the goods and services included in the model. While supply-side sector models of the energy sector have been adapted for use in greenhouse gas mitigation cost analyses, there are no such examples for the forestry and agricultural sectors.

Supply- and demand-side (price-endogenous) models. Sector models can include consumer behaviour along with producer behaviour. This is usually done by including final demand equations in the model to show how consumer purchases of goods and services vary with the prices paid for these items. By integrating the demand and supply curves for goods and services in many different markets simultaneously, sector models are able to solve for their associated market clearing output levels and prices. Hence, they are referred to as *price-endogenous* models. Often it is possible to take an existing supply-side sector model and integrate it with a corresponding set of demand equations to produce such a model (Adams *et al*., 1996).

In the land use and forestry sector, the most relevant sector models are forestry sector models, agricultural sector models, and models that combine the two sectors.

Static agricultural sector models. Agricultural sector models can be modified to develop supply curves for afforestation. Given an existing integrated model of the agricultural sector, this can be done by including activities for growing trees to sequester carbon (Callaway *et al.*, 1994). The model can then be used to simulate the competition between agricultural products and these tree-growing activities for crop and pasture land.

This type of approach can also be used in developing countries where there are existing agricultural sector models. Many such models do exist, and modifying them is not difficult. Mitigation costs associated with fermentation from rice paddies can also be estimated this way. The two biggest advantages of the approach are, firstly, that it allows fairly detailed representations of mitigation options, both from a technological and management perspective. Secondly, these models take into account a number of different economic adjustments that may occur in markets when existing activities are displaced. As a consequence, they can capture some of the spillovers and leakage effects that project assessment tools cannot capture. However, the approach has its drawbacks. It requires the use of an existing model or the development of a new model, which is fairly data- and labour-intensive and requires substantial analytical capacity. The models are largely limited to examining afforestation programmes. Consequently, examining forest mitigation options requires a model of forest land use.

Forestry sector models. Forestry sector models generally have two basic components: (1) an inventory projection model to simulate the evolution of trees on forest land over time, and, associated with it, (2) an economic component that determines the optimal level of management associated with these forests, including harvest levels over time, regeneration of new forests after harvest, and investment. The demand for forest products is exogenous in forestry sector models, so that over time harvest levels, timber prices, regeneration, and investment are determined as a part of the model solution. These models are usually multiregional, taking into account spatial variations in important factors influencing supply and demand for wood products. They are usually national in scope, although at least one international model, the Global Trade Model (GTM), exists. The development of these models has been limited primarily to developed countries.

Once they are constructed, forestry sector models can be modified easily to perform carbon accounting of forests. The advantages and disadvantages of developing such models for use in mitigation assessments of the forestry sector are essentially the same as those for developing agricultural sector models. They are also of limited use, in that they can only be used to examine forest mitigation options. In addition, data required to model natural forests is often very limited. Therefore, when considering whether to use this approach, one needs to weigh the analytical advantages of these models against their limitations. That such models are not widely available for developing countries and that they require significant technical capacity to build and use and have limited application are all factors that need to be taken into account when evaluating their use.

Land use models. Land use sector models combine the agricultural and forestry sectors and simulate the competition within and between these two sectors for land. An example of such a model is the Forest and

Agricultural Sector Optimization Model (FASOM), developed for the US by Adams *et al*. (1996). The model has been useful in identifying how different types of policy instruments can influence carbon leakages between regions and sectors. There is also at least one example of a systems model that has been built for developing country applications. This is the LUCS model, which was designed to evaluate land use mitigation options and has been applied in several instances. However, LUCS is not an economic model, and this is both a strength and a limitation. It is a strength insofar as the approach may be applicable in developing countries where land use is determined by the subsistence economy. On the other hand, numerous assumptions have to be made about exogenous forces that largely determine land use changes over time. In an economic model, many of these forces would be treated as endogenous.

4.3.3.3 Review of Cost Estimates

The following is a review of a number of cost estimates for forestry sector studies in developing countries. The costing results are separated into opportunity cost estimates and direct cost estimates.

All forested land has an opportunity cost even though certain types of forest development, such as protection of natural forest, may have no establishment or harvesting cost. Transportation and primary processing costs might also be included in total costs, depending on the system boundary and the product prices chosen. Most cost studies in developing countries place the system boundary at farm level and farm gate prices are used.

Opportunity cost assessment. There are different methods for assessing opportunity cost, including use of land rents, net returns from alternative land uses, or land prices. Most studies that have been conducted in developing countries have failed to include the opportunity cost of land (e.g., Malaysia, Brazil, India, China, Mexico, and Tanzania (*Biomass and Bioenergy Journal*, 1994). This can be a significant component of total costs, especially in forest conservation. For instance, using estimates of the net annual return from alternative land use, the opportunity cost of conserved forests in Thailand was estimated at between $44/ha and $89/ha (TDRI and TEI, 1993). This figure was much higher than the average forest protection budget of less than $3/ha. In order to use market prices to reflect the opportunity cost of land, a well-functioning land market should exist. For instance, the low average land rent assumed in one study in India (Rs 500 or about $16) may have been partially due to the inactive land market in rural areas (Ravindranath and Somasheker, 1994). The study also assumed zero land rent in agroforestry. Despite the difficulty in evaluating the opportunity cost of land use, its inclusion in estimates should be encouraged, as its exclusion may result in analytical bias.

Janssen and Mohr (1998) have estimated land opportunity costs in a very pragmatic way for 13 countries. The costs were estimated on the basis of official FAO and World Bank data on net returns on alternative land uses. Basically, the respective figures were calculated by dividing country-specific data about the value of production in the agriculture and forestry sectors by the land area employed to produce this output. The figures derived, following that, represent upper-bound values for opportunity costs of forest-carbon protection measures.

Direct cost assessment. Establishment/land conversion, maintenance, and tending costs are the main direct costs of forest management, especially in forest plantations, community forests, and agroforestry. Direct costs have been well covered in all developing country studies. In general, establishment costs constitute not less than half of all direct costs. In many cases, establishment costs are the most important costs in forest management. For instance, the establishment/land conversion costs were the only costs used in an analysis of an agroforestry project in China, and they were a huge capital cost in a Malaysian forest plantation (Deying Xu, 1995). However, in some cases, maintenance and harvesting costs were not covered, and it is unclear whether they were neglected or whether there were no such costs. The harvesting cost can be zero, if wood is sold as standing trees, as was done in a Eucalyptus plantation in Thailand (TDRI and TEI, 1993).

The net cost of carbon sequestration in forestry options is affected by other forest benefits. Evaluation of direct benefits from forestry may not be much of a problem, but difficulties often arise in the evaluation of indirect benefits, especially in conserved forests. Indeed, the majority of developing country studies on the carbon costs of conserved forests do not evaluate secondary benefits. As a result of this frequently incomplete coverage of cost and benefit items, applications of land use analysis are still limited. Several refinements can be made, however, to strengthen the analytical capabilities of the approach. There are also other factors, such as income distribution and macroeconomic policy, that must be considered at policy level.

4.3.4 Assessment of Policy Implementation

Implementation policies include specific programmes for technical mitigation options as well as sector-specific programmes and broader land use policies. Implementing the technical, or project-level, options requires specifically targeted programmes in the form of tree planting, education, or supply of technical equipment. By changing market conditions, providing financial incentives, or changing tenure practices or property rules, implementation policies can indirectly affect land use. They can also be initiated outside the forestry sector, for example, by changing agricultural markets. Furthermore, the implementation of forestry and broader land use options can be supported by international collaboration on joint implementation, carbon offset systems, and financial transfers as outlined in more detail in Section 8.3.2.

Some of the main policy categories are listed below:

Forestry policies

- national, regional, and local measures to preserve existing forests and vegetation cover
- policies where responsibility for managing existing protected areas is shared between local communities and the central agencies, as are benefits
- policies governing terms of timber harvest concessions (allowable cut, concession duration, levels and structures of fees and royalties)
- tax rebates and dissemination policies governing the adoption of efficient charcoal kilns and wood stoves
- specific afforestation and reforestation programmes
- export regulations

Broader land use policies

- land tenure programmes, with specific conditions for sustainable land management
- long-term tenure schemes that make tree planting more profitable
- agricultural policies that decrease the pressure on forested land
- infrastructure policies that decrease the demand for forested land and the access to this land
- establishing parks and designated wilderness areas
- economic policies and pricing schemes
- export regulations

The implementation policies can meet a number of barriers that are either related to general national development policies or are specific to the project in question. The barriers include structural conditions, such as the need to conform with national or regional development aspirations and macroeconomic policies. These conditions may imply limited land, labour, capital, or foreign exchange resources. Limited human and institutional capacity for implementing and maintaining projects can be yet another barrier. Finally, the absence of land property rights policies as well as concession and marketing policies can pose a serious problem.

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Chapter 5

Adaptation Costs: A Framework and Methods

by

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5.1 Introduction

Over the last ten to fifteen years a significant amount of effort has been focused on identifying and estimating the costs of undertaking actions that will reduce the expected magnitude of climate change by reducing emissions of greenhouse gases or by expanding the size of carbon sinks. These types of actions are collectively referred to as mitigation because their intent is to reduce the greenhouse effect and associated climatic changes that may occur in the future. This body of work has recently been documented by the IPCC (1996, 1996b) in its Second Assessment Report and continues to grow. These kinds of actions are to be contrasted with measures that are taken to reduce the impacts of expected changes in climate through adaptation. The Second IPCC Assessment Report (IPCC 1996, 1996b) has also reviewed the current literature on both climate change impacts and adaptation.

On the other hand, while the topic of adaptation is often addressed in climate change assessments, the treatment is uneven, and the underlying analytical concepts that have emerged in the mitigation literature have not been forthcoming in adaptation research. With the exception of studies on sea level rise, there are almost no estimates of adaptation costs, and a framework for evaluating these costs is only in a very early stage of development.

The lack of a widely accepted conceptual framework for analysing adaptation actions and costs represents an important gap in the literature on climate change. In that general context, the primary objective of this chapter is to develop a technical framework for estimating the costs of adaptation projects and measures in a manner as consistent as possible with mitigation actions.

The remainder of the chapter is organized as follows. Section 5.2 looks at the literature on adaptation and reviews efforts to develop a conceptual framework for mitigation actions. As in the case of mitigation, such a framework is important for developing cost definitions and cost measures for future use. Section 5.3 elaborates on the conceptual framework developed by Fankhauser (1996, 1997) for defining adaptation costs and comparing them with mitigation costs. It attempts to make his framework more general and addresses some of the associated issues that will need to be resolved in future studies. Finally, Section 5.4 briefly reviews methods for estimating the cost concepts outlined in the previous sections and presents the strengths and weaknesses of the different types of models employed for this purpose.

5.2 Review of Adaptation Studies

5.2.1 Guidelines and Conceptual Frameworks

The clearest conceptual statements about adaptation appear in Chapter 7 (Jepma *et al*., 1996) of the Working Group III contribution to the IPCC's Second Assessment Report and in the *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations* (Carter *et al.*, 1994).

Both studies make an important distinction between adaptation that occurs in the absence of government policy (and would have occurred anyway) and actions that require deliberate policy intervention. Jepma and his coworkers distinguish between: (1) passive adaptation, which involves a conscious decision to let society adapt to climate change without taking any additional action except research, and (2) active adaptation, which involves policy actions that will directly reduce climate change damages or that will decrease the vulnerability or increase the resilience of societies and ecosystems. However, this distinction is not a very useful one, because it does not identify the motivation for either type of action.

Carter *et al*. (1994) take a more systematic approach. They make a distinction between automatic or built-in responses (autonomous adjustment) and responses requiring deliberate policy actions (adaptation strategies). They spell out the need to include the former types of actions in the base case that is used to evaluate the actions taken by government and indicate some of the difficulties in doing this, unless one uses an economic model. However, while they emphasize the need to distinguish between adaptation actions that are market-driven and those that are "additional," they do not discuss where one draws the line to determine what level of additional action is optimal. Unfortunately, the definition and estimation of adaptation costs are not addressed in this study, nor is there any discussion of how to compare and evaluate mitigation and adaptation options within a common framework.

The distinction between these two forms of adaptation is important. It recognizes implicitly that, even if governments do nothing to mitigate climate change or adapt to its effects, economic agents (i.e., consumers, firms, and factor owners) will still have some incentives to offset the impacts of climate change, once it has been detected. For example, timberland owners may change rotation ages and plant different species once they become aware that climate change is causing trees to grow slower (or faster). In a market economy, passive adaptation measures will be driven by the incentives various economic agents have to maximize personal utility (consumers), or wealth (factor owners), or profits (firms), even if government does not intervene in the economy to provide support for such actions.

However, it is important to note that, even though economic agents will respond to price signals that are caused directly or indirectly by climate change, these responses will not be optimal if prices do not reflect private as well as marginal social costs and all individuals do not have access to the same information about climate change and its consequences. As will be pointed out later on, one rationale for active public sector involvement in climate change adaptation strategies is to reduce these types of market failures and information problems. Of course, government action can also distort market incentives and, in economies where markets do not play a big role, there will be different kinds of incentives for individuals to adapt autonomously to climate change.

A number of other authors have proposed frameworks for differentiating between various forms of adaptation and for developing procedures for evaluating adaptation measures. For example, Smith and Lenart (1996) and Tol *et al*. (1998) distinguish between reactive adaptation and anticipatory adaptation, depending on whether the adaptation takes place before or after climate change takes place. Anticipatory actions are further broken down into those that are justified for reasons other than climate change (i.e., “no regrets”) and those that are focused on mitigating climate effects before they occur. The authors consider anticipatory adjustments to climate justified, for example, in situations where adaptation costs are rising over time while benefits are falling. However, these costs are not defined and no specific methodology is spelled out for estimating such costs.

Similar types of adaptation typologies have been developed in Smit (1993), Ringius *et al.* (1996), Titus (1990), OTA (1993), Smith and Lenhart (1996), Toman and Bierbaum (1996), and Fankhauser (1996 and 1997) to name a few. Almost all of these studies emphasize the differences between whether or not the actions are undertaken autonomously or not and whether they are taken in advance of or after the climate has changed. All of them propose methodological steps for assessing adaptation to climate, including the use of cost-benefit assessment. However, with the exception of Fankhauser, there is no further discussion of cost concepts, definitions, and methodologies. Moreover, while all these studies stress the need to compare adaptation and mitigation measures, there is no serious treatment of this topic.

5.2.2 Sector Level Studies

The literature on adaptation, such as it is, is summarized in the IPCC Second Assessment Report. The treatment of adaptation in the individual chapters in the Working Group II report (IPCC 1996b) is uneven, reflecting both the lack of research in this area and confusion about the meaning of the term. A number of these chapters, for example, those on forests, rangelands, desertification, and non-tidal wetlands, take a primarily ecological perspective and do not even include human actions, while some other chapters, namely those on oceans, coastal zones, agriculture, and water resources management, explicitly consider adaptation. The literature reported in these studies, taken as a whole, exhibits a number of shortcomings.

First, in almost all cases, the studies in this report do not address autonomous adaptation in any way but focus instead on the role of the public sector in evaluating adaptation measures. Furthermore, they tend to highlight the importance of technological, as opposed to behavioural, responses and financial costs, as opposed to economic costs (see Chapter 2). In particular, there is almost no discussion of the role of autonomous adaptation and associated economic costs in these impact studies, and whether these damages and impacts take into account the adjustments that economic agents may make autonomously. For example, some studies of agricultural impacts, using only crop models, focus on how changes in temperature and precipitation affect crop yields, while other studies focus on the economic impacts of climate change on the sector. Ostensibly, the impacts in the former studies do not include adaptation, while the latter studies sometimes use market models (Adams *et al.*, 1993) that take into account some, but not all, forms of autonomous adaptation.

Second, the treatment of adaptation tends to concentrate on measures whose sole objective is to offset climate change impacts. These include undertakings such as the construction of dikes to protect against sea level rise, the building of dams to store more water, and the substitution of more climate-tolerant crops to maintain agricultural productivity. These are important measures; however, emphasizing these measures alone gives the misleading view that adaptation to climate change is a special issue. It ignores the fact that adaptation is a more general process involving the substitution of many inputs and outputs in response to changes in environmental conditions. In this respect, adaptation to climate change can be seen as part of a more general process of adaptation to changing environmental conditions.

Finally, except for studies that assess the costs of protecting coastal areas from sea level rise, there is very little information on the costs of climate adaptation, and the topic of adaptation costs is addressed, explicitly only in the chapter on oceans, which is an area where the role of adaptation is extremely limited.

The state of the art with respect to sectoral adaptation has recently been surveyed by Tol *et al.* (1998). They identify four types of approaches for modelling adaptation that appear in the literature:

- **No adaptation.** A number of studies assume that humans are passive in the face of climate change and do not change their behaviour at all. This concept is unworkable or unrealistic in most impact areas, as most economic agents will have some incentives to adapt to climate change, even if governments do not intervene. However, as we will see, this type of assumption is useful as a reference point for measuring adaptation benefits and costs.
- **Arbitrary adaptation.** Some studies assume that adaptation of some kind will take place but that the levels of adaptation, both autonomous and additional, are selected arbitrarily, either by individuals (in the case of autonomous measures) or governments (in the case of additional measures).
- **Observed adaptation.** This involves the use of either spatial or temporal analogues to examine how different societies (the spatial dimension) have adapted to climate variability in the present or past (the temporal dimension). The problem with this approach is that, while such analogues may be useful for predicting the scope of physical impacts, social and economic conditions vary so greatly over time and space that these comparisons can only be suggestive of the scope of human actions and cannot serve as a reliable basis for projection or prediction.
- **Modelled adaptation.** This approach utilizes behavioural models, usually economic market models, to predict how humans will behave when climate changes. So far, this approach has been used to model adaptation to sea level rise (West *et al.*, 1997; Yohe *et al.*, 1996, 1998) and to forest impacts (Songhen and Mendelsohn, 1998). These and other studies like them have generally used models that assume that economic agents behave rationally in an economic sense, although the study by West *et al.* (1997) uses a more descriptive model of human behaviour in response to sea level rise

As implied above, most of the studies in the last category fall under the heading of *optimal adaptation*. This approach to adaptation is based on economic efficiency and involves using models to project the behaviour of economic agents who adjust to climate change by equating marginal benefits (however defined) and marginal costs. Tol and his coauthors regard this as the “ideal” approach to assessing adaptation because it can be used to project[1] the economically efficient (their definition of optimal) levels of private (autonomous) adaptation and public (additional) adaptation, given specific changes in climate.

There is a growing body of literature about the value of the economic impacts of climate change that takes adaptation into account in estimating the imposed costs of climate change, but these works fall short of specifically estimating the costs and benefits of adaptation. This literature is best represented by studies such as that by Yohe *et al.* (1996) of the economic value of damages due to sea level rise, the work of Adams *et*

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[1] Optimal is a normative term, referring to how economic agents would behave if they equated marginal benefits to marginal costs in making consumption and production decisions. A normative model does not forecast actual behaviour if economic agents base their decisions on other objectives or there are market imperfections.

al. (1993) on the US agricultural sector, and a new publication edited by Mendelsohn and Neumann (1998) that contains estimates of the value of damages due to climate change in the US for seven different impact sectors (agriculture, forests, water resources, sea level rise, energy, recreation, and commercial fishing). Several of these studies, for example, the examination by Hurd *et al.* (1998) of the effects of climate change on the supply and allocation of US water resources, include both market and non-market adaptation.

These studies, and others like them, have in common the use of economic market models that contain supply and/or demand curves that are linked to climate variables, such as monthly precipitation and temperature, so that changes in the values of these variables induce changes in relative prices of inputs and outputs. This, in turn, affects the relative profitability of various goods and services in markets and leads to different levels of input use and commodity production. The resulting levels of profits, after these adjustments occur, are higher than if the adjustments did not occur (in other words, if economic agents acted as if relative prices had not changed and made economic decisions in the same way that they did prior to climate change). The adjustments that occur in input and output production levels in response to climate-induced changes in relative prices are in the broadest sense adaptive responses to climate change. These responses can be very broad in scope, ranging from changing the planting dates of crops to changing the type of technology used to treat waste water.

As a rule, these studies do not explicitly report adaptation costs. Rather, they report the imposed costs of climate change, measured as the difference between net social benefits (i.e., welfare) with and without climate change and assuming optimal adaptation to the existing climate (without climate change) and the altered climate (with climate change). While these studies take into account a wide range of normal market adjustments to climate change in response to relative price changes in inputs and outputs, they do not generally include estimates of both the benefits and costs associated with making the switch in adaptation from one climate to the other. However, in some cases, for example sea level rise (Titus *et al*., 1991; Fankhauser, 1995; Yohe *et al*., 1996; and Yohe *et al*., 1998) the costs of specific adaptation measures – sea walls and retreat – are estimated.

Finally, it needs to be stressed that optimal adaptation may not imply economic efficiency in countries where markets operate poorly or where the economy contains a large informal element where transactions of goods and services are based on non-economic objectives. Unfortunately, the ability to identify and model these objectives in a formal mathematical framework in order to predict behaviour and levels of economic activity is not well developed.

5.3 A Framework for Estimating Adaptation Costs

5.3.1 Fankhauser's Adaptation Cost Framework

Fankhauser (1996, 1997) has developed a conceptual framework for estimating adaptation costs. This involves defining the optimal level (in economic terms) of adaptation in a region where the amount of climate change (and implied level of global mitigation) is not under national control. To find the optimal level of adaptation, Fankhauser's analytical model uses the approach of minimizing the sum of the two cost elements – adaptation cost and unmitigated[2] damage cost – assuming that the level of damages due to climate change and the level of global mitigation are fixed. Both of these costs depend on the level of adaptation; however, adaptation costs increase as the level of adaptation increases, while the level of unmitigated damages decreases as adaptation increases. In this framework, adaptation actions are justified as long as the additional costs of adaptation are lower than the additional benefits from reduced damage levels. The level of adaptation is optimal when the last dollar spent on adaptation just equals the reduction in climate change damages achieved by this expenditure.

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[2] In Fankhauser's framework unmitigated damages are the climate change damages that remain after mitigation and adaptation have taken place.

Fankhauser uses this model to identify five types of costs, which can be defined for different climate states:

1. *Adaptation costs (AC)* are the costs of the resources forgone by society to undertake adaptation measures both in the baseline and future climates.
2. *Climate change damages (CD)* are the value of the extra damages that occur exclusively because of climate change (these are zero in the baseline scenario).
3. *Ordinary climate damages (OD*) include the adverse effects associated with the current climate, that is, all climate related costs that would also occur in the absence of climate change.
4. *Other relevant costs (OC)* are the indirect costs that result from taking an adaptation action.
5. *Imposed costs of climate change (ICCC)* are defined as the difference in overall costs (AC+CD+OD+OC) between the climate change and the reference scenario, taking economically optimal adaptation into account.

We see two general problems with Fankhauser's framework. The first is that it is not general enough and is focused primarily on adaptation measures whose sole objective is to counteract the effects of climate variability and climate change. The second, and related problem, is that many of the cost definitions require that one be able to quantify specific adaptation costs in both a reference scenario and a climate change scenario in order to estimate the difference between the two. This may be possible with some measures that are focused exclusively on offsetting the effects of climate change, such as sea walls and dikes. However, this is not possible for many other types of adaptation actions that include more general forms of input and output substitution, as in the agricultural sector, where many adjustments, such as crop mix, and water inputs, occur already because of a wide range of factors. More generally, it will not be possible to isolate the partial components of cost changes due to climate change, adaptation, and other factors without being able to separate these costs in the two scenarios to be compared. The remainder of Section 5.3 addresses these limitations.

5.3.2 What is Adaptation?

Fankhauser (1996, 1997) defines adaptation as "projects and policy measures that are undertaken to ease the adverse impacts of climate change." This is an institutional not an economic definition of adaptation. An economic definition of adaptation would be much broader, stating that: *adaptation consists of actions taken by economic agents and government to (1) learn about climate change and disseminate this information, and (2) reallocate resources to adjust to the impacts of climate change.*[3] This definition includes actions that take the form of projects and policies, but it also embraces a wide range of behavioural adjustments that economic agents undertake directly, in response to observed or expected climate impacts, and indirectly, as a result of climate-induced changes in relative input and output prices. Seen from this perspective, all input and output substitution that is due, in a "partial"[4] sense, to expected changes in climate constitutes adaptation. This includes substitution of variable, fixed, and quasi-fixed factors in production and substitution of consumption goods (both market and non-market) by consumers. Thus, adaptation actions include such measures as building or modifying sea walls and reservoirs; abandoning coastal property; adjusting planting and harvest dates, altering input use, or switching crops/species in the agricultural and forest sectors; modifying reservoir operating rules; constructing early warning systems for climatic hazards; and adjusting insurance premiums.

This definition of adaptation embraces both autonomous adaptation and adaptation strategies undertaken by governments. It also emphasizes the role of markets and market forces in two ways. First, there are many instances in which the goods and services produced by society are either used primarily for adapting to climate change and variability (dikes, flood warning systems and reservoirs are all examples of this) or are used as inputs in producing these goods and services. Second, autonomous adaptive behaviour can be explained, at least in part, in terms of market forces. For example, switching to more drought-tolerant crops and adjusting planting dates and input use accordingly is an economic response to an environmental change, based on the relative profitability of various crops. Even migration away from low-level coastal areas in the face of increased climate variability and higher sea levels can be viewed in this manner (Yohe *et al.*, 1996;

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[3] This definition is broad enough to encompass resource reallocations that are optimal from an economic perspective, as well as those that are not.

[4] Partial, in this sense, refers to partial analysis: the effect of changes in climate on resource allocation, holding all other exogenous factors, except climate (and mitigation), constant.

Fankhauser, 1995). In the very short run, individuals may well flee from coastal areas, and their decisions to do so may be highly constrained. Nevertheless, within the context of existing constraints, it can be argued that households and firms weigh the costs and benefits, broadly defined, of alternatives and take actions accordingly. Differences across time and space can be explained in terms of different objectives, different preferences, and different constraints of all forms – environmental, cultural, and economic.

Adaptation also involves learning about climate change and disseminating this information to potential users. Learning has several components: forecasting climate change before it occurs, monitoring observed climate as changes occur, and detecting climatic changes through these observations. Unfortunately, real changes in climate may go undetected for many years because of the natural variability of the weather and the short length of observed meteorological records. Thus, decision makers may have to rely on model projections, which are themselves highly uncertain, and this will introduce some element of risk into decision making at the individual and governmental level. Information about the nature of these risks thus constitutes an important element of climate change information. Without it, individual economic agents and policymakers will find it hard to diversify their activities, to create flexible systems to respond to a wide range of climatic risk, and to spread risks through insurance.

The cost definitions developed by Fankhauser are useful for analysing projects and policy measures, such as sea walls, flood warning systems, and water supply dams, that are directly focused on adapting to climate and that have “price tags” on them. However, this approach does not work as easily on behavioural actions that are taken to adapt to climate or to climate changes. Take the example of a planting date for a crop. This is determined largely by climatic factors. What is the adaptation cost of this action in the baseline? What is the value of the ordinary climate change damage of this action in the baseline? These costs, today and in the future, are not easy to measure because they are not observed and are not independent of other costs. However, changing a planting date as a direct response to climate change is an adaptation action, and its costs and benefits are measurable, even though Fankhauser’s framework may not work perfectly to do this.

One way to alter this framework is to introduce a slightly different accounting structure, based more specifically on measuring benefits and costs due to changes in climate instead of defining costs and benefits in each climate state. Using this approach, it is possible to separate the effects of climate change from those of adaptation actions.

The cost and benefit concepts associated with this approach can be defined as follows:

- *Climate change damages (costs) are* the net costs to society of climate change if no adaptive measures are taken. These costs are equal to the sum of the net adaptation benefits and the imposed costs of climate change.
- *Adaptation benefits* are the value of the climate change damages avoided by adaptation actions.
- *Adaptation costs* are the value of the real resources society gives up – an opportunity cost – to create adaptation benefits.
- *Net adaptation benefits* are the value of adaptation benefits minus adaptation costs.
- *Imposed costs of climate change* are the net costs to society of climate change if adaptation actions are taken. These costs are the difference between climate change costs and net adaptation benefits.

5.3.3 Alternative Baselines and Scenarios for Calculating Imposed Costs and Climate Change Benefits

Fankhauser’s adaptation cost framework, as modified in this paper, is based on making benefit and cost comparisons in two dimensions, namely (1) an existing climate and an altered climate and (2) adaptation to the existing climate and adaptation to the altered climate, assuming that level(s) of climate, and therefore mitigation, are exogenous. This approach is illustrated in Table 5.1. The two columns represent different climate states, with the current climate represented in column 1 and the altered climate in column 2. The two rows represent different optimal adaptation levels, to the current climate in row 1 and the altered climate in row 2.[5] Each cell represents a scenario of climate change effects and adaptation to these effects over time under the four different climate adaptation states.

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[5] For the purposes of this table, it does not matter if the transition between the two climatic states is viewed from an equilibrium or transient assessment framework. The underlying principles hold in either case.

Table 5.1. Alternative scenarios for estimating adaptation costs and benefits (modified from Fankhauser, 1997)

Adaptation Type	Existing Climate (C_0)	Altered Climate (C_1)
Adaptation to existing climate (A_0)	Existing climate. Society is adapted to existing climate: (C_0, A_0), or base case	Altered climate. Society is adapted to existing climate: (C_1, A_0).
Adaptation to altered climate (A_1)	Existing climate. Society is adapted to altered climate: (C_0, A_1).	Altered climate. Society is adapted to altered climate: (C_1, A_1).

The top left box is descriptive of conditions when society is always adapted to the existing climate, which does not change over time. This is sometimes referred to as the base case. The lower right box represents a situation where society is always adapted to a climate that is changing over time. The top right box describes a situation in which society behaves as if the climate was not changing and is adapted to the existing climate but not the altered climate. This is what economists sometimes refer to as the so called “dumb farmer” scenario. The bottom left box represents a case in which society decides to behave as if the climate was changing over time, when, in fact, the climate is not changing. Economists sometimes refer to this privately as the “dumb engineer” scenario.

The imposed cost of climate change is calculated as the difference between net welfare in the lower right scenario (C_1, A_1) minus net welfare in the top left scenario (C_0, A_0). However, this is not the correct comparison to be used for measuring the costs and benefits of adaptation. To measure these, one must compare the costs and benefits of actions that are taken in the top right box with those in the bottom right box, or between the following two states: (1) when climate changes but society is adapted to the existing climate (C_1, A_0) and (2) when climate changes and society adapts to the altered climate (C_1, A_1).

This is a well-recognized principle in partial analysis and is necessary to isolate the benefits and costs associated solely with adaptation from the combined effects of climate change and adaptation. Whatever metric is used to capture the appropriate benefits and costs of adaptation, either autonomous or additional, should be based on this comparison, whether or not it is used as the basis for forecasting adaptation, developing adaptation policy, or for compensating economic agents.

This point can be made graphically in Figure 5.1 below. This figure shows how societal welfare evolves over time under three different climate-welfare scenarios.

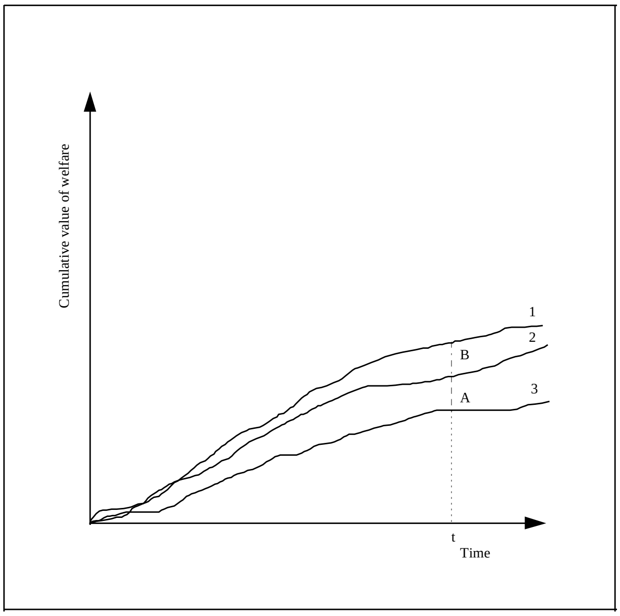

Figure 5.1. Illustrated welfare under three different climate change and adaptation scenarios.

The three scenarios shown in the figure and their corresponding welfare paths over time are:

1 = Base case: $W(C_0, A_0)$
2 = Altered climate, with adaptation to it: $W(C_1, A_1)$
3 = Altered climate, with adaptation to base case (existing climate): $W(C_1, A_0)$

Welfare in the baseline scenario is indicated by the welfare path labelled 1. Welfare is higher, at any point in time, in this case than in path 2, because climate change impacts are assumed to represent, on balance, a negative technological externality. Path 3 represents a scenario where climate changes and damages occur, while society remains adapted to the base case climate. In this case, society, at any point in time, is worse off than in path 2 because economic agents are constrained from adapting to the altered climate. After adaptation to the altered climate takes place, the welfare path shifts up to 2. Assuming that there are no distortions in an economy, society can be no better off than 2 under the altered climate. At any given point in time (*t*), the vertical distance between paths 1 and 2, as indicated by B, represents the imposed costs of climate change. These are the net welfare costs (damages) incurred by society when adaptation to the altered climate takes place. If society does not adapt to the altered climate, then climate change damages at time *t* equal the vertical distance between 1 and 3 (A+B). However, assuming adaptation to the altered climate does take place, some costs are incurred (adaptation costs) and some damages are avoided (adaptation benefits). The difference between these benefits and costs are the net benefits of adaptation. At any point in time, they are measured by the vertical distance between 2 and 3, labelled A.

5.3.4 Graphic Presentation of Adaptation Costs and Benefits

To illustrate how Fankhauser’s framework can be made more general and simplified somewhat, we consider a market example.

5.3.4.1 Adaptation Benefits

The example applies to the production of any good or service in a market or non-market context where the adjustment of at least one input in the production process avoids some climate change damages. This could be the provision of irrigation water through increases in storage capacity or alterations of water management arrangements, or it could involve nothing more complicated than a farmer altering a planting date or adjusting fertilizer use.

The example is presented graphically in Figure 5.2. The figure can be used to show how the various costs, defined above, can be measured. The marginal benefit associated with the consumption of the good Q in the baseline is shown by the downward sloping demand curve D. It is important to understand that good Q in this example is *not* necessarily the output of an adaptation measure (for example, the protection afforded by a sea wall). It can also represent any market (or non-market) good, the production or consumption of which is affected by climate change . Let us assume that this is an agricultural commodity instead of an adaptation measure itself. It is produced using a mix of market (and perhaps non-market) inputs and is affected by climate. Adjustments in the input mix, including location and timing, in response to climate change represent adaptive behaviour on the part of economic agents and/or governments.

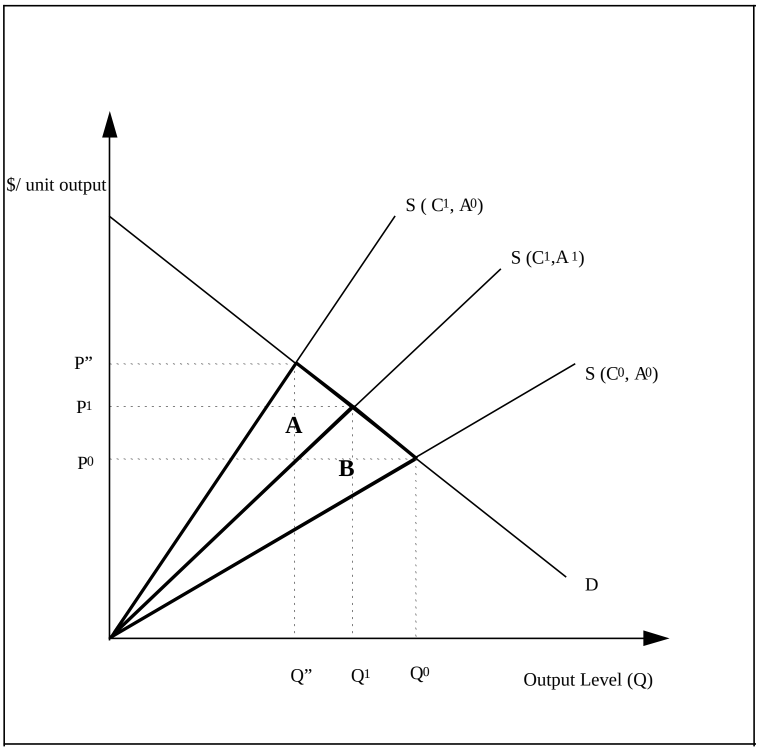

Figure 5.2. Illustration of adaptation in a goods market.

The market supply curve for the good in the base case is shown by the upward sloping supply curve $S(C_0, A_0)$. For any level of production and consumption, the area underneath D is the total willingness of consumers to pay for Q, while the area below the supply curve is a measure of the cost of the resources society must give up to produce Q. The difference between the two areas is an approximate measure[6] of the social benefits to consumers and producers, measured in terms of societal welfare, as in Figure 5.1. In the baseline climate state, the optimal level of consumption and production is given by the production-consumption level Q_0, and the marginal benefit (market or shadow price) is P_0.

The supply curve for the altered climate scenario, including adaptation to that climate, is represented by $S(C_1, A_1)$. For any given level of output, this supply curve always lies above the base case supply curve, meaning that it is now more costly at the margin to produce to Q than before. For example, hotter, drier conditions may require farmers to use additional or supplemental irrigation, thus increasing production costs in the market. This shift in the supply curve reflects the effects of climate change on the marginal cost of producing the commodity Q, given some level of mitigation. Thus, the level of mitigation that is selected is external to the analysis and independent of adaptation actions. In this climate state (C_1, A_1), the production of

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[6] This area is formally known as the sum of producer and consumer surplus. The change in consumer and producer surplus is often used to approximate the various welfare gains and losses that can occur as a result of environmental changes. The underlying welfare theory that lies behind this can be found in any intermediate microeconomic theory text book (for example, Silberberg, 1978).

Q decreases to Q_1 and the marginal benefit increases to P_1. It is important to understand, however, that the output of Q may also increase if the demand increases sufficiently. Presumably, if Q stood for the output of an adaptation action (such as a sea wall), the primary purpose of which was to adjust to climate change, demand would substantially increase, and this would be reflected by a shift in the demand curve to the right. (This is not shown, here, to make the graphical analysis tractable.)

The *imposed costs of climate change* are measured by the change in net welfare between these two scenarios. This is shown by the bold outlined area illustrated by the entire triangular area outlined in bold, labelled B. This is the decline in net welfare that results from climate change when adaptation to the altered climate is taken into account.

However, the damages due to climate change would be greater if society were adapted to the existing, instead of the altered, climate. For example, if farmers continued to use the same amount of irrigation water, as in the base case climate, this would lead to even lower production levels in the altered, hotter and drier, climate. This situation is illustrated by the supply curve $S(C_1, A_0)$. In this situation, output would be even lower, at Q”, and the marginal benefit would be even higher at P”. In this scenario, *the climate change damages* associated with (1) the change in climate and (2) adaptation to the base case climate (i.e., no change in adaptation) would be equal to the sum of the two bold-outlined areas A+B. *The net adaptation benefits* are represented by the triangular area in bold, A, which measures how much better off society is as a result of undertaking adaptation actions consistent with the altered climate as opposed to the base case climate.

5.3.4.2 Adaptation Costs

The incremental cost has been defined as the real resource cost required to create net adaptation benefits. The net adaptation benefits (A) in both figures 5.1 and 5.2 equal the climate change benefits less the adaptation cost. The adaptation cost is equal to the real resource cost of producing the good in the scenario with altered climate and adaptation to the current climate, or $C(C_1, A_0)$, minus the real resource cost, $C(C_1, A_1)$ in the scenario with the altered climate and adaptation to the altered climate. Since the climate is held constant in both scenarios, the difference between these two areas is the opportunity cost associated with reallocating resources in order to move from adaptation to the current climate to adaptation to the altered climate, or adaptation cost.

Adaptation Cost = $C(C_1, A_0) – C(C_1, A_1)$

Graphically, this is the area under the supply curve $S(C_1, A_0)$ minus the area under the supply curve $S(C_1, A_1)$. There are at least two more important issues to be discussed in connection with this cost measure.

The first issue is whether the incremental adaptation cost is always a cost (i.e., negative). This will be the case if $C(C_1, A_0) – C(C_1, A_1) < 0$. We can examine this issue better with the aid of Figure 5.3, which includes only two of the supply curves from Figure 5.2 but is otherwise identical. If we look at Figure 5.3, we can see that the change in costs, which is equal to the adaptation cost, is equal to the area OM”Q” – OM_1Q_1. This difference is divided into two components, 1 + 2, in the figure. When the supply curve shifts down, marginal cost decreases at every level of output, so component 1 is clearly positive.

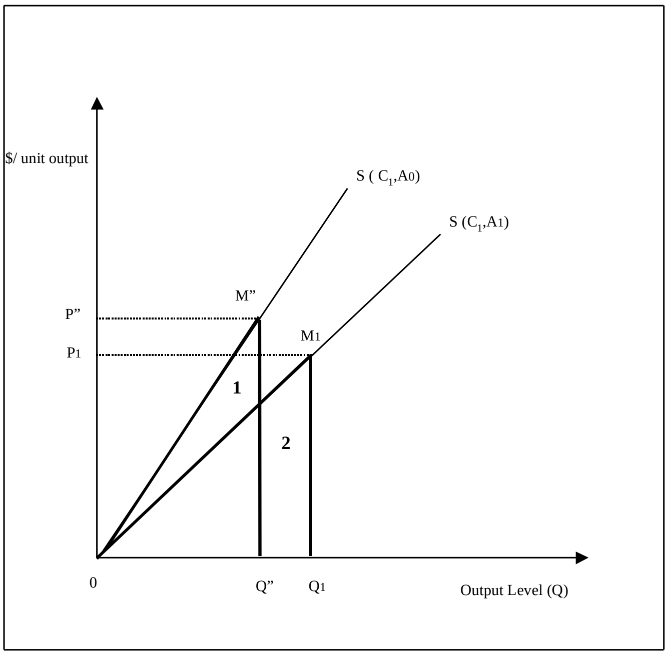

Figure 5.3. Illustration of adaptation costs.

However, at the equilibrium implied by M_1, the quantity of output increases and so costs in component 2 rise, meaning the component is always negative. If area 2 is greater than area 1, incremental cost will be negative. While the net adaptation benefits must always be positive (because adapting to the altered climate is unconstrained), there is no economic “law” requiring the incremental adaptation cost to be negative. This is strictly an empirical issue, depending on the shapes of the supply and demand curves in the relevant regions and the magnitude of the supply shift. If this cost is negative, it means that the net adaptation benefits are largely due to reductions in cost and the gross benefits of adaptation are actually negative (but the net benefits are still positive). The fact that this cost can be either positive or negative clearly creates a policy problem, as it suggests that cases may arise when a subsidy would be in order to overcome the negative benefits associated with adaptation. Fortunately, this issue probably does not arise in the case of building climate change protection structures, but it may arise in many other cases involving more subtle input and output adjustments in response to climate change.

The second, related issue is whether $C(C_1, A_0) = C(C_1, A_1)$. Fankhauser (1997), for example, uses examples of two projects, a hurricane warning system and a set of flood protection measures, in which he suggests this is the case. If the costs in the base case are the same as in the no adaptation scenario, the calculation of incremental adaptation costs will be greatly simplified. Clearly, this could be true in situations involving the development of additional climate change structures, where no additional structures are a part of both the (C_1, A_0) and (C_0, A_0) scenarios. This assumption makes it easy to calculate the adaptation costs. However, it is too strong to be generally true for the following reasons:

1. Prices of inputs used for adaptation will adjust due to other factors (unrelated to climate change) in the (C_1, A_0) scenario, and these adjusted prices need to be used in the comparison. If the cost of sea walls doubles, then this needs to be reflected in the calculation of adaptation costs in the climate change scenario and the (C_1, A_0) case.
2. More fundamentally, the adaptation cost in the (C_1, A_0) scenario will be affected by exogenous responses in output and input prices that are not part of adaptation. In a partial analysis framework, price changes due to climate change consist of three parts: (1) an exogenous adjustment in prices due to other factors unrelated to climate (see above), (2) a direct adjustment due to physical changes in the environment, such as reduced crop yields, and (3) an induced adjustment when economic agents do respond. The first two effects are legitimately included in the cost and damage calculations in both of the relevant scenarios, while the third constitutes adaptation.

This means that if governments intend to fund measures to adapt to climate change, they need to be careful about calculating adaptation costs in the (C_1, A_0) scenario, taking into account input price adjustments that are due to other factors as well as those due directly to climate. The need to do this raises a more general problem regarding the methodologies required to accurately estimate climate change damages and adaptation benefits and costs.

5.3.5 Policy Issues in Adaptation

In this section we address several issues related to the use of adaptation costs in a policy context. The first involves the meaning and relevance of the concept of optimal adaptation. The second discusses the problems of free-ridership and moral hazard that may occur when economic agents are compensated for autonomous adaptation measures and the biases that may be introduced into the economy when governments finance adaptation measures in general. The third issue is whether or not it makes more sense to reduce the emphasis on adaptation and to focus instead on correcting current market failures that may be distorting current and future incentives to adapt to climate change. The fourth issue is whether or not it is possible to use cost-effectiveness measures to compare national adaptation policies with global emission reduction policies.

5.3.5.1 Optimal Adaptation

The cost definitions presented here are implicitly based on the concept of optimal adaptation, with the proviso that the scope and amount of optimal adaptation depends on the level of mitigation, which is independent of the level of adaptation. The concept of optimal adaptation is an economic one, which is based on the principle of economic efficiency. Optimal adaptation consists of two components:

- Economic agents adapt autonomously to climate change in their production, consumption, and investment decisions by setting their own “private” marginal costs equal to “private” marginal benefits, taking into account the direct and indirect effects of climate change on supply and demand.
- Governments take additional actions to address market imperfections by (1) creating regulations or incentives for economic agents to set marginal social costs equal to marginal social benefits in their behaviour, (2) facilitating voluntary agreements over resource conflicts based on these economic principles, and (3) by undertaking investments in adaptation activities based on the same marginal rule.

The concept of optimal adaptation has two important limitations. First, it is based on the objective of economic efficiency. One can argue that this objective is hard to pursue in economies that are not entirely market-based, and perhaps meaningless in economies with a large informal sector. It is equally valid to argue from a policy perspective that economic efficiency is not the only objective that economic agents and governments adhere to when making resource-allocation decisions. In theory, the concept of optimal adaptation can be broadened to include other objectives, and marginal allocation rules can be derived for multiple-objective resource-allocation problems. However, this is much easier said than done. The use of other objectives is not built into the adaptation cost definitions presented here, simply because it is so hard to model these objectives formally. However, research in this area is encouraged.

The second limitation of this concept is that it is only partially optimal because the level of climate change, which depends on the level of mitigation, is exogenous. As such, this concept does not take into account the fact that the emissions that are causing the climate to change are the result of an externality and are, therefore, not optimal. According to this argument, current greenhouse gas emissions are too high (supra-optimal) because the economic agents that are causing them are not taking into account the current and future damages done by these emissions. From that perspective, correcting the emissions externality through mitigation is the most important aspect of a truly optimal climate change strategy, and, if such a policy is implemented, it will reduce the emphasis on adaptation.

The set of cost definitions developed in this paper are not inconsistent with this line of reasoning. The level of mitigation is treated as exogenous. It could be the optimal level of mitigation, taking into account the emissions externality. However, even in that case, global optimality (i.e., including the emissions externality) may still call for some optimal adaptation actions. This is an empirical, not a policy, issue.

5.3.5.2 Compensation: Free Ridership and Moral Hazard

In this paper, we have defined adaptation cost in an incremental cost framework. An important question is whether economic agents ought to be compensated for undertaking autonomous adaptation actions. A potential problem with government support for autonomous adaptation action is that, because economic agents are being subsidized for what they would do anyway, there is a tendency to "free ride." In other words, subsidies tend to create incentives for economic agents not to take actions to avoid climate change impacts and to wait for the compensation instead. A second, related problem is "moral hazard," which occurs when economic agents are given incentives to cheat by altering their behaviour (from optimal to suboptimal) in response to government programmes to spread risks. Both problems are typified by crop insurance, disaster relief, and flood control programmes that induce individuals to free ride and take risks they would not otherwise bear, in the expectation of government payments.

Free riding and moral hazard can be compounded by misallocation of resources when governments show a preference for one kind of action over another. For example, we have seen that Fankhauser's definition of adaptation tends to focus on projects and policies whose sole objective is to adapt to climate variability and/or climate change. This tends to favour structural measures and technological solutions – capital-intensive measures – over other forms of resource reallocation. Subsidies for these more easily identified and quantified actions can induce economic agents to take advantage of these payments and forgo some other forms of adjustment, which would be optimal without the subsidy. Until recently, this bias toward structural, or technological, adaptation has been a dominant aspect of disaster relief policies in many developed and developing countries.

This view suggests that governments need to be cautious about compensating economic agents for autonomous adaptation and about creating an adaptation policy that favours some kinds of actions over others on the basis of administrative or practical criteria as opposed to social benefit-cost criteria.

5.3.5.3 No-Regrets Actions and the Elimination of Market Imperfections

Some authors (e.g., Smith and Lenhart, 1996; Tol *et al.*, 1998) have defined a class of adaptation actions that they call "anticipatory" climate change adaptation. As a part of this category, they include actions that are analogous to no-regrets actions in greenhouse gas mitigation. These are actions that are already justified by social benefit-cost calculations that (1) could be taken to adjust to the existing climate and (2) would also be beneficial in adapting to climate change. They cite a number of measures related to water resources supply and demand that are currently optimal but which are not undertaken due to market imperfections or government policy.[7] These include water conservation measures, market pricing of water, interbasin transfers, and elimination of subsidies for crops that are intensive users of water.

No-regrets measures look attractive on paper but are hard to implement because the barriers that prevent the adoption of these measures are either hard to identify or difficult to eliminate for various reasons, often political in nature. Unfortunately, the use of subsidies, demonstration programmes, and subsidized research by governments to encourage no-regrets actions has generally produced disappointing results. A key problem is existing government policies and law. Take the example of water resources. Vaux and Howett (1984) and Wahl (1993) have shown that water could be allocated efficiently if its use and transfer were based on market principles. Currently, the development of water markets in the United States has been inhibited by existing water law. In the case of interbasin transfers, even their study is prohibited by Congress. Allocation of water based on market mechanisms would undoubtedly provide substantial climate change benefits through resource conservation, eliminating the need to rely on more costly structural measures. However, only modest headway has been made in this area.

There are numerous other examples like these that suggest that changes to government policies that encourage inefficient resource conservation in climate-sensitive economic sectors – agriculture, forests, fisheries, energy, and water resources – would substantially increase the capacity of economic agents in these sectors to adapt to climate change at lower costs. The costs and benefits of such measures remain to be quantified in a systematic fashion from the perspective of climate change.

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[7] Smith (1997) cites a number of other reasons for undertaking anticipatory adaptation and develops criteria for evaluating adaptation projects based on those criteria.

5.3.5.4 Comparison of Mitigation and Adaptation Actions

The issue of how to compare mitigation and adaptation policies in order to formulate a balanced approach to climate change damage reduction has two parts. The first relates to the type of analysis that is best suited for comparing the two, and the second is whether this analysis should be national or global. The two questions are related. Adaptation cost, as we have defined it, measures the value of the resources that society must give up in order to obtain the benefits of adapting to climate change as opposed to not adapting to it. Similarly, incremental mitigation cost is a measure of the value of the real resources society gives up to mitigate the buildup of greenhouse gases in the atmosphere as opposed to not undertaking that action. Both definitions require that actions be additional to those in a reference case in which these actions do not take place. In the case of mitigation, the reference case is a projection of economic and social evolution, including climate change but without any policies or measures to mitigate it.[8] In the case of adaptation, the reference case is a projection of the economic and social evolution that includes the unmitigated effects of climate change, but with adaptation to the existing rather than the altered climate.

Currently, mitigation actions are evaluated in terms of their cost-effectiveness under the Framework Convention on Climate Change. In this approach, the incremental costs of a mitigation measure are compared to the greenhouse gas emissions reductions achieved by that measure in terms of a cost-effectiveness ratio (i.e., the incremental costs divided by the avoided emissions). However, this specific approach is not suitable for evaluating adaptation actions because they do not reduce emissions. This still leaves open the possibility of making cost-effectiveness comparisons between mitigation and adaptation actions on the basis of avoided physical damages. However, except in very limited situations, there is no single measure, in physical terms, of the effectiveness of an adaptation action that is common to all adaptation (or mitigation) actions. For example, while one can use cost-effectiveness analysis to compare different types of sea walls in a single location, it is very hard to compare the physical damages avoided by constructing a sea wall with the physical damages avoided by changing the operating rules for a reservoir, using a single measure for physical damage.

What adaptation and mitigation actions have in common is that they both avoid climate change damages. Since it is hard to compare these actions on the basis of physical measures of damages, another common metric for climate change damages is required. One such metric is the economic value of the damages avoided by both types of actions, which is a measure of their benefits. This can be done using cost-benefit analysis to compare the value of the net benefits of mitigation and adaptation actions. This, however, greatly increases the sophistication required by the models and methods that are used to evaluate mitigation actions. It also introduces numerous model uncertainties into the analysis and raises the issue of whether or not the environmental impacts of climate change can be valued with the same accuracy as the market impacts of climate change.

But this is only one part of the problem. The other part is that greenhouse gas emissions represent the extreme case of trans-boundary pollution. A tonne of greenhouse gas emissions from a specific source affects radiative forcing at the global level and gives rise to global damages. This means that, while the climate change damages avoided by mitigation measures are both economy-wide and global in scope, the benefits of adaptation policies are much more limited in their geographic and sectoral scope. In that sense, the output of a mitigation measure can be viewed as a global public good, while the output of an adaptation measure can be viewed either as a private good, in the case of autonomous adaptation, or a regional or national public good, in the case of an adaptation strategy. Thus, when a nation reduces its emissions, most of the benefits that result from that action will occur outside the nation’s borders, thereby limiting the incentives for nations to undertake unilateral mitigation actions on the basis of their economic self-interest.

Because of the trans-boundary nature of greenhouse gas emissions, therefore, the incentive structure to institute the two types of actions is not symmetrical. If each country acts in its own self-interest, the incentives to mitigate climate change decrease relative to the incentives to adapt. If climate change damages were distributed spatially in exactly the same way as greenhouse gas emissions, incentives to mix the two measures in a policy framework would be stronger but still not perfect. Unfortunately, emissions and

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[8] In fact, many mitigation cost studies do not include unmitigated climate change effects because they are so hard to project and because it is assumed that these effects will not influence mitigation costs.

damages are not equitably distributed. Indeed, there is some evidence that developed nations, which have the largest emissions and are generally closer to the poles, will experience relatively smaller damages, and perhaps even net benefits (as suggested by Mendelsohn *et al*., 1996), in comparison to developing countries, which have much lower emissions and are generally clustered closer to the equator.

An economic solution to trans-boundary pollution is to employ the principle of sole ownership. Under this principle, an externality such as trans-boundary pollution can be internalized by vesting decision making about how to address the externality in a single owner who experiences all of the damages of the externality as well as all the costs of correcting for these damages. Under these conditions, the sole owner will have the proper incentives to equate the marginal social costs of its actions to correct the externality to the marginal social benefits of doing so, and the resulting actions will be optimal in economic terms.

In the case of greenhouse gas emissions, application of the sole ownership principle directly implies the need for a global body to (1) compare the global benefits and costs of mitigation and adaptation actions by individual nations and (2) undertake policies to finance and implement these measures. This means that, according to this principle, a globally optimal solution to excessive greenhouse gas emissions – one that combines mitigation and adaptation – requires global cooperation. This does not mean that individual countries cannot, or will not, analyse and undertake adaptation and mitigation actions based on less than global consequences. In fact, autonomous adaptation, which cannot and should not be prevented, will necessarily be based on the consequences to individual economic agents. However, without invoking the principle of sole ownership in some way, it is hard to see how individual governments can fashion a balance of mitigation and adaptation strategies that is globally optimal.

5.4 Models for Evaluating Adaptation Benefits and Costs

We have indicated that conducting assessments of adaptation actions will probably require the use of sophisticated modelling techniques to capture the market dynamics associated with autonomous adaptation and to quantify the benefits and costs of both autonomous adaptation and governmental policy strategies. This section briefly identifies the kinds of modelling tools available to do this and discusses their strengths and weaknesses in that capacity.

In this section, we examine the following types of models[9] that can be used to assess the benefits and costs of climate change adaptation:

- accounting models
- market and sector-level economic models
- computable general equilibrium models
- integrated assessment models

5.4.1 Accounting/ Project Models

By accounting, or project, models, we refer to a broad class of bottom-up models that can be used to compute the market costs and benefits of adaptation projects in specific sectors. These models include a great deal of detail about sectoral technologies but are scenario-driven and, as such, do not simulate market behaviour. For the energy sector, in particular, there are off-the-shelf planning models, such as LEAP, which can be adapted to compute the market benefits and costs of individual adaptation projects. For other sectors, models used ordinarily to evaluate the benefits and costs of alternative investments can also be employed, or else special accounting models can be developed to evaluate adaptation projects as they arise. Because these models do not contain the required structure to project the effects of climate change, such as changes in input and output levels and prices, on markets for goods and services, they are best suited for use by individual firms for comparing the costs and benefits of their adaptation actions. Finally, these types of models are not well suited for estimating and valuing the effects of climate change on the environment. However, if

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[9] This classification does not include all of the structural differences between economic models, such as econometric models and mathematical programming models, which can be important in assessing both autonomous adaptation and adaptation strategies but are secondary to this paper.

information about these impacts and values is supplied from other sources, it could be integrated into the accounting analysis.

5.4.2 Market and Sectoral Models

These are economic models that include structural representations of market supply and demand relationships and that use economic principles to determine market clearing prices for inputs and outputs and sometimes for investment (i.e., interest rates). These models can represent single markets or multiple markets, and they can be regional or international in scope. For use in climate change analyses, they must contain "end points" that link the supply and demand relationships to environmental variables that will be influenced by climate change. For example, models of the agricultural sector must contain enough information and structure to link information about crop yields and water availability and use to supply and demand relationships as required. Similarly, market models used to project the response of land owners to sea level rise require the ability to establish linkages between sea level, land surface characteristics, and the spatial distribution of property and land rents.

A number of models that fit these requirements have been developed for the US. Several of these models were used recently by EPRI to estimate the residual damages of climate change for agriculture (Adams *et al*., 1998), forests (Sohngen and Mendelsohn, 1998), energy (Morison and Mendelsohn, 1998), water supply and quality (Hurd *et al*., 1998), coastal property (Yohe *et al*., 1998), and recreation demand (Mendelsohn and Markowski, 1998). Sector models, particularly in the agricultural sector, also exist for a number of developed and developing countries, although their coverage is not as complete as it is for the US. At the global level, sectoral models have been used to assess the economic impacts of climate change on the agricultural sector (Reilly *et al*., 1994) and commercial forestry (Perez-Garcia, 1994).

It is interesting to note that while all of these models are able to simulate some forms of adaptation to climate change, and while those used in the EPRI study integrate adaptive behaviour into the final estimates of the imposed costs of climate change, none of the studies yet completed includes an estimate of adaptation benefits and costs. It is likely that this omission stems from confusion over the meaning of these terms and the conceptual difficulties inherent in formulating the no-adaptation reference case.

The prescription for overcoming this difficulty involves creating an additional scenario in which the effects of climate change are included but input use is constrained at the base case level. Estimates of the costs, benefits, and net benefits of adaptation can be obtained from many of these models by comparing the sector-wide benefits, costs, and net benefits in this scenario with currently available estimates of the corresponding benefits, costs, and net benefits in the scenario where climate changes and adaptation to these changes are allowed. There are, admittedly, technical difficulties associated with creating the new scenario. For example, the level of input detail in different types of models varies widely. Moreover, the decision about which variables to constrain at base case levels, to reflect base case adaptation, may be somewhat arbitrary, while the sensitivity of the models to different assumptions about which variables to constrain may be quite large. However, these are empirical and modelling issues which one always faces in scenario design and model application and should not be viewed as impediments to developing estimates of the benefits and costs of adaptation.

Despite all their strengths, market and sector models contain limitations. First of all, they are inherently partial equilibrium models. That is, they do not contain a complete representation of the inter-industry flow of goods and services that connect the markets of interest to all other input and output markets in the economy. Thus, the market adjustments to climate change projected by these models do not include the effects of price feedbacks between other sectors and markets when climate changes. Second, the ability to depict and value non-market impacts on the environment is limited. While there exists a body of theory that allows economists to place monetary values on these impacts, there is often too little information on the demand and supply relationships for these goods and services to model them empirically. One exception is recreational demand, where there exists a large body of empirical studies, based on travel cost modelling (see, for example, Mendelsohn and Markowski, 1998). Given the potential importance of the non-market impacts of climate change, this is a serious limitation. Third, the geographic coverage of these models is limited, and while sector models exist for climate-sensitive sectors in developing countries, the coverage is not complete enough to perform comprehensive analyses. This problem is further compounded by the fact that the modelling of the large informal sector of the economies in many developing countries is not explicitly addressed. Sector models of developing countries tend to focus instead on the commercial portion of modelled sectors.

5.4.3 Computable General Equilibrium (CGE) Models

CGE models examine the complex market-based interactions among the various sectors or actors of a mixed economy or region. As the name suggests, CGE models are based on the idea of equilibrium or market clearing and involve the simultaneous study of all markets in a regional economy. CGE models vary from simple closed economy simulations based on a few equations to complex open economy models that are as comprehensive as the social accounting matrix.

The identification of interdependencies among the goods, factors, assets, or capital markets of a regional economy as well as the identification of economic variables and market clearing are the fundamental characteristics of general equilibrium analysis. Consequently, CGE models include explicit representations of the demand and supply for final and intermediate goods and for primary factor inputs, such as land, labour, and capital. To construct a CGE model of a regional economy, one needs information on commodity and factor prices, quantities of traded and non-traded goods, availability of factors of production, consumption and saving functions, tax structure, exports, imports, capital flows, and factor mobility.

CGE models are used in all major branches of applied economics. They are commonly used, for example, to examine the effects of taxation on income distribution, the impact of technological change on the composition of outputs and prices, problems of economic growth and equity, and issues of international trade. Computable general equilibrium models are being increasingly used in mitigation analysis to model the carbon tax required to achieve given reductions in greenhouse gas emissions at the national and regional level (Bohringer *et al*., 1997; Harrison and Kristrom, 1997; and Jorgenson and Wilcoxen, 1993). CGE models are just beginning to be used to estimate the imposed damages of climate change. For example, the Economic Research Service of the US Department of Agriculture has developed a global CGE to estimate imposed climate change damages on the agricultural, forestry, and other sectors in eight global regions (Darwin *et al*., 1995). Examples of the application of CGEs to assess the regional economic impacts of climate change include Lazo, *et al*. (1996) and Li *et al*. (1995).

As discussed above, the strength of CGE models is that they make it possible to project the impacts of climate change on several markets simultaneously, and they account for economic feedbacks of climate change through the inter-industry flow of goods and services. Thus, one can use a CGE to show how a climate change that increases the demand for inputs in one sector will affect the prices and levels of those inputs and the outputs that are produced using them.

Early efforts to estimate the economic impacts of climate change using CGE models involved determining the effects of climate change on sector-specific costs and then adjusting CGE cost function parameters so as to be consistent with the time path of impacts simulated by the sector-specific cost models. This approach was used by Scheraga *et al*. (1993) to assess the impacts of a single climate change scenario on GNP, consumption, investment, and sector level prices in the US. Practically, this approach is limited by the availability of sector models. Theoretically, it is limited by the lack of a feedback mechanism between the sector-level model and the CGE, thus casting into doubt the nature of the general equilibrium properties of the resulting joint model market equilibrium.

A better approach is (1) to link production and consumption at the regional level with important land and water resource variables that may be affected by climate change, and (2) to do this in a way that makes it possible to analyse transient climate change scenarios. These are not easy tasks, because the specification of CGE models is frequently not detailed enough at the market and spatial level to effectively model the linkages between supply and demand on the one hand and regional environmental variables that are affected by climate change on the other. However, progress is being made in this direction wthin the framework of the General Trade Analysis Project (GTAP), which includes 37 sectors in 30 regions (McDougall, 1997), the Megabare model (Stuart *et al*., 1997), a CGE model under development for Australia, and the ongoing work by Darwin and coworkers (Darwin *et al*., 1995).

5.4.4 Integrated Assessment Models (IAM)

IAMs seek to link all of the relevant systems in analysing the effects of climate change. These include:

- emissions of greenhouse gases
- atmospheric chemistry and the ocean carbon cycle
- climate and oceans, including sea level rise
- ecosystems
- human activities

These systems are linked so that changes in emissions are transmitted through and transformed by each system until they result in impacts on ecosystems and human activities, which, in turn, adapt to these changes. As of the last count (Weyant, 1997), there were 23 IAMs in active use or under development, and more have been under development since that report.

Weyant (1997) has classified these models into three groups: (1) policy evaluation models that project the physical, ecological, economic, and social consequences of policies, (2) policy optimization models that optimize key policy control variables, given alternative policy objectives, and (3) models for decision making under uncertainty. To date, these models have been used almost exclusively to evaluate mitigation policy actions on the global level.

The major reason that these models have not been used to evaluate adaptation policies is that the models are too highly aggregated at the market and spatial levels to include all of the necessary linkages between the physical environment and supply and demand in regional markets. This is not true for all markets and all sectors in some models. For example, land use is relatively well detailed in the Image (Alcamo, 1994), the MiniCAM/GCAM/proCAM (Edmonds *et al.*, 1994), and MIT (1994) models to allow this. However, the "mechanics" of land use vary in these models, and only in the MIT model is there any real market optimization.

To get around this problem, modellers are developing new strategies in which they use information about the relationship between changes in environmental variables and changes in the value of the residual damages of climate change, which have been generated by sector models, to parameterize the damage value functions in the IAMs. This process, which is under development, may work well for regions where there is extensive sector model coverage, but there are many gaps when it comes to developing countries. Efforts have been made to transfer these damage functions from developed countries to developing countries (Mendelsohn *et al.*, 1996); however, the underlying assumption that the economic structure of a sector is the same in developing nations as it is in the US is not taken seriously. Therefore, the application of the transfer function approach will require additional work on sector models in developing countries before it can be widely regarded as credible.

5.5 Concluding Comments on Optimal Adaptation

The framework that this paper has presented for defining adaptation to climate change has several important dimensions. First, it differentiates between adaptation that economic agents would undertake on their own to avoid (or benefit from) the impacts of climate change and actions that governments undertake to adapt to climate change. Second, it includes not only adaptation measures that are structural in nature, such as dams and sea walls, but also behavioural adjustments that economic agents make directly in response to the physical impacts of climate change or indirectly in response to climate-induced changes in input and output market prices. Finally, it includes a wide range of activities to improve and disseminate information about how the climate is changing, based on monitoring and projecting emissions, climate, and the impacts of climate change on the environment and society.

The paper has also presented a framework for estimating adaptation benefits, costs, and net benefits that allows for benefit-cost comparisons to made between adaptation benefits and costs and mitigation benefits and costs. The framework is consistent with traditional approaches to estimating the imposed costs of climate change, as presented in a number of recent studies about the economic value of the effects of climate change in specific sectors of developed country economies. This means that sector models that have been used to estimate the imposed costs of climate change can also be used to estimate adaptation benefits, costs, and net benefits. This can be done by creating a new scenario to reflect the altered climate with adaptation to the base case climate and comparing the benefits, costs, and net benefits in this scenario with the same model outputs (which already exist) from a scenario that includes climate change and allows adaptation to the altered climate.

The paper has also argued that this framework for comparing the benefits and costs of mitigation and adaptation actions needs to be applied at the global level to ensure that the resulting balance of actions is globally optimal. This requirement stems from the fact that mitigation projects provide benefits that are in the nature of a global public good, while the benefits of adaptation actions represent either private goods, in the case of autonomous adaptation, or regional or national public goods in the case of adaptation strategies. The problems caused by the asymmetry in the costs and benefits of these different actions can be solved by employing the sole owner principle. This sole owner would be a global body, since only a global body experiences both the costs and benefits of both kinds of actions.

The definition of adaptation and the framework for estimating adaptation benefits, costs, and net benefits is based on optimizing behaviour by individual economic agents – consumers, producers, and factor owners. As such, it is a normative framework, no different than the normative framework that is employed by many governments and international funding agencies to evaluate alternative investments. But normative in relation to what? Optimizing behaviour depends on the objectives being pursued by economic agents and governments.

This paper has leaned partly toward a definition of optimal adaptation (and mitigation) that is based on the concept of economic efficiency. This normative framework not only describes how rational economic agents will respond to climate change in a perfectly competitive economy, it also provides a prescription for governments to take actions to remove various forms of market failure, including the global externality created by greenhouse gas pollution. However, the use of economic efficiency as the basis for judging optimality can be criticized on the grounds that the concept of perfectly competitive markets is just that, a concept, which is rarely duplicated in reality, although the economies of some nations come closer to it than others. Moreover, rational behaviour, is also an elusive concept because both governments and individuals often pursue objectives other than welfare maximization and have different definitions of the welfare they are seeking to maximize.

Ideally, this means that the definitions of optimal adaptation and mitigation need to be tailored to the objectives and structures of different economies. Doing so retains the normative character of the analysis framework but allows it to be more descriptive of and applicable to different economies, especially those with a large informal sector. The question is not so much whether this should be done, but how it can be done within an analytical and policy framework.

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Chapter 6

Macroeconomic Cost Assessment

by

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6.1 Introduction

Various sectors of the economy are interrelated, both directly, through purchases of goods and services, and indirectly, through mechanisms such as changes in government spending or borrowing. What happens in one sector can therefore have significant repercussions on others. This is why the direct costs of mitigation or adaptation actions do not provide all of the information needed for decision making.

A macroeconomic cost assessment seeks to estimate the net overall cost of a mitigation or adaptation action after taking all of the indirect economic effects into account. Some of these indirect effects are negative while others are positive, so the sign and magnitude of the difference between the direct costs and the macroeconomic costs varies from case to case. In some studies, relatively large direct costs in the energy sector can be counterbalanced by the economic stimulus provided by recycling carbon tax revenue. In other studies, a relatively small shock to the energy sector can result in a significant net cost. To interpret such results it is necessary to understand the assumptions and feedbacks incorporated into the economic model used for the analysis.

Cost, as used in the term macroeconomic cost assessment, means the net cost to a national or the global economy. The models used to assess macroeconomic costs provide highly aggregated descriptions of the economies they represent. The models are grouped into two main categories: Keynesian models and general equilibrium models. Kenyesian models were first developed during the 1960s to analyse public policies over the short and medium term (specifically, with respect to the problems of effective demand and the role of monetary policy). General equilibrium models, first developed during the 1980s, are designed primarily to analyse the long-run implications of policies. Some of the following comments apply only to specific types of models; where this is the case it will be made clear in the text which type of model is being referred to.

The cost of a mitigation or adaptation action is estimated by comparing the performance of a national or the global economy under the assumption that the action is not implemented with the performance of the same economy assuming the action is implemented. Such calculations require:

- one or more measures of the performance of the economy
- assumptions about what happens if the action is not implemented and about how the action is implemented
- the use of a macroeconomic model

Each of these topics is discussed below. But to avoid any misunderstanding, it must be understood that any macroeconomic assessment depends intrinsically on the assumptions that are made about the future in the absence of the mitigation or adaptation action. The assumptions about the future may reflect an extrapolation of historic trends or scenarios that depict alternative futures. Thus, macroeconomic analysis seeks to understand the nature and magnitude of the indirect economic impacts of climate change policies, not to predict the future.

6.2 Measures of the Performance of the Economy

In principle, the macroeconomic cost of a mitigation or adaptation action should be estimated by comparing the welfare of society assuming the action is implemented with the welfare of society assuming the action is not implemented.

In practice, social welfare is not reported by statistical agencies because it is extremely difficult, if not impossible, to measure (see Box A). Rather, policymakers focus on one or more measures of the performance of the economy – such as GDP, income, employment, and income distribution – that are of particular concern.

Box A: Social Welfare

Individual welfare is usually assumed to depend on the goods and services the person consumes (which are constrained by income), the public goods and services (such as the environment) the person enjoys, and other factors. Aggregating individual welfare to get social welfare raises two difficulties:

- Firstly, it involves ethical and policy judgements about the weight given to the welfare of different individuals. A well-known theorem in economics states that it is impossible to find a scientific basis for comparisons of well-being between individuals.[1] However, there are numerous ways in which individuals' assessments of their own well-being can be aggregated to yield a measure of social welfare. All individuals can be weighted equally, for example, but this implicitly accepts the existing distribution of income. If it is felt that welfare should not depend on the distribution of income, each person's welfare could be weighted by his or her income relative to the mean income of the society.
- Secondly, economists consider that an additional dollar of income increases welfare more for a poor person than for a rich person – the so-called decreasing marginal utility of income. This means that the distribution of income has to be taken into account in aggregating individual welfare.

In addition, since individuals affect each other, social groups provide welfare for their members, depending on their rules for behaviour, means of sharing benefits, social provisions for those unable to work, and other criteria. Thus, when, for analytical purposes, social welfare is calculated as a weighted sum of individual welfare, it should not be forgotten that the aggregation rules reflect value judgements and policy views on social institutions and arrangements.

Most models use the aggregate income or gross domestic product (GDP) of the society as a proxy for social welfare. This approach can be criticized on the following grounds, which are well understood by economists:

- Every unit of income or GDP is weighted equally regardless of the distribution of income, but the distribution of income has an impact on welfare.
- Income and output do not incorporate non-market goods and services, including many public goods and services such as the environment, and goods and services produced by the informal and traditional sectors, which are so important in many developing countries.
- GDP growth may be associated with lower consumption and welfare. For example, building sea walls to provide protection against the effects of sea level rise due to climate change increases output but may not increase welfare relative to a situation with no climate change.
- Finally, despite considerable efforts to adjust GDP to account for effects such as deterioration of the environment, these adjustments have not yet been incorporated into macroeconomic assessments in a systematic way, and it is difficult to draw robust conclusions regarding the level of adjustment, as many effects are difficult to monetize.[2]

Despite these well-understood difficulties, measuring the costs of mitigation or adaptation actions in terms of changes to GDP or income provides useful information for policy making, since it indicates how the level of activity is affected.

Some general equilibrium models try to estimate the impacts on welfare of mitigation or adaptation actions by considering the impact on consumer welfare of changes in income, in the relative prices of goods and services, and, for a few models, in the non-market components of welfare. This provides useful insights, but these insights are valid only at the margin of a given scenario and cannot capture fundamental changes in consumer preferences fostered by a shift in public concerns or the dynamic effects on lifestyles of changes in technology and infrastructure that determine the goods and services available.

The difficulties of estimating welfare have led policymakers and researchers to consider additional economic and social indicators when assessing alternative mitigation or adaptation actions. The main ones in the literature are changes in employment, consumption, inflation, and the distribution of income. Such a multicriteria framework has the advantage that it can be extended to include environmental benefits

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[1] Arrow's impossibility principle holds that it is impossible to compare welfare across individuals. The Hicks-Kaldor compensation principle seeks to circumvent this problem by allowing potential "winners" to compensate "losers" and so to identify the aggregate output that maximizes welfare. Samuelson pointed out the many theoretical and empirical difficulties associated with the compensation principle.

[2] The United Nations has been working on approaches to adjusting standard estimates of GDP for items outside the market economy, such as changes to the quality of the environment, for about a decade. Implementing such adjustments is difficult because these items must be assigned monetary values, but because they are outside the market economy their monetary values cannot be observed.

associated with mitigation or adaptation actions, such as improvements in health and mortality, where monetary valuation is very uncertain and controversial. The choice of criteria rests with the decision maker, and the issue for the analyst is whether the models used provide the desired information, such as the effects on the distribution of income.

Changes to economic indicators such as output, income, and employment can be affected by the type of model used for the analysis. A general equilibrium model assumes full employment in both the base case and the mitigation or adaptation case. Total employment may differ between the two cases because workers choose the mix of paid labour and leisure they prefer, but the differences are likely to be smaller than with an effective demand (Keynesian) model, where full employment is not assumed. Output and income are, likewise, less variable when a general equilibrium model is used.

6.3 Assumptions that Affect the Sign and Magnitude of Macroeconomic Impacts of Climate Policies

Macroeconomic costs are estimated as the difference between activity levels with and without mitigation or adaptation action. In both cases economic conditions are projected into the future for a period ranging from a few (3–5) years to a century or more. It is not surprising, then, that assumptions concerning future economic development can have a dramatic effect on the results. This is why it would be misleading to base policy decisions on a specific numerical result. Rather, macroeconomic models should be used to understand the reasons for particular results, to better frame the policy decisions, and to support the appropriate policy judgements.

We examine below key parameters that significantly influence the costs of climate policies as estimated by macroeconomic models, regardless of their nature.

6.3.1 Is the Economy Operating Efficiently and at its Potential Output at the Start and End of the Assessment Period?

This issue is illustrated in a simple way by Figure 6.1. Abstracting from considerations of uncertainty, dynamics, and technological change, it represents the whole economy at a given point in time as producing two goods and services: (1) environmental quality, E, measured in terms of greenhouse gas emission reductions, and (2) a composite good Q, which is an aggregate of all other goods and services. The theoretical curve F(Q,E), which economists call the production frontier, represents the various possible combinations of emissions reductions and other goods the economy could produce if it were operating efficiently at its potential output.

However, the economy may be operating at less than its full potential (there may be unemployment or idle capacity) or it may not be operating efficiently (because of a gap between the efficiency of the techniques currently in use and the best techniques available). In those cases, the output of the economy would be represented by a point such as U, below the production frontier.

If the economy is not operating efficiently and at its full potential, it is possible to produce more output without increasing emissions (G), or to lower emissions without reducing the output of other goods and services (D), or to both increase output and reduce emissions (any point, such as C, between D and G on the production frontier).

If the economy is operating inefficiently or at less than full capacity, mitigation actions may reduce emissions in ways that have less effect on the output of other goods and services than if the economy were operating on the production frontier. Models that assume that the economy is in equilibrium at full capacity do not allow for no-regrets strategies, which reduce emissions without reducing the output of other goods and services. This is the case, for example, for general equilibrium models that assume perfect flexibility in the labour market, no structural unemployment, and no informal sector.

The production frontier shown in Figure 6.1 shifts with changes in technology and economic growth, as shown in Figure 6.2. When estimating macroeconomic costs, it is important to distinguish between long-run outcomes for the economy that are the result of improvements in efficiency (i.e., shifts towards the production frontier) and those that are efficient but imply different outcomes due to changes in relative prices (i.e., movements along the frontier). Some mitigation policies, such as carbon taxes, aim to change relative prices and can be analysed in terms of changes in macroeconomic costs at the same level of efficiency. Other policies, such as energy-labelling schemes, aim to improve efficiency but may also change relative prices.

General equilibrium models assume that the economy is operating efficiently at full employment. When such models are used to estimate the macroeconomic costs of mitigation and adaptation, the same level of efficiency must be assumed in both the base case and the policy case[3]. This is done in either of two ways:

- The level of suboptimality is constrained to be the same in both the base case and the policy case (from U1 to U2),[4]

  or
- Appropriate economic reforms are made to bring the economy to full employment (from U1 to B) and then climate policies are applied in a way that maintains full employment (from B to A).

In the latter case, if the economic reforms and the climate policies are viewed as being a policy package, then the net cost of the package in terms of GDP growth may be low, zero, or even negative (from U1 to H for example).

In general, the effect of the economic reform policies should not be included in the mitigation costs unless the reform is conditional upon climate policies being implemented. That decision, however, involves both a technical and a policy judgement. An instance of such conditionality occurs when the climate policy raises substantial revenues (e.g., through a carbon tax), and government action to reduce taxes on employment has been constrained by the consequent loss in revenues. The carbon tax revenues can then be used to reduce employment taxes. In this example, the environmental policy provides an opportunity to reform the tax structure when there is no other politically acceptable way to implement such reforms.

In practice all policies have effects on efficiency, economic growth, employment, equity, and emissions, and it is often not possible to design a policy that only affects one intended objective. Thus, an adaptation or mitigation policy and its effects have to be compared with a base case (no action) or with an alternative policy.

6.3.2 Rate of Economic Growth in the Absence of Mitigation or Adaptation Actions

Greenhouse gas emissions typically increase with economic output; thus, the higher the rate of economic growth over the period of the analysis, the higher the emissions in the absence of mitigation actions.[5]

Commitments to mitigate greenhouse gas emissions are often expressed as reductions from historic emissions (e.g., *x*% below 1990 levels). As the rate of economic and emission growth increases, the emission reductions that must be achieved by the mitigation actions to achieve such a target become larger. Thus, the higher the rate of growth of emissions in the absence of mitigation actions, the higher the total cost of meeting mitigation commitments defined relative to historic emissions (see Chapter 4 section 4.2.5.4 for a more detailed discussion).

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[3] This is the case because the general equilibrium models by definition can not explain transformation processes where the economy improves its overall efficiency.

[4] Note that U1 and U2 are the same fraction of the distance from the origin to the earlier and later production frontiers, thus indicating the same relative level of suboptimality. U2 corresponds to higher absolute emissions than U1. The mitigation measure, then, has offset part but not all of the increase in emissions associated with the shift in the production frontier.

[5] The relationship between economic development and pollution levels is the subject of a long-standing debate. A number of studies have found that discharges of many pollutants begin to fall once per capita income reaches a particular level. This phenomenon is known as the environmental Kuznets curve. A recent analysis of industrial CO_2 emissions for a large number of countries for the period 1962–1991 suggests that since 1975 CO_2 intensity has begun to fall in some wealthy countries but continues to rise elsewhere (Roberts and Grimes, 1997).

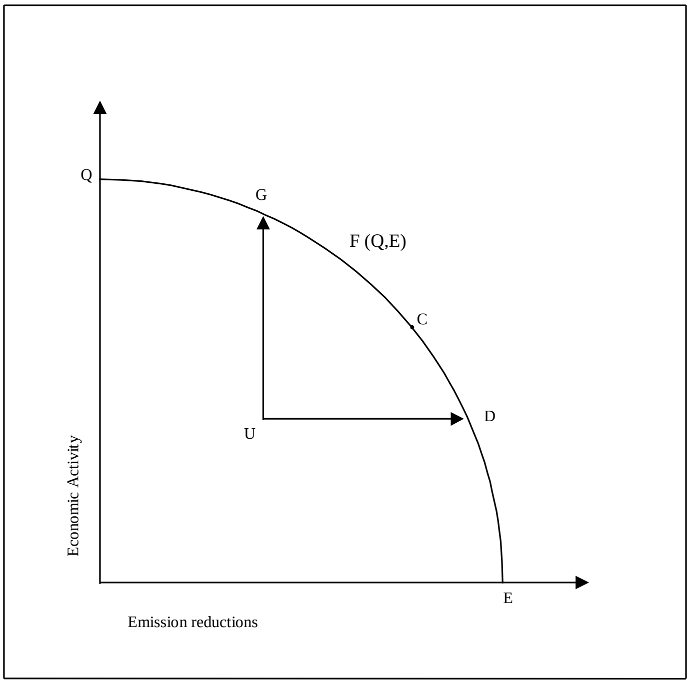

Figure 6.1. The relationship between economic activity and emission reductions (IPCC, 1996).

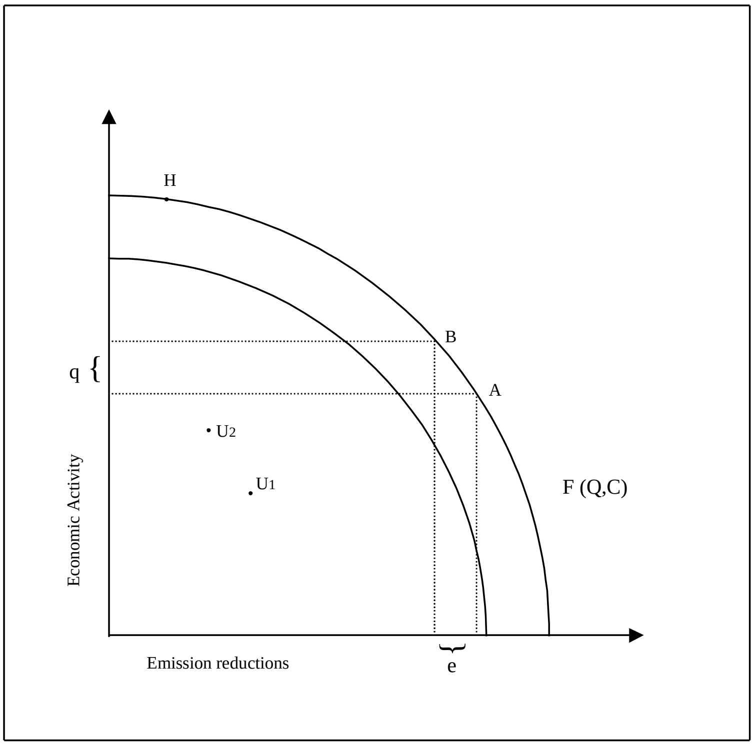

Figure 6.2. Expansion of the production frontier with neutral technological change.

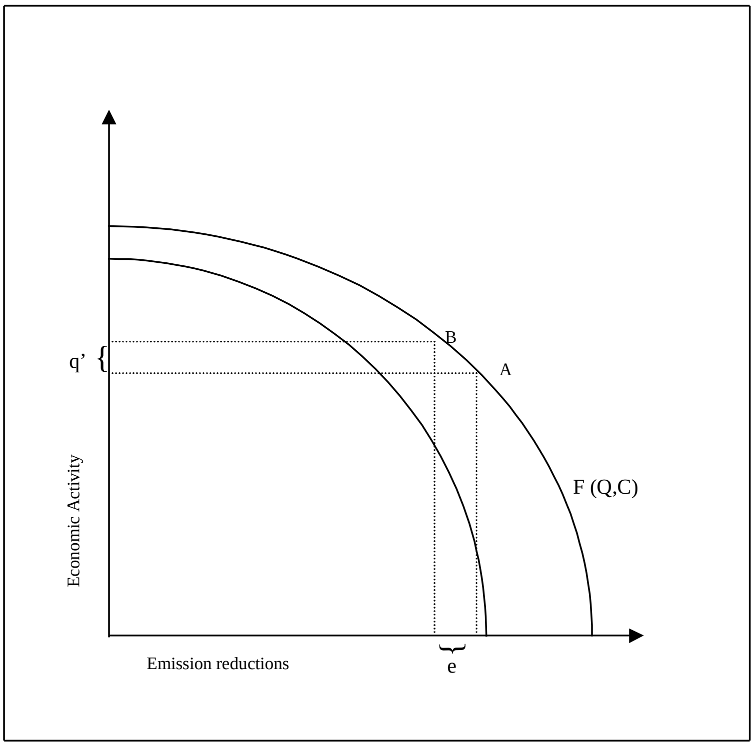

Figure 6.3. Expansion of the production frontier with technological change biased toward emisssion reduction.

6.3.3 The Rate and Nature of Technological Change in the Base Case and Mitigation Case

Some models do not consider technological change at a macroeconomic level and consequently introduce an upward bias into the cost estimates. However, most models currently treat technological change as shifting the production frontier outwards over time.[6] The rate of technological change affects how far the production frontier shifts beyond the changes due to economic growth and changes in relative prices (price of emissions reduction relative to the price of other goods). If the shifts in the production frontier due to technological change are parallel to each other, the technological change is said to be "neutral" (the increased output of other goods and services per unit of input and the increase in emissions reduction per unit of input are the same). Otherwise, the technological change is "biased" toward economic output or emissions reduction. Most historical data suggest that technological change is biased toward lower emissions per unit of output, except during the early stages of economic development.

This bias is, together with structural change in the economy, a key determinant of the level of emissions in the base case, since carbon-saving technological change allows outputs of other goods and services to increase faster than emissions.

On the demand side, many models include autonomous energy efficiency improvement (AEEI) to account for all factors other than energy prices that decouple energy demand and economic output, thus yielding carbon-saving technological change.[7] Other models obtain the observed progress in energy efficiency improvement through changes in energy prices, a procedure that implies that energy prices are the dominant force driving such innovation.

On the supply side, technological change determines the availability and cost of low-carbon technologies in the long run. More precisely, technological change determines the difference between the costs of the technologies used in the base case and the costs of low-carbon technologies in the mitigation case. If technological change in the base case creates the potential for relatively large emission reductions at low cost

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[6] A few models incorporate technological change into the model structure. A common approach is to assume that costs decline with increased deployment of a technology (e.g., with cumulative investment in the technology).

[7] See Section 7.3.1 for a more extensive discussion of technological change and diffusion.

and small increases of emissions for a given economic output, it reduces the cost of actions to meet a given abatement target.

Figure 6.3 illustrates the effect of technological change that is biased toward emissions reduction. To achieve the same emissions reduction (*e*) as in Figure 6.2 costs less (i.e., *q'* in Figure 6.3 is less than *q* in Figure 6.2). Alternatively, a larger emissions reduction can be attained for the same cost. Technological change biased toward economic output produces the opposite pattern.

But the key question is whether mitigation policies will alter the pattern of technological change. If technological change is treated as autonomous, the abatement cost per unit of emissions declines steadily with time. In the real world, mitigation policies will trigger carbon-saving technological change and so reduce the projected cost of meeting a given abatement target. At present only a few models attempt to relate technological change explicitly to factors such as research and development spending and/or cumulative investment in a given technology (learning). The ability to model technological change is limited by a lack of empirical data.

6.3.4 Nature of the Mitigation or Adaptation Policies

Macroeconomic models provide a simplified description of the economy. Consequently, the range of policies they can simulate is limited. A tax, such as a carbon or energy tax, and tradable permits are the policy instruments most commonly used in macroeconomic models.

Mitigation or adaptation policies when actually implemented, however, tend to be more varied and complex. Regulations may be imposed to control emissions from some types of sources, for example, or to force groups to adapt to the impacts of climate change. If a carbon tax or tradable permit system is imposed, some industries or consumers may be exempted.

As modelled, policies such as carbon taxes and tradable permits will generally lead to lower estimated costs than the policies actually implemented if

- these policies rely on standards and regulations which are less efficient than economic instruments (which is true in most cases but not necessarily when standards result from agreement between industry and government and the number of industries is small)
- there are policy distortions such as exemptions, and
- there are important transaction costs, such as the administration and enforcement costs of the policy.

This simply means that macroeconomic cost estimates will generally be understated, because the policies are assumed to be implemented efficiently in the model when this is typically not the case in practice.

However, there are also reasons for thinking that the costs of the policies as modelled may be overstated. If climate policies are stable and progressive, they can focus the long-run expectations of economic agents, reduce uncertainties, and facilitate penetration of low-cost, carbon-saving technological change and so reduce costs. Most models work with energy price elasticities that have been econometrically calibrated over the past 25 years, covering the oil price shocks and subsequent price declines. If, in contrast to that price uncertainty, the climate policy provides a stable signal, the response of economic agents could be more efficient. Hence, macroeconomic models may overstate the costs of climate policies.

In short, there may be a difference between the macroeconomic cost estimates and actual costs, but because the reasons for the difference are understood the models can still help with the design of appropriate policies. Chapter 8 contains a further discussion of policy instruments.

6.3.5 The Question of the Macroeconomic Double Dividend

Using a carbon tax to achieve a greenhouse gas emission reduction target often generates large amounts of revenue. A tradable permit system in which government auctions the permits has the same result, but for the sake of simplicity we will only speak about taxes in this section. These revenues must be recycled in some way, and the assumptions concerning how the revenue is recycled can have a major impact on the cost of the policy.[8] Under some circumstances, the way in which the revenue is recycled can yield economic benefits that offset some or all of the cost of the mitigation policy. Then the policy has both environmental and economic benefits, a "double dividend".

The possibility of a double dividend depends on conditions in the economy where the carbon tax is to be introduced. If the economy is at full employment and if all other taxation is for social or health reasons (i.e., imposed to correct for non-environmental externalities), the introduction of a carbon tax will yield an environmental benefit in the form of reduced greenhouse gas emissions, but the possibilities of an economic benefit such as employment growth or reductions in distortionary tax rates are small or non-existent.

If the economy has unemployed resources and government action to reduce unemployment is constrained by lack of revenue, the introduction of a carbon tax can lead to an economic benefit in the form of increased employment, provided the revenues are used for policies that stimulate employment, such as reducing taxes on labour and stimulating investment through lower taxes on capital.

If the economy has other taxes that are distortionary (in the sense that they are not intended to correct for an externality or other distortion or investment), the revenues from a carbon tax can be used to reduce these taxes and therefore to increase the efficiency of the economy and possibly to increase employment.

Macroeconomic analyses, then, must carefully consider how revenues from a carbon tax are used. The economic effect will differ depending on whether they are used to increase spending, reduce debt, or lower taxes. The effects will differ as well depending on whether the revenues are used to reduce payroll, personal income, corporate income, investment income, or expenditure taxes. Models can be very informative in helping to understand why the effects of a given recycling strategy may differ from one country to another. For example, for the United States economy, capital appears to be overtaxed relative to labour while the reverse is true for the European Union.

Many analyses use lump-sum recycling of carbon tax revenue. This assumption does not allow a double dividend and consequently overstates the cost of the mitigation measures. A decision to implement a carbon tax would undoubtedly include consideration of options for recycling the revenue. Options that yield a double dividend are likely to be more attractive than lump-sum recycling.

Analytically, the correct approach is to separate the various components of the effects of a tax reform package into:

a) the effects of the carbon tax with revenues redistributed as a lump-sum payment to all individuals
b) the effects of using the revenues to reduce distortionary taxes rather than for lump sum payments
c) the effects of restructuring the fiscal system in the absence of a carbon tax.

Comparison of (a) and (b) shows the difference between the effect of a carbon tax at a constant level of distortion and the same carbon tax with the revenues being used to reduce existing distortions. Comparison of (b) and (c) shows the difference between the reduction of existing distortions that could be achieved using the carbon tax revenue and the optimal fiscal system. However, this approach is never used because of the technical and political difficulties of determining the optimal fiscal system leading to full employment.

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[8] For a good discussion of this issue see Bohm (1997a).

The key debate is whether or not the macroeconomic costs of the mitigation policy should reflect any economic benefits due to revenue recycling.[9] This is essentially a policy judgement on the part of the decision maker. Clearly, if other taxes are reduced, part of the benefit is due to tax reform.[10] On the other hand, tax reform requires a large new revenue source, such as a carbon tax, and climate change mitigation commitments offer an opportunity to implement such a tax. So climate change mitigation is one of a limited number of options for realizing the tax reform benefits.[11]

Climate change policy may also yield secondary environmental benefits by reducing emissions and effects (such as noise and vibration) that lead to environmental damage other than that associated with climate change. For example, carbon taxes, which lead to reductions in the burning of fossil fuels such as coal, will also lead to reductions in other emissions, such as sulphur dioxide, oxides of nitrogen, carbon monoxide, smoke, and dust, as well as other environmental benefits.

6.3.6 Policies of Other Countries

The macroeconomic costs of mitigation actions for a country can be significantly affected by the assumptions made about the actions of other countries. This is because countries are related to each other economically through international trade and capital flows.

Since climate change is a global problem, it can be argued that the focus should be on the *global* costs of mitigation actions. And many studies do estimate the global costs of proposed mitigation actions. However, global action takes the form of national commitments to limit greenhouse gas emissions, so countries are interested in the costs of meeting their proposed or negotiated commitments. The macroeconomic costs of such commitments are calculated from a *national* perspective and are affected by the actions of other countries.

If a country acts unilaterally, greenhouse gas emission mitigation actions might adversely affect the international competitiveness of some industries and reduce national income relative to a base case with no commitments. However, as discussed in the previous section, unilateral action can benefit a country under some circumstances if carbon tax revenue is used to reduce existing taxes that reduce employment or investment.

If all countries implement actions to reduce their greenhouse gas emissions, the demand for fossil fuels will be reduced.[12] Prices of energy-intensive products will also be affected, but they could increase or decrease depending on the mitigation actions implemented. These changes will affect incomes and the relative prices of products differently in different countries. As a result trade patterns and domestic production will change.

If some countries implement much larger greenhouse gas emission reductions than others, as is contemplated by the Framework Convention on Climate Change, production of energy-intensive products increases in the countries with the less stringent commitments. However, income in the countries with more stringent commitments may decline relative to a base case with no mitigation actions, so their imports may decline as well. The international economic ramifications of implementing more stringent mitigation actions in some

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[9] Some papers compare a carbon tax with various forms of revenue recycling to a base case with no carbon tax. Bohm (1997b) notes that this involves comparing the carbon tax to a base case with no environmental policy. A fair comparison requires that the carbon tax be compared to a base case that uses other policies to achieve the same environmental goal. In that situation Goulder *et al.* (forthcoming) show that, for a given environmental goal, using non–revenue-raising policies is more costly than using revenue-raising policies with revenue recycling.

[10] Even if mitigation actions are undertaken jointly by several countries, the economic impacts in any single country depend not only on the way in which tax revenues are recycled in that country, but also on the tax recycling strategy chosen by other countries (see Welsch, 1996).

[11] The following analogy may help. Assume that the advertised price of a product (or lump-sum redistribution of the carbon tax revenue) is $100 but that a manufacturer's rebate of $25 (or reducing existing, more distortionary taxes) is available to every customer so that the net cost of purchasing the product is $75. Is the price $100 or $75?

[12] The price of fossil fuels to producers should fall relative to the base case as a result of the lower demand. But the price to consumers depends on the policies adopted. Reducing CO_2 emissions through regulations on fossil fuel use could reduce prices to consumers. But using a carbon tax to achieve the emissions reductions would raise the cost of fossil fuels to consumers.

countries are complex, and they at least partially offset each other. Consequently, the net effect is difficult to predict.
Models can provide useful information about the sensitivity of the cost estimates to assumptions concerning the responses of other countries. A given model with the same set of assumptions can be run under scenarios in which the country acts unilaterally, or as part of various groups of countries with common policies, or as part of a world agreement.

6.3.7 Changes to Social Welfare Due to Changes in Income Distribution

One aspect of the welfare effects of climate change policies is the effect on the distribution of income: for a given aggregate income, a more uniform distribution is generally believed to yield higher social welfare.

Policies to induce implementation of mitigation or adaptation actions will generally affect the distribution of income. Each source may be required to implement particular mitigation measures at its own cost, or incomes may be affected by the redistribution of carbon tax revenue, for example. Other policies, such as income tax changes, may mitigate the effect on income distribution somewhat, but some change to income distribution is likely as a result of any mitigation or adaptation actions.

As noted earlier, most models use aggregate income or GDP as a proxy for social welfare. These proxies are not sensitive to the distribution of income; each dollar of income or output is weighted equally regardless of the income distribution.[13]

Some studies analyse the distributional effects of proposed mitigation policies, such as a carbon tax, separately. However, this approach is relatively uncommon, and such studies do not include the distributional effects of the environmental benefits or those of recycling revenues.

In general, then, changes in social welfare due to changes in income distribution are ignored.

6.4 Macroeconomic Models

The previous section discussed several important assumptions that affect any estimate of the macroeconomic costs of mitigation or adaptation actions. This section discusses model characteristics and how they affect the cost estimates.

A macroeconomic model is a highly simplified characterization of the economy, and the model’s assumptions concerning the structure of the economy can have a significant impact on the cost estimates. These structural issues are discussed below, after which different types of models are compared briefly.

6.4.1 Model Structure

6.4.1.1 How are Expectations Handled?

Individuals and organizations make investments and other decisions on the basis of their expectations about the future. Models often incorporate expectations about the future into the decisions of consumers and producers.

Some models assume perfect foresight – the conditions during future periods are known with perfect accuracy when decisions in the current period are made. In such models the requirements for mitigation action in a future period will alter the nature of the investment decisions before the requirements come into effect.

Other models have limited foresight – conditions are known only for a limited period into the future. Some models have virtually no foresight. In practice, individuals and organizations have both limited and

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[13] Although they still do not provide a complete treatment of the issues related to the distribution of income, some models use a logarithmic utility function based on per capita income and hence do not weight each dollar of income equally.

inaccurate foresight, but it is not possible to define how limited or how inaccurate. None of the approaches to dealing with foresight, therefore, accurately represents reality.

A model with perfect foresight should yield lower cost estimates than the same model with no foresight. With foresight, investment decisions made before mitigation or adaptation requirements come into effect will anticipate such requirements, so there will be less need to retire capital early because it is no longer economic.

6.4.1.2 Treatment of Capital Stock

Capital stock consists of all long-lived equipment, buildings, and infrastructure. The lifetimes of different types of capital range from a few years to more than a century. Mitigation or adaptation policies or the impacts of climate change may reduce the economic value of long-lived capital. Coal-fired generating stations may become uneconomic if a carbon tax is implemented, for example, or buildings located on the coast may be inundated as a result of sea level rise.

In practice it can be costly to modify capital or to replace it before the end of its useful life. Although some models assume that capital is perfectly malleable – that it can be modified without cost – most models incorporate some restrictions on the ability to adjust the capital stock.

Models that restrict the adjustment of capital typically track major capital stocks by vintage and assume that the capital cannot be changed once the investment has been made. During each period the portion of the existing capital stock replaced will reflect the age distribution of that type of capital. The net additional investment in a particular type of capital will reflect the demands of the economy and the cost of capital. New investment can be directed to any type of capital. This is called a putty-clay structure – capital is malleable until an investment has been made, then it cannot be changed.

Since mitigation and adaptation actions will affect capital stocks, the treatment of capital in the model will affect the cost estimates. A model that treats capital as being perfectly malleable will yield lower cost estimates than the same model with a putty-clay capital structure.

6.4.1.3 Labour Market Adjustments

Policies to promote mitigation actions will cause production processes and the mix of goods and services produced to change. This will cause changes to employment levels, say lower employment in coal mining and higher employment in computer software production, relative to a base case with no mitigation actions.

How the model treats labour market adjustments of this type can affect the estimated cost of mitigation actions. Many models treat labour as being homogeneous. They assume that over the time intervals they work with (often 10 years) shifts in employment from coal mining to computer programming are accommodated by retirement and shifts to other jobs by some coal miners and hiring of newly trained staff for computer programming. Moreover, they assume that the labour market is perfectly competitive, at least over the medium term, and that there is no unemployment. Over shorter time periods, such as a year, those assumptions are not realistic. Adjustments to changes in policies or economic conditions are more difficult and lead to changes in the unemployment rate.

Most models do not address structural unemployment and the informal economy, which are longer-term labour market concerns. In most models, when the demand for labour falls, wages decline and people choose to work less and to enjoy more leisure. Empirical evidence suggests that the downward flexibility of wages is limited and that the market adjusts by increasing unemployment. Empirical evidence also indicates that many people do not respond to unemployment or lower wages by increasing their leisure time. Rather, many people, in developing and developed countries, try to maintain their standard of living by working in the informal economy. This is a source of economic distortion and social problems not considered in most applied macroeconomic models.

A model that incorporates unemployment, or other costs for labour market adjustments, will yield higher cost estimates for mitigation actions over the short run than a model that assumes labour is homogeneous and is fully employed. Over the long run the existence of structural unemployment increases the potential for a double dividend if the carbon tax revenues are recycled in ways that reduce labour costs in the formal market.

6.4.1.4 Treatment of International Trade and Financial Flows

Climate change is a global problem. Mitigation actions of comparable severity are likely to be implemented by groups of countries. Mitigation actions will lead to shifts in production activity and changes in incomes across countries.[14]

Some models assume that mitigation actions have no impact on international trade except for the trade in energy commodities. Such models do not allow countries to adjust production internationally to the changes in their cost structures. Other models allow trade in different types of goods and services and allow the trade patterns to adjust to the effects of mitigation actions.

Knowledge of the importance of different treatments of international trade and financial flows on macroeconomic cost estimates is very limited.

6.4.1.5 Government Budgets

Some policies employed to address climate change, such as research and development subsidies, carbon taxes, auctioned tradable permits, subsidies to correct the distribution effects of policies, and infrastructure investments, affect government budgets. The overall macroeconomic cost then will be determined in part by

- the way in which the government budget is treated (in some models, the budget is fixed as a share of national income, in others the government budget is determined by the model), and
- the opportunity costs of public expenditures. Higher government budgets mean lower incomes for the private sector (including state-owned industries in competitive markets) and a loss of the revenues generated by higher investments in the private sector.

While public sector spending on education, health care, transportation, and other items can be shown to yield high returns, most models treat such spending as a cost with no possibility of a return. As a result, models with higher government budgets tend to produce higher estimates of the macroeconomic costs of mitigation or adaptation actions.

6.4.1.6 Elasticities and Model Parameters

Models incorporate specific numerical values for a large number of parameters. Some of these parameters determine how quickly consumer and producer behaviour adjusts to changes in prices. These parameters are usually expressed as elasticities, or the percentage change in quantity demanded or produced for a one percent change in price after one year.

The values of the parameters used in the models are based on empirical estimates. A range of values can be found in the literature for most of these parameters. Needless to say, different models use different parameter values, and these can affect the cost estimates for a given mitigation action.

Typically, parameter values that imply a slower adjustment to price changes will yield higher cost estimates because consumers and producers would be operating inefficiently for a longer period of time after a policy, such as a carbon tax, was introduced.

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[14] International trade and investment flows are affected by market exchange rates. Consumer behaviour depends more on purchasing power, which is measured by purchasing power parity (PPP) exchange rates. Some models incorporate PPP exchange rates for this reason. They typically assume that the gap between the PPP exchange rate and the market exchange rate closes as incomes rise, because the observed differences are smallest for higher income countries.

6.4.2 Types of Models

There are many possible taxonomies of models that can be used to analyse the macroeconomic costs of climate change mitigation or adaptation measures. Zhang and Folmer (1998) identify the following categories:

- *Dynamic optimization models.* Energy sector optimization models, such as MARKAL, show how exogenously determined energy demands can be met at the least cost. They are very useful for assessing the potential of new technologies, but the energy demands are independent of energy prices. To deal with this weakness, the energy sector model is linked to a highly aggregated description of the economy, as in GLOBAL 2100 (Manne and Richels, 1992) and MARKAL-MACRO (Manne and Wene, 1992). Because of the level of energy technology detail, these models are best suited to time horizons of less than 40 years.
- *Input-output (I-O) models.* These describe the complex relationships among sectors of an economy in terms of a set of simultaneous linear equations. I-O models take aggregate demand as given and provide considerable sectoral detail on how the demand is met. They are often used where the sectoral consequences of mitigation or adaptation actions are of particular interest (Fankhauser and McCoy, 1995). However, the high level of sectoral disaggregation carries a price in the form of a number of strong restrictions that limit the validity of the model to the short run (5–15 years).
- *Macroeconomic (Keynesian or effective demand) models.* These carefully model the role of prices and incorporate supply-side equilibrating mechanisms. Final demand remains the principal determinant of the size of the economy. The equilibrating mechanisms work through quantity, rather than price, adjustments. Temporary disequilibria that result in underutilization of production capacity, unemployment, and current account imbalances are possible. Many macroeconomic models are available.[15] The equations in such models are estimated using econometric techniques on time-series data so that the models implicitly reflect past behaviour. As a consequence, macroeconomic models are an inappropriate tool for analysing the economic effects of large changes in the demand and/or supply structure of an economy and questions of a long-run nature.
- *Computable general equilibrium (CGE) models.* These model the behaviour of economic agents according to microeconomic principles. CGE models typically simulate markets for factors of production (labour, capital, energy), products, and foreign exchange, with equations specifying supply and demand behaviour. The model is solved for a set of wages, prices, and exchange rates to bring all of the markets into equilibrium. CGE models examine the economy in different states of equilibrium and so are not able to provide insight into the adjustment process. Most CGE models are calibrated rather than econometrically estimated, making it more difficult to defend the validity of the parameter values.
- *Hybrid approaches.* Increasingly, different types of models are being linked to provide greater detail on the structure of the economy and of the energy sector. Good examples are the linked HERMES-MIDAS model (Capros *et al*., 1990) and E3M3 (Barker, 1995; European Commission, 1995). While a hybrid approach is able to shed light on both the economic and technological aspects of reducing energy-related CO_2 emissions, it does present some drawbacks. To obtain consistent results, a hybrid approach needs to remove all the inconsistencies built into the two models This process can be cumbersome and time-consuming.

Such classifications are becoming less useful. First, differences in parameter values among models within a given category may be more significant than the differences in model structure across categories. Second, there are many differences between the theory underlying a particular category of models and the actual models. Some CGE models incorporate structural unemployment or monopolistic behaviour, even though the theory underpinning these models is based on perfectly competitive markets. Third, an increasing number of models are hybrid constructs.

To answer the questions of concern to policymakers, it is important to select a model with an appropriate structure, and it may be necessary to use more than one model. The Interagency Analysis Team created in the United States in 1997 to analyse the economic impacts of possible commitments under the Kyoto Protocol used three different models – a MARKAL model to provide energy sector detail, the DRI

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[15] A good example is the Harmonized European Research for Macrosectoral and Energy Systems (HERMES) model constructed for the Commission of the European Communities (CEC) (see Italianer, 1986).

macroeconomic model to study short-term economic impacts, and a CGE model to analyse longer-term national and international adjustments. Unfortunately, the number of models available for a particular country is frequently quite small, so in reality a choice must often be made from among a limited number of imperfect options.

6.4.3 Interpretation of Model Results

This section discusses three issues related to the interpretation of model results that often cause misunderstanding. These issues relate to:

- dynamic optimization, recursive models, and comparative static analysis
- macroeconomic (effective demand) models versus general equilibrium models
- top-down and bottom-up models

6.4.3.1 Dynamic Optimization, Recursive Models, and Comparative Static Analysis

Dynamic optimization models optimize a trajectory over a specified time period. The results of these models can be interpreted as what would occur in a "first best" world guided by a benevolent central planner or in a competitive market with perfect foresight. These models are widely used for the energy sector (MARKAL-type models), where they show how exogenously determined energy demands can be met at the least cost. The energy sector models lack demand-price interactions and have no linkages to the rest of the economy. To overcome these limitations, some models, such as MARKAL-MACRO, link a highly aggregated description of the economy with a detailed treatment of the energy sector.

Recursive models include both Keynesian macroeconomic models and simulation models. In these models the state of the economy at time *t* depends on the state of the same economy during one or more previous periods. Keynesian macroeconomic models are econometrically calibrated to past data and require a relatively large body of data to estimate the relationships used to simulate the future. Since these relationships cannot be assumed to remain constant for very long, the time horizon for which they are useful is limited to 15 or 20 years. To overcome this limitation, recursive simulation models have been developed. They are less complex and can be calibrated to historical data or econometrically estimated. Simulation models are used to develop scenarios and conduct sensitivity analyses rather than to predict future economic conditions.

Comparative static analysis is the technique used to derive insights from CGE model results. The model solution provides information on market clearing prices and quantities for output by sector, investment employment, foreign trade, and energy consumption. Comparative static analysis compares selected variables for two periods in time or for two different cases (a base case and a case that includes mitigation or adaptation measures) for the same point in time.

The important point is that the three approaches address different questions. Dynamic optimization models find the first best solution over a given time horizon in a first best world. Keynesian macroeconomic models focus on the adjustment costs associated with policy changes or exogenous shocks. And CGE models examine the economy in different states of equilibrium.

6.4.3.2 Macroeconomic (Effective Demand) Models Versus General Equilibrium Models

Effective demand and general equilibrium models rely on different economic theories and different visions of economic dynamics.

Macroeconomic models are generally considered to be more realistic than CGE models over the short run, because the equations in the former are estimated using econometric techniques applied to reliable time series data. But they implicitly reflect past behaviour, which may no longer hold true in the light of rational expectations regarding policy actions.[16] If this is the case, the estimated effects of the policy action will be

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[16] This has been called the Lucas critique (Lucas, 1976). See also Mankiw (1990) for a good discussion of the Lucas critique in the context of the breakdown of the consensus in macroeconomics.

incorrect. As a consequence, macroeconomic models may be an inappropriate tool for analysing the economic effects of large changes in the demand and/or supply structure of an economy and questions of a long-run nature.

In CGE models the behaviour of economic agents is modelled according to microeconomic principles. These models typically simulate markets for factors of production (labour, capital, energy), products, and foreign exchange, with equations specifying supply and demand behaviour. The parameters in the utility functions and production functions of CGE models are structural parameters representing tastes and technologies. The tendency of most CGE models to borrow elasticity values from a variety of studies in the literature poses some problems of consistency, however. CGE models are best suited to analysing important issues over the long run rather than to predicting transition paths in a realistic way.

A frequent criticism of CGE models is that they cannot analyse disequilibrium issues such as unemployment. This is true in many models, but should not be overstated. Present-day eclectic models, for example, tend to incorporate both market failure (e.g., unemployment), as used in Keynesian-monetarist models, and market clearing, as used in CGE models (Blanchard and Kiyotaki, 1987). In addition, CGE techniques can easily incorporate structural unemployment, depending upon the closure rule of the system.

The key distinction, then, is between models that assume monopolistic prices and wage-price rigidities and models that assume competitive prices and flexible labour markets. If the former features are incorporated into a CGE framework, the difference with a neo-Keynesian model narrows, since, for example, a cut in labour taxes will induce firms to employ more labour and increase the effective demand. The debate is more about the nature of the economic mechanisms at work than about the modelling framework *per se*.

6.4.3.3 Top-down and Bottom-up Models

Information on mitigation costs from bottom-up or engineering models and that from top-down macroeconomic or CGE models may appear to be mutually inconsistent. The former provide estimates of the direct costs of meeting specified emissions restrictions at a high level of detail. The latter models take a highly aggregated approach to modelling the energy-economy interactions. In such models future energy demand, and the cost of changing it, are largely determined by two parameters: the autonomous (non–price induced) energy efficiency improvement (AEEI) and the price elasticity of substitution between capital, labour, and energy. Neither of these parameters is physically observable or directly measurable.[17]

The relative strengths of bottom-up and top-down models can be made to complement each other if information from bottom-up analyses can be introduced into top-down models. This can be achieved in two ways:

1. By informally linking the top-down and bottom-up models so that the models are operated independently but the results from one model are reflected in the other. The calculations proceed iteratively until convergence is achieved. More recent examples in this tradition are the efforts in various countries to link a MARKAL model with a macroeconomic model (Kram, 1993).
2. By formally linking a simple bottom-up energy model with a top-down model, as in the HERMES-MIDAS model (Capros *et al.*, 1990), by eliminating the energy equations from the top-down model and the macroeconomic equations from the energy model.

While linked top-down and bottom-up models are able to shed light on both the economic and technological aspects of reducing energy-related CO_2 emissions, they do present some drawbacks. One criticism of bottom-up models is that they do not incorporate real behaviour. Coupling one to a top-down model does not fully address this criticism. This concern is less serious when the top-down model is a CGE model, because a CGE model is designed to be used for sensitivity tests and not for making predictions of the future.

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[17] The AEEI parameter accounts for all but energy price–induced energy conservation. Energy conservation of this type is available at zero or negative net cost and takes place regardless of the development of energy prices. It may be brought about by regulations or may also occur as a result of "good housekeeping" or a shift in the economic structure away from energy-intensive manufacturing towards services. The price elasticity of substitution is a measure of the ease or difficulty of substituting other factors for energy during a period of rising energy prices.

Conversely, econometrically estimated macroeconometric models are supposed to incorporate such behaviours but are criticized for describing them without modelling the role of market imperfections and for being unreliable over the long run. Relaxing the econometric discipline in the bottom-up portion of the model raises concerns of internal consistency. For example, changes to industrial energy demand in the bottom-up model will not be reflected in the production function of the top-down model which describes the substitution between capital, labour, and energy.

6.5 Conclusions

A macroeconomic cost assessment seeks to estimate the net overall cost of a mitigation or adaptation action after taking all of the indirect effects into account. Various sectors of the economy are interrelated, both directly, through purchases of goods and services, and indirectly, through mechanisms such as changes in government spending or borrowing. Thus mitigation and adaptation actions induce costs and benefits in various sectors of the economy which cause the net overall cost to differ from the direct cost of the measure.

The macroeconomic cost of a mitigation or adaptation action is estimated by comparing the performance of a national or the global economy under the assumption that the action is not implemented with the performance of the same economy assuming the action is implemented. The comparison must be framed correctly for the question being analysed. If the question is the cost of meeting a proposed commitment, then a base case with no mitigation actions is appropriate. If the focus is on alternative policies for meeting a commitment, then the base case should reflect the commitment.

A model or models should be selected for the analysis on the basis of their suitability for the task and their ability to provide the information desired by policymakers. Each model has strengths and weaknesses for particular applications. To answer the questions of concern to policymakers, it may be necessary to use more than one model. Unfortunately, the number of models available for a particular country is often quite small, and consequently a choice must usually be made from among a limited number of imperfect options.

The scale of the proposed mitigation or adaptation action obviously affects the macroeconomic cost. The specific nature of the actions also affects the costs. The purpose of a macroeconomic cost assessment is to understand precisely how costs vary with the nature and magnitude of the proposed action. But the estimated costs also depend significantly on the assumptions embedded in the model(s) and those adopted for the analysis. Assumptions that are particularly important include the:

- rate of economic growth in the base case
- rate and nature of technological change
- arrangements for revenue recycling
- adjustments for changes in the performance of the economy relative to its potential output
- policies adopted by other countries.

To better understand how modelling assumptions affect the predicted economic impacts of actions to limit greenhouse gas emissions, Repetto and Austin (1997) analysed 162 runs from 16 of the most reputable and widely used economic models for the United States. They examined the relationship of the percentage change in GDP in a future year to the percentage change in CO_2 emissions in the same year. Both were measured relative to a base case scenario specific to the model run. They found that eight factors[18] explain about 80% of the variation in the predicted economic impacts. For a 50% reduction of CO_2 emissions from

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[18] The eight factors relate to the following issues: (1) Is the model of the CGE type, which assumes that the economy adjusts efficiently in the long-run, or is it a macroeconomic model that assumes the economy suffers persistent transitional inefficiencies? (2) How much scope for interfuel and product substitution does the model assume, as indicated by the number of different energy sources and industrial sectors in the model? (3) Does the model assume that one or more backstop non-fossil energy sources are available at some constant cost? (4) How many years does the model assume to be available to achieve the specified CO_2 reduction target? (5) Does the model assume that reducing CO_2 emissions would avoid some economic costs from climate change, or that no such costs exist? (6) Does the model assume that reducing fossil fuel combustion would avoid some damages from air pollution, or not? (7) Does the model assume that carbon tax revenues are returned to the economy through the reduction of a distorting tax rate, or through lump-sum rebates? (8) Does the model assume that international emissions trading (or joint implementation) options are available, or not?

the baseline in 2020, the predicted economic impacts ranged from a loss of almost 6.0% to a gain of about 4.5% relative to baseline GDP in that year.

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Chapter 7

Long-term and Cross-sectoral Cost Issues

by

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7.1 Introduction

Climate change can be characterized by a system of events from emissions to impacts. One way to categorize these events is depicted in Figure 7.1 (IPCC, 1996):

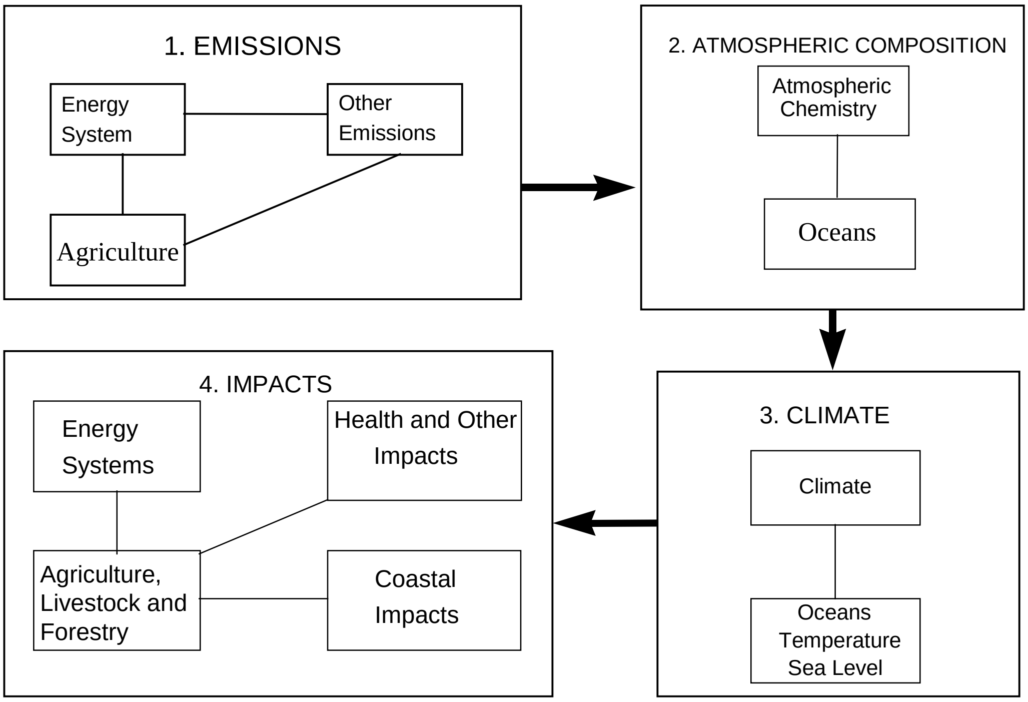

Figure 7.1. A schematic overview of climate change and its impacts.

Emissions of greenhouse gases result from human activities in the energy, agriculture, and forestry sectors, and from industry and waste management. Energy production from fossil fuels leads to the release of carbon dioxide and fugitive methane emissions. Forestry sector biomass decomposition and burning mostly releases carbon dioxide and methane, and agricultural systems are largely responsible for the release of methane and, to a smaller extent, nitrous oxide from paddy fields, livestock, and soil management. The emissions of carbon dioxide from human activities and natural sources increase its concentration in the atmosphere, depending on the extent to which oceans and terrestrial sinks remove the gas. These sinks do not remove other greenhouse gases, however, and their concentration depends on chemical reactions and decomposition in the atmosphere. Climate and sea level are partly determined by the atmospheric concentration of greenhouse gases and atmospheric interactions with the oceans, which act as enormous heat reservoirs. Finally, changes in climate and sea level have impacts on various human and natural systems as indicated in Figure 7.1, each with significant social and economic implications.

Cost concepts feature prominently in Categories 1 and 4, which deal with *emissions* of greenhouse gases and with the *impacts* on natural and human-made systems respectively. In these two categories costs are explicitly evaluated and there is potential for significant differences between countries. Energy systems, for example, are country-specific, not only because the types of fuels used vary by country and by regions within a country but also because the types of uses vary according to the socioeconomic systems in place. Similarly, land use patterns, which reflect the geographic distribution of forestry, agriculture, and other related sectors, are dictated by the natural resources of the country, and their exploitation is a function of its socioeconomic systems. Conservation of ecosystems or additions to the forested area depends on a specific country′s land use policy. Some Category 4 issues, however, such as the impacts on ecosystems or issues related to the sustainable stewardship of natural resources, may bring forth cost considerations that have territorial relevance but cannot always be adequately addressed by conventional valuation techniques.

The other two categories are largely global in nature; consequently, cost considerations do not directly enter into the analysis and regional or country-specific interactions are not as important. Because *atmospheric composition* is not determined by any particular country (although the associated concentration of local air pollutants does vary across countries and cities), the inclusion of externalities into cost considerations needs to be addressed separately. Likewise, the interaction between *oceans and climate* is global in nature, although the impacts of sea level rise and temperature increases need to be considered on a country-specific basis.

The cost concept employed in assessing mitigation and adaptation projects and/or policies is no different than that applied in other economic analyses involving activities of limited and discernible impact (see Section 2.2.2 for a definition of the cost concept). In this context, *costs* are defined as the value of resources forgone for the purpose of implementing a project or policy. By project we refer to an economic activity with a clearly defined system boundary that covers objectives, mode of operation, time horizon, and bearers of costs and benefits, as well as assignment of responsibility. In general, cost refers to social as well as private costs (see definitions of these concepts in Chapter 2, section 2.25). The costs can be measured as financial costs or as economic opportunity cost, where the former reflects the actual expenditures incurred to perform the activity and the latter represents the value of alternative opportunities forgone in order to implement the activity or policy. If the value of the resources used to perform the task is correctly determined through the market, the financial and economic opportunity costs are the same. Since the market can hardly price all the inputs, products, and externalities, however, the two values rarely coincide (Little and Mirrlees, 1974).

For the above cost concept to be applicable within a benefit-cost analysis framework, the mitigation or adaptation project or policy must meet a critical underlying assumption, which stipulates that the impact of the project is not large enough to significantly influence the price vector in the sector or in the economy (Varian, 1992). If a large project such as an extensive afforestation program is under consideration for mitigation, it may, for instance, affect wages, land prices, and prices of timber, woodfuel, or agricultural produce. Assessment of such mitigation projects or policies requires other methods of the partial or general equilibrium type, which can capture the feedbacks and the cascading effects across the economy over time.

The estimation of costs of climate change mitigation and adaptation raises two types of issues that are generic to the events represented in Figure 7.1. Since the consequences of increasing concentrations of atmospheric carbon dioxide will be felt over decades and centuries, long-term issues become important in the estimation of costs. At the same time, because many sectors and geographic regions are involved, cost concepts are used in a variety of ways in the formulation of strategies to arrest climate change. In this chapter, we discuss these two issues: namely, (1) cross-sectoral and (2) long-term considerations in the estimation of costs for climate mitigation and adaptation.

7.2 Cross-sectoral Correspondence of Cost Concepts

A lack of uniformity in applying cost concepts across mitigation options either within sectors or across different sectors may lead to misunderstanding. What is meant by the cost of reducing a tonne of carbon, for instance, can vary considerably from one study to another. In some cases the cost includes only a limited number of items. For example Dixon *et al.* (1993) only cover the establishment cost of forestry projects, whereas studies like those in Sathaye and Makundi (1995) include a variety of other items such as silvicultural operations and the opportunity cost of land. Across sectors, energy costs are often reported in terms of the lifecycle cost of energy supply or use, and these are not directly comparable to the investment costs reported for forestry in Dixon *et al.* (*1993*). Differences can also arise because those who are estimating costs may not distinguish between (1) average, marginal, and incremental costs, (2) financial and social costs, and (3) project and macroeconomic costs. Different terminology to represent the same costs across sectors can also be a source of confusion, especially given the difference in project duration for mitigation options in various sectors.

Application of the cost concepts is made much more complex when the project spans several sectors. The following generalized example, which covers both the land use and energy sectors, will be used to elaborate on the complexity of application of the concepts as described in this section.

Example 1. Short rotation forestry for electric power generation

Let us consider a short-rotation forestry project in which a eucalyptus plantation will produce biomass for firing an electric power generator. The plantation is to be located in a rural area, replacing a sparsely stocked natural woodland used by the peasants as a source of fugitive forest products such as fruits, honey, fibre, and herbs, and for grazing land. At the same time, the natural forest regulates the water run-off from the catchment. It is further assumed that the project is to be established in a rural area where the farmers have seasonal agricultural activities and some of the land for this project would have ultimately been used for agricultural production. The project also involves generation of electricity intended to supply nearby urban areas that would have otherwise installed diesel generators to meet the growth in demand. The power plant is to be located near the township, and this requires that the wood be harvested, chipped, and transported by lorries to the power plant.

7.2.1 Representation of Costs in Different Sectors

The project and non-project costs differ among sectors because of the unique nature of the projects and/or policies that constitute mitigation in each sector. Whereas mitigation projects in the energy sector mostly consist of activities and policies that reduce greenhouse gas emissions per unit of energy service delivered, mitigation projects in land use sectors entail both emission reduction (through measures such as forest preservation and substitution of biofuels for fossil fuels) and measures to sequester carbon in vegetation, soils, and biomass-based products. The main cost elements associated with projects in these sectors will vary correspondingly, as shown below.

Energy Sector

Fixed Costs
- plants and equipment
- construction of cleaner energy power plants such as hydroelectric dams
- acquisition of energy efficient appliances and fleets
- installation of infrastructure to service a fuel-switched system
- energy efficiency improvements in existing and new buildings

Variable Costs
- fuel (e.g., gas versus coal)
- plant maintenance and operation
- system maintenance to reduce energy leakage

Land Use Sectors

Fixed Costs
- acquisition of land for afforestation or reforestation schemes
- resettlement of displaced residents
- installations and buildings
- infrastructure (e.g., roads and fire breaks and other communication)
- acquisition of more efficient mills, kilns, and stoves
- opportunity costs associated with the land use change
- intangible costs such as visual intrusion
- negative externalities

Variable Costs
- establishment costs (e.g., land preparation and planting)
- silvicultural operations
- saw timber and pulpwood for mills
- project operating costs
- monitoring and protection

Although a project such as the one described in Example 1 covers both the land use and energy sectors, each of these cost elements can be applied separately. However, if the planning and implementation of the project are integrated, then some of the costs will be affected. For example, the location of the Power Company relative to the plantation will determine the extent of insfrastructural costs such as roads. In the classical case, the plantation management would like to locate the roads at the top of ravines because it is cheaper to transport and distribute labour, seedlings, and other materiel, while on the other hand the power company would prefer to locate the roads in the valley, since it is cheaper to harvest and skid logs to the roadside. The costs associated with each road location are quite different.

Since it is the *net cost* of mitigation projects that is of interest, the value of the change in the output of the project compared to a baseline should be compiled (GEF, 1994). If a renewable energy project produces more electricity, the amount and its price should enter into the computation of net cost. In the example above, the price of the generated electricity may be determined outside the project boundaries. If a forest project yields a product (e.g., timber, fruit, and water) in excess of the baseline projection, its value has to be accounted for in estimating the net cost of the mitigation project. Due to the existence of costs and benefits whose value cannot be determined by market forces, the issues of externalities, shadow prices, and other intangible elements need to be addressed explicitly, as discussed in the following section.

7.2.2 Appropriate Use of Shadow Prices

The concept of shadow prices is indispensable in mitigation analysis, in cases where markets for inputs and products of mitigation projects are distorted. Shadow price is defined as an adjusted price that equates the market price with the opportunity cost of the input or product in question. Due to market failures, the market price may exceed or fall short of the true scarcity value of the resource. Market failure occurs when the conditions for perfect competition are significantly violated and the price reached by such a market mechanism does not represent the true value of the item being traded. Such failures can arise from an imperfect flow of information, the existence of transaction costs, the dominance of a few large players who influence prices (e.g., a monopoly or oligopsony), externalities, non-existence of markets for some goods and services, or the existence of public goods (Stokey and Zeckhauser, 1978). Taxes and subsidies are a good example of elements that may be responsible for the disparity between market prices and the economic opportunity cost. Determination of the appropriate shadow price depends on the nature of the market failure.

In the example described above, the wage paid to the manual workers in the plantation may exceed the true opportunity cost of their time, since they would have been fully employed in agricultural activities only during the farming season, and for the rest of the year they would have been either unemployed or underemployed. In this case, the shadow price of the labour cost should be accordingly lower than the wage bill. On the other hand, the actual value of the land should include the value of the goods forgone from the woodland. Because of the long-term nature of a project like this, it is more difficult to correctly identify the forgone opportunities, especially for years ahead. On the contrary, the opportunity cost of inputs in the power plant differs from those in the plantation. Since we assumed that the plant is located close to the urban area, the wage rate for manual workers in the plant is closer to the actual opportunity cost by virtue of the existence of similarly paying opportunities in town. On the other hand, if the country in question has a scarcity of foreign exchange reserves, the shadow price of the plant may be higher than a market price based purely on the exchange rate (which would, under the circumstances be overvalued). The actual value of the wood chips will therefore depend on the correct assignment of the value of labour, land, and capital in the plantation, which the market may be unable to impute.

For non-traded goods, the shadow price is compiled from the cost of producing the good, where the value of the inputs used is the economic opportunity cost. If the markets for these inputs are competitive, market prices are used. In the event that the upstream markets are distorted, one has to apply shadow pricing in the relevant factor markets, with reasonable cut-off points being drawn at some point (Little and Mirrlees, 1974). However, it ought to be noted that this process may be very cumbersome and at times recursive when dealing with severely distorted markets (or sectors), as is the case in centrally planned economies. In such cases, one may have to use a cross-sectional shadow price borrowed from a comparable economy with reasonably functional markets.

The shadow prices for labour, capital, and foreign exchange are more complicated, since they are based on the functioning of whole economies, and the distortions embedded in them can mostly be evaluated through an examination of the functioning of the economy, often using analyses of the general equilibrium type. For mitigation analysis, shadow prices of these inputs could be extracted from existing data obtained from the statistical bureau, the central bank, or other such institutions that make use of information of this nature on a regular basis. The imputation of shadow prices when the market failure is due to externalities and/or the existence of public goods depends on how the externalities and the value of public goods are measured.

7.2.3 Measurement of Externalities

The measurement of externalities involves the evaluation of third party effects where property rights and the assignment of responsibility may not be altogether clear. Externalities exist when the value of an objective (such as profits or welfare) depends on incidental by-products of some activity of others (Bergstrom, 1974; Arrow, 1971). A number of approaches have been suggested for achieving optimal allocation of resources under externalities, with the original bias being towards a system of taxes and bounties (Pigou, 1932) and later approaches favouring the internalization of externalities, where bargaining between the affected parties is purported to lead to optimal allocation (Coase, 1960; Buchanan, 1966). Many variations and combinations of these two approaches have been explored. The ongoing international discussions to put in place a mechanism for tradable permits for greenhouse gas emissions is a broad attempt to at least partially internalize the emission externality.

The core issues affecting the resolution of the externality question include (1) the vagueness of definitions of property rights, (2) the existence of high transaction costs for bargaining, especially when many parties are involved, (3) problems in estimating the opportunity costs of affected parties, and (4) the initial extent of the externality, which tends to influence the outcome of the bargain between parties. Measurement of the extent of the externality is directly linked to the nature of the externality itself. In situations where the impact (positive or negative) is quantifiable, as in the case of an increase or decrease in productivity, it can be measured in the same way that the value of the affected objective function was measured without the externality. If the product has no market price, it can be valued using the methods discussed in the shadow prices section. In mitigation projects, evaluation of spillover effects is project and sector specific. In the example discussed above, the reduction of run-off control as the result of the replacement of a natural woodland by a eucalyptus plantation is a negative externality which could be estimated by using the difference in cost of meeting the downstream water requirements and/or retiring and replacing dams before their useful lifetimes had been completed.

In the energy sector, if a project increases the use of a more energy-efficient appliance, which, in turn, leads to a reduction of hazardous emissions, then the extent of this externality is equivalent to the reduction in commensurate health problems, some of which have a market price. A project that involves switching from coal to natural gas for power generation will have positive externalities on local pollution reduction; however, the measurement and valuation of this spillover carry all the inherent problems associated with the assessment of pollution impacts. On the other hand, the effect of a mitigation project that protects a forest and increases its recreational use will be estimated using such methods as the travel cost approach or willingness to pay (WTP), as would have been the case without the greenhouse gas benefits (Fisher and Krutilla, 1972). There may be a set of externalities that are presently non-quantifiable, (e.g., aesthetic effects or community coherence), and the best that can be done with these is to describe them and, in some cases, to assign subjective ordinal values to them that may be useful in comparing close alternatives.

7.2.4 Capital Market Imperfections

Like any other investment, mitigation projects require capital in the form of financial resources for purchasing the necessary inputs such as power plants, equipment, land, and labour services. The main sources of capital include public funds (e.g., for reforestation and large hydro power plants), bilateral financing (e.g., country-to-country loans or grants), and both local and international private funds. Capital markets form a source of funds at a price, normally the borrowing rate. Under efficient capital markets, the demand and supply of capital would be driven by the price of capital (Greenwald *et al.*, 1984), and credit rationing would be minimal. In reality, however, credit rationing is a common practice in many capital markets. Also, it has been observed that private implicit discount rates are higher than those for public investments.

Many explanations exist for the distortions observed in capital markets, including the functioning of financial institutions, monetary policy, cost of information, and political interference. It is also argued that one reason for the disparity between private and social discount rates is the tendency to include non-timing issues like risk, capital constraints, and information in the discount rate. The disequilibrium in the capital markets leads to an excess demand for funds at ruling interest rates, which can lead to non-interest credit rationing based on factors such as collateral, special relations, and political objectives (Jaffe and Stiglitz, 1990).

Distorted capital markets are quite common in developing countries and tend to lead to an inefficient allocation of capital among competing investments. In such economies, where credit and equity rationing are acute, the market will consistently discriminate against mitigation projects, which may have long gestation periods and significant externalities. This fact, combined with the belief that the use of discount rates that are lower than market rates unduly directs resources to investments that are suboptimal, puts mitigation projects at a disadvantage in capital markets.

7.2.5 Income Distribution

Income distribution is one of the main equity issues to be addressed by policymakers when considering any new projects. Assuming that procedural equity issues, such as the participation of those affected by the policy, have been adequately covered within the country, the main area of emphasis critical to the implementation and success of a mitigation project involves consequential equity. Within a given country, the classical tenets of equity in outcomes of policies have to be observed to an extent. A number of useful yardsticks for measuring equity of outcomes have been proposed (Young, 1994).

The first of these is *parity*, which requires that benefits be distributed equally. As a rule this does not mean justly, since this will depend on the initial endowments of the stakeholders, and on other criteria discussed below. In the context of a given mitigation project, the issue becomes one of defining the relevant community upon which the benefits should be so distributed. The second criterion requires a *proportional distribution* of costs and benefits in accordance with the participants' contributions. This, however, will not apply in the case of many projects where the burden is borne by people or institutions external to the project. The third criterion demands that the most needy be given a *priority* in the allocation of net benefits from a project. A more *utilitarian* approach requires that the costs and benefits should be shared in such a way that the project provides the most good to the largest number of people. However, with the exception of a few small pockets of pluralistic economic democracy (e.g., kibbutzim and small communes), this criterion has been shown not to hold within normal socioeconomic systems (Kneese and Schulze, 1985) Finally, the most radical criterion demands *distributive justice*, which requires parity, unless an unequal distribution operates to the benefit of the most needy (Rawls, 1971).

It is not obvious which of the above approaches is appropriate for judging the extent of income distribution from a mitigation project. However, once the project boundaries have been defined, the most preferred projects would seem to be those that use the utilitarian criterion as a basis for evaluating the impact of the project on redistributing income. This is particularly true in developing countries and especially in mitigation projects related to land use, since these two cases are associated with much lower income levels. All else being equal, a more equitable distribution of benefits among low income countries and sectors has a higher net social payoff, due to the higher marginal utility of income. However, the parity and/or proportionality criteria could be used in projects that do not involve large *a priori* income disparities.

The same distributional criteria would seem to be desirable in international mitigation policies and/or projects, although the mechanisms to compel their application are not as effective and coherent as those for national or local mitigation projects (Rose, 1992). Similar concerns exist about intergenerational equity, but these are more difficult to take into account, since the current generation lacks some fundamental knowledge about the material conditions and value basis for future generations. Despite these shortcomings, it has been argued that an additional sustainable development criterion is necessary to ensure a more equitable transfer of resources between generations (Norgaard and Howarth, 1993).

7.2.6 Infrastructure Costs

These need to be mentioned separately from other project costs, since they have extensive positive externalities. Large projects related to greenhouse gas abatement are likely to involve the construction of communication lines, utility networks, and social amenities such as schools and dispensaries, which may find current and future use beyond the mitigation project objectives. Secondly, the cost of infrastructure is relatively high compared to the other cost elements. Given the significant backward and forward linkages associated with infrastructure, there is a need to examine whether the cost can be borne by the community at large (e.g., through direct investment or subsidies, tax rebates, or other concessions). Ascribing all the infrastructural costs to the mitigation project will reduce the cost effectiveness of large projects and tend to create a bias towards the choice of smaller projects.

7.3 Long-term Issues

As policymakers strive to decide the extent to which resources should be allocated to mitigation and adaptation, several key issues come to the fore. The allocation of resources for climate change mitigation and adaptation will be in competition with demands placed by other activities. The timing of emissions reduction (i.e., when should we reduce emissions and to what extent?) becomes a crucial question to which policymakers will seek an answer. Excessive allocation at an early stage will draw resources away from other competing sectors, but inadequate allocation may lead to an unacceptable level of damages. The IPCC Second Assessment Report illustrates that various pathways may be followed for the stabilization of climate change. A recent paper (Wigley *et al.,* 1996) suggests that pathways in which abatement is deferred are economically preferable, and it cites four main factors for this conclusion: capital stock considerations, greater absorption of carbon emitted earlier, technical change, and discount rates. On the other hand, different views have been put forth in some studies (e.g. Grubb *et al*.,1994; Grubb, 1997; Manne and Richels, 1992; Nordhaus, 1994) that attempt to balance the expected costs of postponing abatement measures versus immediate emissions controls. These studies point to the possibilities of inducing the development of new cleaner energy technologies than would have been the case with gradual emission controls that could ‘lock-in’ a new generation of carbon-intensive technologies.

The speed with which climate-friendly technologies diffuse through economies is one factor that will decide whether extraordinary resources need to be allocated to emission reduction. Higher economic growth, which could lead to faster capital stock turnover, and rapid penetration of energy-efficient and/or climate-friendly technologies with negative cost would put future baseline emissions of greenhouse gases on a low growth trajectory. Discounting of costs is seen to be a crucial issue. A high rate of discount will cause the present value of costs incurred over decades or that of impacts occurring far into the future to seem negligible, and the actions recommended to be initiated today therefore become less attractive compared with a case where a small discount rate is used. The choice of the rate of discount is complicated, particularly since climate change has implications beyond the lifetimes of the current generation and the perspectives of future generations have to be factored into the discounting procedure. In addition, discount rates may vary by several multiples among countries, just as individuals and institutions within a country attach different values to this parameter.

Our discussion below reflects the fact that economists have had difficulty coming to a consensus on the quantitative values and procedures that should be used to determine a rate of discount. Each of the three factors listed above – timing of emission reductions, technological change and diffusion, and discounting – constitutes a vast subject on which many books have been published. We therefore dwell primarily on the literature on integrated assessment of climate change and on the way these factors have been dealt with in attempting to estimate the costs of climate change mitigation and adaptation.

7.3.1 Technological Change and Diffusion

A critical feature in integrated assessment is the representation of technological change, particularly as it affects changes in the productivity of energy use in industry, agriculture, and other sectors. Changes in energy productivity in turn affect the emissions of carbon dioxide from these sectors. If energy productivity improves, and if the emission coefficients of fuels do not increase, then, for the same level of future output, less energy will be required and less carbon will be emitted. What causes energy productivity to improve and how it is linked to changes in other factors of production (i.e., capital, labour, and materials) are issues that are being debated by modellers of climate change.

Prior to addressing the issue of technological change, it is important to define what we mean by technology. Technology has two aspects: embodied and disembodied. Embodied technology is identified with hardware and consists of the tools, machinery, vehicles, and other equipment that together make up the category of capital goods. Disembodied technology is identified with software and encompasses the knowledge and skills required for the use, maintenance, production, adaptation, and innovation of capital goods. Changes in either or both types can lead to productivity growth. Technological change need not affect all factors of production equally. When it does, it is considered neutral technological change in the Hicksian sense at constant factor prices (Hicks,1963); otherwise, it may be biased towards uses or savings related to a specific factor. A technological change that leads to the use of proportionately less energy than is used by other factors of production is said to have a technical bias in favour of saving energy.

In order to measure technological change, a production function that defines the relationship between factor inputs, such as labour and capital, and industry output is established. Productivity improves if the same level of output is produced with less input. Solow’s (1956) original paradigm for technological change asserted that the rate of growth of economic output is driven by factors such as population, relative prices of the factors of production, and technological change, which was assumed to be exogenously determined. Exogenous stimuli include government policies or the effective transfer of government-driven research and development of technologies from laboratories to industry. The model, however, ignores several factors that affect technological change, and over the years many improvements have been proposed and made to this basic paradigm. These include innovation, which is influenced by company-level decision making; sizes of production facilities and industrial capacity utilization, which affect factor productivity; and type of ownership, which influences a firm′s profit motivation.

Inherent in the production functions in many integrated assessment models are assumptions concerning the effects of factor prices and the particular factors of production that are augmented by a given technological change. For instance, the assumption of Hicksian neutrality implies that technological change is embodied in physical capital (capital augmenting) and in an increasingly knowledge-rich labour force (labour augmenting). Underlying this is the assumption that the economy is perfectly competitive and that inputs such as land and natural resources are relatively less important.

The estimation of technological change depends on the level of aggregation at which economic sectors are analysed. At higher levels of aggregation much of the improvement in energy efficiency may appear to be due to technical factors. At a more disaggregated level, some fraction of the improvement would be due to a shift of economic activity from high to low energy intensity sectors. Deciding on the level of sectoral aggregation becomes a matter of trading off computational difficulty and the availability of detailed data against better insights into the specific causes and underlying structure of energy efficiency improvements.

An issue that continues to be debated is the size and sign of the technical bias that has, and will, occur with respect to energy use. This bias may occur due to higher relative prices for energy and to an autonomous (non–price-induced) energy efficiency improvement (AEEI) over time. Non–price efficiency improvement may be brought about by deliberate changes in government policy (e.g., with respect to appliance or pollution standards) and government-sponsored research and development. The AEEI is an aggregate concept and subsumes changes that may occur to the (1) structural, (2) technological, and (3) behavioural components of energy efficiency. At the economy-wide level, structural change represents the share of value added shifting away from one sector to another. Technological change may occur as newer machines replace older ones. Behavioural changes may dictate the way a technology is used, as, for instance, when a vehicle is used for commuting instead of shopping. For each of the three components of AEEI, however, one needs to distinguish between the portion that is price-induced and that which is not. AEEI can then be estimated by suitably adding the non–price-induced share of the estimated value of each component. The non–price-induced component could be further divided into an income-induced part and the rest. While conceptually this provides a consistent framework for estimating AEEI, in practice, this level of decomposition has been done only partially for specific technologies and not at an economy-wide level.

In Integrated Assessment Models (IAMs), the aggregate value of AEEI has been noted to be crucial to the rate at which the baseline energy use would decline in the future (Manne and Richels, 1994). Manne and Richels (1994) illustrated the importance of the AEEI in their model, Global 2100, when they showed that by the year 2100, with an AEEI rate of 1.5% per year, the economy would consume only 20% of the amount of energy that would be required with an AEEI of zero. Their poll of 22 experts indicated an average AEEI value ranging from 0.10% to 1.38% with a 50th percentile value of 0.7%. A positive AEEI would imply that energy efficiency improves over time in the absence of changes in relative energy prices, which means that an energy scenario would show lower future energy use and associated carbon emissions. Using an econometric approach, Hogan and Jorgenson (1991) estimated a lower AEEI rate of 0.34% per year for the US economy. . The typical top-down model now uses an AEEI of 0.7% per year with some as high as 1% per year (Weyant, 1996). This 0.7% value implies a 19% non–price-induced reduction in baseline energy use by 2030 and 34% by 2050.

Much of the economic analysis that takes an integrated view of climate change has been performed using a neo-classical paradigm, where transaction costs and externalities are not fully captured and competitive markets with costless entry and exit prevail. Real-world decision making is usually more complex and relies on other attributes, which may not be fully costed. Models that capture these other attributes, where institutional, sustainability, and other considerations are explicitly accounted for, are needed to provide an alternative dimension to the evaluation of costs. In addition, literature on the transport sector suggests that habit and familiarity play an important role in consumer decisions, implying that modellers need to consider inertia and flexibility as important parameters in determining behavioural reactions to, say, a carbon tax on fuels. For example, Grubb (1997) and Michaelis (1997) argue for the consideration of an evolutionary paradigm in modelling technological change in climate change models, one that would mimic the way biological evolution occurs.

A significant array of integrated assessment models (IAMs) has been used to undertake long-term analysis of different emission reduction strategies and the relative effectiveness of applicable economic instruments. One major weakness in the current models of integrated assessment relates to the rate and nature of technology diffusion from developed to developing countries, including prediction of energy-use paths, effects of changes in international trade patterns, and carbon leakage. Current IAMs treat technology diffusion at an aggregate level, where energy use in transportation and in the residential and commercial sectors is estimated at the regional level in per capita terms as a function of income, energy service prices, and autonomous energy efficiency improvement. In the other sectors, aggregate energy consumption in industry is estimated as a function of industrial output, prices, and autonomous energy efficiency improvements. Also, energy use in electrical generation is estimated as a function of the efficiency of the technology employed, where specific vintage technologies are chosen on a life cycle cost basis, with technology performance improving over time. It has typically been assumed that technologies, once developed, are available everywhere, after allowing for a frictional time lag. Technology diffusion in this framework takes the form of different rates of energy efficiency improvement in different regions.

However, in many instances non-price factors such as political, historical, and cultural differences greatly influence technology choices and their rates of penetration across countries. These patterns are deeply ingrained in the national consciousness and are difficult to change, and hence need to be factored explicitly into IAMs. So far, few studies have explicitly tried to differentiate the way technological development and adoption decisions are made among countries or their groupings. Issues that need to be explicitly considered include (1) the availability of specific technologies in individual regions in the future; (2) the cultural and institutional context that could accelerate or delay adoption; (3) differences in context such as rural isolation, small scale of market, or characteristics of users; and (4) differences in the purchasing agent (collective, public utility, or government agency vs. individual firms and households).

7.3.2 Discounting

The single most important cross-sectoral long-term issue in mitigation analysis is the concept of discounting, which is a temporal adjustment mechanism intended to enable the comparison of the value of economic resources that are transacted at different points in time. Although discounting is most commonly applied to monetary magnitudes, it can be applied to goods and services as long as they are carefully defined and compared in their *numeraire* forms. In some cases, physical magnitudes such as greenhouse gas emissions can be discounted because of their implicit correspondence to monetary magnitudes like the value of their impacts (Sathaye *et al*, 1993).

Two different approaches have been used for choosing discount rates in climate change and other long-term environmental studies, and each leads to a different recommendation. The *prescriptive* approach, which recommends the use of low discount rates, is based on the argument that, due to market imperfections, the market interest rate is not a correct measure of the marginal rate of substitution between current and future consumption. The market interest rate is not correct because of market distortions such as "wrong" prices for factors and products, the inappropriateness of applying the current generation’s marginal rates of substitution in both production and consumption to future generations, and the inability of performing intergenerational capital transfers via the market. Cline (1992) uses the prescriptive rate to arrive at his results, which call for precautionary measures to mitigate climate change to be taken early.

The prescriptive rate is often referred to as the *social rate of time preference* and is the sum of the pure rate of time preference and a term representing the decline in utility derived from rising income. The decline in utility, in turn, is estimated as the product of growth in consumptive income and the absolute value of elasticity of marginal utility. The second term guarantees that even if the term for impatience were zero, the discount rate would still be positive, the actual size depending on the rate of economic growth and the decline in marginal utility at higher consumption levels. The prescriptive discount rate approach is often criticized for misdirecting resources from more productive areas in the economy, since the rate is often less than the shadow price of capital.

The *descriptive* approach, on the other hand, proposes the use of market interest rates to represent social discount rates for use in the evaluation of mitigation projects or policies. This approach is based on the school of thought that advocates the use of a rate that leads to the greatest total consumption over time and believes that the only justifiable social welfare function to be used in trade-off decisions between current and future resource use is that of the current generation. The approach is used in most integrated assessment optimization models (Nordhaus, 1994; Peck and Teisberg, 1993; Manne *et al.*, 1993). The proponents argue that the revealed pure rates of time preference are significantly above zero in most societies. The descriptive approach suggests that the intergenerational resource transfers should be done outside the process of economic decision making, since they are based on ethics and not economic efficiency. This position has been challenged extensively on account of the fact that it completely disregards the suboptimality of market rates that are derived from distorted markets, mostly operating under the sanctity of existing resource endowments, which themselves do not conform to economic efficiency criteria. Any significant realignment of endowments will unambiguously lead to a different competitive equilibrium, with market interest rates quite different from those existing prior to the realignment.

The discount rates arising from the descriptive approach are in general higher than the social rate of time preference. The proponents of the prescriptive approach claim that such high rates eliminate investment in many environmentally desirable projects, which cannot meet the profitability hurdle. The other side contends, however, that, due to the long-term nature of these projects, the difference in net present value (NPV) is much higher even when the rate of return is only different by a few percentage points. It is further argued that as long as the rate of growth of damage associated with, for example, climate change is less than the difference between the shadow price of capital and the social rate of time preference, it makes sense to use the descriptive rates. Since the damage function and the probability distribution of the damage are largely unknown, however, it is often argued that the use of the prescriptive approach will result in investment in more mitigation projects, thus forcing the present generation to err on the side of caution if the damage rate is lower than the difference in the rates from the two discounting approaches.

Discount rates used in mitigation assessment will be country-specific, regardless of whether they are determined using the prescriptive or the descriptive approach; because of the wide variation among countries in the value of the constituent factors such as rate of time preference, growth of income and elasticity of marginal utility. In general, developing countries have higher discount rates than higher income countries. For the evaluation of regular investment options, country analysts have adopted discount rates that are closer to a country’s social discount rate, because the environmental assessment done has been perceived as a social planning consideration. In evaluating long-duration mitigation options such as those in the forestry sector, it may be prudent for developing countries to use declining rates over time, the schedule of which can be adopted from the evolution of such rates in the industrialized countries.

Conventional discounting has been criticized for penalizing future generations by using the current generation's parameters for resource trade-offs. More recently, in an attempt to address the social structure of overlapping generations, valuation models have used various discounting schemes that explicitly assign some weights to the discount factors used for different generations (Nijkamp and Rowendal, 1988; Pasqual, 1993). The basis for determining these factors remains elusive. An example of these schemes is the modified discount method, which assigns weights by calculating the NPV for each generation affected by the project, taking as an origin the first period of each generation and then summing them up (Kula, 1988). The implicit assumption of a zero discount rate between generations disregards the likely unevenness of the stream of costs and benefits across generations as well as the observed increased productivity of each succeeding generation due to, among other things, technological progress and bequeathed capital.

It is noteworthy that there is a school of thought that believes that decisions about intergenerational resource trade-offs should not be based on economic efficiency criteria, which employ discounting as a central tool, but rather on philosophical and ethical criteria (Norgaard and Howarth, 1992; Pearce and Turner, 1990). This approach would require decisions to be made about the physical resource path to be taken and then use efficiency criteria to steer society along that path. It is evident that even under this approach, the choice and use of discount rates is inescapable whenever efficiency criteria are relied upon to arbitrate resource trade-offs. Efficiency criteria currently dominate decision making on issues with significant economic consequences.

7.3.3 Timing of Emissions Reduction

The timing of actions taken to reduce emissions is extremely important to policymakers, since it will decide what resources need to be allocated for this purpose and how the allocation will affect economic growth and change the distribution of benefits. If the economic value of future damages due to greenhouse gases were known, it would be a relatively simple matter to estimate the marginal benefit to be gained from avoiding their release. The evaluation of the marginal costs of avoided carbon, if not greenhouse gas emissions, has been done extensively (IPCC, 1997). Thus, in a static analysis, one would be willing to incur costs to the point where marginal costs balance the marginal benefits gained from avoided damage. The fact that the damage that greenhouse gas emissions might cause is highly uncertain makes the determination of this balance point difficult. The analysis needs, therefore, to include the probabilities and expected values of future emission paths in order to estimate potential damages. This situation is further complicated because both greenhouse gas emissions and damages occur over a period of decades, with damages lagging emissions. Thus, the time dynamics of the two factors need to be considered in analyzing the extent to which emissions abatement ought to be pursued in the near term.

If near-term actions taken to abate carbon emissions are inadequate, it is possible that future actions may be sufficiently more expensive so as to increase the overall cost of emissions reduction. The cost-benefit analysis in optimization models results in a trade-off between substantial abatement costs early in the horizon and avoidance of potentially large damages later in the horizon. The rate used to discount future damages plays a crucial role in determining the costs that nations bear to reduce emissions. The time path of emissions reduction is an important determinant of the cost of meeting an atmospheric greenhouse gas concentration target. Postponing abatement to future dates is preferred if the value put on future climate change damages is low relative to benefits of using resources in current alternative activities. Also, delayed abatement gives room for capital stock to adapt to a less carbon-intensive economy. The slow turnover rate of the existing energy capital stock argues for a gradual imposition of controls. Abrupt actions to reduce emissions could be costly because it could require premature replacement of investments or significant decreases in economic activity levels.

On the other hand, early abatement may induce further cost reductions, at the same time diverting economies from carbon-intensive development paths. Certain technologies, not necessarily the least-cost ones, can lock in and spread rapidly. Once they achieve a minimum market share, which endows their proponents with undue market power, the technologies are difficult to dislodge. Grubb (1997) cites the example of hydrocarbon refrigeration technology, which got locked out once chlorofluorocarbons (CFCs) were introduced as a refrigerant. The former technology is now making a come back because of the need to protect the ozone layer. Similarly, inertia may increase later costs of abatement. Inertia can be in the form of (1) the locking in of technology in factories, buildings, urban infrastructure, and the like and (2) the evolution of social and cultural beliefs and lifestyles that are carbon-intensive. Both will be difficult to change, but the latter will be particularly demanding, especially in the urban parts of the developing world, which are rapidly emulating a Western lifestyle and consuming goods and services that are correspondingly carbon-intensive.

Studies such as those of Manne and Richels (1992) and Nordhaus (1994) have evaluated the problem of balancing the expected costs of over- or under-controlling emissions. As Weyant (1996) notes, these studies suggest the desirability of more immediate control of the growth in annual emissions (perhaps as much as a 50% reduction relative to the baseline), but not an immediate reduction in annual emissions, unless catastrophic damages are envisaged that would incur substantial costs. However, the Kyoto Protocol seems to have gone further and requires a reduction of annual emissions by Annex 1 countries to specific levels below the base year (UNFCCC, 1997).

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Chapter 8

Cost Concepts in Climate Policies and Strategies

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8.1 Introduction

Political decision making relating to the issue of climate change takes place at different levels of aggregation: globally as in the convention negotiation context, regionally (as in the European Union) where countries make joint action decisions, and nationally where all countries are required to develop and present strategies for meeting their obligations under the Framework Convention on Climate Change (FCCC). Within countries, meanwhile, analysis and decision making are typically carried out at the national and local level.[1]

In most cases, decisions will be based on a number of criteria and concerns. Economic analysis can make important contributions. However, it is important for both national and international discussions and policy-making processes that the different economic concepts be understood and applied in a manner consistent with their theoretical and practical limitations. This naturally applies also to concepts from disciplines other than economics.

This chapter will discuss and recommend approaches for the application of cost concepts to the development of climate policies and strategies. To discuss how the different analytical principles may be applied, the chapter builds on the detailed discussion of the different cost analysis principles presented in Chapter 2, as well as on material presented in the subsequent chapters, which address the key application areas and levels of analysis. The discussion will not only focus upon the correct tool for the decision problem in question but also upon the limitations of, and interactions between, the different concepts.

The chapter is divided into three parts. The first focuses on decision problems within the national context. The second discusses some of the main policy instruments that have been proposed to facilitate action, particularly, though not exclusively, in the area of mitigation. These are examined in the context of both national and international policy making. The aim in this second part is not only to describe the instruments, but also to relate them to decision making at the national level in order to see how the different applications of cost concepts interrelate. Finally, the third part examines the multilateral financing mechanisms relating specifically to climate change and their use of cost concepts.

In principle, the climate change problem should not be treated separately from other environment and development issues, but it does present some unique problems that require special consideration. These problems include large uncertainties, possible nonlinearities and irreversibilities, and the asymmetric distribution of impacts, both geographically and temporally. Such issues are described in detail in the Second Assessment Report (IPCC, 1996).

The concluding section of the chapter identifies areas where further work is needed in order to develop or adapt concepts for solving decision-making problems related to climate change.

8.2 National Policy and Strategy

8.2.1 Factors Affecting Climate Change Strategy Development

From a national point of view the development of an adaptation and/or mitigation strategy will have to reflect a number of political, economic, and institutional interests and objectives. It will be important to emphasize and understand the different factors shaping the development of such a strategy. They include:

- the need to meet (partially or fully) commitments under the FCCC
- the priority placed upon climate change in the national political system
- the desire to influence the FCCC process through action and example
- the need to respond to anticipated climate change impacts (with both an adaptation strategy directly addressing the impacts and a mitigation strategy contributing to a globally coordinated effort)

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[1] The local level (meaning state/county, municipality, etc.) will not be investigated systematically in this chapter, but many of the concepts and ideas similarly apply to it.

- the concern about the possibility of extreme climatic events and their direct and indirect consequences (flooding, drought, hurricanes, etc.)
- the desire to attract funding and other project support
- the need to develop national capacity for broader environmental management

Some of the developed country parties to the FCCC have already established some level of climate change strategy, with policies and measures having been identified for possible mitigation action in key sectors.With the conclusion of the Kyoto Protocol (FCCC/CP,1997), industrialized countries face real emission reduction commitments if they decide to ratify the Protocol and it enters into force. This will obviously require much greater efforts to be devoted to the analysis and development of national mitigation strategies.

Adaptation analyses and strategies are generally less advanced. This situation reflects the uncertainty surrounding global warming impacts at national and even regional levels and the present expectation that countries in temperate regions will generally be less affected than those in the tropics, at least in the short to medium term. Thus, in terms of the factors just listed above, the main forces driving the development of strategies in the industrialized countries are likely to be the level of national policy priority, commitments under the FCCC, the desire to influence the FCCC process, and some concern about possible direct and indirect effects of extreme climatic events both nationally and internationally.

Most developing countries recognize the seriousness of the issue, but climate change is generally not a policy priority for them. Instead, their emphasis is placed on economic and social development needs, including the eradication of poverty, while environmental policy focuses primarily on local problems. In addition, many developing countries consider, correctly, that industrialized countries are largely responsible for the present risk of climate change as a result of their past levels of greenhouse gas emissions. Consequently, the present rationales for climate change policy in developing country parties are likely to include the possibility of influencing the FCCC process (in particular, through efforts to ensure that the industrialized countries act on emission reductions and funding), concern about national climate change impacts, plus the possibility of attracting additional international funding for national activities, including augmentation of environmental institutional capacity. The Kyoto Protocol contains no further obligations for developing countries, but it is clear from the negotiations that pressure will be increasing on the developing countries in general, or selected groups, to enter into some kind of future commitment concerning emission limitation. Most developing countries are presently in the process of preparing their first national communication to the FCCC, with support from the GEF, as discussed in Section 8.2.5. Some countries have, however, already worked on national action plans under bilateral support programmes (Benioff and Warren, 1996), and the results here reflect the broad priorities discussed above.

8.2.2 The Strategy Development Process

Detailed analysis of national decision processes is beyond the scope of the present paper, but it is important to emphasize that national governments, political institutions, non-governmental organizations, the business community, and researchers within the country will all be important actors in both the establishment of action plans and project implementation. The success of climate change policies will depend on how well the proposed actions can generate support from and make use of local interest groups, implementing agents in the concerned sectors, and the population in general.

Present climate change policy efforts in most countries are relatively modest and will, in many cases, involve only incremental changes to existing development programmes for sectors such as power, agriculture, forestry, and transport. The implications of the Kyoto Protocol commitments will vary between countries, but more ambitious climate change policies in the future may need to involve large cross-cutting efforts and may be closely linked with macroeconomic policies and many broader sustainable development issues. Implementation of activities on such a scale can generate significant structural changes and will require a broad public and political understanding of the underlying rationales and the possible consequences of inaction.

Some key experiences from previous and present national policy development processes suggest that it is important to

- involve a diverse group of governmental agencies and departments actively in the development of the plan (to ensure ownership)
- secure participation of non-governmental stakeholders in the planning process (for example, non-governmental organizations, businesses, and other representatives of civil society)
- ensure that the planning process identifies, and maintains focus upon, a well-defined set of objectives
- ensure that planning has a practical orientation and emphasizes implementation
- create action plans that are dynamic and considered part of an ongoing process to address climate change
- secure national control of planning processes, so that priorities are not driven by the perceived priorities of possible external donors or funders, and
- secure increasing public and political awareness of climate change issues, which is vital for both policy development and implementation.

In such a process, the full development of national climate change policies and strategies will be a long-term effort, during which time the awareness and participation of local stakeholders and decision makers will grow. However, within the long-term perspective, it is important to establish an ad hoc process to implement priority actions that contribute to the overall strategy.

8.2.3 Strategy Development and Cost Assessment

Any national climate change strategy will be based on a comparison of actions under a non-policy case with specific mitigation or adaptation actions in a policy case. The analytical problem is to assess the socio-economic and environmental impacts of implementing climate change actions. The assessment will need to consider a number of issues – for example, possible policy conflicts, opportunity costs of resources used for climate change actions, cost-effectiveness of different actions, and potential “win-win” actions where climate change priorities are combined with welfare and environmental improvements. The latter can be achieved in cases where the benefits of a climate change action exceed its incremental costs. Examples of such benefits could be improved environmental quality, increased production efficiencies, opportunities for developing new technologies for emerging markets, institutional strengthening, or the positive macroeconomic impacts of external financial support.

A climate change strategy can generally be based on individual projects, sector programmes, and cross-sectoral national programmes. The corresponding cost assessment can focus upon project level, sector level, or macroeconomic assessment. The general rule is that the most detailed assessment can be done at project level, while sector and macroeconomic assessments focus on market feedbacks and integrated impact assessment rather than on details of policies and options.

The actual focus of the assessment will depend on the specific sub-elements to be included in a national strategy and established capacity in similar analytical areas.

Project assessment considers the implementation of individual projects. The standard approach is to compare a specific activity with the non-policy case and assess the social costs and benefits of the climate change project compared with the alternative action. A simple national strategy could consist of a compilation of individual projects, but such an assessment should preferably be supplemented by considerations of technical and economic linkages, relative cost-effectiveness of actions, other economic, social, and environmental impacts, and so on.

Sector assessment considers the total impacts of implementing either a large number of projects in a sector or making structural changes, such as large-scale fuel-switching in the energy sector. In many cases, the technical potential and social costs of individual actions are interdependent, and such interdependencies are often best addressed in a sector level assessment. A very straightforward example is electricity savings, where the greenhouse gas reduction associated with specific options depends on the electricity supply system, which is, in turn, an integral part of the mitigation potential considered. Similarly, the potential benefits of reduced electricity demand depend on the production costs of the electricity supply system. Here, sectoral models for the entire energy system will represent the preferred approach. Sectoral assessments should also include efforts to evaluate different types of policies to achieve sector level goals.

National assessment focuses on the total impacts of implementing mitigation projects and system changes in one or more sectors. The focus here should be on the wider sectoral and macroeconomic impacts, such as land allocation, capital and foreign exchange demand, trade, employment, consumption, and production. National assessments should also attempt to evaluate different types of strategies for achieving both sector level and national goals.

Ideally, the analysis will be consistent between levels and will provide a coherent information set to the policymaker. The approach is then in Chapter 2 of this report outlined to be as follows:

- The national level macroeconomic analysis should be based on greenhouse gas mitigation targets and adaptation programmes and should look at the implications of meeting such targets and implementing such programmes with different macroeconomic policy instruments. These include economic instruments such as government spending on adaptation, increases in energy prices, and incentives for energy efficiency. The "without policy" option will provide a baseline for the economy as a whole and will include predicted emissions for the period of the analysis.
- The sectoral analysis should follow from the macroeconomic analysis, which will have identified broad policy variables for all sectors. Sectoral policies and investment programmes should be consistent with the broader macroeconomic analysis. As an example of how the sectoral cost estimation is influenced by the macroeconomic policies, consider energy efficiency programmes, the costs of which are dependent on prevailing tax regimes. With higher energy taxes, certain measures will automatically be adopted by the private sector. It would be incorrect if the sectoral analysis did not take account of such adoptions or did not include them in the selected programme.
- The project level analysis must only include only projects that are part of the solution thorown up by the sectoral analysis. Although the costs that emerge from the in-depth investigation may be different from estimates generated by the higher level analysis, the overall set of projects should be in the sectoral plan. Likewise, the baseline emissions for the project evaluation have to be consistent with those for the sectoral evaluation.

In the real world, however, the ideal approach is often not possible, and in many countries, especially developing ones, the analytical process is approached from the project level and compiled or integrated into sectoral programmes which are then discussed, compared or, if possible, analysed in terms of national level impacts. At present, most developing countries do not have macroeconomic tools for their national analysis, nor the necessary data or institutional capacity to make use of such tools.

It may, however, be possible to supplement the project and sector analysis with a simplified macroeconomic assessment based on available national economic statistics, that addresses the following elements:

- the macroeconomic structure and growth perspectives for the main economic and greenhouse gas-emitting sectors, such as manufacturing, agriculture, forestry, transportation, and energy (including an evaluation of the relationships between economic output, technological development, energy consumption, and other resource inputs in the sectors)
- capital, labour, land resources, and other production factors demanded by specific mitigation projects
- intermediate production inputs, including exports and imports, connected to mitigation projects (with the use of national input-output statistics or models)
- policy instruments in the context of macroeconomic price and tax policies

8.2.3.1 Differences Among National Costing Methodologies

Within the energy modelling field in particular there has been extensive debate about the appropriateness of cost estimates generated by top-down (macroeconomic) models and bottom-up (sector and project level) models respectively.

Cost estimates developed by top-down (TD) and bottom-up (BU) approaches can differ for a large number of reasons. The variation can emerge from differences in the basic structure and policy options addressed in the different approaches, and from differences in technical and economic assumptions. As discussed in Chapter 2, it is important to emphasize a number of issues to qualify the discussion of the two analytical approaches.

- The cost measure at the macro level of analysis is typically the change in GDP as a consequence of implementing economic instruments such as carbon taxes. Sector and project level analyses, on the other hand, examine the social costs of allocating specific resources for climate change mitigation policies. Some macroeconomic models include rather detailed information about policy options that also can be assessed in sector models or in project assessments. In such cases, the different analytical approaches can arrive at very similar cost estimates. In other cases, where macroeconomic models consider only general market instruments, the macroeconomic cost estimates are not directly comparable with detailed sector or project level assessments.
- The two general approaches encompass a number of different analytical approaches. Major differences are related to baseline definitions, market clearing assumptions, and technological change. Experience shows that even at the same level of aggregation, analyses that use different approaches or tools can generate different results, although it is often possible to explain and understand these at the given level of analysis.
- There are distinct strengths and weaknesses with both the TD and BU approaches in terms of their ability to deal with analytical issues at the different levels of analysis. Generally, the strength of the TD approach lies in its ability to assess policy instruments, structural change, and long-run effects on the overall economy, whilst that of the BU approach lies in its disaggregated analysis of demand and supply and technological options (IPCC, 1996, Chapter 8).

Therefore, the conclusion for national policymakers and analysts is that it is not a question of which approach to choose but rather of how to design a national analysis structure that incorporates both macro and sector/project analysis. The precise structure will depend upon specific national experience, analytical capabilities, and data availability.

Cost concepts in climate policies and strategies, as discussed in this chapter, are therefore directly linked to the level of aggregation of the analysis and the different policy objectives. The general rule is that the development of general national strategies that include multiple sectors and greenhouse gases should be carried out at the highest possible level. Thus, macroeconomic and sector level assessments are to be preferred. Specific national project or sector policy implementation, however, should be supported by a detailed assessment of the technologies and economic, environmental, and institutional resources involved.

8.2.3.2 National Cost Estimates and Broader Impact Assessment

Actions taken to mitigate or to adapt to climate change will generally divert resources from alternative uses. Within the general analytical framework, the purpose of the cost assessment is therefore to translate the effects of climate change action into comparable quantitative units which reflect the impacts on society's welfare. In practice, it is difficult to develop a consistent and comprehensive definition of all the important project impacts to be measured. Therefore, in many cases, national assessments have started with a traditional cost-benefit assessment of those impacts that can be measured in monetary units. This information has then been used to screen for options that ought to undergo a more elaborate assessment of broader social, environmental, and political impacts. The danger of this approach is obviously that the narrow assessment of economic impacts in monetary units shortcuts the national decision process, ignoring other important impacts.

The national cost assessment should, therefore, become an integrated part of a broader national decision framework for climate change mitigation, given the variety and importance of non-economic factors that will inevitably play a role at every stage of policy formulation. Chapter 2 (Section 2.5.4) describes how cost assessment can be supplemented with other selection criteria.

Since all potential impacts cannot possibly be analysed, choices must be made as to what should be studied. To make such a selection, any of a variety of other decision-making criteria could, consciously or subconsciously, be utilized. Moreover, once impacts are identified and assessed, the question arises as to how they should be compared – that is, weighted with respect to one another. The determination of weights is naturally critical, and it should be noted that several different methodologies offer a framework for this process. The assignment of monetary values to project impacts, as is done in cost-benefit analysis, can be seen as one methodology for determining weights. In this case, the basic source of information is consumer preference as revealed by the markets. Other methodologies design systems to reveal preferences through interviews with decision makers, stakeholders, experts, and others.

It is worth spelling out some of these other decision-making criteria to which we have repeatedly referred. Equity is one that receives a good deal of emphasis (see Section 8.3.2.3). However, it is important to recognize that there is not one universal interpretation (let alone application) of the term. With respect to climate change mitigation, equity arguments can be used to support prescriptions for “polluter pays,” “ability to pay.” “meeting basic needs,” and other operational rules (IPCC, 1996, Chapter 3). Views will differ on the most desirable distribution of costs and benefits. Another decision-making criterion is risk. Some decision makers are highly risk-averse, while others are risk-neutral, and still others are risk-loving. Given these differences, the criterion of risk can also yield a wide range of prescriptions.

In conclusion, factors other than economic costs and benefits will be important in determining the national decision framework for climate change mitigation. Nevertheless, it is also worth noting that decisions may not be made as rationally as has been suggested here. There is a strong process element, which means that climate policies will evolve over time as part of a process involving a number of iterations. Given the various pressures placed upon decision makers, from both within and outside government, it stands to reason that different pressures will be felt at different times, and not always for expected reasons. Again, the message is simply that the policy-making process will inevitably use a range of criteria to make and implement decisions and that not all of these actions will necessarily be predictable at the outset.

8.2.4 Implementation Issues

Once a strategy has been established on the basis of the preceding criteria, it is necessary to examine how the actions can be implemented in reality. This assessment should address the costs and incentives as seen from the perspectives of the private agents or institutions that are actually going to implement the strategy. The implementation costs will therefore depend on the policy instruments or regulatory measures applied.

In this context it may be relevant to revisit the discussion in Section 2.2.5 of Chapter 2 regarding the relationship between social, external, and private costs. National strategies should be based on the assessment of social costs, including externalities associated with environmental impacts and other important social impacts. These costs will often be different from the private costs facing private consumers or investors.

The implementation of climate change policies in a national context will therefore need to consider the most appropriate way of making actions attractive to the implementing agents. This can be done, for example, through general economic policy instruments (taxes, subsidies, grants), specific regulation measures (creating standards, setting up auditing requirements, establishing norms), market creation efforts, or direct project implementation efforts, including specific action to address any non-economic implementation barriers. For a discussion of implementation issues and costs, see UNEP (1998).

Developing countries and some countries with economies in transition may be eligible for support from the financial mechanism under the FCCC (the Global Environment Facility) or other bilateral or multilateral funding. It will therefore be necessary to examine the specific implementation conditions for this funding as part of the analysis. However, this should not change the strategy development process or the economic, social, and environmental criteria to be examined, although it may require inclusion of the assessment of incremental costs in the analytical process for individual projects or sector programmes. This will be discussed further in Section 8.4 below.

8.2.5 National Communication to the FCCC

Article 4.1 of the FCCC requires parties to the Convention to submit particular climate-related information to the Conference of the Parties (COP). This requirement has been further strengthened in Articles 3 and 7 of the Protocol. The general form that these communications should take is laid out in Article 12 of the Convention.

It is worth noting that the FCCC is deliberately vague in addressing issues relating to cost assessment. The most direct references are the following:

- *Article 12.4*, which invites developing country parties to propose projects for financing, asks them to include, if possible, "an estimate of all incremental costs, of the reductions of emissions and increments of removals of greenhouse gases, as well as an estimate of the consequent benefits."
- *Article 12.3* states that each "developed country Party and each other developed Party included in Annex II shall incorporate details of measures taken in accordance with Article 4, paragraphs 3, 4 and 5". Article 4.3 requires developing country parties to "provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under Article 12, paragraph 1." Additionally, they agree to meet the "full incremental costs of implementing measures that are covered in [Article 4.1]." Moreover, the commitment to meet the "costs of adaptation" of developing country parties that are particularly vulnerable to the adverse effects of climate change is pledged in Article 4.4.

Thus, an understanding of the concepts "all incremental costs," "agreed full costs," "full incremental costs," and simply "costs" is obviously necessary for successful completion of all national communications.

Attention was initially focused upon the national communications of developed country parties and other parties included in Annex I, as these were the ones required to make their initial communications within six months of the FCCC's entry into force in their respective countries (Article 12.5). However, only some of the cost concepts noted above refer to these parties.

Initial guidance on the first communications by these parties was limited, and it was not until the Second Conference of the Parties that the need to enhance the comparability and focus of the communications was discussed in depth. Nevertheless, it is still too early to assess the extent to which guidance from the COP will be taken by individual parties, as the second communications from non–Annex I countries are only now being submitted.

In the case of national communications from non–Annex I countries, only vague guidance was offered by the Second Conference of the Parties. Nevertheless, it is virtually inevitable that cost concepts will have to be used appropriately in the completion of all national communications, if the communications are going to be the basis for further enhancing the commitments under the Convention.

In addition to these direct (though rather vague) references to cost concepts, the Convention refers to various broader issues. Some of these are clearly linked to cost concepts and some are not. It is useful to start with Article 3, which lays out the principles that should guide the parties. Although noting that "policies and measures to deal with climate change should be *cost-effective* so as to ensure global benefits at the lowest possible costs" (Article 3.3). Article 3 also stresses the importance of equity. The article's first principle is that the climate system should be protected on the basis of "equity and in accordance with [the parties'] common but differentiated responsibilities and respective capabilities" (Article 3.1). The second principle, which recognizes the specific needs and special circumstances of developing country parties and others, could also be interpreted as an equity principle. Much of the thrust of the third principle (which includes the aforementioned reference to cost-effectiveness) is about uncertainty and the precautionary principle. It notes that "Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures …" Economic development is also given great prominence (principle 4), as is the importance of a "supportive and open international economic system" (principle 5). The point to take is simply that, though the FCCC does highlight the role that cost concepts should and must play in societal response, there are clearly other guiding principles as well.

It can be concluded, therefore, that there are no requirements for national communications to include any analysis or cost assessment in addition to that which has already been discussed for national policy and strategy development. The only necessary addition is for non–Annex I countries to undertake an analysis of the incremental cost of any proposed actions eligible for GEF financing (FCCC/CP,1996 p. 44).

8.3 Policy Instruments

In the FCCC negotiation context and in other international fora, there has been significant discussion of national and international regulatory and economic instruments that could be used to implement future agreed emission reduction targets. The purpose of this section is to examine a few of these key instruments, especially in the light of the Kyoto Protocol, Article 2 of which calls for the implementation of appropriate policy instruments, including emissions trading and joint implementation.

The non-economic concepts that are needed to make use of these instruments will also be investigated. The section will illustrate how economic concepts can make a contribution to ensuring that society's overall response is as positive as possible; but the importance of other inputs will be revealed as well. The short presentation here cannot, however, cover the issue of policy instruments in detail. Given the immense amount of work and literature on the subject, the reader is referred to the detailed discussion and assessment of the issues presented in Chapter 11 of the IPCC's Second Assessment Report (IPCC, 1996).

8.3.1 Regulations

Historically, the most direct approach to regulation has been through the use of so-called "command and control" (CoCo) systems. These have been broadly applied to environmental issues in the past, both nationally and internationally, especially for the limitation of air pollution emissions. More recently, the focus has shifted to a broader set of regulatory instruments, which have been applied to fuel use and energy efficiency and practices. Given the diffuse nature of greenhouse gas emission sources, a wide range of measures is potentially available. These include:

- direct regulation of greenhouse gas emissions from fossil fuel burning
- regulation of the chemical content of fuels
- standards to regulate energy efficiency in buildings and energy-using durable goods in the industrial, residential, and commercial sectors
- regulations to mandate carbon-conserving forest and agricultural practices and land use
- automobile fuel efficiency standards
- voluntary agreements

A sound regulatory policy depends on

- setting objectives
- targeting the types of regulation to important sources and sectors
- selecting the appropriate emission targets, efficiency levels, and practice levels, and
- developing an effective and efficient set of mechanisms and protocols for monitoring emissions and practices and for verifying regulatory compliance and enforcement.

Selecting appropriate types of regulations is critical when using CoCo systems to regulate greenhouse gas emissions, because these sources vary widely from country to country. In a country dependent upon the use of wood fuels, for example, a combination of energy efficiency standards and forest practice laws will be more effective than the regulation of power plant stack emissions.

Targets for emissions, energy efficiency, and practice can be based on a variety of objectives. Economic efficiency, cost, and equity are a few of these. However, each of these targets is usually supported by some analysis of alternative emission or performance levels and their ability to satisfy a given objective. If each source is regulated separately, then these estimates can be built from the bottom up, source by source. However, when emissions or practices in non-energy sectors are considered, the modelling can become more difficult, especially with respect to emissions and regulatory effectiveness in the forestry, agriculture, and waste sectors.

Regulations directed at large point sources of greenhouse gas emissions are the easiest to monitor, verify, and enforce. However, it is a much more complicated problem when regulations are targeted at energy efficiency and land management practices. In the latter case, changes in emissions cannot be monitored directly to verify and enforce compliance, and compliance itself is hard to detect. This substantially increases the cost of regulating emissions from these sources.

Besides the need to estimate control costs at company level from the bottom up, there are two additional cost issues related to regulation. The first is the effect that regulations have on market prices of the inputs and outputs associated with a specific emission source. Regulations increase output costs as a rule, and this can often have an effect upon prices in other markets. Estimating these price effects in order to calculate the true costs of a regulation is an important part of estimating mitigation costs.

The second issue is the cost of monitoring, verifying, and enforcing regulations. These costs are hard to estimate because they vary widely, depending on the type of regulation, the source being targeted, and governmental accounting of costs. They are often “hidden” in governmental accounting as fixed costs and rarely disaggregated by regulation and source.

8.3.2 Market-based Instruments

Regulations do not provide automatic incentives to achieve regulatory targets at least cost.[2] To do this, economic instruments can be used in conjunction with regulations. The traditional approach is through the use of taxes and, in some cases, tradable emission permits.

The purpose of market-based instruments is to create a direct incentive for market agents to control emissions, increase absorption of greenhouse gases, and innovate appropriately. Market instruments fall into two categories:

- those that act directly via prices (taxes) or subsidies levied on each tonne of emissions or on fuels, and
- those that reduce the cost of achieving a given target (“cost-based measures”), namely tradable emission permits, offset systems, and joint implementation.

The success of cost-based measures in the long run must be judged by their effectiveness in inducing the socially desired direction of technological and behavioural change.

8.3.2.1 Emissions Taxes

Emissions taxes, such as a carbon tax, provide consumers and producers with incentives to conserve resources by increasing the price of energy. Taxes on energy consumption can also be used to reduce emissions, but they give firms less flexibility in how they respond to the tax. Most authors (UNCTAD, 1992)[3] agree that taxes related to the carbon content of fuels or greenhouse gas emissions as such are the most effective approach to taxation, because a carbon or greenhouse gas tax will ideally seek to equalize the marginal greenhouse gas abatement costs across fuels and therefore seek to minimize the overall reduction costs.

Imposing emissions taxes does not do away with all of the problems of monitoring, verification, and enforcement. Indeed, it substantially increases the sophistication of the methods required to determine the effect a particular tax will have on emission levels. Furthermore, monitoring and verification of emission levels are still needed to ensure that the tax is performing as projected, so that adjustments can be made to the tax if it is not.

The size of the emissions tax required to produce a given reduction in emissions depends on the price responsiveness/elasticity of the supply and demand for energy. For example, if energy demand is not very responsive to price, a larger tax will be required to produce a given reduction in emissions, but it will substantially increase tax revenues. If a carbon tax works efficiently and there are no market distortions, the emission reductions achieved by introducing a given tax will be the same as the ones assessed in an emission reduction curve. The tax rate can then be interpreted as the market price signal that gives implementing agents the incentive to implement the options depicted in the cost curve. A tax rate can also be linked to

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[2] For further discussion, see Teitenberg, “Relevant experience with tradable entitlements” in UNCTAD (1992).

[3] See, for example, M. Grubb’s discussion in “Options for an international agreement” in UNCTAD (1992).

macroeconomic studies. In this case the tax rate is the price signal that gives consumers and producers an incentive to change behaviour and thereby generate emission reductions. What to do with these tax revenues is an issue. Using the emission tax money to pay for activities like environmental programmes or to reduce distortionary taxes generally would provide a double dividend.

Estimating the mitigation costs associated with both taxes and regulations requires the ability to determine the effects of these measures on prices in different markets and their influence on GNP or net welfare. Furthermore, both regulations and taxes can produce leakage effects by creating incentives for the targeted industries to move to other countries without regulations or taxes or by inducing comparable shifts in the geographic distribution of these industries.[4] Such responses would clearly affect the desired global level of emissions. In addition, taxation schemes do not eliminate the need for an administrative structure to monitor and verify the effects of taxes. These costs must be included in the analysis, although it is complicated to estimate them.

8.3.2.2 Cost-based Measures

Tradable emission permits require that emission sources be initially allocated a specific quantity of permits to emit specified quantities of greenhouse gases in amounts below historic levels. Emitters then have three options:

- hold the permits and emit the allotted level of greenhouse gases
- sell some of their permits to other market agents, which requires sellers to reduce their own pollution and allows buyers to increase their emissions accordingly, or
- buy additional permits in order to increase greenhouse gas emissions, while sellers reduce their emissions by a like amount.

Furthermore, individual buyers, such as NGOs, can effectively lower total emissions by purchasing permits and retiring them. If these permits are exchanged in a fully competitive market, the marginal emission reduction cost will ideally be the same for all emitters and the total emission reduction will be achieved at least cost. To do this, a market must be created to bring buyers and sellers together and to facilitate low-cost exchanges.

Some experience has already been gained with emission trading for SO_2. The market for these emissions is characterized by the fact that the sources of emissions are easily identified and regulated and the main options for reducing emissions can be controlled by the sources (firms or individuals). This makes the implementation of the trading system relatively simple. In the case of CO_2 and other greenhouse gases, sources are more diffuse and the opportunities for reducing emissions are much more numerous but not always under the direct control of the sources. However, the fact that greenhouse gases are generally uniformly mixed and abatement costs may vary significantly would ideally mean that the emissions are amenable to a trading regime. On the other hand, these same characteristics mean that a trading regime for greenhouse gases will be much more difficult to monitor and enforce than the SO_2 system.

Moving from a national emission trading system for SO_2, or greenhouse gases for that matter, to an international trading system does, however, raise important policy issues such as national sovereignty (Mohr, 1995). For a detailed discussion of rules, regulations, and administrative arrangements for a global market in CO_2 emission entitlements see UNCTAD (1994).

Emissions offset systems expand the range of least-cost emission reduction opportunities, allowing individuals and firms that are not regulated to trade emission reductions with those that are. For example, it is possible that all firms on which emission limits are imposed may have very high control costs relative to some other options, such as planting trees to sequester carbon. The offset system would allow either the utility itself (in this example) or another firm, NGO, or developer that was not regulated to create an emission offset through a tree planting program. This requires an agreed methodology for calculating the size of the offsets (from a base case emission level) resulting from carbon sequestration and other approved

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[4] Moreover, given the decreased demand in, for example, fossil fuels, we would expect to see the price of fossil fuels decrease outside the tax area, while their use inside it would increase.

activities. For an offset system to work, an instrument for exchanging these credits is required that does not allow both parties to inflate the quantity of the offsets. The system also requires a method for monitoring and verifying the offsets to ensure compliance. Offset trading could take place at the international level as well, where its operation would be very similar to that of tradable permits.

Once an offset system is established, the regulated sources could essentially go shopping for offsets and negotiate, directly with second parties (the offset sellers) or indirectly through a third party (perhaps a clearing house or trading exchange), to obtain offsets in exchange for compensation. This system functions, in theory, in exactly the same manner as an emission trading system. Regulated sources have an incentive to buy, and unregulated sources have an incentive to sell, as long as the marginal cost of reducing emissions to the buyers of the offset is higher than the marginal cost of the seller to create the offset.

Joint implementation (JI) is a mechanism that is specifically mentioned in the Convention and is now incorporated in the Protocol. If implemented through the FCCC, it would allow non-annex I countries to meet their obligations to reduce net greenhouse gas emissions by trading emission offsets with other non-annex I countries. The use of this instrument is based on the assumption that the costs of reducing greenhouse gas emissions vary widely among countries. JI has been extensively discussed in the literature over the last few years (for a summary of issues, see Jepma, 1995). In addition, bilateral programmes have been established to test the concept in practice.[5] A major objective of these programmes has been to gather experience with the key problems associated with the implementation of a JI scheme. These involve such areas as project selection and analysis, bilateral arrangements, and especially the so-called transaction costs[6]. An interesting development in this context has been the establishment of the “clean development mechanism” (CDM) as part of the Protocol (Article 12). The CDM is not well defined at this stage and the structures under discussion vary from a new sustainable development agency to a simple broker for JI type projects and facilitator of transactions. The modalities for the CDM will be further elaborated by the Conference of Parties, and some of the key issues will evidently be the structure, governance, and balance between the sustainable development and the emissions crediting objectives. On a more detailed level, the issues of transaction costs and the CDM's adaptation support role will need to be resolved.

Bilateral JI programmes are typically set up between industrialized and developing or transitional countries, although the Nordic Council has initiated a simulation experiment on JI within the context of emission quota trading between the four Nordic countries (Bohm, 1997). The experiment showed that quota trading between developed countries can offer significant cost savings for overall reductions and avoid monitoring problems.

Finally, it is useful to make some brief mention of “activities implemented jointly” (AIJ). AIJ refers to the pilot phase for JI that was established by the First Conference of the Parties in 1995. Under this scheme, those parties that wanted to establish emission reduction and/or sink enhancement projects in other countries that were parties to the Convention could do so. However, no credits would be forthcoming – that is, no Annex I country would be able to meet its Article 4.2 obligations through AIJ. Instead, the pilot phase was intended to gather and analyse experience, so that a review could be completed by the turn of the century.

How does cost assessment then apply to AIJ/JI, and what is the link to national strategy analysis? Beyond deciding that the Subsidiary Body for Scientific and Technological Advice – SBSTA (in co-ordination with the Subsidiary Body for Implementation - SBI) should establish “a framework for reporting, in a transparent, well-defined and credible fashion, on the possible global benefits and the national economic, social and environmental impacts” (FCCC/CP, 1995 p. 19), the COP I decision on AIJ gives little explicit direction for those interested in cost concepts. What has, however, taken place in practice is that those entities that are reporting their experiences to the SBSTA are calculating the costs associated with particular emission reductions (or sink enhancements). As such, the procedure for executing mitigation calculations – as outlined in Chapter 2 previously – has been followed. The Convention Secretariat has been asked to examine the experiences achieved so far, and these will evidently form part of the basis for negotiation on the JI and CDM concepts as they are introduced in the Kyoto Protocol.

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[5] Several countries have established programmes (e.g., the US, the Netherlands, Japan, and Norway).

[6] Transaction costs are the costs associated with the JI process itself: for instance, searching for partners, design, selection, implementation, and monitoring. For further discussion of transaction costs, see, for example, Collamer and Rose, 1996; OECD 1996).

To be acceptable, emissions from proposed activities will need to be reduced from what they would have been in the absence of the program *(emission additionality);* financing must be in addition to normal development assistance *(financial additionality);* and in many cases, it must be shown that the project was initiated as a result of, or in reasonable anticipation of, AIJ *(program additionality).* Other considerations include leakage (the potential for the project to lead to changes in greenhouse gas emissions outside the boundaries of the project), potential negative impacts on local employment and health benefits, and the question of whether there is adequate verification and monitoring to ensure that real, measurable reductions are taking place. It is important to ensure that greenhouse gas reductions, whether achieved through reductions in emissions or through sequestration, will not be lost over time.

8.3.2.3 Equity Considerations

The welfare impacts of introducing economic instruments depend on the structure (and efficiency) of the existing tax system. Instruments such as carbon taxes offer a large opportunity for revenue collection and can potentially be used to replace more distortionary taxes. In Europe, for example, calculations have been made as to how energy and/or carbon taxes could be substituted for payroll taxes and thereby stimulate employment (IPCC, 1996, Chapter 9). Macroeconomic emission reduction studies have shown negative or low costs for such policies.

Another important, but often overlooked, issue involves the distributional aspects of introducing economic carbon reduction instruments. Carbon taxes, for example, will generate incentives for replacing energy intensive industries with those of low energy intensity and will also have major distributional impacts on private households.

A macroeconomic assessment will provide information about how the tax will affect different parts of society – that is, upon whom the burden will fall. A decision to try to make the impact as fair as possible could be taken, and revenue recycling may be used to make social or industrial compensation payments. Of course, how fairness is defined may well differ from society to society.

The main complication in implementing a tradable permit system is that the global community will have to decide how to determine the initial distribution of permits.[7] Since emission permits are tradable, they have a high potential market value, and therefore the allocation of permits is similar to a capital allocation. In a tradable permit system, the distributional consequences depend on the established permit market price and the present and future commitments of the parties. It must therefore be expected that the establishment of a permit system and appropriate trading mechanisms will be developed in several steps where economic and equity principles will be evaluated.

8.4 Multilateral Financing Mechanisms

8.4.1 Global Environment Facility

The FCCC (Article 11) states that the "financial mechanism" shall provide "financial resources on a grant or concessional basis."[8] On an interim basis, the Global Environment Facility (GEF) has been designated as the Convention's financial mechanism. Recalling Article 4 of the Convention, the GEF should be meeting the following costs for developing country parties:

- the full costs of preparing communications
- the agreed full incremental costs of implementing Article 4.1 commitments
- the costs of adapting to adverse effects of climate change, but only for developing country parties that are particularly vulnerable (UN/FCCC, 1992)

Of these, the concept of "agreed full incremental costs" is perhaps the most difficult to define.

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[7] For a discussion of the allocation principle, see, for example, Scott Barrett "'Acceptable' allocations of tradable carbon emission entitlements in a global warming treaty" in UNCTAD (1992).

[8] As of the end of 1996, "all GEF financing in the area of climate change has been through grants" (FCCC/SBI, 1997, p.5).

In broad terms, the concept of incremental costs is relatively straightforward. It is the extra cost incurred in terms of expenditure patterns, policy implementation, and human and physical infrastructure requirements as a result of new obligations arising from ratification of a global convention (in this case, the FCCC). In simple terms, this equates to the difference between the costs of the GEF-supported activity and the costs the country would have incurred without the GEF project. It is therefore necessary to estimate both the expenditure of the activity in question, and the cost saving on activities that, as a result of the GEF activity, can be assumed to be substituted.

In practice, however, it is often impossible to identify two alternative actions that provide identical services, and in the incremental cost calculation the value of the "difference in service" should therefore be included. In addition, it will always be a question of what the country would have done without the climate concerns. The term "agreed" is deliberately introduced into the concept to reflect the need to analyse and agree on a realistic basis for the calculation (King, 1993)

Following guidance from the COP, the GEF Council has established an operational strategy which consists of three categories of activities in the area of climate change:

- Long-term measures
    1) removing barriers to energy conservation and energy efficiency
    2) promoting the adoption of renewable energy by removing barriers and reducing implementation costs
    3) reducing the long-term costs of low greenhouse gas–emitting energy technologies
- Enabling activities
- Short-term response measures

Countries can submit projects if they fall within one of these categories. With respect to the incremental cost assessment, it should be noted that enabling activities are, by definition, additional for the eligible countries (mainly developing countries) and that incremental costs are therefore equal to the full costs of this type of activity. Application of the incremental cost concept is most straightforward for the short-term measures, although the inherent comparison problem mentioned above naturally applies, and suitable projects can be identified directly from the national mitigation strategy. The long-term measures are conceptually more difficult to assess in terms of incremental costs, as GEF funding would be aiming at changing the implementation conditions and would not directly substitute a mitigation option for a baseline activity.

8.4.2 Other Financial Mechanisms

The Global Overlays programme of the World Bank is an example of action taken by multilateral financing agencies to integrate climate change concerns into their programmes.

Climate Change Global Overlays are an analytical tool developed to integrate global environmental externalities into economic and sector work. While the program has been established at the World Bank, the basic principle can be extended to any sectoral development strategy with significant greenhouse gas emissions. The overlay calculates greenhouse gas emissions for a given sector, such as energy, industry, transport, or forestry, and outlines the cost-effective greenhouse gas mitigation options that are available to the country if it seeks to limit its greenhouse gas emissions in that sector.

Global Overlays are a screening tool for identifying cost-effective GEF investment projects. The focus of the overlay method allows more in-depth analysis of mitigation options than general World Bank country-level studies and a closer identification of cost-effective investment opportunities for greenhouse gas reduction. In addition, the Global Overlays approach offers some potential advantages for the bank and its clients – for example, reinforcing the rationale for capturing "win-win" options through pricing and sector reforms, recognizing the potentially large greenhouse gas emission reduction benefits associated with many World Bank projects, and supporting capacity building at national level.

Comparing the guidance of the Global Overlays with the recommendations for the application of cost concepts and the proposed structure for national strategy development presented in Section 8.2 leads to the general conclusion that the two approaches are compatible. Consequently, the application of the Global

Overlays approach should not require significant additional analysis apart from the integration of what is termed a “Bank Reform” baseline. This is essentially a reflection on the baseline issue, moving from a “business-as-usual baseline” to a more efficient one as a basis for the national analysis and calculation of incremental costs.

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Annex A

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