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Costing Methodologies

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EXECUTIVE SUMMARY

Using resources to mitigate greenhouse gases (GHGs) generates opportunity costs that should be considered to help guide reasonable policy decisions. Actions to abate GHG emissions or increase carbon sinks divert resources from other uses like health care and education. Assessing these costs should consider the total value that society attaches to the goods and services forgone because of the diversion of resources to climate protection. In some cases, the benefits of mitigation could exceed the costs, and thus society gains from mitigation.

This chapter addresses the methodological issues that arise in the estimation of the monetary costs of climate change. The focus is on the correct assessment of the costs of mitigation measures to reduce the emissions of GHGs. The assessment of costs and benefits should be based on a systematic analytical framework to ensure comparability of estimates and transparency of logic. One well-developed framework assesses costs as changes in social welfare based on individual values. These individual values are reflected by the willingness to pay (WTP) for environmental improvements or their willingness to accept (WTA) compensation. From these value measures can be derived measures such as the social surpluses gained or lost from a policy, the total resource costs, and opportunity costs.

While the underlying measures of welfare have limits and using monetary values remains controversial, the view is taken that the methods to "convert" non-market inputs into monetary terms provide useful information for policymakers. These methods should be pursued when and where appropriate. It is also considered useful to supplement this welfare-based cost methodology with a broader assessment that includes physical impacts when possible. In practice, the challenge is to develop a consistent and comprehensive definition of the key impacts to be measured. In this chapter the costing methodology is overviewed, and issues involved in using these methods addressed.

The costs of climate protection are affected by decisions on some key elements, the analytical structure, and the assumptions made. Among other key presumptions, these include the definition of the baseline, assumption about associated costs and benefits that arise in conjunction with GHG emission reduction policies, the flexibility available to find the carbon emissions of lowest cost, the possibility of no regret options, the discount rate, the assumption of the rate of autonomous technological change, and whether revenue is recycled.

First, defining the baseline is a key part of cost assessment. The baseline is the GHG emissions that would occur in the absence of climate change interventions. It helps determine how expensive GHG emissions reduction might be. The baseline rests on key assumptions about future economic policies at the macroeconomic and sectoral levels, including structure, resource intensity, relative prices, technology choice, and the rate of technology adoption. The baseline also depends on presumptions of future development patterns in the economy, like population growth, economic growth, and technological change.

Second, climate change policies may have a number of side-impacts on local and regional air pollution associated, and indirect effects on issues such as transportation, agriculture, land use practices, employment, and fuel security. These side-impacts can be negative as well as positive and the inclusion of the impacts then can tend to generate higher as well as lower climate change mitigation costs compared with studies that do not include such side-impacts.

Third, for a wide variety of options, the costs of mitigation depend on the regulatory framework adopted by national governments to reduce GHGs. The more flexibility allowed by the framework, the lower the costs of achieving a given reduction. More flexibility and more trading partners can reduce costs, as a firm can search out the lowest-cost alternative. The opposite is expected with inflexible rules and few trading partners.

Fourth, no regrets options are by definition actions to reduce GHG emissions that have negative net costs. Net costs are negative because these options generate direct or indirect benefits large enough to offset the costs to implement the options. The existence of no regrets potential implies that people choose not to exercise some carbon-reducing options because of relative prices and preferences, or that some markets and institutions do not behave perfectly. The presumption of effective policies that capture large no regrets options reduces costs.

Fifth, there are two approaches to discounting—an ethical or prescriptive approach based on what rates of discount should be applied, and a descriptive approach based on what rates of discount people (savers as well as investors) actually apply in their day-to-day decisions. For mitigation analysis, the country must base its decisions at least partly on discount rates that reflect the opportunity cost of capital. Rates that range from 4% to 6% would probably be justified in developed countries. The rate could be as high as 10%–12% in developing countries. It is more of a challenge to argue that climate change mitigation projects should face different rates, unless the mitigation project is of very long duration. Note that these rates do not reflect private rates of return, which typically must be greater to justify a project, at around 10%–25%.

Sixth, modellers account for the penetration of technological change over time through a technical coefficient called the "autonomous energy efficiency improvement" (AEEI). AEEI reflects the rate of change in the energy intensity (the ratio of energy to gross domestic product) holding energy prices constant. The presumed autonomous technological improvement in the energy intensity of an economy can lead to significant differences in the estimated costs of mitigation. As such, many observers view the choice of AEEI as crucial in setting the baseline in which to judge the costs of mitigation. The costs of mitigation are inversely related the AEEI–a greater AEEI the lower the costs to reach any given climate target. The costs decrease because people adopt low-carbon technology unrelated to changes in relative prices.

Other issues to be considered in the assessment of mitigation policies include the marginal cost of public funds, capital costs, and side effects. Policies such as carbon taxes or auctioned (tradable) carbon-emissions permits generate revenues that can be recycled to reduce other taxes that are likely to be distortionary. There has been considerable debate as to whether such revenue recycling might eliminate the economic costs of such mitigation policies. Theoretical studies indicate that this result can occur in economies with highly inefficient tax systems. Some empirical studies obtain the no-cost result, although many such studies do not. Tax recycling reflects several complicated assumptions in the baseline and policy case regarding the structure of the tax system and the overall policy framework, among others. Target setting and timing also affect cost estimates. Reduction targets defined as percentage reductions of future GHG emissions create significant uncertainty about GHG emission levels.

In addition, several issues on technology use in developing countries and economies in transition (EITs) warrant attention as critical determinants for climate change mitigation potential and related costs. These include current technological development levels, technology transfer issues, capacity for innovation and diffusion, barriers to efficient technology use, institutional structure, and human capacity aspects.

Equity is another issue in evaluating mitigation policies. The use of income weights is one approach to address equity. Under this system each dollar of costs imposed on a person with low income is given greater weight relative to the cost for a person with a high income. This method is, however, controversial and it is difficult to obtain agreement on the weights to be used. An alternative method is to report the distributional impacts separately. In this case it is important that all the key stakeholders are identified and the distributional effects on each reported. A third possibility is to use average damage estimates and apply these to all those impacted, irrespective of their actual WTP.

Given these presumptions on structure, the costs of climate protection can be modelled and assessed at three levels:

- Project level analysis estimates costs using "stand-alone" investments assumed to have minor secondary impacts on markets.
- Sector level analysis estimates costs using a "partial-equilibrium" model, in which other variables are presumed as given.
- Macroeconomic analysis estimates costs by considering how policies affect all sectors and markets, using various macroeconomic and general equilibrium models. The modeller confronts the trade-off between the level of detail in the cost assessment and complexity of the system. For example, a macroeconomic system tries to capture all direct and indirect impacts, with little detail on the impacts of specific smaller scale projects.

Modelling climate mitigation strategies can be done using several techniques, including input–output models, macroeconomic models, computable general equilibrium models, and models based on the energy sector. Hybrid models have also been developed to provide more detail on the structure of the economy and the energy sector. Two broad classes of integrated assessment models can be identified: policy optimization models and policy evaluation models. The appropriate use of these models depends on the subject of the evaluation and the availability of data.

Finally, the main categories of climate change mitigation policies include market-oriented, technology-oriented, voluntary, and research and development (R&D) policies. Climate change mitigation policies can include elements of two or more policy options. Economic models, for example, mainly assess market-oriented policies and in some cases technology policies, primarily those related to energy supply options. In contrast, engineering approaches mainly focus on supply and demand-side technology policies. Both approaches are relatively weak in the representation of R&D policies.

7.1 Introduction

7.1.1 *Background and Structure of the Chapter*

This chapter addresses the methodological issues that arise in the estimation of the monetary costs of climate change. The focus here is on the correct assessment of the costs of mitigation measures to reduce the emissions of greenhouse gases (GHGs). The other two areas in which cost issues arise are the estimation of the climate change impacts in monetary terms, and the assessment of measures to adapt to climate change. Working Group II (WGII) is charged with the responsibility to evaluate the impacts and adaptation measures. It is important, though, that much of the discussion in this chapter is relevant to these areas. The basic principles of cost estimation certainly apply in all three areas. Moreover, some of the key issues in cost estimation that arise in the assessment of impacts are also relevant to the estimation of the costs of mitigation. Hence, the relationship between the costs discussed by WGII and those discussed by WGIII is close.

The chapter begins by providing the background to this assessment report; by giving a summary of the Second Assessment Report (SAR) and of the developments in the literature since SAR (IPCC, 1996a, 1996b). Section 7.2 discusses the elements in any climate change cost estimation. It begins by setting out the decision-making framework for mitigation decisions. Unfortunately, this framework is complex, as it involves the application of different modelling techniques and assumptions. Important within the framework are issues of ancillary and co-benefits of climate change mitigation, evaluation techniques, the treatment of barrier removal and implementation costs, discounting, and the linkages between adaptation and mitigation. The conventional cost-effectiveness and the cost–benefit tools used for making decisions to reduce GHGs, or to select adaptation measures, provide only part of the information required by the decision maker. The extensions that are currently being discussed, and used in some cases, include the valuation of external effects, and considerations of equity and sustainability. The outline of the extended decision-making framework and its relationship to the cost methodology is discussed in Sections 7.2.1 to 7.2.5.

Section 7.3 discusses the critical assumptions made in the application of the methodology to climate change problems. The key issues are:

- different systems in which the cost analysis is carried out–project sector and macro level;
- determination of baselines;
- treatment of technological change;
- assessment of cost implications of including alternative GHG emission reduction options and carbon sinks; and
- treatment of uncertainty.

Section 7.4 covers the practical problems that arise in cost estimation, particularly relating to the linkages between the "micro" cost exercise and the broader "macro" picture. The problems covered are:

- relationship to objectives of development, equity, and sustainability (DES);
- income and other macroeconomic effects of mitigation and adaptation policies;
- issues of spillovers;
- treatment of equity; and
- treatment of future costs and sustainability issues.

Section 7.5 considers the special issues that arise in the estimation of costs in developing countries and economies in transition (EITs).

Section 7.6 discusses the relationship between the cost assessment methodology and the models used to estimate mitigation costs. Issues discussed include classification of models (Section 7.6.2), top-down and bottom-up models (Section 7.6.3) integrated assessment models (IAMs; Section 7.6.4), categorization of climate change mitigation options (Section 7.6.5), and critical assumptions (Section 7.6.6).

The links between this chapter with others is as follows. Section 7.1 overlaps with Chapter 10, Section 7.2 with Chapter 6, and Section 7.6 with Chapters 8 and 9.

7.1.2 *Summary of the Second Assessment Report on Cost Issues*

IPCC's SAR published a separate volume on the economic and social dimensions of climate change (IPCC, 1996a). This report considered all aspects of climate change, including impacts, adaptation, and mitigation of climate change. The volume on economic and social dimensions was supplemented by a report from another working group of the IPCC that dealt with scientific and technical analyses of the impacts, adaptation, and mitigation of climate change (IPCC, 1996b). The Third Assessment Report (TAR) is structured in a different way. Impacts and adaptation are addressed together by one working group (WGII), and mitigation by another group (WGIII). All the technical areas, including scientific, engineering, economic, and social aspects of climate change impacts, adaptation, and mitigation, however, are integrated in the working groups.

The WGII SAR (IPCC, 1996b) reported a number of cost estimates for individual climate change mitigation technologies, but did not include specific subsections or extensive discussions on the cost assessment framework or methodological issues related to valuation issues. This section therefore only provides a short summary of the coverage of costing methodologies in the report of the social and economic dimensions by WGIII (IPCC, 1996a).

Costing methodologies were addressed as part of several chapters in the WGIII SAR (IPCC, 1996a). These included chapters on the decision-making framework, equity and social considerations, and intergenerational equity: discounting and economic efficiency. Furthermore, the report included two conceptual chapters on cost and methodologies, namely Chapter 5 (Applicability of Techniques of Cost–Benefit Analysis to Climate Change) and Chapter 8 (Estimating the Costs of Mitigating Greenhouse Gases). The first of these chapters included a general outline of analytical approaches applied to climate change cost assessment, with emphasis on cost–benefit analysis and further development of this framework to facilitate multi-attribute analysis. The analytical approaches presented were discussed in relation to different decision frameworks and valuation approaches.

Chapter 8 of the WGIII SAR (IPCC, 1996b) was a methodological introduction to a subsequent chapter on comparative assessments of the modelling results for mitigation costs. A taxonomy of the mitigation cost components applied in the models was presented, including the direct engineering and financial costs of specific technical measures, economic costs for a given sector, macroeconomic costs, and welfare costs. The importance of different assumptions, such as development patterns, technological change, and policy instruments, were then assessed in relation to cost concepts and modelling approaches. Some of the focal areas considered were "top-down" versus "bottom-up" models, double dividend issues and no regret options, long-term projections, and special issues related to mitigation-cost analysis for developing countries.

The WGIII SAR (IPCC, 1996a) also included an extensive review of the mitigation costs for different parts of the world based on top-down and bottom-up methodologies. The review, which was based on an assessment of several hundred studies, raised a number of important costing issues that are critical to the further development of cost concepts and models. These issues include, *inter alia,* model structure, assumptions on demographic and economic growth, availability and costs of technical options, timing of abatement policies, discount rate, and the effect of research and development (R&D).

7.1.3 Progress since the Second Assessment Report

A number of IPCC activities based on SAR have developed cost methodologies and applied them to the appraisal of specific policies. Some of the main activities are the IPCC Technical Paper on Technologies, policies, and measures for mitigating climate change (IPCC, 1996c) and the UNEP report on *Mitigation and Adaptation Cost Assessment Concepts*, *Methods and Appropriate Use*, which was developed on the basis of an IPCC workshop in June 1997 (Christensen *et al*., 1998).

The IPCC Technical Paper (IPCC, 1996c) summarizes the information on mitigation technology costs provided by WGII SAR (IPCC, 1996b), and the chapter on policy instruments of WGIII SAR (IPCC, 1996b, Chapter 11). The aim of the Technical Paper was to provide a short overview of cost information to be used by climate change policymakers and by the Subsidiary Body for Scientific and Technical Advice (SBSTA) of the UN Convention on Climate Change.

The UNEP report (Christensen *et al*., 1998) defines and clarifies mitigation and adaptation cost concepts to be used in the field of climate change based on WGIII SAR (IPCC, 1996a). The aim is to overcome some of the variations in the cost concepts that were presented in various chapters of SAR and to develop a generic overview of cost concepts that are easier to use for practitioners in the field. The report includes chapters on general mitigation and adaptation cost concepts, sectoral applications, macroeconomic analysis, and special issues in costing studies for developing countries, and concludes on the applicability of the various cost concepts in the formulation of national climate change policies and programmes.

During the TAR process, a crosscutting issues paper was prepared (Markandya and Halsnaes, 2000). The purpose was to provide a non-technical guide to the application of cost concepts in the analysis of climate change policies by any of the working groups involved in the TAR. Costs of mitigation, adaptation, or GHG emissions are likely to be estimated and their implications discussed in many parts of the TAR. It is essential, therefore, that a common understanding of the use of different cost concepts is employed. The crosscutting paper proposed a set of definitions for these concepts. The paper also identified categories of costs and their relevance in the climate change area. In this chapter the crosscutting issues paper is taken as the point of departure, the ideas are developed further and an elaboration of some of them provided. The purpose, however, is the same: to ensure a common understanding of commonly used cost terms, and the role of cost analysis within the broader decision-making framework for climate change policies.

After SAR, extensive debates arose regarding suitable costing methods to quantify the relative indirect economic impacts of various policies in distinct regions, with no consensus on the most suitable methods to be employed. However, a consensus is now beginning to emerge on how to quantify some ancillary benefits (OECD, 2000), and Chapters 8 and 9 herein**.** In preparation for TAR, Burtraw *et al*. (1999) provide a synthesis of methodological issues relevant to the assessment of ancillary costs and benefits of GHG mitigation policies. The magnitude of potential ancillary benefits depends upon the regulatory, demographic, technological, and environmental baselines. The magnitude and scope of potential benefits of GHG mitigation policies can be expected to be greater in cases in which higher emission baselines obtain and lower for cases in which regulatory and technological innovation have been more long standing (Morgenstern, 2000).

7.2 Elements in Costing

7.2.1 Introduction

This section addresses a number of key conceptual issues related to mitigation cost concepts, including definitions of private and social costs and methods to assess the side effects and equity aspects of mitigation policies. An overview is given of analytical approaches to assess mitigation costs, including a classification and discussion of different modelling approaches and critical assumptions. The issue of ancillary and co-benefits of climate change mitigation is discussed. Valuation techniques are presented, as is the treatment of barrier removal and implementation costs. A review of recent developments in the field of discounting is then presented and the section concludes with an investigation of the linkages between adaptation and mitigation.

7.2.2 Cost Estimation in the Context of the Decision-making Framework

Actions taken to abate GHG emissions or to increase the size of carbon sinks generally divert resources from other alternative uses. The theoretically precise measure of the social costs of climate protection, therefore, is the total value that society places on the goods and services forgone as a result of the diversion of resources to climate protection. A social cost assessment should ideally consider all welfare changes that result from the changes in resources demanded and supplied by a given mitigation project or strategy in relation to a specific non-policy case (see Hazilla and Kopp, 1990). The assessment should include, as far as possible, all resource components and implementation costs. This means that both the benefits and the costs of a mitigation action should be included in the estimation. In some cases, the sum of all the benefits and costs associated with a mitigation action could be negative, meaning that society benefits from undertaking the mitigation action.

The conceptual foundation of all cost estimation is the value of the scarce resources to individuals. Thus, values are based on individual preferences, and the total value of any resource is the sum of the values of the different individuals involved in the use of the resource. This distinguishes this system of values from one based on "expert" preferences, or on the preferences of political leaders. It also distinguishes it from value systems based on ecological criteria, which give certain ecological goals a value in themselves, independent of what individuals might want, now or in the future.

The values, which are the foundation of the estimation of costs, are measured by the applied welfare economic concepts of the willingness to pay (WTP) of individuals to buy the resource, or by the individuals' willingness to accept (WTA) compensation to part with the resource. The WTP measure of value reflects the maximum people are willing to pay to live in a world with climate policy in force rather than not. WTA is the minimum compensation people would accept to live without this climate policy (e.g., Willig, 1976; Randall and Stoll, 1980; Hanemann, 1991; Shogren *et al*., 1994). The concepts of WTP and WTA therefore play a critical part in defining the social cost method.

WTP or WTA is most commonly approximated by the consumer and producer surplus as revealed in the demand and supply schedules for the resources whose consumption and production is affected by the mitigation action. These measures are standard economic tools of cost–benefit analysis (Hanley *et al*., 1997). In some cases, however, the resources that are affected do not have well-defined markets and hence lack identifiable demand and supply schedules. Examples are changes in air quality, or changes in recreational use of forests. In such cases other methods of measuring WTP and WTA are required. These have been developed recently and can now provide credible estimates for a range of non-marketed resources, though some debate remains over the application of such values to all policy-relevant impacts.

There is also a relationship between WTP and WTA and the conventional aggregate measures of economic activity such as gross domestic product (GDP). The classic paper on this is Weitzman (1976), which showed that GDP less depreciation of capital (or "net national product") is a measure of the net output that represents the income on the economy's capital stock when that economy is operating according to competitive market rules. However, a competitive economy is also one that maximizes the sum of consumer and producer surpluses. Hence GDP is closely linked to consumer and producer surplus maximization for commodities that operate through the market place. However, the relationship breaks down if competitive markets do not exist for all scarce resources. In this case, GDP changes do not fully reflect changes in social welfare.

A frequent criticism of this costing method is that it is inequitable, as it gives greater weight to the "well off". This is because, typically, a well-off person has a greater WTP or WTA than a less well-off person and hence the choices made reflect more the preferences of the better off. This criticism is valid, but there is no coherent and consistent method of valuation that can replace the existing one in its entirety. Concerns about, for example, equity can be addressed along with the basic cost estimation. The estimated costs are one piece of information in the decision-making process for climate change that can be supplemented with other information on other social objectives, for example impacts on key stakeholders and the meeting of poverty objectives.

7.2.2.1 Analytical Approaches

Cost assessment is an input into one or more of the rules for decision making, which are discussed in more detail in Chapter 10 of this report. Economic approaches to decision making include cost–benefit analysis, and cost-effectiveness analysis, and these approaches can be supplemented with multi-attribute analysis that facilitates an integrated assessment of economic impacts and other quantitative and non-quantitative information. These approaches are briefly described in *Box 7.1.*

It should be recognized that some types of impacts can be measured in both monetary terms and physical terms. This applies, for example, to changes in air pollution as a result of the reductions in GHGs.
There is a major difference between the economic approaches and multi-attribute analysis in how the various dimensions of

the assessment are summarized. The economic approaches seek to provide aggregates to single measures based on an economic welfare evaluation, while multi-attribute analysis does not provide an aggregation of the different dimensions of the analysis.

7.2.2.2 *Cost Analysis and Development, Equity, and Sustainability Aspects*

The underlying objective behind any cost assessment is to measure the change in human welfare generated as the result of a reallocation or change in use of resources. This implies the existence of a function in which welfare or "utility" depends on various factors such as the amounts of goods and services that the individual can access, different aspects of the individual's physical and spiritual environment, and his or her rights and liberties. Constructing a "utility function", representing social welfare, that is an aggregate measure of all such impacts for all individuals involves a number of complexities and controversial equity issues that have been intensively studied by economists (see, for example, Blackorby and Donaldson, 1988). However, the sum of the individual WTPs and WTAs can be taken as a measure of the social welfare, which finesses these difficulties to a considerable extent. There remain, however, issues that cannot be fully addressed in this WTP–WTA framework, most important of which are equity and sustainability.

Box 7.1. Decision-making Approaches

Cost–benefit analysis
This measures all negative and positive project impacts and resource uses in the form of monetary costs and benefits. Market prices are used as the basic valuation, as long as markets can be assumed to reflect "real" resource scarcities. In other cases the prices are adjusted to reflect the true resource costs of the action. Such adjusted prices are referred to as shadow prices (Squire and van der Tak, 1975; Ray, 1984).

Cost-effectiveness analysis
A special case of cost–benefit analysis in which all the costs of a portfolio of projects are assessed in relation to a policy goal. The policy goal in this case represents the benefits of the projects and all the other impacts are measured as positive or negative costs. The policy goal can, for example, be a specified goal of emissions reductions for GHGs. The result of the analysis can then be expressed as the costs (US$/t) of GHG emissions reductions (Sathaye *et al*., 1993; Markandya *et al*., 1998).

Multi-attribute analysis
The basic idea of multi-attribute analysis is to define a framework for integrating different decision parameters and values in a quantitative analysis without assigning monetary values to all parameters. Examples of parameters that can be controversial and very difficult to measure in monetary values are human health impacts, equity, and irreversible environmental damages (Keeney and Raiffa, 1993).

The above analysis of welfare focuses on the narrowly economic dimension. Even within this framework there are complexities that make a full assessment difficult. In addition, however, issues of DES need to be taken into account.[1]

A key question in broadening the analysis of costs to cover these dimensions is whether they can be measured in the same units as the costs (i.e., in money). The authors take the view that the methods to "convert" some of these other dimensions into monetary terms are useful and should be pursued. These are discussed further in Section 7.2.3. At the same time, there is some controversy about the measurement of equity, of environmental impacts and sustainability in monetary terms, as, for example, in the discussion on social cost-benefit analysis in Ray (1984).[2] This is because of disagreement about what values should be attached to physical and social changes that are of interest. Furthermore, it is generally accepted that not all these impacts can be put in monetary terms.[3] Hence it is important, indeed imperative, that the cost methodology be supplemented by a broader assessment of the impacts with physical values reported wherever possible. These questions are discussed further in Sections 7.3 and 7.4.

7.2.2.3 *Ancillary Benefits and Costs and Co-Benefits and Costs*

The literature uses a number of terms to depict the associated benefits and costs that arise in conjunction with GHG mitigation policies. These include co-benefits, ancillary benefits, side benefits, secondary benefits, collateral benefits, and associated benefits. In the current discussion, the term "co-benefits" refers to the non-climate benefits of GHG mitigation policies that are explicitly incorporated into the initial creation of mitigation policies. Thus, the term co-benefits reflects that most policies designed to address GHG mitigation also have other, often at least equally important, rationales involved at the inception of these policies (e.g., related to objectives of development, sustainability, and equity). In contrast, the term ancillary benefits connotes those secondary or side effects of climate change mitigation policies on problems that arise subsequent to any proposed GHG mitigation policies. These include reductions in local and regional air pollution associated with the reduction of fossil fuels, and indirect effects on issues such as transportation, agriculture, land use practices, employment, and fuel security. Sometimes these benefits are referred to as "ancillary impacts", to reflect that in some cases the benefits may be negative. From the perspective of policies to abate local air pollution, GHG mitigation may be an ancillary benefit.

[1] Other issues that may need to be considered include incomplete information, perceptual biases, and learning.

[2] Indeed, many of the comments on earlier drafts of this chapter took different positions on this issue.

[3] For some impacts, such as those on "sustainability", the selection of physical indicators is also a matter of controversy.

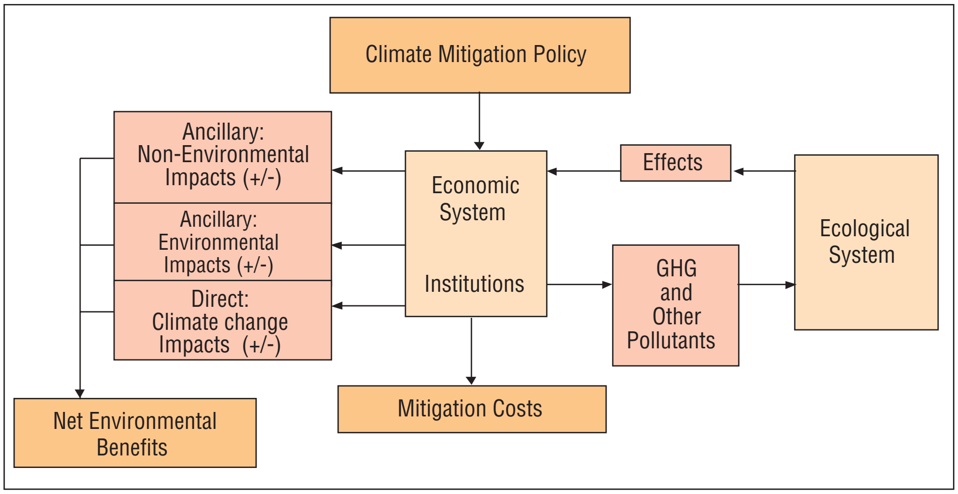

Figure 7.1: *Mechanism for the Generation of Ancillary Impacts. Please note that climate change impacts are not discussed in this report, but in the Third Assessment Report of Working Group II.*

Figure 7.1 illustrates the generation of ancillary benefits to GHG emission reduction policies.[4] These policies operate through the economic and institutional system within a country and lead to reductions in GHGs, changes in other pollutants, and mitigation costs. Changes in GHG emissions in turn lead to changes in air and water pollution, which ultimately extend throughout the environment and feed back into the economy. Then, depending on baseline conditions, technologies, and institutions, such as labour markets, tax systems, and existing environmental and other types of regulations (represented by "institutions" in the economic system box), these feedbacks may become:

- environmental impacts (such as the value of changes in conventional air or water pollution);
- non-environmental impacts (such as the value of employment effects); and,
- direct climate change impacts.

There appear to be three classes of literature regarding the costs and benefits of climate change mitigation:

(1) literature that primarily looks at climate change mitigation, but that recognizes there may be benefits in other areas;
(2) literature that primarily focuses on other areas, such as air pollution control, and recognizes there may be benefits in the area of climate mitigation; and
(3) literature that looks at the combination of policy objectives (climate change and other areas) and looks at the costs and benefits from an integrated perspective.

Each of these classes of literature may have their own preferred terms, and for class (3) it seems to be "co-benefits". TAR acknowledges the relevance of all three, yet specifically wants to make the case for an integrated approach, linking climate change mitigation to the achievement of sustainable development and other policy objectives. Therefore, in this report, the term "co-benefits" is used only when speaking generically about the issue because of the limited availability of literature. The term "ancillary benefits" is used when addressing class (1) and (2) literature. Class (1) literature appears to be the most extensive; it is this literature on the ancillary benefits of climate change mitigation that is primarily covered in this section.

The discussion of ancillary impacts and/or co-benefits and costs, and the estimation of these are closely related to the concept of external cost, which is discussed below.

7.2.2.4 Market Failures and External Cost

The term external cost or externality is used to define the costs that arise from any human activity when the agent responsible for the activity does not take full account of the impacts on others of his or her actions. Equally, when the impacts are positive and not accounted for in the actions of the agent responsible they are referred to as external benefits. Consider first the following example of external costs. Emissions of particulate pollution from a power station affect the health of people in the vicinity, but this is not often considered, or is given inadequate weight in private decision-making, as there is no market for such impacts. Such a phenomenon is referred to as an externality, and the costs it imposes are referred to as the external costs.

External costs are distinct from the costs that the emitters of the particulates take into account when determining their outputs, costs such as the prices of fuel, labour, transportation, and energy. Categories of costs that influence 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, which together are defined as social cost:

$$\textit{Social Cost} = \textit{External Cost} + \textit{Private Cost}$$

[4] Various additional interrelationships are omitted from this graphic. An example is that estimated health benefits might be lower if a GHG mitigation policy reduces temperature increases, thereby creating less ozone (O_3).

The private cost component is generally taken from the market prices of the inputs. Thus, if a project involves an investment of US$5 million, as estimated by the inputs of land, materials, labour and equipment, that figure is used as the private cost. That may not be the full cost, however, as far as the estimation of social cost is concerned. If, for example, the labour input is being paid more than its value in alternative employment, the private cost is higher than the social cost. Adjustments to private costs based on market prices to bring them into line with social costs are referred to as shadow pricing. A fuller discussion of shadow pricing is given in Ray (1984).

External costs typically arise when markets fail to provide a link between the person who creates the "externality" and the person who is affected by it, or more generally when property rights for the relevant resources are not well defined. If such rights were defined, market forces and/or bargaining arrangements would ensure that the benefits and costs of generating the external effect balanced properly. The failure to take into account external costs, however, may be a product not only of a lack of property rights, but also the result of a lack of full information and non-zero transaction costs.

7.2.2.5 Critical Assumptions in Studies of Ancillary Benefits and Co-benefits

Policies aimed at mitigating GHGs, as stated earlier, can yield other social benefits and costs (here called ancillary benefits and costs), and a number of empirical studies have made a preliminary attempt to assess these impacts. It is apparent that the actual magnitude of the ancillary benefits or co-benefits assessed critically depends on the scenario structure of the analysis, in particular on the assumptions about policy management in the baseline case (IPCC, 2000b; Krupnick *et al.*, 1996; Krupnick *et al.*, 2000).[5] This implies that whether a particular impact is included or not depends on the primary objective of the programme. Moreover, something that is seen as a GHG reduction programme from an international perspective may be seen, from a national perspective, as one in which local pollutants and GHGs are equally important.

A second point is that the economic accounting of ancillary benefits depends crucially on assumptions about the demographic characteristics, regulatory regime, and available technology and how these will evolve. For example, consider the case in which a government imposes a cap on emissions of sulphur. If a GHG mitigation programme is introduced it may reduce the associated amount of sulphur produced, but other activities may take up the slack and so result in no net change in emissions. Alternatively, consider the situation in which the government has a tax on emissions. If the tax is set equal to the marginal damage from sulphur, a small mitigation programme will not generate any direct benefits in terms of sulphur reductions (the value of the reductions is exactly matched by the loss of charge revenue). As a third example, consider the case in which the regulator has a plan to tighten the controls on local pollutants. Any GHG mitigation programme that reduces the levels of these emissions has then to be valued relative to the costs of achieving the dynamic baseline, and not in terms of the benefits of reduced emissions themselves. To sum up, the valuation of ancillary and/or co-benefits requires the policymaker to look not only at the external costs of the pollutants, but also at the net costs and benefits of measures being introduced to deal with them.

Externalities do not necessarily arise when there are effects on third parties. In some cases, these effects may already be recognized, or "internal", contained in the price of goods and services. Consider a stylized example, such as damages to vehicles in an automobile accident. If each driver is fully liable for damages to other vehicles and one can reliably assess fault and enforce liability, the damage in an accident would not be an externality because the party at fault would fully recognize the costs. Only if the drivers are not fully liable, or if fault cannot be established, or if liability is not enforceable is there a justification for treating the damage to vehicles in the example as an externality. The key idea is that such exceptions constitute a deviation from ideal institutions. In economic vocabulary, this is referred to as market failure. For damage to be considered an externality from the viewpoint of economic efficiency, some kind of failure in markets or other institutions that causes individuals to fail to take into account the social costs and benefits of their individual actions should be identifiable. From a practical perspective, it is also important that such failures result in an important misallocation of resources.

A full discussion of the empirical relevance of ancillary and/or co-benefits is provided in Chapters 8 and 9.

7.2.2.6 A Partial Taxonomy

A variety of effects may result from GHG policies that are secondary to the reduction in GHG emissions. Existing studies have identified mortality and morbidity benefits associated with collateral reductions in particulates, nitrogen oxides (NO_x), and sulphur dioxide (SO_2) from power plants and mobile sources as a major source of ancillary benefits. Reduced private vehicle use and substitution of mass transit will reduce air pollution and congestion and may also reduce transportation-related fatalities from accidents, although the size of this effect and the degree to which it counts as an ancillary benefit are unclear.[6] Substitution to mass transit may also involve additional costs, in terms of the opportunity cost of

[5] See Burtraw *et al*. (1999) and reviews by Burtraw and Toman (1997), Ekins (1996), and Pearce (2000).

[6] A major study in the early 1990s considered externalities throughout various fuel cycles for electricity generation in the USA. It concluded that of the highest-valued endpoints (among many specifically defined endpoints) were fatalities associated with the rail transport of coal and damage to roadway surfaces beyond those internalized in road fees (Lee *et al*., 1995).

Table 7.1: *Ancillary Impacts*

Ancillary Impact	**Expected sign**
Reduction in particle pollution when fossil fuel use is reduced	(+)
Increases in urban air pollution when diesel vehicles are introduced to substitute gasoline	(–)
Increased availability of recreational sites when reforestation programmes are introduced	(+)
Increases in household air pollution relative to a baseline when electrification rates are reduced	(–)
Increases in technological efficiency when new technologies are adopted and unit costs fall	(+)
Increases in welfare with a shift to carbon taxation and a reduction in unemployment	(+)
Reductions in road-use related mortality when a shift from private to public transport takes place	(+)
Reductions in congestion with a shift from private to public transport	(+)
Decreases in employment when energy technologies that substitute the use of local fuels are introduced	(–)
Increases in employment that result from GHG projects in which there is an excess need for labour	(+)
Decline in employment because of decreased economic activity resulting from costs associated with GHG projects	(–)
Savings in household time in poor rural households when fuel wood use is replaced by biogas energy	(+)

time, and these ancillary impacts may also need to be considered. Additional areas that might be considered include improvements in ecosystem health (for instance, from reduction in nitrate deposition to estuaries), visibility improvements, reduced materials damages, and reduced crop damages.

At the same time, there may be ancillary costs of GHG mitigation, such as an increase in indoor air pollution associated with a switch from electricity to household energy sources (such as wood or lignite) or greater reliance on nuclear power with its attendant externalities. In developing countries pollution may rise if electrification slows as a result of policy-induced increases in electricity prices relative to other fuels (Markandya, 1994). A related cost stems from forgoing the benefits of electrification, which include increased productive efficiency and emergence of new technologies, to increases in literacy (Schurr, 1984). *Table 7.1* offers an illustrative set of examples of ancillary benefits (+) and costs (–). Under certain conditions, some of these observed impacts do not necessarily count as externalities from the standpoint of economic efficiency, depending on whether the market or institutions fail to account for these impacts in the incentives they provide for individual behaviour.

A taxonomy of the main externalities linked with the public health impacts of air pollution, which was developed in the social cost of electricity studies and is likely to be relevant to ancillary benefit estimation, is provided in *Table 7.2*.

7.2.3 Valuation Techniques for External Effects

The external effects described above cannot be valued directly from market data, because there are no “prices” for the resources associated with the external effects (such as clean air, or clean water). Hence indirect methods have to be adopted. Values have to be inferred from individuals’ decisions in related markets, or from directly eliciting the WTP for the environmental good through questionnaires. Values of environmental goods are broadly divided into use values and non-use values. The former comprises those values that result from some direct or indirect use to which the environment is put. Non-use values arise when individuals have a WTP for an environmental resource even when they make no use of it, or never will make any use of it, see Perman *et al*. (1999) for a discussion of this distinction.

The following methods have been developed and used in valuing environmental (and other) externalities. Further details can be found in several books (Hanley *et al.*, 1997; Bateman and Willis, 1999; Markandya *et al.*, 2000).

7.2.3.1 Impact Pathway Analysis

Impact pathway analysis measures the losses of goods and services affected by environmental impacts which are themselves (or their substitutes) priced in the market. To identify these losses, the effects of an action are traced from the release of pollutants and their dispersion in the ambient environment through to their impacts on natural resources and on humans. Based on the changes of market prices of these goods and services caused by the environmental impacts, demand schedules and the respective consumer surplus, measures can be estimated to reflect the welfare losses. This method has been used extensively to value the impacts of air pollution generated by electricity generation and transport (ExternE, 1995; 1997; 1999). Its main limitations are (a) the physical data on the linkages are not always quantified and those that are can be highly uncertain, (b) market prices are not available for all impacts, and (c) the more sophisticated analysis of price changes requires a level of modelling that is not always possible.

7.2.3.2 Property Prices or the Hedonic Method

Property prices vary according to the many attributes associated with them. House prices, for example, reflect size, commercial facilities, local infrastructure, and other attributes such as environmental quality of the house location. From statistical

Table 7.2: *A Sample of externalities assessed in studies of electricity generation*

	Health		Materials	Crops	Forests		Amenity[a]	Ecosystems
	Mortality	**Morbidity**			**Timber**	**Other**		
PM10	AM	AM	AM	NE	NE	NE	AM	NE
SO_2[b]	AM	AM	AM	AM	AM	AP	AM	AP
NO_x[b]	AM	AM	AM	AM	AM	NA	NE	AP
Ozone	AM	AM	AM	AM	NA	NA	NE	NE
Mercury and other heavy metals	NA	NA	NE	NE	NE	NE	NE	?
Routine operations[c]	AM	AM	NE	NE	NE	NE	NE	NE
Water pollutants[d]	NE	NE	NE	NE	NE	NE		AP
Noise	NE	NA	NE	NE	NE	NE	AM	NE

AM, assessed in monetary terms, at least in some studies. AP, assessed in physical terms and possibly partly in monetary terms. NA, not assessed, although they may be important. NE, no effect of significance is anticipated.

[a] Effects of particulate matter less than 10 microns (PM_{10}), NO_x, and SO_2 on amenity arise with respect to visibility. In previous studies these have not been found to be significant in Europe, although they are important in the USA.

[b] SO_2 and NO_x include acid-deposition impacts.

[c] Routine operations generate externalities through mining accidents, transport accidents, power-generation accidents, construction and dismantling accidents, and occupational health impacts. All these involve mortality and morbidity effects and are externalities to the extent that labour markets do not allow individuals to choose employment with different combinations of risk and reward.

[d] Water pollution effects include impacts of mining (including solid wastes) on ground and surface water, power-plant emissions to water bodies, and acid deposition and its impacts on lakes and rivers (partly quantified).

Source: Developed from Markandya and Pavan (1999).

analyses of house prices, the contribution of environmental quality to house price variations can be assessed, which is an estimate of how much people are willing to pay for changes in environmental quality. This measure represents a use value for that environmental change from which a demand function can be estimated. The method has been used to value external effects such as noise, air quality, and visibility. The main limitation is that to work efficiently it requires the affected parties to be well informed about the impacts and markets, so that decisions about location can be made freely and easily. For examples of relevant studies see ExternE (1999), Palmquist (1991), and Zabel and Kiel (2000).

7.2.3.3 Contingent Valuation Method

By asking people directly how much they are willing to pay for a change in a provision of benefits from an environmental resource, a hypothetical market can be created in which a demand curve for ecological goods and services can be estimated. This method is the only one by which non-use values can be estimated, since hypothetical markets can be created for them. Since it is not based on revealed preferences, on which the other demand approaches are based, contingent valuation may incur in various biases, from strategic answers to lack of information. Such biases are currently well documented and techniques have been developed to reduce them. Contingent valuation methods have been used to value the use and non-use of sites of special significance, health effects (including changes in the risk of death), and damages to ecosystems (Bateman and Willis, 1999). Despite the considerable amount of work on reducing the biases that arise because such data do not report actual transactions, this method arouses considerable scepticism among policymakers and its results are not always accepted.

Nevertheless, although such methods of valuation have problems, there is often no suitable alternative and they provide policymakers with important information for decision-making purposes. As suggested above, both physical impacts and values should be used in this process. In relation to climate change, the estimation of external effects arises primarily in the assessment of damages that result from such change, including those in agriculture, forests, energy use, recreation, and health. In relation to mitigation, the applications are primarily in valuing the impacts of O_3, NO_x, SO_x, particulate matter, and secondary particles. In adaptation, the valuation of external effects arises with respect to loss of land, changes to recreational facilities, and changes to agriculture.

7.2.3.4 Benefit Transfer

The valuation of improvements in environmental quality can be expensive. As research budgets are tight, economists explored the concept of "benefit transfer" as a cost-effective alternative to new non-market valuation studies (Desvousges *et al*., 1992; McConnell, 1992). The term benefit transfer reflects its purpose: transfer the estimated economic value from one environmental good or site to another. Benefit transfer reduces the need to design and implement a new and potentially expensive valuation exercise for the second site. A general four stage process (Atkinson *et al*., 1992):

- defines the purpose and desired precision of the benefit estimates;
- develops the transfer protocol for the question in hand;
- identifies existing studies that satisfy the protocol; and
- selects the appropriate statistical transfer method that allows for efficient extrapolation of economic data.

Consider the transfer of health risk estimates. For instance, an estimate of WTP for a given risk reduction from contaminated water in Wyoming could be transferred to a reduced risk of poor water quality in Mongolia, as long as the transfer protocol is satisfied. This protocol can be rather strict, however. For a health risk, the researcher must first specify the commodity. This includes defining the response (death or illness) and causal agent (e.g., chemical), as well as understanding the probability and severity of the risk and risk reduction methods, the temporal dimensions of the risk, whether the risk is voluntary or involuntary, and the exposure pathways and exposure levels. Once the risk is defined, the sample and site characteristics have to be classified, including socioeconomic and location particulars. Finally, the protocol has to address the market and exchange mechanisms that define the frame of how risk is reduced. Three elements are likely to matter–the set of risk reduction mechanisms (e.g., mitigation and adaptation options), the measure of value (e.g., WTP or WTA), and the exchange institution or "payment vehicle" (see Kask and Shogren, 1992).

7.2.4 Implementation Costs and Barrier Removal

All climate change policies necessitate some costs of implementation, that is costs of changes to existing rules and regulations, making sure that the necessary infrastructure is available, training and educating those who are to implement the policy as well those affected by the measures, etc. Unfortunately, such costs are not fully covered in conventional cost analyses. Implementation costs in this context are meant to reflect the more permanent institutional aspects of putting a programme into place and are different to those costs conventionally considered as transaction costs. The latter, by definition, are temporary transition costs. 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 considered in Chapter 6 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 (see the review on mitigation costing studies given in Chapters 8 and 9 of this report). Low mitigation costs, for example, may result from energy-efficiency improvements relating to end-use savings, as well as from the introduction of more efficient supply technologies. There is also potential for the introduction of renewable energy technologies with low costs, such as wind turbines, biomass combustion, and solar water-heating systems. The implementation of such low-cost options in many cases implies that a number of current institutional failures and market barriers exist and that policies should be implemented to correct these.

Following this, mitigation cost assessment, in addition to the direct costs of the programmes, should consider implementations costs that arise in the following areas:

- financial market conditions;
- institutional and human capacities;
- information requirements;
- market size and opportunities for technology gain and learning; and
- economic incentives needed (grants, subsidies, and taxes).

Only some of these implementation conditions can be included in the formal cost assessment carried out for individual mitigation options. It is generally more complicated to design implementation programmes targeted to many individual actors (e.g., a demand-side management (DSM) scheme or a tradable carbon permits scheme) than those with 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 small "marginal" efforts (which create an incentive to change specific behaviour or introduce new technologies), and more general policy efforts, like economic instruments or general educational programmes (which work by changing the general market conditions and the capability of the actors).

Whether an implementation policy is "marginal" or "general" depends on the 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 in which 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 other specific regulation efforts. However, 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 includes 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, to design the most effective policy options.

It is difficult to integrate general implementation policies, like price changes, into specific project and sector assessments. For a DSM programme in the commercial lighting sector, implementation costs include information and training programmes, institutional capacity building, and sometimes also "costs" of changing the 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 the removal of subsidies can cause significant structural effects that, again, change energy demand and technology choice. Thus, the proper full analysis of the implementation costs necessitates an economy-wide analysis that involves, for example, the use of computable general equilibrium (CGE) models and intersectoral macroeconomic models.

To a limited extent, such feedbacks can be integrated into 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. Importantly, however, implementation costs assessed using shadow prices do not pick up factors such as quantitative or physical constraints on the use and allocation of some resources, particularly financial ones.

A framework to assess implementation costs thus includes the costs of project or policy design, institutional and human capacity costs (management and training), information costs, and monitoring costs. The costs of resources involved should, in each case, be based on economic opportunity costs.

7.2.5 Discounting

The debate on discount rates is a long-standing one. As SAR notes (IPCC, 1996a, Chapter 4), there are two approaches to discounting; an ethical, or prescriptive, approach based on what rates of discount should be applied, and a descriptive approach based on what rates of discount people (savers as well as investors) actually apply in their day-to-day decisions. SAR notes that the former lead to relatively low rates of discount (around 2%–33% in real terms) and the latter to relatively higher rates (at least 6% and, in some cases, very much higher rates).

The ethical approach applies the so-called social rate of time discount, which is the sum of the rate of pure time-preference and the rate of increase of welfare derived from higher per capita incomes in the future. The descriptive approach takes into consideration the market rate of return to investments, whereby conceptually funds can be invested in projects that earn such returns, with the proceeds being used to increase the consumption for future generations. Portney and Weyant (1999) provide a good overview of the literature on the issue of intergenerational equity and discounting.

For climate change the assessment of mitigation programmes and the analysis of impacts caused by climate change need to be distinguished. The choice of discount rates applied in cost assessment should depend on whether the perspective taken is the social or private case. The issues involved in the application of discount rates in this context are addressed below.

For mitigation effects, the country must base its decisions at least partly on discount rates that reflect the opportunity cost of capital. In developed countries rates around 4%–6% are probably justified. Rates of this level are in fact used for the appraisal of public sector projects in the European Union (EU) (Watts, 1999). In developing countries the rate could be as high as 10%–12%. The international banks use these rates, for example, in appraising investment projects in developing countries. It is more of a challenge, therefore, to argue that climate change mitigation projects should face different rates, unless the mitigation project is of very long duration. These rates do not reflect private rates of return, which typically need to be considerably higher to justify the project, potentially between 10% and 25%.

For climate change impacts, the long-term nature of the problem is the key issue. The benefits of reduced GHG emissions vary with the time of emissions reduction, with the atmospheric GHG concentration at the reduction time, and with the total GHG concentrations more than 100 years after the emissions reduction. These are very difficult to assess.

Any "realistic" discount rate used to discount the impacts of increased climate change impacts would render the damages, which occur over long periods of time, very small. With a horizon of around 200 years, a discount rate of 4% implies that damages of US$1 at the end the period are valued at 0.04 cents today. At 8% the same damages are worth 0.00002 cents today. Hence, at discount rates in this range the damages associated with climate change become very small and even disappear (Cline, 1993).

A separate issue is that of the discount rate to be applied to carbon. In a mitigation cost study, should reductions of GHG in the future be valued less than reductions today? It could argued that this is the case, as the impacts of future reductions will be less. This is especially true of "sink" projects, some of which will yield carbon benefits well into the future. Most estimates of the cost of reductions in GHGs do not, however apply a discount rate to the carbon changes. Instead, they simply take the average amount of carbon stored or reduced over the project lifetime (referred to as flow summation) or take the amount of carbon stored or reduced per year (flow summation divided by the number of years). Both these methods are inferior to the application of a discount rate to allow for the greater benefit of present reductions over future reductions. The actual value, however remains a matter of disagreement, but the case for anything more than a very low rate is hard to make (Boscolo *et al*., 1998).

More recent analysis on discounting now examines rates that vary with the time period considered. In surveys of individual trade-offs over time, Cropper *et al.* (1994) estimated a nominal rate of around 16.8%, based on a sophisticated questionnaire approach to valuing present versus future risks. Most importantly, however, these authors found evidence that respondents do not discount future lives saved at a constant exponential rate of discount. Rather, median rates seem to be decline over time (i.e., a rate is not constant over time but decreases as the time horizon lengthens). Using different econometric specifications that allow the discount rate to decline over time, Cropper *et al*. (1994) estimate that mean discount rates are greater for short time periods relative to long time horizons. For example, fitting their data to a hyperbolic function suggests that mean discount rate is 0.80 for 1 year and 0.08 for 100 years. While the pattern is consistent, the implied rates using linear discount rate functions are much larger: 34% for the initial period and about 12% for the last period.

Hyperbolic discounting implies that a person's relative evaluation of two payments depends on both the delay between the two payments and when this delay will occur–sooner or later. For instance, people often have an impulsive preference for immediate reward. Some people prefer to receive US$1000 today over US$1010 in a month's time, and yet they also prefer US$1010 in 21 months to US$1000 in 20 months, even though both choices involve a month's wait to obtain $10 more (see Lowenstein and Prelec, 1992). Theoretical support for hyperbolic discount rests on the idea that, while interest rates from financial instruments can be used to identify appropriate discount rates for time horizons of a few decades, they do not apply to future interest rates for far distant horizons. These will be determined by future opportunity sets created by many factors, such as economic growth. The fact that the scope of these future opportunity sets for the far distant future is not known adds another layer of uncertainty into climate policy, which tends to drive discount rates down.

Weitzman (1998) surveyed 1700 professional economists and found that (a) economists believe that lower rates should be applied to problems with long time horizons, such as that being discussed here, and (b) they distinguish between the immediate and, step by step, the far distant future. The discount rate implied by the analysis falls progressively, from 4% to 0%, as the perspective shifts from the immediate (up to 5 years hence) to the far distant future (beyond 300 years). Weitzman (1998) suggests the appropriate discount rate for long-lived projects is less than 2%. Finally, hyperbolic discounting has less support if it leads to time-inconsistent planning, as argued by Cropper and Laibson (1999). Time inconsistency arises when a policymaker has an incentive to deviate from a plan made with another person, say in the future, even when no new information has emerged. Policymakers of today try to commit future policymakers to a development path that is sustainable. But when the future actually arrives, these new policymakers deviate from the sustainable path and reallocate resources that are efficiently based on prevailing interest rates.

Finally the case is made for calculating all intertemporal effects with more than one rate. The arguments outlined above for different rates are unlikely to be resolved, given that they have been an issue since well before climate change. Hence it is good practice to calculate the costs for more than one rate to provide the policymaker with some guidance on how sensitive the results are to the choice of discount rate.[7] A lower rate based on the ethical considerations is, as noted above, around 3%.

7.2.6 Adaptation and Mitigation Costs and the Linkages between Them

Climate change puts society at risk. It is possible to prevent damages through mitigation and adaptation. Mitigation strategies against the risks of climate include curtailing GHG emissions to lower the likelihood that worse states of nature will occur. Adaptation strategies to climate risk include the changing of production and consumption decisions to reduce the severity of a worse state in the scenario if it does occur (Ehrlich and Becker, 1972; Crocker and Shogren, 1999). A portfolio of mitigation and adaptation actions jointly determines climate risks and the costs of reducing them. Since individuals in their private capacity have the liberty to undertake adaptation to climate change on their own accord, modellers and policymakers need to address these adaptive responses when choosing the optimal degree of public mitigation. If this is not the case, then policy actions are likely to be more expensive than they need be, with no additional reduction in climate risk (see, e.g., Schelling, 1992).

While most people appreciate that actions on adaptation affect the costs of mitigation, this obvious point is often not addressed in climate policymaking. Policy is fragmented–with mitigation being seen as addressing climate change and adaptation seen as a means of reacting to natural hazards. As a consequence, the estimated costs of each can be biased (see Kane and Shogren, 2000). Usually, mitigation and adaptation are modelled separately as a necessary simplification to gain traction on an immense and complex issue. One question that must be addressed is "How reasonable is this assumption?" Another is "What are the likely consequences of this assumption on the estimated costs of mitigation?"

[7] It is also useful to display graphically the time path of undiscounted costs, as discounting can obscure important information.

First, separability presupposes that the overall effectiveness and costs of mitigation do not depend on adaptation. However, for this assumption to hold, the implicit presumption is that climate risk is exogenous–a risk beyond people's private or collective ability to reduce. The necessary economic conditions for this to hold are rather restrictive. In particular, climate risk can be considered as exogenous only if markets are complete. A complete set of markets exists if people can contract to insure against all risks from each conceivable state of nature that might be realized (Marshall, 1976). Complete markets allow for perfect risk spreading and risk pooling such that the only remaining risk is outside the control of human actions (e.g., phases of the moon). However, markets for climate risk are notorious incomplete or non-existent because of the high cost of contracting (Chichilnisky and Heal, 1993). People make private and collective adaptation decisions through the markets that do exist and through collective policy actions. The economic circumstances that influence these choices matter to the level of risk, and addressing these conditions is essential for the successful estimation of costs. People choose to create and reduce risk. How people perceive risk, the relative costs and benefits of alternative risk reduction strategies, and relative wealth affect these choices.

Similar to income and substitution effects, adaptation can have two effects on the costs of mitigation. First, more adaptation can lower mitigation costs because policymakers choose to move to another point on the same mitigation cost curve - adaptation does not alter the marginal productivity of mitigation, it induces a shift along the cost curbe. Second, adaptation acting as a technical substitute or complement shifts the mitigation cost curve. For example, flood defences change land use and thereby change costs and prices in an area, which impacts on mitigation costs. Whether adaptation causes a shift along the mitigation cost curve or a shift of the entire curve itself, or both, then becomes a modelling question, and an empirical one to determine the magnitude of the shift along and to a new cost curve.

Second, sectoral work in agriculture, forestry, and coastal areas shows that cost estimates are sensitive to the inclusion of adaptation (see, e.g., Sohngen and Mendelsohn, 1997; Sohngen *et al*., 1999). Greater climate variability, for instance, can influence how adaptation affects mitigation in agriculture. Increased levels of risk directly induce a nation to adapt more by switching its crop mix and crop varieties to those more tolerant of drier or wetter conditions, and by modifying its weed control strategies. The magnitude of this adaptation depends on how risk affects the perceived marginal productivity of mitigation (e.g., more or less effective soil sequestration per unit of area), and how mitigation and adaptation work with or against each other. Bouzaher *et al*. (1995), for example, estimate that winter cover crops can be used to increase soil organic carbon by expanding annual biomass production. They also show that conservation tillage, the Conservation Reserve Program, and the Wetlands Reserve Program can increase soil carbon by minimizing soil disturbance and targetting bottomland for hardwood trees. For non-climate risk, models that account for mitigation and adaptation risk estimate that benefits are underestimated by 50% when adaptation is ignored (e.g., Swallow, 1996).

Third, uncertainty in cost is affected by interaction of the technologies for risk reduction–mitigation and adaptation. By mitigation, humans reduce the odds that a deleterious event happens; by adaptation, they reduce the consequences when a damaging event actually does occur. For the most part, climate change literature contains models that deal with mitigation and adaptation separately. This is unfortunate, since significant interactions are likely to exist between how people choose to mitigate and adapt (Shogren and Crocker, 1999). These risk-reduction strategies probably complement or negate each other. Understanding the interaction between the two can help formulate better the analysis of mitigation costs. The benefits of mitigation will be lower if more people can adapt to the climate.

These results suggest that more it would be worthwhile to pay more attention to the interaction of mitigation and adaptation, and its empirical ramification. The challenge is to capture in a reasonable way the linkages between these sets of actions, and to establish how this interaction can impact the estimated costs of climate protection. Even if a complete empirical application of the portfolio of risk avoidance is currently unreachable, an understanding of which unmeasured links might be most valuable to decision makers in the future could indicate whether the costs of mitigation are being underestimated.

7.3 Analytical Structure and Critical Assumptions

7.3.1 System Boundaries: Project, Sector, Macroeconomic

Assessing climate change mitigation involves a comparison between a policy case and a non-policy case, otherwise referred to as a baseline case. The two should, as far as possible, be defined in a way that the assessment can include all major economic and social impacts of the policies, spillovers, and leakages, as well as GHG emission implications. In other words, the cases should be assessed in the context of a "system boundary" that include all major impacts. The system boundary can be a specific project, include one or more sectors, or the whole economy.

The project, sector, and macroeconomic levels can be defined as follows:

- *Project.* A project level analysis considers a "stand-alone" investment that is assumed not to have significant impacts on markets (both demand and supply) beyond the activity itself. The activity can be the implementation of specific technical facilities, infrastructure, demand-side regulations, information efforts, technical standards, etc. Methodological frameworks to assess the project level impacts include cost–benefit analysis, cost-effectiveness analysis, and lifecycle analysis.

- *Sector.* Sector level analysis considers sectoral policies in a "partial-equilibrium" context, for which other sectors and the macroeconomic variables are assumed to be as given. The policies can include economic instruments related to prices, trade, and financing, specific large-scale investment projects, and demand-side regulation efforts. Methodological frameworks for sectoral assessments include various partial equilibrium models and technical simulation models for the energy sector, agriculture, forestry, and the transportation sector.
- *Macroeconomic.* A macroeconomic analysis considers the impacts of policies across all sectors and markets. The policies include all sorts of economic policies, such as taxes, subsidies, monetary policies, specific investment projects, and technology and innovation policies. Methodological frameworks include various sorts of macroeconomic models such as general equilibrium models, Keynesian models, and Integrated Assessment Models (IAMs), among others.

A "trade-off" is expected between the details in the assessment and the complexity of the system considered. For example a project system boundary allows a rather detailed assessment of GHG emissions and economic and social impacts generated by a specific project or policy, but excludes sectoral and economy-wide impacts. Conversely, an economy-wide system boundary, in principle, allows all direct and indirect impacts to be included, but has little detail on the impacts of implementing specific projects.

The system boundaries may be selected on the basis of the specific scope of the study and the availability of analytical tools, such as models. Many studies have been organized, in practice, on the basis of the scope and structure of the modelling tools applied. For example, climate change mitigation studies for the energy sector were frequently structured according to traditional modelling approaches used in that sector, which are often rich in detail on technologies, but do not include market behaviour. In contrast, macroeconomic models are often rich in detail on market behaviour and price relationships, but do not explicitly include major GHG emitting sources and related technologies.

Project assessment methodologies are generally very rich in detail and include an assessment of various direct and indirect costs and benefits of the GHG reduction policy considered. The assessments are often conducted as very data-intensive exercises, in which various project assessment tools and expert judgements are combined. They require rather strong technical skills of the experts in the collection of data, to ensure consistency in the structure and results of the analysis.

A combination of different modelling approaches is required for an effective assessment of the options. For example, detailed project assessment has been combined with a more general analysis of sectoral impacts, and macroeconomic carbon tax studies have been combined with the sectoral modelling of larger technology investment programmes.

7.3.2 Importance of Baselines

7.3.2.1 Development Patterns and Baseline Scenario Alternatives

The baseline case, which by definition gives the emissions of GHGs in the absence of the climate change interventions being considered, is critical to the assessment of the costs of climate change mitigation. This is because the definition of the baseline scenario determines the potential for future GHG emissions reduction, as well as the costs of implementing these reduction policies. The baseline scenario also has a number of important implicit assumptions about future economic policies at the macroeconomic and sectoral levels, including sectoral structure, resource intensity, prices and thereby technology choice.

Macroeconomic issues that are particularly relevant to developing countries (such as instability of output, constrained capital, and foreign exchange) similarly have important implications on GHG emissions through impacts on energy sector investments and energy-intensive production sectors. These assumptions have important implications for the efficiency of policy instruments applied to climate change mitigation strategies and thereby for implementation costs, which are discussed in Section 7.2.3.

Economic policies have a number of direct and indirect impacts on GHG emitting sectors. It is generally expected that successful economic policies generate increased growth and the emissions intensity of the economy then depends on the mix of products produced as well as on the efficiency with which they are produced. Economic policies in some cases can imply a more efficient use of resources, which means that the GHG emission intensity per unit of economic output decreases. The tendency to increase GHG emissions alongside economic growth is expected to be particularly "strong" in countries that presently have low energy consumption. The challenge is to pursue a development pattern in which economic development is achieved alongside relatively low GHG emissions and other environmental impacts.

Many macroeconomic and sectoral policies have important consequences for future GHG emissions through the impacts on sectoral structure, resource intensity, prices, and thereby technology choice. Macroeconomic issues like constrained capital and foreign exchange can lead to low investments in the energy sector, to major energy-intensive production sectors, or to the high utilization of pollution-intensive domestic fuels. In the same way, uncertainty or macroeconomic instability has a tendency to slow down investments because of the risk perceptions of foreign and national investors, and because of high interest rates.

As noted, GHG emissions are interlinked with general economic development patterns and economic policies. These policies have an influence both on the baseline as well as on the effectiveness of the mitigation options, and thereby on GHG emission levels. It is useful to "decompose" the GHG emission/GDP intensity factor into subcomponents that explain the implicit resource components behind the GHG emissions. One way to achieve this for the energy sector is based on the so-called Kaya identity (Kaya, 1989):

$$\frac{GHG\ emissions}{GDP} = \frac{GHG\ emissions}{energy} \times \frac{energy}{GDP}$$

The first component of the identity, GHG emissions per energy unit, reflects the GHG emission intensity of energy consumption, which again reflects natural resource endowment and relative prices of the different energy sources. The second factor (energy consumption per GDP unit) reflects both the weight of energy-intensive processes in GDP and the efficiency of the resources used. The same approach can be used to assess GHG emission intensities of other sectors, such as agriculture, forestry, waste management, and industry.

Development may follow different paths in countries according to socioeconomic conditions, resources, national policies and priorities, and institutional issues. For instance, a rapidly growing economy develops a different composition of capital stock and energy use pattern compared with a slowly growing country. A nation following development policies that emphasize greater investments in infrastructure, such as efficient rail transport, renewable energy technologies, and energy efficiency improvements, exhibits a low GHG emission trajectory. However, a nation with substantial coal resources, scarce capital, and a low level of trade can be pushed towards a development path with high emissions.

7.3.2.2 Multiple Baseline Scenarios

The above discussion identifies a number of reasons why the establishment of a baseline case is very difficult and uncertain. There are some additional reasons why this is so. 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 endogenous, their direction being determined at least partly by political decisions. There are also many general uncertainties that impact on the establishment of a baseline case, for example political and social changes.

The above considerations further emphasize the need for work on the basis of several alternative baseline scenarios characterized by different assumptions regarding development patterns and innovation. This allows the mitigation or adaptation assessments to create an estimate range for 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.

In reality, this 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 within a much wider analytical perspective. Using a number of different development patterns is of particular importance to 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. A baseline scenario approach that assumes current development trends to continue is therefore not very useful in these countries (IPCC, 1996a, Chapter 8).

The scenarios of the IPCC *Special Report on Emissions Scenarios* (IPCC, 2000a) show that alternative combinations of driving-force scenario variables can lead to similar levels and structure of energy use and land-use patterns. Hence for a given scenario outcome, for example in terms of GHG emissions, alternative pathways can lead to that outcome. The conclusion is therefore that one and only one development path does not exist and studies preferably should include multiple baseline scenarios that facilitate a sensitivity analysis of the key scenario variables and assess the consequence of different development patterns.

7.3.2.3 Baseline Scenario Concepts

The literature reports several different baseline scenario concepts, including (Sanstad and Howart, 1994; Halsnæs *et al*., 1998; Sathaye and Ravindranath, 1998):

- efficient baseline case, which assumes that all resources are employed efficiently; and
- "business-as-usual" baseline case , which assumes that future development trends follow those of the past and no changes in policies will take place.

These different baseline scenario concepts represent different expectations about future GHG emission development trends, as well as different perspectives on the trade-offs between climate change mitigation policies and other policies. The costs of a given GHG emissions reduction policy depend in a very complicated way on numerous assumptions about future GHG emissions, the potential for emissions reductions, technological developments and penetration, resource costs, and markets.

The different GHG emission profiles of the alternative baseline-scenario approaches depend on a number of assumptions. These include economic growth, mix of products, GHG emissions, intensity of energy production and consumption, and other material use. A "business-as-usual" baseline case is often associated with high GHG emissions, particularly if current main GHG emission sources, such as the energy industry, run at low efficiency. Such a baseline case can reflect the continuation of current energy-subsidy policies (which implies relatively high energy consumption and thereby high GHG emissions) or various other market failures of particular importance for GHG emission intensive sectors, such as capital market constraints. An efficient baseline case that assumes properly

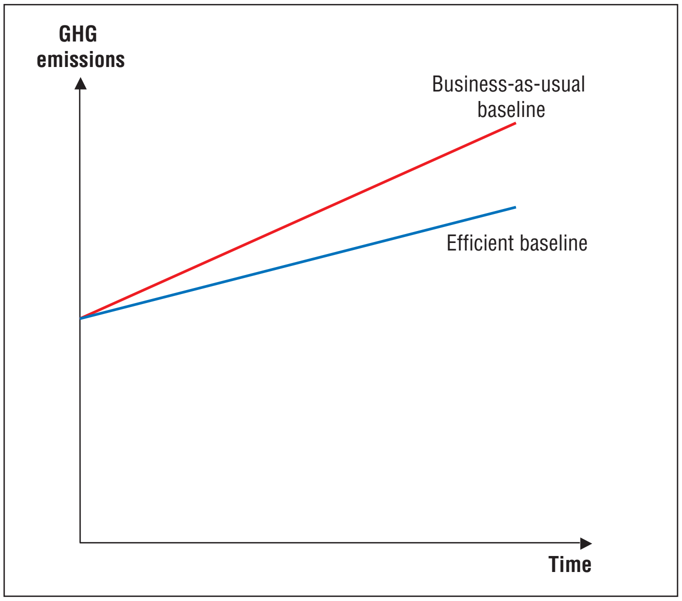

Figure 7.2: *Greenhouse gas emission profiles of different baseline case approaches.*

functioning markets, all other things being equal, can be expected to reflect relatively high energy efficiency and thereby lower GHG emissions than a business-as-usual baseline case. GHG emission profiles of the different baseline case approaches are illustrated in *Figure 7.2*.

The GHG emission reduction potential of a given policy is to be measured as the difference between the GHG emissions in the baseline case and the GHG emissions after the implementation of the policy. Clearly, this difference depends on both the baseline and the options chosen for the mitigation. High baseline-scenario GHG emissions based on a business-as-usual scenario approach in some cases can imply that the net mitigation costs measured per unit of GHG emission reduction are relatively low. Such a result, for example, can reflect that the mitigation scenario is assumed to imply a general efficiency improvement of the energy systems compared with the baseline wich both reduces GHG emission and generates fuel cost savings. The total costs of achieving a given GHG emission level (e.g., defined in relation to 1990 emissions), however, can be relatively high when the mitigation strategy is assessed in relation to a business-as-usual baseline scenario that has a large growth in GHG emissions. Conversely, GHG emission reduction costs per unit of emission can be relatively high in relation to an efficient baseline case, but total reduction costs of meeting a target can be low.

It is important to emphasize consistency and transparency in the definition of baselines, and in the reporting of any costs associated in moving from a given baseline case to a climate change policy case. Furthermore, when reporting the range of cost estimates for the different baselines, it is important also to provide information about the assumptions that underlie each baseline.

7.3.2.4 Specific Baseline Issues Related to International Co-operative Mechanisms for Greenhouse Gas Emission Reductions

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) includes a number of mechanisms for international co-operation about GHG emission reductions. The Protocol includes two project-based mechanisms, namely the clean development mechanism (CDM) and joint implementation (JI). The operational details of these two mechanisms are discussed in a number of studies which include a number of different arguments for baseline case approaches. A number of these arguments are subsequently referred and discussed.

A number of studies suggest the use of a so-called standard methodology for setting the baseline case for CDM and JI projects. Here, the baseline case serves as a metric for calculating GHG emission reductions that originate from the approved projects and the main issue is therefore to specify GHG emissions in the absence of the project. A number of specific complexities arise in relation to the definition of baseline cases for projects that do not include major new capital equipment, such as projects that include changes in operational practice, land use, land-use changes, and forestry projects.

Papers that evaluate alternative options for the baseline determination of CDM projects include Michaelowa and Dutschke (1998), Chomnitz (1999), Jepma (1999), Matsuo (1999), Parson and Fisher-Vanden (1999), and Harrison *et al.* (2000). These papers deal with various baseline issues including technology benchmarks, normative benchmarks that are politically chosen, and historical benchmarks based on GHG emission trends. Other important aspects considered include assumptions about baseline development over the timeframe of the CDM project.

He and Chen (1999) have suggested a set of criteria to establish baseline cases from a micro level perspective. In this approach, GHG emissions reduction projects are divided into three project categories:

- technology innovation, in which the GHG emission reduction project should be compared with existing technologies;
- new constructed plants, in which the GHG emission reduction project should be compared with alternative new advanced technologies; and
- technology substitution, in which the GHG emissions reduction project should be compared with a newly constructed existing plant.

A benchmark technology baseline to assess power-sector CDM projects could include assumptions about the efficiency and costs of power production technologies in a specific national or regional area, or could be based on international standards. The actual definition of baseline technologies will has major implications on the GHG emission reduction "performance" of the CDM project.

The choice of baseline case approach for CDM projects or JI projects might have major implications on the global cost effectiveness of climate change mitigation projects. A baseline scenario approach that uses internationally standardized technology data implies that the GHG emission reduction potential and related costs are estimated to be similar for projects implemented at quite different sites. Project host countries that have a relatively low GHG emission intensity from their power system compared with the international baseline standard have a relatively strong "market position" in this case, because the GHG emission reductions achieved with the particular CDM or JI project will be assessed to be relatively high. Project host countries with a relatively high GHG emission intensity compared with the international standard will tend to have a weaker market position than in the alternative approach, in which the baseline case reflects specific national GHG emissions. Baseline cases that underestimate the reductions from a particular project in this way result in fewer projects than is justified. This use of international benchmark technology standards can tend to imply a loss in the global cost-effectiveness of CDM or JI projects.

Another drawback to using a baseline case not related to the specific development context of the project host country is that it can be difficult to design the project such that it creates both global (GHG emission reduction) and local benefits (improvements in the local environment, employment, and income generation, and institutional strengthening). Such drawbacks, however, should be balanced against the expected decrease in transaction costs from using an international benchmark baseline case approach.

7.3.3 Cost Implications of Different Scenario Approaches

The costs of climate change mitigation policies are, by definition, a net incremental cost relative to a given scenario, which includes assumptions on both the baseline case and the policy case. The following section presents a taxonomy of baseline cases and policy scenario cases and discusses these in relation to cost assessments.

In Section 7.2 it is stated that cost assessments should include, in principle, all costs and benefits related to the policies as well as any ancillary benefits and costs. The actual determination of impacts related to the policies, however, is open to interpretation and discussion, and the actual selection of system boundaries for the cost assessment will reflect specific assumptions in the baseline as well as in the policy case scenario.

One way to evaluate the impact of different scenario structures on costs is to distinguish between the gross and the net costs of climate change mitigation policies. Gross costs are here defined to reflect all direct and indirect costs and benefits of the mitigation policy, when this policy is considered as the primary policy objective. Net costs are the gross costs corrected for side effects that result from potential synergies or trade-offs between mitigation policies and general economic policies or non-GHG environmental policies. These side effects can be divided into three categories (IPCC, 1996a, Chapter 8):

- A double dividend related to recycling of the revenue of carbon taxes in such a way that it offsets distortionary taxes.
- Ancillary impacts, which can be synergies or trade-offs in cases in which the reduction of GHG emissions have joint impacts on other environmental policies (i.e., relating to local air pollution, urban congestion, or land and natural resource degradation). These are referred to as ancillary or co-benefits and are discussed in Section 7.2.2.
- Impacts on technological development and efficiency. These include specific incentives to develop and penetrate new technologies, technology learning, and reduction of current barriers to efficiency improvements in existing technical systems (part of these impacts are considered as part of the so called no regret potential, see Section 7.3.4.2 for a more detailed discussion).

7.3.3.1 Double Dividend

The potential for a double dividend arising from climate mitigation policies has been extensively studied during the 1990s. In addition to the primary aim of improving the environment (the first dividend), such policies, if conducted through revenue-raising instruments such as carbon taxes or auctioned emission permits, yield a second dividend, which can be set against the gross costs of these policies.

The literature demonstrates theoretically that the costs of addressing greenhouse targets with policy instruments of all kinds–command-and-control as well as market-based approaches–can be greater than otherwise anticipated, because of the interaction of these policy instruments with existing domestic tax systems.[8] Domestic taxes on labour and investment income change the economic returns to labour and capital and distort the efficient use of these resources.

The cost-increasing interaction reflects the impact that GHG policies can have on the functioning of labour and capital markets through their effects on real wages and the real return to capital.[9] By restricting the allowable GHG emissions, permits, regulations, or a carbon tax raise the costs of production and the prices of output, and thus reduce the real return to labour and capital. If government revenues are to remain unchanged, labour or capital tax rates have to be raised, exacerbating prior distortions in the labour and capital markets. Thus, to attain a given GHG emissions target, all instruments have a cost-increasing "interaction effect".

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[8] For a very readable account of the basic analytics and economic intuition at the heart of this literature, see pages 281–284 in Kolstad (2000).

[9] See, for example, Parry *et al*. (1999).

For policies that raise revenue for the government (carbon taxes and auctioned permits), this is only part of the story, however. These revenues can be recycled to reduce existing distortionary taxes. Thus, to attain a given GHG emissions target, revenue-generating policy instruments have the advantage of a potential cost-reducing "revenue-recycling effect", as compared to the alternative, non-auctioned tradable permits or other instruments that do not generate revenue (Bohm, 1998). In a simple, stylized representation of the economy, Bovenberg *et al.* (1994) and Goulder (1995a, b) suggest that in only a few cases is the tax interaction effect fully offset by the revenue-recycling effect. In theoretical, numerical analyses, the "interaction effect" is found to be larger than the "revenue-recycling effect" (Parry *et al*., 1999), which means that the introduction of an environmental policy, regardless of the policy instrument(s) used, has a net cost to the economy.[10] It is also true, however, that under some circumstances the (cost-reducing) "revenue-recycling effect" might exceed the (cost-increasing) "interaction effect". This could happen if, for example, the interaction effect was small, for example because of a sufficiently inelastic labour supply, or if some highly distortionary pre-existing taxes could be lowered.[11]

However, it is unclear whether the empirical findings of the interaction effect are due more to the assumptions invoked for tractable general equilibrium analysis than to real-world considerations (Kahn and Farmer, 1999).

In summary, all domestic GHG policies have an indirect economic cost from the interactions of the policy instruments with the fiscal system, but in the case of revenue-raising policies this cost is partly offset (or more than offset) if, for example, the revenue is used to reduce existing distortionary taxes. Whether these revenue-raising policies can reduce distortions in practice depends on whether revenues can be "recycled" to tax reduction. See Chapter 6 for the policy relevance of these estimated effects and Chapter 8 for model-based empirical studies.

[10] The environmental policy should yield environmental benefits, including some non-market benefits. A cost–benefit analysis of the proposed policy compares these benefits with the estimated cost of the policy.

[11] The term "strong double dividend" has been used in the literature for cases in which the revenue-recycling effect not only exceeds the interaction effect but also the direct (GDP) costs of reducing emissions, thus making revenue-generating environmental policy costless. A revenue-recycling effect this large presupposes that the original tax structure is seriously inefficient (e.g., that capital is highly overtaxed relative to labour). This in itself calls for a tax reform the benefits of which should not be ascribed to the introduction of a revenue-generating environmental policy, even if the two were made on one and the same occasion (see SAR, Chapter 11). In this perspective, the term "strong (or weak) double dividend" becomes redundant (see also Chapter 8).

7.3.3.2 Ancillary Impacts

The definition of ancillary impacts is given in Section 7.2.2.3. As noted there, these can be positive as well as negative. It is important to recognize that gross and net mitigation costs cannot be established as a simple summation of positive and negative impacts, because the latter are interlinked in a very complex way. Climate change mitigation costs (gross and well as net costs) are only valid in relation to a comprehensive specific scenario and policy assumption structure.

An example is transportation sector options that have an impact on both GHG emissions and urban air pollution control programmes. GHG emission control policies, like vehicle maintenance programmes, reduce both GHG emissions and other pollution, but another option, like the introduction of diesel trucks as a substitute for gasoline trucks, decreases GHG emissions but increases NO_x emissions and thereby local air pollution. The gross and net costs assessed for these programmes depend on specific baseline and policy case scenarios (specifically, the assumptions on urban air pollution control policies are critical).

It is important that assumptions about environmental control policies outside the specific area of GHG emissions reduction be carefully specified in relation to the baseline as well as to the policy case. If the baseline assumes that some environmental control policies are implemented in the time frame considered, the side effects of the GHG reduction policy in relation to these areas cover part of these environmental policy objectives. The mitigation costs then eventually offset part of the control cost in the baseline case. However, if the baseline case includes specific flue-gas cleaning systems on power plants to control SO_2 and NO_x emissions that are already installed, then investments in these plants are irreversible. In this case, the joint benefit of climate change mitigation programmes in the form of avoided control cost on the other emissions is low, while the public health ancillary benefits may be substantial (see also the discussion on ancillary and/or co-benefits in Section 7.2.2).

7.3.3.3 Technological Development and Efficiency Impacts

Assumptions about technological development and efficiency in the baseline and mitigation scenarios have a major impact on mitigation costs, in particular in bottom-up mitigation cost studies. Many of these studies structure the cost assessment around an estimation of the costs and other impacts of introducing technological options that imply lower GHG emissions. The existence and magnitude of a potential for technological efficiency improvements depends on expectations about technology innovation and penetration rates given consumer behaviour and relative prices. These assumptions are discussed in more detail in Section 7.3.4.

A number of cost studies assessed different parts of the three above-mentioned side effects. The double dividend is assessed predominantly in macroeconomic studies on the basis of fairly detailed modelling representation of tax systems and specific labour market constraints that cover the short-to-medium term time horizon. Joint environmental impacts of climate change mitigation policies are examined in various studies, including macroeconomic studies, sectoral studies, and technology-specific engineering studies. Impacts of technological development and efficiency are basically addressed in all sorts of studies, sometimes explicitly but sometimes implicitly. The lack of an integrated treatment of all three issues is, *inter alia*, a consequence of the different approaches to the technology characterisation in top-down models (macroeconomic) and bottom-up models (technology- or policy-specific models), which are further explained and discussed in Section 7.6. A few studies exist, however, that attempt such an integration (see, e.g., Walz, 1999).

7.3.4 Assumptions about Technology Options

7.3.4.1 Technological Uncertainty

Costing climate change policy is an uncertain business. This uncertainty often manifests itself in the choice of technologies to mitigate and adapt to risks from climate change. Firms and nations can attempt to reduce risk by using more of the low-carbon technologies presently on the shelf or they can invent new ones. How quickly people will switch within the set of existing technologies with or without a change in relative energy prices is open to debate; how creative people are at inventing new technologies given relative prices is also a matter of discussion.

The key to addressing uncertainty is to capture a range of reasonable behaviours that underpins the choice to adopt existing or develop new low-carbon technology. Two key questions that should be addressed are:

- What explains the rate of adoption of existing low-carbon technologies given the relative price of energy?
- What explains the rate of invention of new low-carbon technologies given relative prices?

Which answers to these questions are accepted determines whether some weighted average of the estimates or a lower or upper estimate is used to guide policy.

For any given target and set of policy provisions, costs decline when consumers and firms have more plentiful low-cost substitutes for high-carbon technologies. Engineering studies suggest 20%-25% of existing carbon emissions could be eliminated (depending on how the electricity is generated) at low cost if people switched to new technologies, such as compact fluorescent light bulbs, improved thermal insulation, heating and cooling systems, and energy-efficient appliances. The critical issue is how this adoption of efficient technologies occurs in practice and which sort of regulation and economic instruments could eventually support this adoption. Chapter 5 of this report assesses the literature regarding technology adoption and regulation frameworks.

Many economists have emphasized that technological progress is driven by relative prices, and that people do not switch to new technologies unless prices induce them to switch. New efficient technologies, according to this argument, then are not taken up without a proper price signal. People are also perceived to behave as if their time horizons are short, perhaps reflecting their uncertainty about future energy prices and the reliability of the technology. Also, factors other than energy efficiency matter to consumers, such as a new technology's quality and features, and the time and effort required to learn about it and how it works. This issue has already been flagged in relation to technology adoption and implementation costs, but it also has an uncertainty element to it.

The different viewpoints on the origin of technological change appear in the assumed rate at which the energy-consuming capital can turnover without a change in relative energy prices. Modellers account for the penetration of technological change over time through a technical coefficient called the "autonomous energy efficiency improvement" (AEEI). The AEEI reflects the rate of change in energy intensity (the energy-to-GDP ratio) holding energy prices constant (see IPCC, 1996a, Chapter 8). The presumed autonomous technological improvement in the energy intensity of an economy can lead to significant differences in the estimated costs of mitigation. As such, many observers view the choice of AEEI as crucial in setting the baseline scenario against which to judge the costs of mitigation. The costs of mitigation are inversely related the AEEI– the greater the AEEI the lower the costs to reach any given climate target. The costs decrease because people adopt low-carbon technology of their own accord, with no change in relative prices.

Modellers have traditionally based the AEEI on historical rates of change, but now some are using higher values based on data from bottoms-up models and arguments about "announcement effects". For instance, some analysts have optimistically argued that the existence of the Kyoto Protocol will accelerate the implementation of energy efficient production methods to 2% per year or more. Policymakers and modellers continue to debate the validity of this assumption (see, e.g., Kram, 1998; Weyant, 1998). A range of AEEIs has been adopted in the modelling literature (see Chapter 8 for more details). The AEEI has ranged from 0.4% to 1.5% per year for all of the regions of the world, and has generated large differences in long-term project baselines (e.g., Manne and Richels, 1992). Edmonds and Barns' (1990) sensitivity study confirms the importance of the AEEI in affecting cost estimates. However, as noted by Dean and Hoeller (1992): "unfortunately there is relatively little backing in the economic literature for specific values of the AEEI ... the inability to tie it down to a much narrower range ... is a severe handicap, an uncertainty which needs to be recognized."

7.3.4.2 No Regrets Options

No regrets options are by definition GHG emissions reduction options that have negative net costs, because they generate direct or indirect benefits that are large enough to offset the costs of implementing the options. The costs and benefits included in the assessment, in principle, are all internal and external impacts of the options. External costs arise when markets fail to provide a link between those who create the "externality and those affected by it; more generally, when property rights for the relevant resources are not well defined. External costs can relate to environmental side-impacts, and distortions in markets for labour, land, energy resources, and various other areas. By convention, the benefits in an assessment of GHG emissions reduction costs do not include the impacts associated with avoided climate change damages. A broader definition could include the idea that a no regrets policy would, in hindsight, not preclude (e.g., by introducing lock-in effects or irreversibilities) even more beneficial outcomes, but this is not taken up in the mitigation literature. The no regret concept has, in practice, been used differently in costing studies, and has in most cases not included all the external costs and implementation costs associated with a given policy strategy.

The discussion of "no regrets" potential has triggered an extensive debate, which is particularly well covered in the SAR (IPCC 1996a, Chapters 8 and 9). The debate is summarized rather simply in graphical form in *Figure 7.3*.

Figure 7.3 illustrates the production frontier (F) of an economy that shows the trade-off between economic activity (Q) and emissions reduction (E). Each point on the curve shows the maximum level of emissions reduction for a given level of economic activity. The economy is producing composite goods, namely an aggregation of all goods and services Q and environmental quality E, which here represent GHG emissions. Given such an assumption it is possible to construct a curve

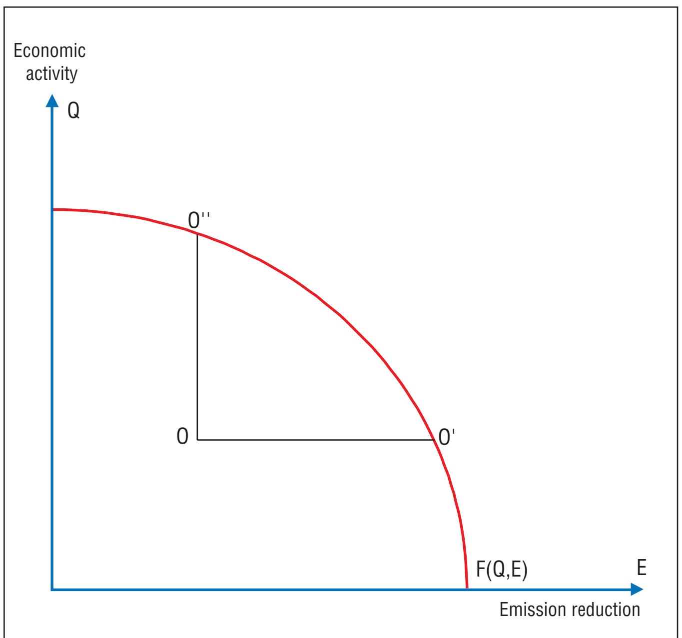

Figure 7.3: *Trade-off between emissions reduction and economic activity.*

F(Q,E) that represents the trade-off between Q and E. For a given economy at a given time, each point on F shows the maximum size of the economy for each level of GHG emissions, and therefore it shows the loss in economic output measured by Q associated with reductions in GHG emissions level E. If the economy is at a level below F then it is possible to increase the total production of Q and/or E. If O is taken as the starting point of the economy in *Figure 7.3* then all movements in the "triangle" OO′O′′ increase environmental quality E and/or economic output Q, but do not decrease either of these goods. Movements to positions outside this "triangle" imply a decrease in both economic activity Q and environmental quality E, or a trade-off in which one of these two goods decreases.

In estimating the costs, the crucial question is where the baseline scenario is located with respect to the efficient production frontier of the economy F. If the chosen baseline scenario assumes that the economy is located on the frontier, as in the efficient baseline case, there is a direct trade-off between economic activity and emissions reduction. Increased emissions reduction moves the economy along the frontier to the right. Economic activity is reduced and the costs of mitigation increase. If the economy is below the frontier, at a point such as O, there is a potential for combined GHG emissions reduction policies and improvements of the efficiency of resource use, implying a number of benefits associated with the policy.

Returning to the implications for the cost of climate change mitigation, it can be concluded that the no regrets issue reflects specific assumptions about the working and efficiency of the economy, especially the existence and stability of a social welfare function, based on a social cost concept. Importantly, the aggregate production frontier is uncertain, as it is dependent on the distribution of resources and is changed by technological development. Since it also involves the weighting of different goods and services by market valuations to form an aggregate, it is also affected by personal and social preferences that influence those valuations.

The critical question is how climate change mitigation policies can contribute to efficient and equitable development of the economy.

In this way it can be argued that the existence of a no regret potential implies:

- that market and institutions do not behave perfectly, because of market imperfections such as lack of information, distorted price signals, lack of competition, and/or institutional failures related to inadequate regulation, inadequate delineation of property rights, distortion-inducing fiscal systems, and limited financial markets;
- that it is possible to identify and implement policies that can correct these market and institutional failures without incurring costs larger than the benefits gained; and

- that a policy decision is made to eliminate selectively those failures that give rise to increased GHG emissions.

In other words, the existence of market and institutional failures that give rise to a no regrets potential is a necessary, but not a sufficient, condition for the potential implementation of these options. The actual implementation also requires the development of a policy strategy that is complex and comprehensive enough to address these market and institutional failures and barriers.

The costs that actually face private agents are different from the social costs, and therefore the market potential (as defined in Chapter 5) may be very different from the potential based on social costs. This implies that the actual implementation of no regrets options requires that it be possible to introduce policies that "narrow the gap" between the market potential and a potential estimated on the basis of social costs. Cameron *et al*. (1999) give a systematic overview of market failures and market barriers important to the implementation of no regrets options.

Returning to the implications for climate change mitigation cost, it can be concluded that the no regrets issues reflect specific assumptions about the location of the economy in relation to the efficient production frontier. Bottom-up studies have (in most cases on the basis of a specific assessment of production practices in main GHG emitting sectors, such as the energy sector) assumed that the economy in the baseline case operates below the optimal frontier and that mitigation policies imply an increased efficiency of technologies. The costs of implementing mitigation policies are then partly offset by direct and indirect benefits, which sometimes are large enough to generate a negative cost result. Top-down approaches, however, assume that the economy is efficient in the baseline case and mitigation policies therefore always imply a trade-off with other goods and thereby have a positive cost.

7.3.5 Cost Implications of Alternative GHG Emission Reduction Options and Carbon Sinks

For a wide variety of options, the costs of mitigation depend on what regulatory framework is adopted by national governments to reduce GHGs. In general, the more flexibility the framework allows, the lower the costs of achieving a given reduction. A stringent, inflexible carbon-mitigation policy induces greater economic burden than a loose, flexible policy. More flexibility and more trading partners can reduce costs. The opposite is expected with inflexible rules and few trading partners.

Flexibility can be measured as the ability to reduce carbon emissions at the lowest cost, either domestically or internationally, including "when and where" flexibility—which assumes a world emissions budget could be spent optimally over space and time to capture all potential intra- and intertemporal efficiencies. Providing a firm or nation with more flexibility to reach a given target and timetable also reduces costs.

The details as to how flexibility is achieved matter. Many advocates prefer emissions trading over carbon taxes because the quantity of carbon flowing into the atmosphere is fixed, thereby shifting risk from the environment to the economy in the form of price uncertainty. However, some suggestions on the design of emissions trading create relatively high transaction costs that would limit the cost savings of a trading system. Furthermore, the key issue of how the emissions rights should be allocated has yet to be resolved (IPCC, 1996a; Jepma and Munasinghe, 1998).

Another source of flexibility is to include carbon sinks in the policy framework. Recall that a carbon sink is a process that destroys or absorbs GHGs, such as the absorption of atmospheric carbon dioxide by terrestrial (e.g., trees) and oceanic biota. The main anthropogenic sink is tree planting and other forest management actions. Soils and other types of vegetation also provide a potential sink. It is estimated that forests around the world contain roughly about 1,146GtC in their vegetation and soil, with about twice as much in soil as in vegetation (See IPCC, 2000c). For the USA, forests are an important terrestrial sink, given that they cover about 750 million acres (about 300 million hectares). Land use changes in the USA have increased the uptake of carbon to an estimated $200MtC_{eq}$.

A few studies found that carbon sequestration through sinks could cost as little as US$25/tonne C in the USA for $150MtC_{eq}$ (Stavins, 1999). But serious uncertainties remain about how to measure and account for estimates of net carbon. For example, how forest management activities affect soil carbon is unknown, and since forest soils contain over 50% of the total stored forest carbon in the USA, this difference can have a significant impact on estimates. And some researchers have shown that sinks are not as effective as predicted when the interaction of forest reserves and the timber market is accounted for. The more land that is set aside for carbon sinks, the quicker the cycle of harvesting on other forestland, and the less total net carbon sequestration. Some fear that these ambiguities about sinks could divert attention from first-order priorities to second-order technicalities (Jacoby *et al*., 1998).

To sum up, flexibility in the regulatory framework can play a major role in reducing the costs of GHG emissions reduction. The extent to which particular instruments can be adopted, however, depends on resolving serious political differences as to how the burden of emissions reduction should be shared, between developed countries themselves, and between both developed and developing countries. It is important also not to underestimate the costs of implementing changes in regulatory policy (see Section 7.2.3), especially in developing countries. For some of the practical problems in using flexible instruments in such countries, see Seroa da Motta *et al*. (1999).

7.3.6 Uncertainty[12]

A thread that runs through much of the discussion of costs is that of uncertainty. The whole exercise of estimating mitigation costs is confounded by imprecise information about baselines, and the costs of mitigation and adaptation measures (especially future costs). It is critical that such uncertainties be recognized and conveyed to the policymakers in the most effective manner possible.

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

Technological uncertainty is another key area. As noted in Section 7.3.4.1, the autonomous rate of improvement in the energy-to-GDP ratio that underlies almost all models of climate economics is a clear example of an exogenous parameter currently subject to uncertainty. This is not easy to overcome by endogenizing technical change, as practical models currently available have difficulties in dealing with endogenous technical change. Thus, the way firms develop new technologies is probably an issue surrounded by a greater uncertainty than uncertainty on the consumer side. There is a moderate degree of consensus in the literature on these issues. As with baselines, a scenario approach is essential and results have to be reported for both "optimistic" and "pessimistic" development paths.

Taking a different approach, the way consumers adopt existing lower carbon technologies and firms develop new ones can be viewed as key sources of uncertainty in costing methodologies. These assumptions are crucial, as different valuations are likely to affect the conclusions. However, the ways in which guidance and information about these two crucial issues are provided are radically different. Two different options are available from the consumer side. First, energy oriented macroeconometric models can provide a price elasticity to show how changes in the fuel mix are driven by relative prices. No specific direction of technological change can be derived from this class of model. However, differences in the results in terms of different energy structures (and different carbon impacts) could easily emerge. Second, engineering studies can provide some indications about available lower energy technologies to show the impact on energy demand and carbon emissions. Hence, from the point of view of uncertainty there is no *a priori* reason to choose between bottom-up and top-down models.

[12] Uncertainty that is relevant to cost estimation arises from three sources. First, the intrinsic uncertainty of the climate system, second uncertainty about the impacts, and third uncertainty about the costs. This section only deals with the last of these. The broader issues are discussed in the crosscutting paper devoted exclusively to this topic (Moss and Schneider, 2000).

Finally there are uncertainties in the estimated costs as well as in the estimation of the ancillary benefits and/or co-benefits. As the literature on potential ancillary benefits is continues to develop, current estimates of the net social impacts of various mitigation policies are necessarily incomplete. Private cost figures are generally more certain than the external ones, but some imprecision remains. As with baselines, a scenario approach is recommended, with estimates prepared for a "low value", a "mid value", and a "high value". Uncertainty about the external costs is well recognized. As with the private costs, again a scenario approach that gives a range from low, through mid, to high values is recommended. In both cases the scenario approach provides a sensitivity analysis for the costing exercise.

In the crosscutting paper on uncertainty (Moss and Schneider, 2000), a number of scales are proposed to assess the level of imprecision in the reported impacts, costs, etc. One that has frequently been used for costing exercises is the three-point scale that seeks to evaluate the degree of confidence in a particular result using a scale of: low, medium, and high confidence levels. This has been expanded to a five-point scale, which asks the researcher to select one of the following:

- "very high confidence" (over 95% certain);
- "high confidence" (67%–95% certain);
- "medium confidence" (33%–67% certain);
- "low confidence" (5%–33% certain); and
- "very low confidence" (below 5% certain).

This has not been applied to cost estimates, but it would useful to establish whether it could be applied and, if so, whether it would provide policymakers with better guidance as to the reliability of the results.

7.4 Issues in Estimating Costs

7.4.1 Relationship between Mitigation Costs and Development, Equity, and Sustainability

A number of key concepts applied in cost assessment provide important insights about the DES aspects of mitigation policies without intending to be comprehensive in coverage. This section discusses a number of the important linkages between costing studies and DES approach.

Chapter 1 states that a system's capacity for mitigation depends on a number of characteristics that must be considered in the context of its unique position and aspirations including:

- a range of viable technical options;
- a range of viable policy instruments;
- resource availability and distribution; and
- human and social capital.

Each of these characteristics is interrelated with DES issues, but also has major impacts on mitigation costs. Thus, the interaction between DES aspects and mitigation costs is two-way.

DES policies have, on the one hand, major implications for economic structure and viability of policy instruments, as well for man-made, natural, and social capital. Mitigation policies, on the other hand, have implications for the same DES issues. The focus of this section is on the second of these feedback mechanisms.

The DES implications of mitigation policies are different according to the geographical scale of the efforts. International as well as national large-scale mitigation efforts can potentially impose a large demand for exhaustible resources or can be thought to impose irreversible damages on environmental resources and these impacts should be reflected in mitigation studies. Mitigation policies also have long-term implications on future climate change and thereby on intergenerational equity. A number of issues related to how mitigation costing studies address intergenerational equity issues are discussed in Section 7.4.5.[13]

Climate change mitigation policies implemented at a national level will, in most cases, have implications for short-term economic and social development, local environmental quality, and intragenerational equity. Mitigation cost assessments that follow this line can address these impacts on the basis of a decision-making framework that includes a number of side-impacts to the GHG emissions reduction policy objective. The goal of such an assessment is to inform decision makers about how different policy objectives can be met efficiently, given priorities of equity and other policy constraints (natural resources, environmental objectives). A number of international studies have applied such a broad decision-making framework to the assessment of development implications of CDM projects (Austin *et al*., 2000).

The following sections highlight a number of key linkages between mitigation costing issues and broader development impacts of the policies, including macroeconomic impacts, employment creation, inflation, marginal costs of public funds, capital availability, spillovers, and trade. This leads to discussion of a number of issues involved in an economic assessment of intergenerational equity aspects.

7.4.2 Income and Other Macroeconomic Effects

7.4.2.1 Macroeconomic Indicators

Major programmes of mitigation or adaptation, particularly those that involve the use of instruments such as energy and carbon taxes, cause changes in the values of key macroeconomic variables. These include growth in GDP, employment, external account balance, and the rate of inflation. As part of the decision-making process, information on all these variables should be provided. Changes in GDP, however, have a special role in the analysis. As noted in Section 7.2.2, under certain circumstances GDP is a valid welfare measure of the value of the goods and services produced in an economy. In so far as this is the case, changes in GDP in real terms (i.e., adjusting for price changes) are also a valid measure of the costs of any mitigation policy. The major qualification is that prices should reflect social costs and that all activities that affect welfare should be included. To the extent that this is not the case a change in GDP is not an accurate measure of the costs of a programme. One common reason for divergence between GDP and welfare is the presence of external effects. Another is the failure to account for the economic value of leisure or household work. The macroeconomic models referred to in Section 7.6, and analyzed in detail in Chapter 8, do not report the costs of market-based programmes for GHG reduction at the microeconomic level, but do so in terms of conventional GDP.[14]

It must be recognized that the full set of adjustments to GDP measures needed to obtain a correct welfare measure of the costs is difficult to compute. If the policies have ancillary benefits and/or co-benefits, then the overall costs of the measures are less than any fall in GDP. This adjustment can be made (using the methods discussed in Section 7.2.3) to the GDP measure if the data on the ancillary benefits are collected. Other adjustments relate to changes in distributional effects and the shadow pricing of goods and services for which prices do not reflect social costs. Without a detailed microlevel analysis of which sectors are affected, however, these corrections are not possible. Hence it has to be recognized that GDP changes are less accurate as measures of the true costs of mitigation programmes, and that the use of multi-attribute and other similar analyses is even more important for the assessment of such programmes.

Several authors suggest the inclusion of more comprehensive welfare measures in macroeconomic studies to give a better reflection of social costs. The United Nations Commission for Sustainable Development (UNCSD) has developed a system for Green GDP accounting and a list of sustainable development indicators that can be used to include part of the social cost aspects in GDP measures (UNCSD, 1999). The indicators cover social, economic, environmental, and institutional DES aspects. A study by Håkonsen and Mathiesen (1997), based on a CGE model, assessed large differences in welfare implications of three mitigation policy cases, namely:

- case A, in which carbon tax revenue is recycled lump-sum to the household;
- case B, in which carbon tax revenue substitutes labour taxes; and

[13] To some extent DES impacts overlap with ancillary impacts. Examples are reductions in air pollution, changes in employment, etc. The concept of DES is, however, wider than that of ancillary benefits, covering issues of long-term equity, social and economic development, and sustainability.

[14] A study that summarizes the macroeconomic level costs of alternative climate change policies in Germany and the USA, including the employment impacts, is Jochem *et al*. (2000).

- case C, in which the model includes ancillary benefits related to local air pollution and the transport sector.

Sen (1999) presents a broader perspective on economic development and emphasizes that economic welfare is not the primary goal of development, but is rather an instrument to achieve the primary goal to enhance human freedom. Freedom, at the same time, is instrumental in achieving development. The studies should consider a broad range of development issues including impacts on economic opportunities, political freedoms, social facilities, transparency guarantees, and protective security.

7.4.2.2 The Marginal Costs of Public Funds

As noted in Section 7.2.4 shadow prices have to be applied to market prices when these prices do not reflect the true opportunity costs. Shadow prices have also been applied to the funds used to finance mitigation programmes. Public expenditures, regardless of the benefits they confer, impose a cost on society, which reflects the "marginal excess burden" of a tax policy. The marginal costs of public funds should include the impacts of eventually reduced distortions compared with existing tax systems, as well as administration costs, compliance costs, the excess burden of tax evasion, and avoidance costs incurred by the taxpayers. Slemrod and Yizhaki (1996) also suggest the distributional impacts of public funds collection be included.

The marginal costs of public funds are critically dependent on the dead-weight loss associated with distortionary taxation, which is dependent on the specific tax structure in place in the non-policy case. To evaluate the true social cost of the funds it is necessary to estimate or know the marginal cost of public funds, that is the cost per dollar of finance, which is greater by US$1 than the welfare cost of raising the tax revenue. In general there will not be one figure for this cost for the whole tax system. Each source of finance will have its own marginal cost. In general there will not be one figure for this cost for the whole tax system. Each source of finance will have its own marginal cost[15]. If such a correction is not made, mitigation policies underestimate the costs of reducing GHGs.

Håkonsen (1997) has surveyed the theoretical discussion of the marginal cost of public funds, and empirical estimates of the marginal costs have been made by the World Bank and others (Devarajan *et al*., 1999, European Commission, 1998, Ruggeri, 1999).

Estimates tend to suggest that the marginal costs of public funds are larger in developing countries than in developed countries. Devarajan *et al.(*1999) estimates that these costs vary between US$0.48 and US$2.18 for developing countries and US$1.08 and US$1.56 for the USA. The European Commission uses a value of US$1.28 for the shadow price of public funds.

[15] It remains true, however, that if the system is optimally designed, the marginal costs of different fiscal instruments will be equalized.

7.4.2.3 Employment

This section deals with the valuation of employment impacts on a project basis. If a project creates jobs, it benefits society to the extent that the person employed would otherwise not have been employed or would have been employed doing something of lower value. Conversely, if the project reduces employment there is a corresponding social cost. These benefits depend primarily on the period that a person is employed, what state support is offered during any period of unemployment, and what opportunities there are for informal activities that generate income in cash or kind. In addition, unemployment is known to create health problems, which have to be considered as part of the social cost.

A physical measure of the extent of the employment created is therefore an important task of any project assessment in an area where there is unemployment.[16] The data that have to be estimated are:

- number of persons to be employed in the projects;
- duration for which they are employed;
- present occupations of the individuals (including no formal occupation); and
- gender and age (if available).

This physical information can be used in the multi-attribute selection criteria discussed in Section 7.2.1 (*Box 7.1*). In addition, however, it is possible to place some money value on the employment, or to deduct from the payments made to the workers the value of the benefits of the reduced unemployment.

Before considering the framework for such an evaluation, it is important to set out the theoretical reasons for arguing that unemployment reduction has a social value. In neoclassic economic analysis, no social cost is normally associated with unemployment. The presumption is that the economy is effectively fully employed, and that any measured unemployment results from matching the changing demand for labour to a changing supply. In a well-functioning and stable market, individuals can anticipate periods when they will be out of work, as they leave one job and move to another. Consequently, the terms of labour employment contracts, as well as the terms of unemployment insurance, reflect the presence of such periods, and there is no cost to society from the existence of a pool of such unemployed workers. However, these conditions are far from the reality in most of the developing and some of the developed countries in which the GHG projects will be undertaken. Many of those presently unemployed have poor prospects of employment.

[16] Account must also be taken of any divergence between the market price and the social value of the output derived from the labour, both in its pre-project stage and as a result of the project (for details, see Ray, 1984).

In these circumstances, therefore, it seems entirely appropriate to treat the welfare gain of those made employed as a social gain. For developed economies this welfare gain is calculated as follows (Kirkpatrick and MacArthur, 1990):

a. gain of net income as a result of a new job, after allowing for any unemployment benefit, informal employment, work-related expenses, etc.; minus
b. the value of the additional time that the person has at his or her disposal as a result of being unemployed and that is lost as a result of being employed; plus
c. the value of any health-related consequences of being unemployed that are no longer incurred.

To calculate the social benefits (the unemployment avoided as a result of the project), the welfare cost ((a) minus (b) plus (c)) has to be multiplied by the period of employment created by the project.[17] The above method can also be applied to obtain employment benefit estimates for projects in developing countries (see, e.g., Markandya, 1998).

7.4.2.4 Inflation

Price levels are always changing to reflect changes in the relative scarcity of inputs and other factors. However, when the overall cost of goods and services increases in a certain period, then the economy faces inflation. Two aspects of inflation need to be considered. First, for comparison at different points in time an adjustment should be made for any general increase in the price level, that is the comparisons should be made in real terms. The appropriate deflator is a matter of judgement, but it should be based on a basket of goods consumed by the relevant group of consumers in the country. Also, any such adjustments do not preclude the possibility of increases in "real prices". It is quite possible that the costs and benefits attached to some impacts increase slower (or faster) than the general price level.

The second issue relates to the welfare cost of any inflation generated by the mitigation or adaptation activities. One of the main causes of inflation is when a country incurs a fiscal deficit (i.e., public expenditures exceed tax revenues) that is financed by printing money. Such an increase in inflation is effectively a tax on money holdings, on assets denominated in nominal terms, and on those with fixed money incomes.

The distributional consequences of the inflation tax are germane to the decision-making process. There is no simple way, however, to estimate this welfare cost; doing so requires sophisticated measurements of losses in the consumption level that affect distinct income groups. Moreover, for most mitigation and adaptation measures, the increase in inflation is likely to be quite small. Hence, in the majority of cases it is sufficient to report any increase in inflation that results from the climate change policy and use that information as a direct element in the decision-making process.

7.4.2.5 Availability of Capital

The capital costs of mitigation and adaptation programmes may be underestimated if the true scarcity of capital is not reflected in the costs incurred by the parties that implement the programme. This can arise if capital is "rationed", that is the demand for investment projects exceeds the supply. In such a situation it is appropriate to apply a shadow price for capital,for the estimation of which the World Bank (1991) and others have made estimates. This adjustment is in addition to the adjustment for the marginal cost of public funds (Section 7.4.2.2). Moreover, when a shadow price for capital of greater than one is applied, it acts to ration capital when the discount rate applied is low.

The above discussion assumes that the capital allocated to the project is free to be used for any other project. What happens, however, if capital is not "fungible" in this sense, but is made available by a donor or third party for the specific purpose of implementing climate change programmes? In these circumstances the assessment of the programme from the national viewpoint differs from its assessment from the viewpoint of the third party. The national assessment could take the shadow price of capital as zero if it genuinely could not be used for any other purpose. If, however, there were a number of alternative projects to which the capital could be allocated, a comparison between them should be based on a shadow price of capital that reflects its scarcity relative to the investment opportunities available. The party providing the finance, on the other hand, will have its own set of alternative projects to which the capital could be allocated and it may apply its own shadow price. The important point is that the evaluation and ranking of projects from a domestic viewpoint may differ from their ranking from a donor perspective. When rankings differ, a compromise is usually reached, based on the relative bargaining strengths of the two parties.

7.4.3 Valuation of Spillover Costs and Benefits

In a world in which countries are linked by international trade, capital flows, and technology transfers GHG abatement by one country has welfare effects on others. In some cases these impacts, or spillovers, are positive and in others negative. Spillovers are a broad concept that has been used in relation to a number of different international inter-linkages between GHG emission reduction policies and impacts on industrial competitiveness, reallocation of industry, and a development and implementation of technologies. This section provides a short introduction to these main categories of spillovers as an introduction to Chapters 8 and 9 that include a review of economy-wide and sectoral studies on spillovers.

[17] Note that this method implies a social benefit for the employment that is likely to be much less than the product of the average earnings and hours worked.

7.4.3.1 Industrial Competitiveness and Potential Reallocation of Industries

GHG emission reduction policies potentially will have a major impact on industrial competitiveness because sub-sectors that have relatively high GHG emission intensity or have relatively high reduction costs potentially can lose in competitiveness.

The basic theoretical framework is that of a full employment, open economy, and no international capital mobility (Dixit and Norman, 1984). Within this model an emissions constraint shifts the production possibility frontier inwards, as long as the constraint requires some "no regret" measures to be undertaken. The spillover impact of this shift depends on whether the emissions reductions have a greater impact on the production of the export good, or on the import competing good. If it is the former, abatements turn the terms of trade in favour of the country that undertakes abatement and against the country that does not. In these circumstances the non-abating country suffers some welfare loss, while the abating country could be better or worse off, depending on the size of the shift in terms of trade relative to costs of abatement. Conversely, if emissions have a greater impact on the production of the import-competing good, the terms of trade move in favour of the non-abating country, which should have an increase in welfare. The analysis of industrial reallocation considered in the previous section becomes further complicated when international capital mobility is taken into account. Carbon constraints typically alter relative rates of return against abating and in favour of non-abating countries. A flow from the former to the latter is then likely, which shifts further inwards the production possibility frontier in the abating country. At the same time, it causes an outwards shift of the frontier in the non-abating country. Modelling capital flows is notoriously difficult, however, and no theoretical results can be obtained for the complex and empirically relevant cases. Hence the indisputable need to use simulation models and to undertake primary empirical research. The welfare impacts of changes in international capital flows are seldom reported. Progress depends on the further development of techniques such as decomposition analysis (Huff and Hertel, 1996)[18] and multiple simulations in which some variables are held constant to isolate their influence on the final outcome.

Seen from a more practical perspective the theoretical arguments about competitiveness and international capital flows have at least two versions of what happens without specific developing country targets: either domestic industry relocates abroad, or the demand for domestic energy-intensive goods declines and the trade balance deteriorates; or both occur.

Consider four factors that affect location or trade effects. First, do the non-tradable sectors account for a substantial share of carbon emissions? Second, are energy costs a small or large percentage of the total costs in key manufacturing sectors? Third, is the burden of meeting an emission reduction target partially borne by non-participating countries because of changes mediated through international trade? For example, developed nations could demand fewer exports from non-participating countries. This would shift the terms of trade against these countries, and they would bear some of the costs of reducing GHGs. Fourth, how do resources shift across sectors because of carbon policy? For instance, there could be a shift from the energy-intensive sector to the domestic goods sector that is non-energy intensive. The aggregate impact could be positive or negative depending on the potential returns from the non-energy intensive sector.

First, consider the "pollution havens" hypothesis, in which firms are tempted to relocate to or to build new plants in nations with lax environmental standards (see Dean, 1992; Summers, 1992; Esty, 1994; Jaffe *et al*., 1994). Palmer *et al*. (1995) point out that the following must be considered:

- whether the cost of complying with environmental regulation is a small fraction of total cost;
- whether the differences between the developed nation's environmental regulations and those of most major trading partners are small or large; and
- whether the firms of the developed nation build state-of-the art facilities abroad regardless of the host nation's environmental regulations.

The evidence to date on pollution havens is not strong, although this may change in the future as international agreements on climate change come into force.

In the context of climate change, cost estimates must consider how carbon taxes affect trade flows in the short and long runs. The "leakage effect" reflects the extent to which cuts in domestic emissions are offset by shifts in production and therefore increases in emissions abroad. The empirical question is whether nations that are a net exporter in fossil fuel intensive products (e.g., steel) gain under Annex I-only carbon policies. Other developing nations might not gain because less capital will be available as the income in the developed nations drops, and it becomes more costly to import from developed nations the capital goods that promote growth (e.g., machinery and transportation equipment). See Chapters 8 and 9 for any empirical evidence on the magnitude of leakage.

7.4.3.2 Technological Spillovers

The theoretical discussion about spillovers emerging from impacts on industrial competitiveness and industrial reallocation is based on a comparative static framework. When extended to a dynamic context, the production possibility frontiers of industries are assumed to shift outwards in a way determined by technological change in different sectors as a reflection of

[18] Verikios and Hanlow (1999) illustrate in a comparative static framework how the welfare impacts of international capital mobility can be assessed using decomposition analysis.

an endogenous feedback from GHG emission reduction policies on technological change.

There are three routes by which technology policies in one country affect development in other countries or specific sectors. First, R&D may increase the knowledge base and this will be a general benefit for all the users of a technology. Second, increased market access for low-CO_2 technologies, through niche-markets or preferential buyback rates in one country may induce a generic improvement in technology in others. Third, domestic regulations on technology performance and standards, whether imposed or voluntary can create a strong signal for foreign industrial competitors. A paper by Goulder and Schneider (1999) similarly argues that climate change policies bias technical change towards emissions savings.

The possibility of a positive technological spillover from GHG emission reduction policies has not been taken into account in any of the global mitigation studies reviewed in Chapter 8. If this materializes, it could cause further complex shifts of the production possibility frontier, including an outwards shift in the production of the affected goods.

7.4.4 Equity

7.4.4.1 Alternative Methods of Addressing Equity Concerns

A key issue in evaluating climate change policies is their impact on intragenerational equity, in which one impact indicator is the income distributional consequences of the policies seen in a national context or across countries. Other related equity issues are the distributional impacts of avoided climate change damages that emerge as a result of mitigation policies, which is dealt with by the IPCC WGII TAR, and intergenerational equity, which is discussed in Section 7.2.4.

There are essentially two ways to deal with intragenerational equity. The first is not to deal with it at all in the benefit–cost analysis, but to report the distributional impacts separately. These can then be taken into account by policymakers as they see fit, or the information can be fed into a multi-criteria analysis that formalizes the ranking of projects with more than one indicator of their performance.

The second method of analysis is to use "income weights", so that impacts on individuals with low incomes are given greater weight than those on individuals with high incomes. Although a number of analysts do not support the use of such weights, some do and policymakers sometimes find an assessment that uses income weights useful. Hence they are included in this chapter.

The costs of different GHG programmes, as well as any related benefits, belong to individuals from different income classes. Economic cost–benefit analysis has developed a method of weighting the benefits and costs according to who is impacted. This is based on converting changes in income into changes in welfare, and assumes that an addition to the welfare of those on a lower income is worth more an addition of welfare to richer people. More specifically, a special form can be taken for the social welfare function, and a common one that has been 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, and
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, $\bar{Y}$, as the numeraire, and giving it a value of one gives:

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

and

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

In this way the marginal social welfare impact of income changes by individuals is the elasticity of the ratio of the per capita income $\bar{Y}$ and the income of individual i, Y_i. The marginal social welfare impact of income changes by individual i also can be denoted as SMU_i, where SMU_i is the social marginal utility of a small amount of income going to individual 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 groups relative to different cost and benefit components.

To apply the method, estimates of $\bar{Y}$ and ε are required. The literature contains estimates of the inequality aversion parameter (ε) in the range 1–2 (Murty *et al*. 1992; Stern, 1977). Some recent studies that estimate the value of ε for the Indian economy (Murty *et al*., 1992) resulted in values in the range 1.75–2.0.[19]

7.4.4.2 The Use of Average Damages

A special case of the income distributional weights approach is to estimate the money value of impacts for different groups of individuals or countries and then apply the average damage to all individuals and countries. The best example of this is the value attached to changes in the risk of death. These risks are valued in terms of the statistical value of life, which caused much controversy in SAR (IPCC 1996a, Chapter 6). The "value of a statistical life" (VSL) converts individual WTP to reduce the risk of death into the value of a life saved, when it is not known which life that will be. For example, if each person in a community has a WTP of US$10 to reduce the risk of death by one in a hundred thousand, then the collective WTP of a group of 100,000 is US$1 million for a measure that would, on average, save one life. Hence, the figure of US$1 million is referred to as the VSL. This measure is one way of valuing changes in risks of mortality. Other ways include a "human capital" approach, which values the loss of income and multiplies it by the change in risk, or a "life years lost" approach, which takes the WTP for life years that could be lost as a result of changes in the survival probabilities an individual faces. Of these, the VSL has been used most commonly in recent years. The human capital approach is not well founded in terms of welfare and the life years lost approach is still being developed.

The VSL is generally lower in poor countries than in rich countries, but it is considered unacceptable by many analysts to impose different values for a policy that has to be international in scope and decided by the international community. In these circumstances, analysts use average VSL and apply it to all countries. Of course, such a value is not what individuals would pay for the reduction in risk, but it is an "equity adjusted" value, in which greater weight is given to the WTP of lower income groups. On the basis of EU and US VSLs and a weighting system that has some broad appeal in terms of government policies towards income distribution, Eyre *et al*. (1998) estimate the average world VSL at around 1 million Euros (approximately US$1 million at 1999 exchange rates).[20]

Formally, it can be shown that the use of average values for damages implies income weights based on an elasticity of one, which, as can be seen from above, is broadly consistent with government policies towards income redistribution (Fankhauser *et al*., 1997; Eyre *et al*., 1998). The advantage of this approach is that it addresses equity concerns while retaining a valuation of damages that is broadly consistent with the efficiency approach. Such an approach may be a way to reflect the equal value of lives as seen from a global policy perspective. National perspectives and opportunities should be addressed in another way.

7.4.5 Estimating Future Costs and Sustainability Implications

Mitigation policies that are large in scale can have significant long-term implications on future climate change and thereby have implications for intergenerational equity. The issue is to model future changes in ecological systems and economic welfare associated with different levels of climate change caused by specific mitigation efforts.

Climate change offers an imposing set of complications for the policymaker–global scope, wide regional variations, the potential for irreversible damages or costs, multiple GHGs, a very long planning horizon, and long time lags between emissions today and future impacts on ecosystem services. For the economist, to assess how these distant climate-induced changes in ecosystem services might affect the economic wellbeing of citizens in the far distant future is no less imposing.

The challenge rests in capturing accurately three general issues: (1) how climate change might affect ecological systems; (2) how these altered ecosystems might affect the demand for different market and non-market goods and services; and (3) how this demand change affects the welfare of our descendants. The first two issues can only be dealt with by broad scenario analyses that consider alternative development patterns for ecological systems and the interactions with man-made systems. The third issue can be addressed by applying assumptions about the preferences of future generations, which, for example, can be assumed to reflect the preferences of present generations.

Those who undertake studies of welfare losses brought about by climate change often focus on an assessment of the potential welfare losses suffered by future citizens through climate change. Typically, such an assessment is based on measuring the demand curve for people alive today under today's climate given the substitution possibilities implied by extant technologies and knowledge constraints that define today's opportunity set. Essentially, these analysts ask, "If the climate of the future enveloped us today, what would be our welfare loss?"

The question often not asked is this: "Does the opportunity set of today's citizens reflect, in any way, the opportunity faced by citizens in 2050 or 2100?" A welfare loss based on today's opportunity set may or may not be related to the potential climate-related loss in wellbeing to the citizens of the far distant future. Climate change triggers direct changes in the opportunity set and relative prices, and indirect changes in the adaptation of technology and supply. This is critical. More opportunities in the future will reduce the welfare loss; fewer opportunities could inflate the loss. The opportunities will depend on a complex mix of available substitutes, complementary recre-

[19] One reviewer has pointed out that different values of ε may be appropriate for costs and benefits.

[20] The parameter from which the weights are derived is called the elasticity of the marginal utility of income. The greater this elasticity, the greater the weight given to the WTP of poor households.

ational and non-recreational activities, relative prices, transaction costs, and preferences. These substitutes will be determined by the various different types of capital stock that contribute to human wellbeing, including man-made capital, human capital, natural capital, and social capital, as emphasized by the sustainability literature. For a more elaborate discussion on these issues see Chapter 1.

It is difficult to account for the opportunity sets of citizens in the far distant future and to predict the preferences of future generations, which adds a significant uncertainty to estimates of future damages from climate change. Climate change might affect household resources, human resource investment prices and levels, endowments, preferences, labour market opportunities, and natural environment, all of which influence our descendant's opportunity set–the basic materials needed for attainment in life. These risks indirectly modify our heirs' life chances by reducing and reallocating household resources or by constraining their choices or both. Our descendants may shift resources towards a sick child and away from recreation. Their children might have to forego the life experience of fishing the same river as their ancestors. Faced with these consequences, individuals today might be willing to pay to prevent risks that restrict our heir's opportunities. But this is a different question.

When considering future generations' opportunities the impacts of today's climate change investments on future generations' opportunities should also be considered. Investments might, for example, enhance the capacity of future generations to adapt to climate change, but at the same time they potentially displace other investments that could create other opportunities for future generations.

Two things are likely to be different in the future–the climate and our heirs' opportunities. Accounting for one change and not the other will not markedly advance our understanding of expected benefits. The question should be "How could these future effects be linked to existing models to value non-market effects?" For the most part, the valuation question is how to account for changes, both good and bad, of future opportunities. Accounting for these decisions probably requires a new model that focuses on the value of maintaining or enhancing the future's opportunities so as to maximize their life chances, whatever their preferences might be.

7.5 Specific Development Stages and Mitigation Costs (Including Economies in Transition)

Developing countries and EITs exhibit a number of special characteristics that should be reflected in mitigation cost studies. There is a need for further development of the methodologies and approaches that reflect these issues; this section introduces a number of distinct features for such economies and concludes with a number of suggestions for the expansion of studies and methodology development.

7.5.1 Why Developing Countries Have Special Problems in Their Mitigation Strategies

The term "developing countries" covers a wide variety of countries with distinct differences in their economic, political, social, and technological levels. The group of countries termed "least developing countries" have very little basic infrastructure, the "newly industrialized countries" have a structure closer to that of the developed countries, and others lie between these two extremes. Almost all developing countries have a relatively low level of GHG 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. It is therefore important to understand how these countries might participate in globally cost-effective policies.

Mitigation costs in a country depend critically on the underlying technological and socioeconomic conditions. Studies that assess these costs make assumptions about current and future socioeconomic development patterns and the potential to implement climate change mitigation policies. Developing countries exhibit a number of specific complexities that are of major importance to costing studies. Data are limited, exchange processes are constrained, markets are incomplete, and a number of broader social development issues are potentially important for future GHG emissions, such as living conditions of the poor, gender issues, and institutional capacity needs. Some of these difficulties arise particularly in relation to land-use sectors, but can also be important in relation to the energy sector and transportation.

To sum up, a number of special issues related to technology use should be considered for developing countries as the critical determinants for their climate change mitigation potential and related costs. These include current technological development levels, technology transfer issues, capacity for innovation and diffusion, barriers to efficient technology use, institutional structure, human capacity aspects, and foreign exchange earnings.

The methodology of most current mitigation cost studies was developed on the basis of approaches originally designed for the market-based economies of developed countries. The application of these methodologies in a developing countries 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 in developing countries can lead to a number of inaccuracies in mitigation studies:

- Major GHG emission sources and drivers for future emission can be overlooked. This is especially relevant for the land-use sectors.
- Mitigation studies may focus on specific technical options that are not consistent with national macroeconomic policy contexts and broader social and environmental policy priorities.
- The technical potential of specific options, for example electricity saving options, may be overestimated

because consumer behaviour and power market failures are not captured.

- The impacts of using different policy instruments cannot be assessed because the studies do not include any information on national institutional structure, taxes, and other regulation policies and various technology promotion programmes.
- Implementation issues, including institutional and human capacity aspects and local market development, are not represented.

7.5.2 Why Economies in Transition (EIT) Have Special Problems in Their Mitigation Strategies

Estimating the costs of mitigation for EITs presents its own challenges, which can be described as past, present, and future. In the recent past, prices were not the rationing mechanism of choice. The listed prices (where there were any) did not necessarily reflect the actual level of scarcity, since they were not set by supply and demand. As such, data based on listed prices from which to construct marginal abatement cost curves is sketchy at best, and completely missing at worst.

Today, problems still exist in the construction of such curves, in that each transition economy has its own unique mix of fee markets and state control. The newer sources of data reflect a mix of price and quantity rationing that needs to be better understood on a country-by-country basis.

Finally, using this data to estimate mitigation costs into the near or distant future depends on critical assumptions about how the political, legal, and economic institutions will evolve in these economies. Any estimates of mitigation costs into the twenty-first century made under the assumption that current institutions will be held constant are almost certainly not going to be correct. Hence, it is essential to devote a good deal of effort to develop scenarios of evolution for these institutions and their implications for economic development.

7.5.3 Development Projections

The establishment of long-term projections for GHG emissions is particularly complicated and uncertain for both developing countries and the EITs. These economies are often in a transition process in which important GHG emission sectors, such as the energy sector, industry, and transportation, are expected to play an increasing role. It is not possible, however, to project accurately the actual speed of this growth process and/or the GHG emission intensity of these future activities. Modelling tools and data are also very limited or even non-existent, and the only available information sources from which to generate GHG emission projections are often the official national development plans that cover a time horizon of 5–10 years only.

Changes in the structure of GDP have to be given careful consideration. One important aspect that could be integrated into the scenario development are the changes in economic structure and relative prices that emerge from structural adjustment programmes and other macroeconomic policies that many countries are currently undertaking. Another crucial issue, following that, will be the development of energy intensive and heavily polluting industrial activities, such as steel and aluminium production. As the recent shift of heavy industries from the developed towards the developing countries reaches its end, long-term economic output could come from services and other less energy-intensive activities. In EITs the issue is how fast and deep will the shift out of energy intensive industries be, and what will replace it.

The basic uncertainty of long-term GHG emission projections encourages analysts to use multiple baselines, each corresponding to a particular expectation of the future development pattern. Each development pattern may exhibit a unique emissions trajectory. A nation following development policies that emphasize greater investments in infrastructure, such as efficient rail transport, renewable energy technologies, and energy-efficiency improvements will exhibit a low emissions trajectory. However, a nation with substantial coal resources, scarce capital, and a low level of trade can be pushed towards a development path with high emissions.

The spatial distribution of the population and economic activities is still not settled in the developing countries. This raises the possibility of adopting urban and/or regional planning and industrial policies to strengthen small and medium cities and rural development, and thus reduce the extent of the rural exodus and the degree of demographic concentration in large cities. In the same way, technological choices can substantially decrease the energy demand and/or GDP elasticities. The preservation of a certain cultural diversity, as opposed to the trend towards a global uniformity of lifestyles, also favours less energy-intensive housing, transportation, leisure, and consumption patterns, at least in some cases. One example is related to development policies that avoid low urban population density coupled with long daily trips to work and large shopping centres by car.

It is a special challenge in costing studies to translate preferences for biological and cultural diversity into a useful value measure. The market does not price most of the services provided by biological or cultural diversity. Roughgarden (1995) argues that there is no need to quantify the benefits of these services, which are either so obvious or impossible to capture that measurement is unnecessary. Following this line of argument, "science" should dictate a target that could be used to establish a safe minimum standard–a level of preservation that guarantees survival of the species or culture in question (Ciriarcy-Wantrup, 1952). This minimum standard approach puts an infinite value on avoiding extinction. This view puts biological or cultural diversity beyond the reach of economic trade-offs, and the analyst attempts to find the least-cost solution to achieve some set standard.

However, Epstein (1995) argues that preservation without representation of benefits is unacceptable. It is suggested that hard evidence is needed to prove that the biological and cultural preservation benefits dominate those from development. It is then logical to compare the costs and benefits when resources are scarce, and an attempt should be made to balance the costs and benefits so that funds are allocated to their highest valued use.

Estimating the social value of biodiversity and culture is a major challenge. For biodiversity values there is no consensus as to the usefulness of the primary tool used to reveal the monetary value of these preferences–contingent valuation surveys. These public opinion surveys use a sequence of questions to put a monetary value on personal preferences. However, since people are responding to a survey rather than facing their own budget constraint and actually spending their own money, no market discipline exists to challenge their statements (Brown and Shogren, 1998).

The above possibilities of alternative development patterns highlight the technical feasibility of low carbon futures in the developing countries that are compatible with national objectives. However, the barriers to a more sustainable development in developing countries can hardly be underestimated, from financial constraints to cultural trends in both developed and developing countries, including the lack of appropriate institutional building. Any abatement-cost assessment relies on the implicit assumptions taken in the baseline or mitigation scenarios with regard to the probability of removing these barriers.

Since mitigation costs for different development patterns may vary substantially, one way to reflect this in mitigation cost analysis is to use a scenario-based range of mitigation costs rather than a single mitigation cost (see also Section 7.3.6).

7.5.4 Broadening the National Decision-making Framework

Although cost is a key component of the decision as to which policies to select, it is not the only consideration. Other factors enter the decision, such as the impacts of policies on different social groups in society, particularly the vulnerable groups, the benefits of GHG 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 developed countries. GHG limitation does not have as high a priority relative to other goals, such as poverty reduction, employment, etc., as it does in the wealthier countries. Indeed, it can be argued that the major focus of policy will be development, poverty alleviation, etc., and that GHG limitation will be an addendum to a programme designed to meet those needs. Accounting for the GHG component may change the detailed design of a policy or programme, rather than be the main issue that determines the policy.

Markandya (1998) developed a framework to expand the cost analysis with an assessment of the other impacts of climate change mitigation projects, such as employment, income distribution, environmental changes, and sustainability indicators. The suggestion is that monetary cost and benefit estimates be combined with physical indicators and qualitative information. These include the impacts of projects on vulnerable groups, on the environment more generally, and on sustainability in a broader sense.

Markandya and Boyd (1999) and Halsnæs and Markandya (1999) assessed the implications for cost-effectiveness of using an expanded cost-analysis framework compared with a focus on direct costs. They examined a number of case studies, including renewable energy options (biogas, solar water-heating systems, photovoltaic streetlights, and wind turbines), DSM programmes, and a number of transportation sector options. The expanded cost assessment includes a specific valuation for the welfare impacts of increased employment, local environmental improvements related to reduced non-GHG pollutants, and income distribution weights. The conclusion is that in a number of cases the application of an expanded cost-assessment framework has major implications for the cost-effectiveness ranking of mitigation projects compared with their ranking on direct costs alone. In particular, large differences in cost-effectiveness are seen for a biogas plant in Tanzania, for which combined social costs considered in the expanded framework go down to minus US\$30/tCO_2 reduction compared with a purely financial cost of plus US\$20/tCO_2. This cost difference reflects a positive welfare impact on presently unemployed low-income families and the time saved through reduced fuelwood collection. The case examples generally suggest that the combined social costs of mitigation policies in developing countries in particular will be lower than the purely financial costs, especially if the policies require presently unemployed labour and reduce the damages from local non-GHG pollutants. Similar studies for EITs reveal great large value of ancillary benefits in the form of reduced air pollution and increased employment, especially for carbon sink projects.

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

Climate change studies focus on the cost assessment of activities through their presentation on the markets. The GHG emission sources considered, on this basis, are predominantly those represented in official economic and sectoral statistics, and the prices used to value the resources are derived on a market basis. Such information, however, is incomplete for developing countries for which markets are incomplete, property rights are not well established, and a significant part of the exchange process belongs to the informal economic sector. This section discusses the implications of these specific features for climate change studies.

GHG emissions in the energy and agriculture sectors are greatly influenced by present subsidies. Subsidy removal in the energy sector, if supported by improvements in managerial efficiency, could reduce CO_2 emissions 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 that general macroeconomic policies, such as structural adjustment programmes, already include a number of subsidy removal policies.

Most major markets in developing countries are characterized by supply constraints, but the labour market is an exception for unskilled labour is frequently in excess supply. Examples of such supply constraints are seen in the financial sector, power production, and infrastructure development. This results from high transaction costs that originate from weak market linkages, limited information, inadequate institutional set-ups, and policy distortions. Such market imperfections make it difficult to establish reliable parameters such as price elasticity of demand.

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

Traditional cost–benefit analysis suggests the use of shadow prices to correct for market distortions (see Section 7.2.3.1). Such a procedure is in line with the approach of CGE models. In both these approaches mitigation policies and related costs are assessed in relation to an "optimal resource allocation case", in which markets are in equilibrium and prices (and thereby cost) reflect resource scarcities. However, these conditions are far from those currently found in these countries, so studies should consider how a transformation to the optimal resource allocation case is likely to take place over a certain time frame. Developing countries are presently undergoing market-oriented economic reforms. However, the price distortions are only partially and gradually being remedied because of the high social costs associated with speedy reforms. 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 cost studies should include an assessment of barrier removal policies. Such policies include efforts to strengthen the incentives for exchange (prices, capital markets, international capital, and donor assistance), to introduce new actors (institutional and human capacity efforts), and to reduce the risk of participation (legal framework, information, and general policy context of market regulation). Some of these policies can be reflected in cost studies, such as barrier removal policies that address market prices, capital markets, and technology transfers, while other areas like capacity building need to be addressed in a more qualitative way.

A number of important interrelationships and spillovers occur between the informal and formal sectors with regard to climate change mitigation policies. An example is the potential to introduce advanced production technologies in the energy and agriculture sectors that, 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 energy subsidy removal also depends on potential substitutions to non-commercial wood fuels that might be unsustainable. Mitigation cost studies for developing countries should, as far as possible, include an assessment of energy consumption and biomass potential in the informal sector and apply assumptions about price relations and substitution elasticities between the formal and informal sectors. Similarly studies should consider the capacity of enterprises in both the formal and informal sectors to adapt and manage the advanced technologies that are suggested as cost-effective mitigation options in national programmes.

7.5.6 Suggestions for Improvements in the Costing Study Approach Applied to Developing Countries and Economies in Transition

Climate change studies in developing countries need to be strengthened in terms of methodology, data, and policy frameworks. Although a complete standardization of the methods is not possible, to achieve a meaningful comparison of results it is essential to use consistent methodologies, perspectives, and policy scenarios in different nations.

The following modifications to conventional approaches are suggested:

- Alternative development pathways should be analyzed with 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 versus clean coal, renewable versus exhaustible energy sources);
  - employment; and
  - land-use policies (e.g., modern biomass production and afforestation).
- Macroeconomic studies should consider market transformation processes in the capital, labour, and power markets.
- In the less developed of the developing countries, informal and traditional sector transactions should be included in national macroeconomic statistics. The value of the unpaid work of household labour for non-commercial energy collection is quite significant and needs to be considered explicitly in economic analysis.
- Similarly, in such countries the traditional and informal sectors also account for an overwhelming proportion of

agriculture and land-use activities, employment, and household energy consumption; therefore, insofar as possible, these activities should be integrated into cost studies.
- Non-commercial energy sources, essentially traditional biomass, should be represented explicitly in the model as this has a crucial influence on both future energy flows and GHG emissions.
- The costs of removing market barriers should be considered explicitly.

In addition to paying attention to these factors, it is important to bear in mind that perhaps the most serious limitation of cost studies for developing countries is the paucity of data. Some mitigation studies have tried to circumvent data problems by making opaque assumptions or using estimates from data that relate to different circumstances. It is preferable to use simplified approaches that provide insights into basic development drivers, structures, and trade-offs than to use standardized international models in which the data and assumptions are duplicated from industrial countries.

7.6 Modelling and Cost Assessment

7.6.1 Introduction

The costs of climate policy are assessed by various analytical approaches, each with its own strengths and weaknesses. This section considers first the modelling options currently used to assess the costs of climate policy, and then the key assumptions that influence the range of cost estimates. The focus is on the general conceptual elements of cost assessment and on an evaluation of how model structures and input assumptions affect the range of cost estimates.

7.6.2 Classification of Economic Models

The models presented here are described and discussed in more detail in Chapter 8, in which a review of the main literature on these models is presented. However, it is useful to present an overview of the main modelling techniques applied in this kind of analysis here.

Input–Output Models
Input–output (IO) models describe the complex interrelationships among economic sectors using sets of simultaneous linear equations. The coefficients of equations are fixed, which means that factor substitution, technological change, and behavioural aspects related to climate change mitigation policies cannot be assessed. IO models take aggregate demand as given and provide considerable sectoral detail on how the demand is met. They are used when the sectoral consequences of mitigation or adaptation actions are of particular interest (Fankhauser and McCoy, 1995). The high level of sectoral disaggregation, however, requires strong restrictions that limit the validity of the model to short runs (5–15 years).

Macroeconomic (Keynesian or Effective Demand) Models
Macroeconomic models describe investments and consumption patterns in various sectors, and emphasize short-run dynamics associated with GHG emission reduction policies. Final demand remains the principal determinant of the size of the economy. The equilibrating mechanisms work through quantity adjustments, rather than price. Temporary disequilibria that result in underutilization of production capacity, unemployment, and current account imbalances are possible. Many macroeconomic models are available. They implicitly reflect past behaviour in that the driving equations are estimated using econometric techniques on time-series data. As a consequence, macroeconomic models are well suited to consider the economic effects of GHG emission reduction policies in the short- to medium-horizon.

Computable General Equilibrium Models
CGE models construct the behaviour of economic agents based on microeconomic principles. The models typically simulate markets for factors of production (e.g., labour, capital, energy), products, and foreign exchange, with equations that specify supply and demand behaviour. The models are 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. The parameters in CGE models are partly calibrated (i.e., they are selected to fit one year of data) and only partly statistically or econometrically determined (i.e., estimated from several years of data). Hence it is difficult to defend the validity of some of the parameter values.

Dynamic Energy Optimization Models
Dynamic energy optimization models, a class of energy sector models, can also be termed partial equilibrium models. These technology-oriented models minimize the total costs of the energy system, including all end-use sectors, over a 40–50 year horizon and thus compute a partial equilibrium for the energy markets. The costs include investment and operation costs of all sectors based on a detailed representation of factor costs and assumptions about GHG emission taxes. Early versions of these models assessed how energy demands can be met at least cost. Recent versions allow demand to respond to prices. Another development has established a link between aggregate macroeconomic demand and energy demand. Optimization models are useful to assess the dynamic aspects of GHG emissions reduction potential and costs. The rich technology information in the models is helpful to assess capital stock turnover and technology learning, which is endogenous in some models.

Integrated Energy-System Simulation Models
Integrated energy-system simulation models are bottom-up models that include a detailed representation of energy demand and supply technologies, which include end-use, conversion, and production technologies. Demand and technology development are driven by exogenous scenario assumptions often linked to technology vintage models and econometric forecasts. The demand sectors are generally disaggregated for

industrial subsectors and processes, residential and service categories, transport modes, etc. This allows development trends to be projected through technology development scenarios. The simulation models are best suited for short- to medium-term studies in which the detailed technology information helps explain a major part of energy needs.

Partial Forecasting Models
A wide variety of relatively simple techniques are used to forecast energy supply and demand, either for single time periods or with time development and varying degrees of dynamics and feedback. The main content is data on the technical characteristics of the energy system and related financial or direct cost.

Limits of Economic Models Taxonomy
The macroeconomic and CGE approaches can be further classified as "top-down" methodologies, while the technology-rich dynamic optimization/partial equilibrium, simulation, and partial forecasting approaches can be considered "bottom-up" approaches. It is also noted that the dynamic optimization/partial equilibrium, simulation, and partial forecasting approaches are sometimes collectively referred to as the family of engineering–economic models.

While useful, this taxonomy has its limits. First, differences in parameter values among the models within a given category may be more significant than the differences in model structure across categories. Second, many differences emerge between the theory underlying a particular model group and the actual models. Third, most models are hybrid constructions linked to provide greater detail on the structure of the economy and the energy sector (Hourcade *et al*., 1998). A hybrid approach sheds light on both the economic and technological aspects of reducing energy-related CO_2 emissions, but it does have its drawbacks. Consistent results require that a hybrid approach remove all the inconsistencies across the linked models. This process is often cumbersome and time consuming.

7.6.3 Top-down and Bottom-up Models

Top-down and bottom-up models are the two basic approaches to examine the linkages between the economy and specific GHG emitting sectors such as the energy system. Top-down models evaluate the system from aggregate economic variables, whereas bottom-up models consider technological options or project-specific climate change mitigation policies. IPCC SAR on economic and social dimensions (IPCC, 1996a, Chapter 8) includes an extensive discussion on the differences between top-down and bottom-up models. It concluded that the differences between their results are rooted in a complex interplay among the differences in purpose, model structure, and input assumptions (IPCC, 1996a, Section 8.4.3).

In previous studies, bottom-up models tended to generate relatively low mitigation costs (negative in some cases), whereas top-down models suggested the opposite. Understanding why this range of costs arises requires exploration of the differences in the two modelling approaches.

The terms "top" and "bottom" are shorthand for aggregate and disaggregated models. The top-down label comes from the way modellers apply macroeconomic theory and econometric techniques to historical data on consumption, prices, incomes, and factor costs to model the final demand for goods and services, and the supply from main sectors (energy sector, transportation, agriculture, and industry). Some critics complain, however, that aggregate models applied to climate policy do not capture the needed sectoral details and complexity of demand and supply. They argue that energy sector models were used to explore the potential for a possible decoupling of economic growth and energy demand, which requires "bottom-up" or disaggregated analysis of energy technologies. Some of these energy sector technology data were, however, integrated in a number of top-down models, so the distinction is not that clear-cut.

Macroeconomic models are often also detailed, but in a different way to bottom-up models. Top-down models account for various industrial sectors and household types, and many construct demand functions for household expenditures by summing "individual demand functions". Such functions can facilitate a reasonably detailed assessment of economic instruments and distributional impacts of climate change mitigation policies.

Another distinction between the top-down and bottom-up approaches is how behaviour is endogenized and extrapolated over the long run. Econometric relationships among aggregated variables are generally more reliable than those among disaggregated variables, and the behaviour of the models is more stable with such variables. It is therefore common to adopt high levels of aggregation for top-down models when they are applied to long time frames (e.g., beyond 10–15 years). The longer the period the greater the aggregation gap expected between top-down and bottom-up models.

Top-down models examine a broad equilibrium framework. This framework addresses the feedback between the energy sector and other economic sectors, and between the macroeconomic impacts of climate policies on the national and global scale. As such, early top-down models usually had minimal detail on the energy-consuming side of the economy. Specific technologies were not directly captured. In contrast, bottom-up models mimicked the specific technological options, especially for energy demand. Attention to the detailed workings of technologies required early modellers to pass over the feedbacks between the energy sector and the rest of the economy.

Top-down and bottom-up models also have different assumptions and expectations on the efficiency improvements from current and future technologies. Bottom-up models often focus on the engineering energy-gains evident at the microeconomic level and detailed analysis of the technical and economic dimensions of specific policy options. The sector-specific focus generates lower costs relative to the top-down model, which captures the costs caused by the greater production costs and lower investment in other sectors.

The basic difference is that each approach represents technology in a fundamentally different way. The bottom-up models capture technology in the engineering sense: a given technique related to energy consumption or supply, with a given technical performance and cost. In contrast, the technology term in top-down models, whatever the disaggregation, is represented by the shares of the purchase of a given input in intermediary consumption, in the production function, and in labour, capital, and other inputs. These shares constitute the basic ingredients of the economic description of a technology in which, depending on the choice of production function, the share elasticities represent the degree of substitutability among inputs.

7.6.4 Integrated Assessment Models

Researchers have also assessed the costs of climate protection by considering both the economic and biophysical systems, and the interactions between them. IAMs do this by combining key elements of biophysical and economic systems into one integrated system. They provide convenient frameworks to combine knowledge from a wide range of disciplines. These models strip down the laws of nature and human behaviour to their essentials to depict how increased GHGs in the atmosphere affect temperature, and how temperature change causes quantifiable economic losses. The models also contain enough detail about the drivers of energy use and energy–economy interactions to determine the economic costs of different constraints on CO_2 emissions (see, e.g., Shogren and Toman, 2000).

IAMs fall into two broad classes: policy optimization and policy evaluation models. Policy optimization models can be divided into three principal types:

- cost–benefit models, which try to balance the costs and benefits of climate policies;
- target-based models, which optimize responses, given targets for emission or climate change impacts; and
- uncertainty-based models, which deal with decision making under conditions of uncertainty.

Policy evaluation models include:

- deterministic projection models, in which each input and output takes on a single value; and
- stochastic projection models, in which at least some inputs and outputs take on a range of values.

Current integrated assessment research uses one or more of the following methods (Rotmans and Dowlatabadi, 1998):

- computer-aided IAMs to analyze the behaviour of complex systems;
- simulation gaming in which complex systems are represented by simpler ones with relevant behavioural similarity;
- scenarios as tools to explore a variety of possible images of the future; and
- qualitative integrated assessments based on a limited, heterogeneous data set, without using any models.

A review by Parson and Fisher-Vanden (1997) shows that IAMs have contributed to the establishment of important new insights to the policy debate, in particular regarding the evaluation of policies and responses, structuring knowledge, and prioritizing uncertainties. They have also contributed to the basic knowledge about the climate system as a whole. The review concludes that IAMs face two challenges, namely managing their relationship to research and disciplinary knowledge, and managing their relationship to other assessment processes and to policymaking.

7.6.5 Categorization of Climate Change Mitigation Options

An overview of how the different modelling approaches address the main categories of policies is given here in preparation for a discussion of the main assumptions behind study results. The main categories of climate change mitigation options include:

1. Market oriented policies:
   - taxes and subsidies;
   - emission charges;
   - tradable emission permits;
   - soft loans; and
   - market development and/or efforts to reduce transaction costs.

2. Technology oriented policies:
   - norms and standards;
   - effluent or user charges;
   - institutional capacity building; and
   - market development efforts (information, transaction cost coverage).

3. Voluntary policies:
   - ecolabelling; and
   - voluntary agreements.

4. R&D policies:
   - research programmes; and
   - innovation and demonstration.

5. Accompanying measures:
   - public awareness;
   - information distribution;
   - education;
   - transport; and
   - free consultancy services.

While climate policies can include elements of all four policies, most analytical approaches focus on a few of the options. Economic models, for instance, mainly assess market-oriented policies, and occasionally technology policies related to energy supply options. Engineering approaches primarily focus on supply- and demand-side technology policies. Both of these approaches have opportunities to expand their representation of R&D policies.

Table 7.3 shows the application of market-oriented, technology-oriented and voluntary climate policies in different analytical approaches. The schematic overview covers a large number of applications in global, regional, national, and local analyses. Chapters 8 and 9 of discuss the actual details and specific methods for different assessment levels. A few general conclusions on the representation of different climate policies in the analytical approaches are:

- Market-oriented policies can be examined by macroeconomic models, but only indirectly in technology-driven models through exogenous assumptions. Market descriptions, however, are often stylized representations in many macroeconomic models, which makes it difficult to address transaction costs.
- Technology-driven models can assess various technology-oriented policies. Exogenous assumptions on behaviour and preferences, however, need to be supplied to explain market development. This separation of technology data and market behaviour can make implementation cost-assessment difficult.
- It is a challenge to integrate market imperfections in CGE and partial equilibrium models, because these models tend to be structured around assumptions of efficient resource allocation. Recent work modelled labour market imperfections in such models (see, e.g., Welsch, 1996; Honkatukia, 1997; Cambridge Econometrics, 1998; European Commission, 1998).
- Key presumptions such as technological change, R&D policies and changes in consumer preferences are difficult to assess in both macroeconomic models and technology-driven models.

It is expected that the cost of climate change mitigation policies–all else being equal–decreases with the number of policy categories and options included in the analysis. This means that approaches that are either rich in detail (or facilitate great flexibility) in a number of policy areas can be expected to identify

Table 7.3: *Application of climate change mitigation policies in different analytical approaches*

	Market-oriented policies	**Technology-oriented policies**	**Voluntary-oriented policies**
Macroeconomic models			
IO models Keynesian CGE estimated calibrated	All instruments difficulties with modelling of transaction costs	CGE: Exogenous assumptions; few examples with endogenous assumptions	Demand functions for ecological values
Technology-driven simulation and/or scenario models	Exogenous	Exogenous, learning	Qualitative assumptions
Sectoral models			
Partial equilibrium	All instruments	Changes in capital stock	Exogenous demand function for ecological values
Technology-driven models optimization simulation	All instruments modelled through changes in capital stock	Exogenous assumptions on standards and R&D Leaning curves	Investments reflect future expectations on ecological values and policies
Project assessment approaches			
Cost–benefit analysis	All instruments	Exogenous technology data	Exogenous demand function for ecological values
Cost-effectiveness analyses	All instruments	Vintage models	
Technology assessment	No instruments		

relatively large mitigation potentials and relatively low costs compared with approaches that only address a few instruments or options.

A number of studies have assessed climate change mitigation costs given different regimes of global flexibility mechanism.[21] Climate change mitigation costs in these different policy regimes depend on the specific definition of the policy instrument, and on assumptions about market scale, competition, and restrictions. It is generally expected that climate change mitigation costs decrease with increasing supply of carbon-reduction projects.[22] Restrictions on this supply, or market imperfections in global markets for carbon-reduction projects, have a tendency to increase the "price" of the projects (Burniaux, 1998; Mensbrugge, 1998).

7.6.6 Key Assumptions of Importance to Costing Estimates

There are a number of sensitive issues in the debate about how to interpret cost estimates generated by different models, including assumptions about tax recycling, target setting, and international co-operative mechanisms.

7.6.6.1 Tax Recycling

Tax recycling issues revolve around two critical points concerning the interactions between existing tax systems and a tax system that integrates carbon taxes:

- Assumptions on the structure of the tax system in the baseline and mitigation cases, which include assumptions on tax substitution generated by the recycled revenue of carbon taxes. These baseline assumptions have to be projected into the future for a considerable period if the revenue recycling is to be calculated correctly.
- The total impact of the policy scenario that includes the recycling of carbon taxes, in terms of both distribution and compensation.

The net cost of climate policy depends on (1) the structure of the tax system prior to the introduction of the mitigation policy and (2) the nature of the mitigation policy (e.g., which sectors are covered, what tax instruments are employed, and the way that revenues are recycled). Estimates of the size of the effect are discussed in Chapter 8. This is closely related to the double-dividend literature, which is discussed in Section 7.3.3.1. As noted there, the welfare loss (or burden) of a given climate policy depends on the structure of existing taxes. The more distorted the pre-existing tax the higher the welfare loss. This means that a carbon tax can result in either a totally increased burden (welfare loss of the whole tax system) or a double dividend (in which the total welfare loss of the tax system is lower because the carbon tax substitutes other "burdensome" taxes). In general, however, a larger benefit from a carbon tax is found in comparison with other instruments that meet the Kyoto Protocol targets (e.g., permits issued *gratis*) than is found in comparison between different methods of recycling.

7.6.6.2 Target Setting for Greenhouse Gas Emissions Reduction

The choice of targets and timing affects cost estimates. Emission reduction targets are related to baseline case assumptions, and can be defined in relation to a given base year, or in relation to expected future development trends. Targets defined relative to base-year levels are accurate in terms of the target for the future total GHG emissions, but the actual GHG emissions reduction effort that is required is uncertain because future emission levels are unknown. Reduction targets defined as percentage reductions of future GHG emissions create uncertainty as to the GHG emission levels.

Figure 7.4 illustrates the different target-setting principles. Target setting related to base-year emissions compares the GHG emissions level in the "dotted" line base-year emissions and GHG emissions reduction case 2. In contrast, target setting in relation to future GHG emissions compares the baseline case line and GHG emission reduction case 1.

Climate change damages are related to the accumulated stock of atmospheric GHG concentrations. As such, target setting for GHG reduction policies should reflect the long atmospheric lifetime of the gases. What matters is the accumulated GHG emissions over several decades and the "technically correct" GHG reduction targets imply that the targets were defined for a given time horizon.

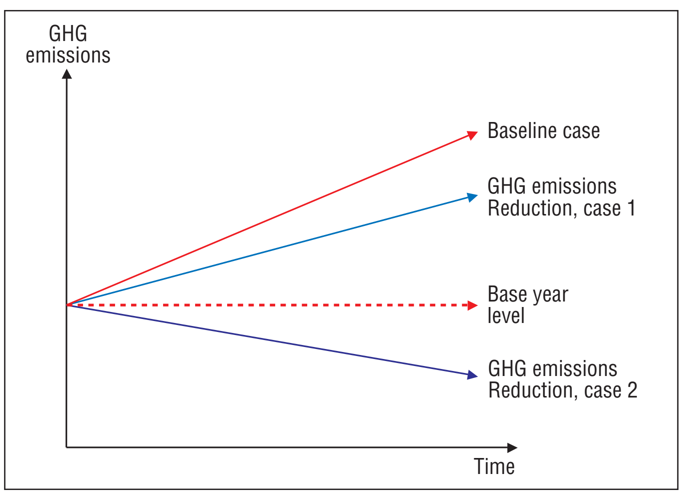

Figure 7.4: *Baseline cases and target setting for GHG emissions reduction.*

[21] As defined by the Articles 6, 12, and 17 of the Kyoto Protocol, these studies include JI between Annex I parties, CDM between Annex I and non-Annex I parties, and emissions trading between Annex I parties. See the discussions about these mechanisms in Chapter 6.

[22] Carbon-reduction projects are projects supplied by the potential host countries, where the policy is to be implemented.

Target setting over the relevant time horizon involves a number of technical challenges. The time dimension of the emissions reduction should reflect the dynamic aspects, such as time and path dependence of emissions and climate change damages. In addition, the costs of climate protection depend on the "when" and "where" flexibility of specific emission targets. Many of these time dimensions have been considered in IAMs.

The time flexibility involves several issues addressed in top-down and bottom-up models. Assumptions about technological change are, as discussed in Section 7.3.4, critical in the studies, and follow a simple "rule" that technological change over time expands the range of available GHG emissions reduction options. Technological change lowers the mitigation costs for a long-term target relative to a short-term target. It is emphasized that the mitigation costs and future technological change depend on GHG emissions reduction policies initiated and planned over the short- and long-term horizons. This reflects the point that technological change itself relates to R&D programmes and to current technology implementation.

The timing of mitigation policies also affects transition costs. From a short-term perspective, mitigation is constrained by the existing capital stock, infrastructure, and institutional structure related to technology. One key cost-determinant during the transition period is the turnover of capital stock. A time profile for mitigation that requires early retirement of capital stock increases the costs of achieving any target. This is predominantly an issue for developed countries, in which the capital stock and infrastructure are well developed.

7.6.6.3 International Co-operative Mechanisms

Mitigation costs vary across countries with different resource endowments, economic structure and development, institutional structure, and various other factors. These cost differences provide the opportunity to create and capture the gains from exchange that arise through international co-operative flexibility mechanisms. Mechanisms such as international carbon trading can facilitate collaborative emission reductions across countries and regions, and thereby minimize global control costs (see Chapter 6 for a detailed discussion on the issues involved in establishing such mechanisms).

The assumptions on international co-operative mechanisms include:

- Sectors and GHGs, which are included in the mechanisms.
- Specific constraints on countries and regions included in the trading regimes.
- Specific constraints on different co-operative mechanisms like those established by the Kyoto Protocol. The Protocol includes two project-based mechanisms: Article 6 on JI and Article 12 on CDM. Both JI and CDM aim to establish exchange institutions for projects to reduce GHG emissions. JI projects are between Annex I countries of the UNFCCC, and CDM projects are between countries with a reduction commitment specified in the Kyoto Protocol (termed Annex B countries) and countries without such a commitment. Another mechanism of the Kyoto Protocol is Article 17 that facilitates emissions trading among Annex B countries.
- Boundaries on GHG emissions trading markets, for example that set the minimum amount of domestic emission reductions for developed countries, specify a relationship between domestic GHG emissions reduction efforts and the GHG emissions reduction they can implement in collaboration with international partners.

Mitigation costs usually fall with greater flexibility for international emissions trading. This suggests that constraints on trading increase the costs of any emission target. Some critics point out that this argument does not address the potential positive impacts on technological development that can arise from implementing GHG emissions reduction policies domestically in developed countries, such as incentives for innovation and R&D.

7.6.6.4 Critical Assumptions in the Energy Sector

Table 7.4 provides an overview of the key assumptions behind mitigation cost studies for the energy sector. It is based on SAR (IPCC, 1996a, Chapter 8) and Halsnæs *et al*. (1998). Some of the new modelling areas that have important implications include assumptions on technology change, transaction costs and barrier removal policies, alternative demand projections (including lifestyle), and ancillary benefits. Similarly, assumptions related to climate change mitigation policies with major implications on costs include timing of the emissions reduction policies, and extent and function of global markets for emissions reduction projects.

The input assumptions are linked between the baseline case and the climate policy case in a complex way. There is the potential for many assumption combinations in baseline and mitigation scenarios, and the full set of assumptions in these two scenarios impacts the assessment of mitigation potential and related costs.

An OECD workshop in September 1998 (Mensbrugghe, 1998) concluded that the emissions reduction costs rely on baseline assumptions. Factors that lead to high cost estimates include high population and GDP growth rates, a relatively clean fuel mix, and relatively high energy costs. Among model parameters two areas were emphasized: the ability to substitute labour for energy, and the interfuel substitution elasticity. Low elasticities lead to high costs.

7.7 Conclusions on Further Needs for Research

It can be concluded generally that, since SAR (IPCC, 1996a, 1996b) was published, much progress has been achieved in the

Table 7.4: *Input assumptions used in energy sector mitigation studies*

Input assumptions	Meaning and relevance
Population	All else being equal, high growth increases GHG emissions.
Economic growth	Increased economic growth increases energy-using activities and also leads to increased investment, which speeds the turnover of energy-using equipment. Various assumptions on GHG emissions and resource intensities can be used for alternative scenarios.
Energy demand	
– structural change	Different sectors have different energy-intensities; structural change therefore has 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.
– "lifestyle"	Explains structural changes in consumer behaviour.
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; this is the upper bound of cost estimates.
– learning	Technology costs related to time, market scale, and institutional capacity.
Price and income elasticities of energy demand	Relative changes in energy demand through changes in price or income, respectively; higher elasticities result in larger changes in energy use.
Transaction costs	Implementation, administration, scale of the activity.
Policy instruments and regulation	
– instruments	Economic versus regulatory measures.
– barriers	Implementation costs, including costs of overcoming barriers either in the form of institutional aspects or improvements in markets (including capacity building and institutional reforms); behavioural assumptions.
Existing tax systems and tax recycling	Recycling of carbon taxes; substitution of distortionary taxes decreases costs.
Ancillary benefits	Integration of local and regional environmental policies in most cases generates secondary benefits. Social policy goals, like income distribution and employment, can result in different policy rankings.

development of consistent and transparent approaches to assess climate change mitigation costs. This has facilitated understanding of the differences in mitigation cost results generated by different modelling approaches, based on different assumptions. A number of new research topics have been considered particularly important in the establishment of more information about globally efficient and fair climate change mitigation policies. These issues include a better understanding of the relationship between economic costs of climate change mitigation policies and the sustainable development implications in different parts of the world. Specifically, a number of key research issues for further work include:

- Development and application of methodological approaches for the integrated assessment of linkages between climate change mitigation costs and sustainable development, including development, environment, and social dimensions:
  - assessment of macroeconomic impacts using different welfare measures,
  - co-benefit studies, and
  - assessment of equity impacts (intragenerational equity impacts should be represented as detailed studies of distributional impacts, and can be integrated as formal decision criteria in policy assessments).
- Development of a framework for the assessment of intra- and intergenerational equity aspects of climate change mitigation studies.
- Integration of environmental impact assessments in climate change mitigation studies. This will require the

development of consistent methodological approaches and empirical studies.

- Establishment of approaches to conduct implementation cost analysis in both top-down and bottom-up models.
- Implementation cost studies that reflect financial market conditions, institutional and human capacities, information requirements, market size and opportunities for technology gain and learning, economic incentives, and policy instruments.
- Development of a systematic approach for reporting baseline assumptions and the costs of moving from one specific baseline case to a climate change mitigation policy.
- Further development of a consistent analytical structure and a format for reporting the main assumptions that underlie costing results, including:
  - main scenario drivers: economic growth, technological development, sectoral activity, and fuel prices;
  - behavioural assumptions;
  - flexibility of climate change mitigation policies, including timing of the reduction policies, GHG emissions included, and international co-operative mechanisms; and
  - assumptions about tax recycling options, side-impacts of climate change mitigation policies, and the potential implementation of no regrets options.
- Development of approaches to and conduct of studies for developing countries and EITs that better reflect the specific characteristics of these economies in implementing climate change mitigation policies. Some of the major research topics are:
  - assessment of alternative development patterns and their relationship to development, social, and environmental sustainability dimensions;
  - macroeconomic studies that consider structural adjustment policies and market transformation processes;
  - studies of the informal sector and implications for GHG emissions and reduction policies;
  - non-commercial energy use; and
  - specific implementation policy issues.
- Estimates of future costs and sustainability implications that both reflect how climate change might affect future ecosystems, how these altered ecosystems might affect the demand for different goods, and how this demand might affect the welfare of our descendants.

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