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Framing Issues

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EXECUTIVE SUMMARY

This chapter frames climate change mitigation policies in the context of general development issues and recognizes that there is a two-way relationship between climate change and sustainable development. These relationships create a wide potential for linking climate change and sustainable development policies, and an emerging literature has identified methodological approaches and specific policies that can be used to explore synergies and tradeoffs between climate change and economic, social, and environmental sustainability dimensions.

Decision-making about climate change policies is a very complex and demanding task since there is no single decision-maker and different stakeholders assign different values to climate change impacts and to the costs and benefits of policy actions. However, many new initiatives emerge from governmental cooperation efforts, the business sector and NGOs (non-governmental organizations), so various coalitions presently play an increasing role. A large number of analytical approaches can be used to support decision-making, and progress has been made both in integrated assessment models, policy dialogues and other decision support tools.

Like most policy-making, climate policy involves trading off risks and uncertainties. Risks and uncertainties have not only natural but also human and social dimensions. They arise from missing, incomplete and imperfect evidence, from voluntary or involuntary limits to information management, from difficulties in incorporating some variables into formal analysis, as well as from the inherently unpredictable elements of complex systems. An increasing international literature considers how the limits of the evidence basis and other sources of uncertainties can be estimated.

Costs and benefits of climate change mitigation policies can be assessed (subject to the uncertainties noted above) at project, firm, technology, sectoral, community, regional, national or multinational levels. Inputs can include financial, economic, ecological and social factors. In formal cost-benefit analyses, the discount rate is one major determinant of the present value of costs and benefits, since climate change, and mitigation/adaptation measures all involve impacts spread over very long time periods. Much of the literature uses constant discount rates at a level estimated to reflect time preference rates as used when assessing typical large investments. Some recent literature also includes recommendations about using time-decreasing discount rates, which reflect uncertainty about future economic growth, fairness and intra-generational distribution, and observed individual choices. Based on this, some countries officially recommend using time-decreasing discount rates for long time horizons.

The potential linkages between climate change mitigation and adaptation policies have been explored in an emerging literature. It is concluded that there is a number of factors that condition societies' or individual stakeholders' capacity to implement climate change mitigation and adaptation policies including social, economic, and environmental costs, access to resources, credit, and the decision-making capacity in itself.

Climate change has considerable implications for intra-generational and inter-generational equity, and the application of different equity approaches has major implications for policy recommendations, as well as for the implied distribution of costs and benefits of climate policies. Different approaches to social justice can be applied when evaluating equity consequences of climate change policies. They span traditional economic approaches where equity appears in terms of the aggregated welfare consequences of adaptation and mitigation policies, and rights-based approaches that argue that social actions are to be judged in relation to the defined rights of individuals.

The cost and pace of any response to climate change concerns will critically depend on the social context, as well as the cost, performance, and availability of technologies. Technological change is particularly important over the long-term time scales that are characteristic of climate change. Decade (or longer) time scales are typical for the gaps involved between technological innovation and widespread diffusion, and of the capital turnover rates characteristic for long-term energy capital stock and infrastructures. The development and deployment of technology is a dynamic process that arises through the actions of human beings, and different social and economic systems have different proclivities to induce technological change, involving a different set of actors and institutions in each step. The state of technology and technology change, as well as human capital and other resources, can differ significantly from country to country and sector to sector, depending on the starting point of infrastructure, technical capacity, the readiness of markets to provide commercial opportunities and policy frameworks.

The climate change mitigation framing issues in general are characterized by high agreement/much evidence relating to the range of theoretical and methodological issues that are relevant in assessing mitigation options. Sustainable development and climate change, mitigation and adaptation relationships, and equity consequences of mitigation policies are areas where there is conceptual agreement on the range of possible approaches, but relatively few lessons can be learned from studies, since these are still limited *(high agreement, limited evidence)*. Other issues, such as mitigation cost concepts and technological change are very mature in the mitigation policy literature, and there is high agreement/much evidence relating to theory, modelling, and other applications. In the same way, decision-making approaches and various tools and approaches are characterized by high agreement on the range of conceptual issues *(high agreement, much evidence)*, but there is significant divergence in the applications, primarily since some approaches have been applied widely and others have only been applied to a more limited extent *(high agreement, limited evidence)*. There is some debate about which of these framing methodologies and issues relating to mitigation options are most important, reflecting (amongst other things) different ethical choices – to this extent at least there is an irreducible level of uncertainty *(high agreement, limited evidence)*.

2.1 Climate change and Sustainable Development

2.1.1 Introduction

This section introduces the relationship between sustainable development (SD) and climate change and presents a number of key concepts that can be used to frame studies of these relationships. Climate change and sustainable development are considered in several places throughout this report. Chapter 12 provides a general overview of the issues, while more specific issues relating to short- and long-term mitigation issues are addressed in Chapters 3 (Section 3.1) and 11 (Section 11.6). Sectoral issues are covered in Chapters 4-10 (Sections 4.5.4, 5.5.5, 6.9.2, 7.7, 8.4.5, 9.7, and in 10.6). Furthermore, the IPCC (2007b) addresses SD and climate change in Chapters 18 and 20.

2.1.2 Background

The IPCC's Third Assessment Report (TAR; IPCC, 2001) included considerations concerning SD and climate change. These issues were addressed particularly by Working Group II and III, as well as the Synthesis report. The TAR included a rather broad treatment of SD (Metz *et al.*, 2002). The report noted three broad classes of analyses or perspectives: efficiency and cost-effectiveness, equity and sustainable development, and global sustainability and societal learning.

Since the TAR, literature on sustainable development and climate change has attempted to further develop approaches that can be used to assess specific development and climate policy options and choices in this context (Beg *et al.*, 2002; Cohen *et al.*, 1998; Munasinghe and Swart, 2000; Schneider, 2001; Banuri *et al.*, 2001; Halsnæs and Verhagen, 2007; Halsnæs, 2002; Halsnæs and Shukla, 2007, Markandya and Halsnæs, 2002a; Metz *et al.* 2002; Munasinghe and Swart, 2005; Najam and Rahman, 2003; Smit *et al.*, 2001; Swart *et al.*,. 2003; Wilbanks, 2003). These have included discussions about how distinctions can be made between natural processes and feedbacks, and human and social interactions that influence the natural systems and that can be influenced by policy choices (Barker, 2003). These choices include immediate and very specific climate policy responses as well as more general policies on development pathways and the capacity for climate change adaptation and mitigation. See also Chapter 12 of this report and Chapter 18 of IPCC (2007b) for a more extensive discussion of these issues.

Policies and institutions that focus on development also affect greenhouse gas (GHG) emissions and vulnerability. Moreover, these same policies and institutions constrain or facilitate mitigation and adaptation. These indirect effects can be positive or negative, and several studies have therefore suggested the integration of climate change adaptation and mitigation perspectives into development policies, since sustainable development requires coping with climate change and thereby will make development more sustainable (Davidson *et al.*, 2003; Munasinghe and Swart, 2005; Halsnæs and Shukla, 2007).

Climate change adaptation and mitigation can also be the focus of policy interventions and SD can be considered as an issue that is indirectly influenced. Such climate policies can tend to focus on sectoral policies, projects and policy instruments, which meet the adaptation and mitigation goals, but are not necessarily strongly linked to all the economic, social, and environmental dimensions of sustainable development. In this case climate change policy implementation in practice can encounter some conflicts between general development goals and the goal of protecting the global environment. Furthermore, climate policies that do not take economic and social considerations into account might not be sustainable in the long run.

In conclusion, one might then distinguish between climate change policies that emerge as an integrated element of general sustainable development policies, and more specific adaptation and mitigation policies that are selected and assessed primarily in their capacity to address climate change. Examples of the first category of policies can be energy efficiency measures, energy access and affordability, water management systems, and food security options, while examples of more specific adaptation and mitigation policies can be flood control, climate information systems, and the introduction of carbon taxes. It is worth noticing that the impacts on sustainable development and climate change adaptation and mitigation of all these policy examples are very context specific, so it cannot in general be concluded whether a policy supports sustainable development and climate change jointly or if there are serious tradeoffs between economic and social perspectives and climate change (see also Chapter 12 of this report and Chapter 18 of IPCC (2007b) for a more extensive discussion).

2.1.3 The dual relationship between climate change and Sustainable Development

There is a dual relationship between sustainable development and climate change. On the one hand, climate change influences key natural and human living conditions and thereby also the basis for social and economic development, while on the other hand, society's priorities on sustainable development influence both the GHG emissions that are causing climate change and the vulnerability.

Climate policies can be more effective when consistently embedded within broader strategies designed to make national and regional development paths more sustainable. This occurs because the impact of climate variability and change, climate policy responses, and associated socio-economic development will affect the ability of countries to achieve sustainable development goals. Conversely, the pursuit of those goals will in turn affect the opportunities for, and success of, climate policies.

Climate change impacts on development prospects have also been described in an interagency project on poverty and climate change as 'Climate Change will compound existing poverty. Its adverse impacts will be most striking in the developing nations because of their dependence on natural resources, and their limited capacity to adapt to a changing climate. Within these countries, the poorest, who have the least resources and the least capacity to adapt, are the most vulnerable' (African Development Bank *et al.*, 2003).

Recognizing the dual relationship between SD and climate change points to a need for the exploration of policies that jointly address SD and climate change. A number of international study programmes, including the Development and Climate project (Halsnæs and Verhagen, 2007), and an OECD development and environment directorate programme (Beg *et al.,* 2002) explore the potential of SD-based climate change policies. Other activities include projects by the World Resources Institute (Baumert *et al.,* 2002), and the PEW Centre (Heller and Shukla, 2003). Furthermore, the international literature also includes work by Cohen *et al.*, 1998; Banuri and Weyant, 2001; Munasinghe and Swart 2000; Metz *et al.*, 2002; Munasinghe and Swart, 2005; Schneider *et al.*, 2000; Najam and Rahman, 2003; Smit *et al.*, 2001; Swart *et al.*, 2003; and Wilbanks, 2003).

2.1.4 The Sustainable Development concept

Sustainable development (SD) has been discussed extensively in the theoretical literature since the concept was adopted as an overarching goal of economic and social development by UN agencies, by the Agenda 21 nations, and by many local governments and private-sector actors. The SD literature largely emerged as a reaction to a growing interest in considering the interactions and potential conflicts between economic development and the environment. SD was defined by the World Commission on Environment and Development in the report *Our Common Future* as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987).

The literature includes many alternative theoretical and applied definitions of sustainable development. The theoretical work spans hundreds of studies that are based on economic theory, complex systems approaches, ecological science and other approaches that derive conditions for how development paths can meet SD criteria. Furthermore, the SD literature emphasizes a number of key social justice issues including inter- and intra-generational equity. These issues are dealt with in Section 2.6.

Since a comprehensive discussion of the theoretical literature on sustainable development is beyond the scope of this report, a pragmatic approach limits us to consider how development can be made more sustainable.

The debate on sustainability has generated a great deal of research and policy discussion on the meaning, measurability and feasibility of sustainable development. Despite the intrinsic ambiguity in the concept of sustainability, it is now perceived as an irreducible holistic concept where economic, social, and environmental issues are interdependent dimensions that must be approached within a unified framework (Hardi and Barg, 1997; Dresner, 2002; Meadows, 1998). However, the interpretation and valuation of these dimensions have given rise to a diversity of approaches.

A growing body of concepts and models, which explores reality from different angles and in a variety of contexts, has emerged in recent years in response to the inability of normal disciplinary science to deal with complexity and systems – the challenges of sustainability. The outlines of this new framework, known under the loose term of 'Systems Thinking', are, by their very nature, transdisciplinary and synthetic (Kay and Foster, 1999). An international group of ecologists, economists, social scientists and mathematicians has laid the principles and basis of an integrative theory of systems change (Holling 2001). This new theory is based on the idea that systems of nature and human systems, as well as combined human and nature systems and social-ecological systems, are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal within hierarchical structures (Holling *et al.*, 2002).

A core element in the economic literature on SD is the focus on growth and the use of man-made, natural, and social capital. The fact that there are three different types of capital that can contribute to economic growth has led to a distinction between weak and strong sustainability, as discussed by Pearce and Turner (1990), and Rennings and Wiggering (1997). Weak sustainability describes a situation where it is assumed that the total capital is maintained and that the three different elements of the capital stock can, to some extent, be used to substitute each other in a sustainable solution. On the other hand, strong sustainability requires each of the three types of capital to be maintained in its own right, at least at some minimum level. An example of an application of the strong sustainability concept is Herman Daly's criteria, which state that renewable resources must be harvested at (or below) some predetermined stock level, and renewable substitutes must be developed to offset the use of exhaustible resources (Daly, 1990). Furthermore, pollution emissions should be limited to the assimilative capacity of the environment.

Arrow *et al.*, 2004, in a joint authorship between leading economists and ecologists, present an approach for evaluating alternative criteria for consumption[1], seen over time in a sustainable development perspective. Inter-temporal consumption and utility are introduced here as measurement

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[1] Consumption should here be understood in a broad sense as including all sorts of goods that are elements in a social welfare function.

points for sustainable development. One of the determinants of consumption and utility is the productive base of society, which consists of capital assets such as manufactured capital, human capital, and natural capital. The productive base also includes the knowledge base of society and institutions.

Although institutions are often understood as part of the capital assets, Arrow *et al.* (2004) only consider institutions in their capacity as guiding the allocation of resources, including capital assets. Institutions in this context include the legal structure, formal and informal markets, various government agencies, inter-personal networks, and the rules and norms that guide their behaviour. Seen from an SD perspective, the issue is then: how, and to what extent, can policies and institutional frameworks for these influence the productive basis of society and thereby make development patterns more sustainable.

The literature includes other views of capital assets that will consider institutions and sustainable development policies as being part of the social capital element in society's productive base. Lehtonen (2004) provides an overview of the discussion on social capital and other assets. He concludes that despite capabilities and social capital concepts not yet being at the practical application stage, the concepts can be used as useful metaphors, which can help to structure thoughts across different disciplines. Lehtonen refers to analysis of social-environmental dimensions by the OECD (1998) that addresses aspects such as demography, health, employment, equity, information, training, and a number of governance issues, as an example of a pragmatic approach to including social elements in sustainability studies.

Arrow *et al.,* (2004) summarize the controversy between economists and ecologists by saying that ecologists have deemed current consumption patterns to be excessive or deficient in relation to sustainable development, while economists have focused more on the ability of the economy to maintain living standards. It is concluded here that the sustainability criterion implies that inter-temporal welfare should be optimized in order to ensure that current consumption is not excessive.[2] However, the optimal level of current consumption cannot be determined (i.e. due to various uncertainties). Theoretical considerations therefore focus instead on factors that make current consumption more or less sustainable. These factors include the relationship between market rates of return on investments and social discount rates, and the relationship between market prices of consumption goods (including capital goods) and the social costs of these commodities.

Some basic principles are therefore emerging from the international sustainability literature, which helps to establish commonly held principles of sustainable development. These include, for instance, the welfare of future generations, the maintenance of essential biophysical life support systems, more universal participation in development processes and decision-making, and the achievement of an acceptable standard of human well-being (Swart *et al.*, 2003; Meadowcroft, 1997; WCED, 1987).

In the more specific context of climate change policies, the controversy between different sustainability approaches has shown up in relation to discussions on key vulnerabilities; see Section 2.5.2 for more details.

2.1.5 Development paradigms

Assessment of SD and climate change in the context of this report considers how current development can be made more sustainable. The focus is on how development goals, such as health, education, and energy, food, and water access can be achieved without compromising the global climate.

When applying such a pragmatic approach to the concept of SD it is important to recognize that major conceptual understandings and assumptions rely on the underlying development paradigms and analytical approaches that are used in studies. The understanding of development goals and the tradeoffs between different policy objectives depends on the development paradigm applied, and the following section will provide a number of examples on how policy recommendations about SD and climate change depend on alternative understandings of development as such.

A large number of the models that have been used for mitigation studies are applications of economic paradigms. Studies that are based on economic theory typically include a specification of a number of goals that are considered as important elements in welfare or human wellbeing. Some economic paradigms focus on the welfare function of the economy, assuming efficient resource allocation (such as in neoclassical economics), and do not consider deviations from this state and ways to overcome these. In terms of analyzing development and climate linkages, this approach will see climate change mitigation as an effort that adds a cost to the optimal economic state.[3] However, there is a very rich climate mitigation cost literature that concludes that market imperfections in practice often create a potential for mitigation policies that can help to increase the efficiency of energy markets and thereby generate indirect cost savings that can make mitigation policies economically attractive (IPCC, 1996, Chapters 8 and 9; IPCC, 2001, Chapters 7 and 8). The character of such market imperfections is discussed further in Section 2.4.

Other development paradigms based on institutional economics focus more on how markets and other information-

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[2] Arrow *et al.* (2004) state that 'actual consumption today is excessive if lowering it and increasing investment (or reducing disinvestment) in capital assets could raise future utility enough to more than compensate (even after discounting) for the loss in current utility'.

[3] Take the benefits of avoided climate change into consideration.

sharing mechanisms establish a framework for economic interactions. Recent development research has included studies on the role of institutions as a critical component in an economy's capacity to use resources optimally. Institutions are understood here in a broad sense, as being a core allocation mechanism and as the structure of society that organizes markets and other information sharing (Peet and Hartwick, 1999).

In this context, climate policy issues can include considerations about how climate change mitigation can be integrated into the institutional structure of an economy. More specifically, such studies can examine various market and non-market incentives for different actors to undertake mitigation policies and how institutional capacities for these policies can be strengthened. Furthermore, institutional policies in support of climate change mitigation can also be related to governance and political systems – see a more elaborate discussion in Chapter 12, Section 12.2.3.

Weak institutions have a lot of implications for the capacity to adapt or mitigate to climate change, as well as in relation to the implementation of development policies. A review of the social capital literature related to economic aspects and the implications for climate change mitigation policies concludes that, in most cases, successful implementation of GHG emission-reduction options will depend on additional measures to increase the potential market and the number of exchanges. This can involve strengthening the incentives for exchange (prices, capital markets, information efforts etc.), introducing new actors (institutional and human capacity efforts), and reducing the risks of participation (legal framework, information, general policy context of market regulation). All these measures depend on the nature of the formal institutions, the social groups of society, and the interactions between them (Olhoff, 2002). See also Chapter 12 of this report for a more extensive discussion of the political science and sociological literature in this area.

Key theoretical contributions to the economic growth and development debate also include work by A. Sen (1999) and P. Dasgupta (1993) concerning capabilities and human well-being. Dasgupta, in his inquiry into well-being and destitution, concludes that 'our citizens' achievements are the wrong things to look at. We should be looking at the extent to which they enjoy the freedom to achieve their ends, no matter what their ends turn out to be. The problem is that the extent of such freedoms depends upon the degree to which citizens make use of income and basic needs'. (Dasgupta, 1993, pp. 54). Following this, Dasgupta recommends studying the distribution of resources, as opposed to outcomes (which, for example, can be measured in terms of welfare). The access to income and basic needs are seen as a fundamental basis for human well-being and these needs include education, food, energy, medical care etc. that individuals can use as inputs to meeting their individual desires. See also Section 2.6, where the equity dimensions of basic needs and well-being approaches are discussed in more detail.

In the context of capabilities and human well-being, climate change policies can then include considerations regarding the extent to which these policies can support the access of individuals to specific resources as well as freedoms.

The capability approaches taken by Sen and Dasgupta have been extended by some authors from focusing on individuals to also covering societies (Ballet *et al.*, 2003; Lehtonen, 2004). It is argued here that, when designing policies, one needs to look at the effects of economic and environmental policies on the social dimension, including individualistic as well as social capabilities, and that these two elements are not always in harmony.

2.1.6 International frameworks for evaluating Sustainable Development and climate change links

Studies that assess the sustainable development impacts of climate change (and vice versa) when they are considering short to medium-term perspectives will be dealing with a number of key current development challenges. This section provides a short introduction to international policy initiatives and decisions that currently offer a framework for addressing development goals.

A key framework that can be used to organize the evaluation of SD and climate change linkages is the WEHAB[4] framework that was introduced by the World Summit on Sustainable Development in 2002 (WSSD, 2002). The WEHAB sectors reflect the areas selected by the parties at the WSSD meeting to emphasize that particular actions were needed in order to implement Agenda 21. Seen from a climate change policy evaluation perspective it would be relevant to add a few more sectors to the WEHAB group in order to facilitate a comprehensive coverage of major SD and climate change linkages. These sectors include human settlements tourism, industry, and transportation. It would also be relevant to consider demography, institutions and various cultural issues and values as cross-cutting sectoral issues.

Climate change policy aspects can also be linked to the Millennium Development Goals (MDG) that were adopted as major policy targets by the WSSD. The MDGs include nine general goals to eradicate poverty and hunger, health, education, natural resource utilization and preservation, and global partnerships that are formulated for the timeframe up to 2015 (UNDP, 2003a).

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[4] WEHAB stands for Water, Energy, Health, Agriculture, and Biodiversity.

A recent report by the CSD (Commission on Sustainable Development) includes a practical plan for how to achieve the Millennium Development Goals (CSD, 2005). Climate change is explicitly mentioned in the CSD report as a factor that could worsen the situation of the poor and make it more difficult to meet the MDGs. Furthermore, CSD (2005) suggests adding a number of energy goals to the MDGs (i.e. to reflect energy security and the role that energy access can play in poverty alleviation). Adding energy as a separate component in the MDG framework will establish a stronger link between MDGs and climate change mitigation.

Several international studies and agency initiatives have assessed how the MDGs can be linked to goals for energy-, food-, and water access and to climate change impacts, vulnerability, and adaptation (African Development Bank *et al.*, 2003), and an example of how the link between climate change and MDGs can be further developed to include both adaptation and mitigation is shown in Table 2.1. A linkage between MDGs and development goals is also described very specifically by Shukla (2003) and Shukla *et al.* (2003) in relation to the official Indian 10th plan for 2002–2007. In the same way, the Millenium Ecosystem Assessment (MEA) presents a global picture of the relationship between the net gains in human well-being and economic development based on a growing cost through degradation of ecosystem services, and demonstrates how this can pose a barrier to achieving the MDGs (MEA, 2005).

Measuring progress towards SD requires the development and systematic use of a robust set of indicators and measures. Agenda 21 (1992) explicitly recognizes in Chapter 40 that a pre-requisite for action is the collection of data at various levels (local, provincial, national and international), indicating the status and trends of the planet's ecosystems, natural resources, pollution and socio-economy.

The OECD Ministerial Council decided in 2001 that the regular Economic Surveys of OECD countries should include an evaluation of SD dimensions, and a process for agreeing on SD indicators. These will be used in regular OECD peer reviews of government policies and performance. From the OECD menu of SD issues, the approach is to select a few areas that will be examined in depth, based on specific country relevance (OECD, 2003).

The first OECD evaluation of this kind was structured around three topics that member countries could select from the following list of seven policy areas (OECD, 2004):

- Improving environmental areas:
  - Reducing GHG emissions
  - Reducing air pollutants
  - Reducing water pollution
  - Moving towards sustainable use of renewable and non-renewable natural resources
  - Reducing and improving waste management
- Improving living standards in developing countries.
- Ensuring sustainable retirement income policies.

Most of the attention in the country choice was given to the environmental areas, while evaluation of improving living standards in developing countries was given relatively little attention in this first attempt.

The use of SD indicators for policy evaluations has been applied in technical studies of SD and climate change (Munasinghe, 2002; Atkinson *et al.*, 1997; Markandya *et al.*, 2002). These studies address SD dimensions based on a number of economic, environmental, human and social indicators, including both quantitative and qualitative measurement standards. A practical tool applied in several countries, called the Action Impact Matrix (AIM), has been used to identify, prioritize, and address climate and development synergies and tradeoffs (Munasinghe and Swart, 2005).

All together, it can be concluded that many international institutions and methodological frameworks offer approaches for measuring various SD dimensions, and that these have been related to broader development and economic policies by CSD, the WSSD, and the OECD. Many indexes and measurement approaches exist but, until now, relatively few studies have measured climate change in the context of these indexes. In this way, there is still a relatively weak link between actual measurements of and climate change links.

2.1.7

Table 2.1: *Relationship between MDGs, energy-, food-, and water access, and climate change*

MDG goals	Sectoral themes	Climate change links
To halve (between 1990 and 2015), the proportion of the world's population whose income is below 1US$ a day	Energy: Energy for local enterprises Lighting to facilitate income generation Energy for machinery Employment related to energy provision Food/water: Increased food production Improved water supply Employment	Energy: GHG emissions. Adaptive and mitigative capacity increase due to higher income levels and decreased dependence on natural resources, production costs etc. Food/water: GHG emissions Increased productivity of agriculture can reduce climate change vulnerability. Improved water management and effective use can help adaptation and mitigation. Increased water needs for energy production
To reduce by two-thirds (between 1990 and 2015), the death rate for children under the age of five years	Energy: Energy supply can support health clinics Reduced air pollution from traditional fuels Reduced time spent on fuel collection can increase the time spent on children's health care Food/water: Improved health due to increased supply of high-quality food and clean water Reduced time spent on food and water provision can increase the time spent on children's health care Improved waste and wastewater treatment	Energy: GHG emissions Food/water: Health improvements will decrease vulnerability to climate change and the adaptive capacity Decreased methane and nitrous oxide emissions
To reduce by three-quarters (between 1990 and 2015) the rate of maternal mortality	Energy: Energy provision for health clinics Reduced air pollution from traditional fuels and other health improvements. Food/water: Improved health due to increased supply of high-quality food and clean water Time savings on food and water provision can increase the time spent on children's health care	Energy: GHG emissions Food/water: Health improvements will decrease vulnerability to climate change and the adaptive capacity
Combat HIV/AIDS, malaria and other major diseases	Energy: Energy for health clinics Cooling of vaccines and medicine Food/water: Health improvements from cleaner water supply Food production practices that reduce malaria potential	Energy: GHG emissions from increased health clinic services, but health improvements can also reduce the health service demand Food/water: Health improvements will decrease vulnerability to climate change and the adaptive capacity
To stop the unsustainable exploitation of natural resources	Energy: Deforestation caused by woodfuel collection Use of exhaustible resources Food/water: Land degradation	Energy: GHG emissions Carbon sequestration Food/water: Carbon sequestration Improved production conditions for land-use activities will increase the adaptive and mitigative capacity
To halve (between 1990 and 2015), the proportion of people who are unable to reach and afford safe drinking water	Energy: Energy for pumping and distribution systems, and for desalination and water treatment Water: Improved water systems	Energy: GHG emissions Water: Reduced vulnerability and enhanced adaptive capacity

Source: based on Davidson et al., (2003).

assessment of how state, market, civil society and partnerships play a role in sustainable development and climate change policies.

2.2 Decision-making

2.2.1 The 'public good' character of climate change

Mitigation costs are exclusive to the extent that they may be borne by some individuals (nations) while others might evade them (free-riding) or might actually gain a trade/investment benefit from not acting (carbon leakage). The incentive to evade taking mitigation action increases with the substitutability of individual mitigation efforts and with the inequality of the distribution of net benefits. However, individual mitigation efforts (costs) decrease with efficient mitigation actions undertaken by others.

The unequal distribution of climate benefits from mitigation action, of the marginal costs of mitigation action and of the ability to pay emission reduction costs raises equity issues and increases the difficulty of securing agreement. In a strategic environment, leadership from a significant GHG emitter may provide an incentive for others to follow suit by lowering their costs (Grasso, 2004; ODS, 2002).

Additional understandings come from political science, which emphasizes the importance of analyzing the full range of factors that have a bearing on decisions by nation states, including domestic pressures from the public and affected interest groups, the role of norms and the contribution of NGOs to the negotiation processes. *Case studies* of many MEAs (Multilateral Environmental Agreements) have provided insights, particularly on the institutional, cultural, political and historical dimensions that influence outcomes (Cairncross, 2004). A weakness of this approach is that the conclusions can differ depending on the choice of cases and the way in which the analysis is implemented. However, such ex-post analysis of the relevant policies often provides deep insights that are more accessible to policymakers, rather than theoretical thinking or numeric models.

2.2.2 Long time horizons

Climate policy raises questions of inter-generational equity and changing preferences, which inevitably affect the social weighting of environmental and economic outcomes, due to the long-term character of the impacts (for a survey see Bromley and Paavola, 2002).

However, studies traditionally assume that preferences will be stable over the long time frames involved in the assessment of climate policy options. To the extent that no value is attached to the retention of future options, the preferences of the present generation are implicitly given priority in much of this analysis. As time passes, preferences will be influenced by information, education, social and organizational affiliation, income distribution and a number of cultural values (Palacios-Huerta and Santos, 2002). Institutional frameworks are likely to develop to assist groups, companies and individuals to form preferences in relation to climate change policy options. The institutions can include provision of information and general education programmes, research and assessments, and various frameworks that can facilitate collective decision-making that recognizes the common 'global good' character of climate change.

At an analytic level, the choice of discount rates can have a profound affect on valuation outcomes – this is an important issue in its own right and is discussed in Section 2.4.1.

2.2.3 Irreversibility and the implications for decision-making

Human impacts on the climate system through greenhouse gas emissions may change the climate so much that it is impossible (or extremely difficult and costly) to return it to its original state – in this sense the changes are irreversible (Scheffer *et al.,* 2001; Schneider, 2004). Some irreversibility will almost certainly occur. For example, there is a quasi-certain irreversibility of a millennia time scale in the presence, in the atmosphere, of 22% of the emitted CO_2 (Solomon *et al*., 2007). However, the speed and nature of these changes, the tipping point at which change may accelerate and when environmentally, socially and economically significant effects become irreversible, and the cost and effectiveness of mitigation and adaptation responses are all uncertain, to a greater or lesser extent.

The combination of environmental irreversibility, together with these uncertainties (Baker, 2005; Narain *et al.*, 2004; Webster, 2002; Epstein, 1980) means that decision-makers have to think carefully about:
a) The timing and sequencing of decisions to preserve options.
b) The opportunity to sequence decisions to allow for learning about climate science, technology development and social factors (Baker, 2005; Kansuntisukmongko, 2004).
c) Whether the damage caused by increases in greenhouse concentrations in the atmosphere will increase proportionally and gradually or whether there is a risk of sudden, non-linear changes, and similarly whether the costs of reducing emissions change uniformly with time and the depth of reduction required, or are they possibly subject to thresholds or other non-linear effects.
d) Whether the irreversible damages are clustered in particular parts of the world or have a general effect, and
e) whether there is a potential that these irreversible damages will be catastrophically severe for some, many or even all communities (Cline, 2005).

Just as there are risks of irreversible climate changes, decisions to reduce GHG emissions can require actions that are essentially irreversible. For example, once made, these long-lived, large-scale investments in low-emission technologies are irreversible. If the assumptions about future policies and the directions of climate science on which these investments are made prove to be wrong, they would become 'stranded' assets. The risks (perceived by investors) associated with irreversibility of this nature further complicate decision-making on abatement action (Keller *et al.*, 2004; Pindyck, 2002; Kolstad, 1996; Sullivan *et al.,* 2006; Hamilton and Kenber, 2006).

Without special actions by governments to overcome their natural inertia, economic and social systems might delay too long in reacting to climate risks, thus leading to irreversible climate changes. Ambitious climate-protection goals would require new investments (physical and intellectual) in climate-friendly technologies (efficiency improvements, renewables, nuclear power, carbon capture and storage), which are higher in cost than current technologies or otherwise divert scarce resources. From an economic point of view these investments are essentially irreversible. As the scale of the investment and the proportion of research and development costs increase, so the private economic risks associated with irreversibility also increase. Therefore, in the presence of uncertainty concerning future policy towards GHG emission reduction, future carbon prices or stabilization targets, investors are reluctant to undertake large-scale irreversible investments (sunk costs) without some form of upfront government support.

2.2.4 Risk of catastrophic or abrupt change

The possibility of abrupt climate change and/or abrupt changes in the earth system triggered by climate change, with potentially catastrophic consequences, cannot be ruled out (Meehl *et al*., 2007). Disintegration of the West Antarctic Ice Sheet (See Meehl *et al*., 2007), if it occurred, could raise sea level by 4-6 metres over several centuries. A shutdown of the North Atlantic Thermohaline Circulation (See Meehl *et al*., 2007) could have far-reaching, adverse ecological and agricultural consequences (See IPCC, 2007b, Chapter 17), although some studies raise the possibility that the isolated, economic costs of this event might not be as high as assumed (See Meehl *et al*., 2007). Increases in the frequency of droughts (Salinger, 2005) or a higher intensity of tropical cyclones (See Meehl *et al*., 2007) could occur. Positive feedback from warming may cause the release of carbon or methane from the terrestrial biosphere and oceans (See Meehl *et al*., 2007), which would add to the mitigation required.

Much conventional decision-making analysis is based on the assumption that it is possible to model and compare all the outcomes from the full range of alternative climate policies. It also assumes there is a smooth trade-off between the different dimensions of each policy outcome; that a probability distribution provides an expected value for each outcome, and that there is a unique best solution – the one with the highest expected value. Consequently, it could suggest that a policy which risked a catastrophically bad outcome with a very low probability might be valued higher than one which completely avoided the possibility of catastrophe and produced merely a bad outcome, but with a very high probability of occurrence.

Assumptions that it is always possible to 'trade off' more of one dimension (e.g. economic growth) for less of another (e.g. species protection) – that there is always a price at which we are comfortable to 'dispense with' a species in the wild (e.g. polar bears), an ecological community or indigenous cultures are problematic for many people. This also applies to assumptions that decision-makers value economic (and other) gains and losses symmetrically – that a dollar gained should always assumed to be valued equally to one that is lost, and that it is possible and appropriate to assume that the current generation's preferences will remain stable over time.

Recent literature drawing on experimental economics and behavioural sciences suggests that these assumptions are an incomplete description of the way in which humans really make decisions. This literature suggests that preferences may be lexicographical (i.e. it is not possible to 'trade off' between different dimensions of alternative possible outcomes – there may be an aversion at any 'price' to losing particular species, ecosystems or communities), that attitudes to gains and losses might not be symmetrical (losses valued more highly than gains of an equivalent magnitude), and that low-probability extreme outcomes are overweighted when making choices (Tversky and Kahneman, 1992; Quiggin, 1982). This literature suggests that under these circumstances the conventional decision axiom of choosing the policy set that maximizes the expected (monetary) value of the outcomes might not be appropriate. Non-conventional decision criteria (e.g. avoiding policy sets which imply the possibility, even if at a very low probability, of specific unacceptable outcomes) might be required to make robust decisions (Chichilnisky, 2000; Lempert and Schlesinger, 2000; Kriegler *et al.,* 2006).

No one analytic approach is optimal. Decision-making inevitably involves applying normative rules. Some normative rules are described in Section 2.2.7 and in Section 2.6.

2.2.5 Sequential decision-making

Uncertainty is a steadfast companion when analyzing the climate system, assessing future GHG emissions or the severity of climate change impacts, evaluating these impacts over many generations or estimating mitigation costs. The typology of uncertainties is explored fully in Section 2.3 below. Uncertainties of differing types exist in key socio-economic factors and scientific phenomena.

The climate issue is a long-term problem requiring long-term solutions. Policymakers need to find ways to explore appropriate long-term objectives and to make judgments about how compatible short-term abatement options are with long-term objectives. There is an increased focus on non-conventional (robust) decision rules (see Section 2.2.7 below), which preserve future options by avoiding unacceptable risks.

Climate change decision-making is not a once-and-for-all event. Rather it is a process that will take place over decades and in many different geographic, institutional and political settings. Furthermore, it does not occur at discrete intervals but is driven by the pace of the scientific and political process. Some uncertainties will decrease with time – for example in relation to the effectiveness of mitigation actions and the availability of low-emission technologies, as well as with respect to the science itself. The likelihood that better information might improve the quality of decisions (the value of information) can support increased investment in knowledge accumulation and its application, as well as a more refined ordering of decisions through time. Learning is an integral part of the decision-making process. This is also referred to as 'act then learn, then act again' (Manne and Richels, 1992; Valverde *et al.,* 1999).

Uncertainties about climate policies at a decadal scale are a source of concern for many climate-relevant investments in the private sector (for example power generation), which have long expected economic lives.

It is important to recognize, however, that some level of uncertainty is unavoidable and that at times the acquisition of knowledge can increase, not decrease, uncertainty. Decisions will nevertheless have to be made.

2.2.6 Dealing with risks and uncertainty in decision-making

Given the multi-dimensionality of risk and uncertainty discussed in Section 2.3, the governance of these deep uncertainties as suggested by Godard *et al.* (2002, p. 21) rests on three pillars: precaution, risk hedging, and crisis prevention and management.

The 1992 UNFCCC Article 3 (Principles) states that the Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective in order to ensure global benefits at the lowest possible cost.[5]

While the precautionary principle appears in many other international treaties, from a scientific perspective the concept of precaution is subject to a plurality of interpretations. To frame the discussions on precaution, three key points should be considered first.

First, 'precaution' relates to decision-making in situations of deep uncertainty. It applies in the absence of sufficient data or conclusive or precise probabilistic descriptions of the risks (Cheve and Congar, 2000; Henry and Henry, 2002) or in circumstances where the possibility of unforeseen contingencies or the possibility of irreversibility (Gollier *et al.,* 2000) is suspected.

Second, in addition to that uncertainty/risk dimension, there is also a time dimension of precaution: the precautionary principle recognizes that policy action should not always wait for scientific certainty (see also the costs and decision-making sections of this chapter).

Third, the precautionary principle cuts both ways because in many cases, as Graham and Wiener (1995) noted, environmental choices are trade-offs between one risk and another risk. For example, mitigating climate change may involve more extensive use of nuclear power. Goklany (2002) has suggested a framework for decision-making under the precautionary principle that considers trade-offs between competing risks.

There is no single agreed definition of precautionary decision-making in the scientific literature.

The risk of catastrophes is commercially important, particularly for reinsurers that are large companies whose business is to sell insurance to other insurance companies (see IPCC, 2007b, Chapter 7, Box 7.2). In the context of globalization and consolidation, many reinsurers are actively developing new instruments to trade some of their risk on the deeper financial markets. These instruments include options, swaps and catastrophe bonds.

At the same time, governments are also developing new kinds of public-private partnership to cope with market failures, uncertainties and really big cataclysms. On a global scale, it can be argued that the best form of insurance is to increase the systemic resilience of the human society through scientific research, technical, economic and social development. This requires the broad participation of society in order to succeed.

Mills (2005) concludes that the future role of insurance in helping society to cope with climate change is uncertain. Insurers may rise to the occasion and become more proactive players in improving the science and crafting responses, or they may retreat from oncoming risks, thereby shifting a greater burden to governments and individuals.

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[5] Section 2.6 discusses the ethical questions concerning burden and quantity of proof, as well as procedural issues.

2.2.7 Decision support tools

Decisions concerning the appropriate responses to climate risks require insights into a variety of possible futures over short to very long time frames and into linkages between biophysical and human systems, as well as ethical alternatives. Structured analysis – both numerical and case-based – can ‘aid understanding by managing and analyzing information and alternatives’ (Arrow *et al.*, 1996a, referenced in Bell *et al.*, 2001). Integrated Assessment Models (IAMs) in particular have improved greatly in terms of the richness with which they represent the biophysical, social and economic systems and the feedbacks between them. They have increasingly explored a variety of decision rules or other means of testing alternative policies. Without structured analysis it is extremely difficult, if not impossible, to understand the possible effects of alternative policy choices that face decision-makers. Structured analysis can assist choices of preferred policies within interests (for example at the national level) as well as negotiating outcomes between interests (by making regional costs and benefits clearer).

The use of projections and scenarios is one way to develop understanding about choices in the context of unpredictability. These are discussed in detail in Chapter 3.

A large number of analytical approaches can be used as a support to decision-making. IPCC (2001) Chapter 10, provides an extensive overview of decision-making approaches and reviews their applicability at geopolitical levels and in climate policy domains. The review includes decision analysis, cost-benefit analysis, cost-effectiveness analysis, tolerable windows/safe-landing/guard-rail approaches, game theory, portfolio theory, public finance theory, ethical and cultural prescriptive rules, and various policy dialogue exercises. Integrated assessment, multi-attribute analysis and green accounting approaches are also commonly used decision support tools in climate change debates.

A major distinction between cost benefit-analysis, cost-effectiveness analysis, and multi-attribute analysis and different applications of these relates to the extent in which monetary values are used to represent the impacts considered. Cost-benefit analysis aims to assign monetary values to the full range of costs and benefits. This involves at least two important assumptions – that it is possible to ‘trade off’ or compensate between impacts on different values in a way that can be expressed in monetary values, and that it is possible to ascertain estimates of these ‘compensation’ values for non-market impacts, such as air pollution, health and biodiversity. By definition, the benefits and costs of climate change policies involve many of such issues, so climate change economic analysis embodies a lot of complicated valuation issues. Section 2.4 goes more into depth about approaches that can be used to value non-markets impacts and the question of discounting.

In multi-attribute analysis, instead of using values derived from markets or from non-market valuation techniques, different dimensions (impacts) are assigned weights – through a stakeholder consultation process, by engaging a panel of experts or by the analyst making explicit decisions. This approach can use quantitative data, qualitative information or a mixture of both. Developing an overall score or ranking for each option allows alternative policies to be assessed, even under conditions of weak comparability. Different functional forms can be used for the aggregation process.

Policy optimization models aim to support the selection of policy/decision strategies and can be divided into a number of types:

- Cost-benefit approaches, which try to balance the costs and benefits of climate policies (including making allowances for uncertainties).
- Target-based approaches, which optimize policy responses, given targets for emission or climate change impacts (again in some instances explicitly acknowledging uncertainties).
- Approaches, which incorporate decision strategies (such as sequential act-learn-act decision-making, hedging strategies etc.) for dealing with uncertainty (often embedded in cost-benefit frameworks).

Another approach is to start with a policy or policies and evaluate the implications of their application. Policy evaluation approaches include:

- Deterministic projection approaches, in which each input and output takes on a single value.
- A stochastic projection approach, in which at least some inputs and outputs take on a range of value.
- Exploratory modelling.
- Public participation processes, such as citizens juries, consultation, and polling.

IAMs aim to combine key elements of biophysical and economic systems into a decision-making framework with various levels of detail on the different sub-components and systems. These models include all different variations on the extent to use monetary values, the integration of uncertainty, and on the formulation of the policy problem with regard to optimization, policy evaluation and stochastic projections. Current integrated assessment research uses one or more of the following methods (Rotmans and Dowlatabadi, 1998):

- Computer-aided IAMs to analyze the behavior of complex systems
- Simulation gaming in which complex systems are represented by simpler ones with relevant behavioral similarity.
- Scenarios as tools to explore a variety of possible images of the future.
- Qualitative integrated assessments based on a limited, heterogeneous data set, without using any model.

A difficulty with large, global models or frameworks is that it is not easy to reflect regional impacts, or equity considerations between regions or stakeholder groups. This is particularly true of ‘global’ cost-benefit approaches, where it is particularly difficult to estimate a marginal benefit curve, as regional differences are likely to be considerable. Such approaches have difficulty in assisting decision-making where there are many decision-makers and multiple interests and values to be taken into account.

Variants of the safe landing/tolerable windows/guard rails approach emphasize the role of regional/national decision-makers by providing them the opportunity to nominate perceived unacceptable impacts of climate change (for their region or globally), and the limit to tolerable socio-economic costs of mitigation measures they would be prepared to accept to avoid that damage (e.g. Toth 2004). Modelling efforts (in an integrated assessment model linking climate and economic variables, and with explicit assumptions about burden sharing through emissions allocations and trading) are then directed at identifying the sets of feasible mitigation paths – known as ‘emissions corridors’ – consistent with these constraints. To the extent that there is some overlap between the acceptable ‘emissions corridors’, the conditions for agreement on mitigation action do exist.

Green accounting attempts to integrate a broader set of social welfare measures into macro-economic studies. These measures can be related to a broad set of social, environmental, and development-oriented policy aspects. The approach has most commonly been used in order to integrate environmental impacts, such as local air pollution, GHG emissions, waste generation, and other polluting substances, into macro-economic studies. Green accounting approaches include both monetary valuation approaches that attempt to calculate a ‘green national product’ (where the economic values of pollutants are subtracted from the national product), and accounting systems that include quantitative non-monetary pollution data.

Halsnæs and Markandya (2002) recognize that decision analysis methods exhibit a number of commonalities in assumptions. The standard approach goes through the selection of GHG emission-reduction options, selection of impact areas that are influenced by policies as for example costs, local air pollution, employment, GHG emissions, and health, definition of baseline case, assessment of the impacts of implementing the GHG emission-reduction policies under consideration, and application of a valuation framework that can be used to compare different policy impacts.

Sociological analysis includes the understanding of how society operates in terms of beliefs, values, attitudes, behaviour, social norms, social structure, regarding climate change. This analysis includes both quantitative and qualitative approaches, such as general surveys, statistics analysis, focus groups, public participation processes, media content analysis, Delphi etc.

All analytical approaches (explicitly or implicitly) have to consider the described elements, whether this is done in order to collect quantitative information that is used in formalized approaches or to provide qualitative information and focus for policy dialogues. Different decision-making approaches will often involve very similar technical analysis in relation to several elements. For example, multi-criteria-analysis, as well as cost-benefit analysis (as, for example, applied in integrated assessment optimization modelling frameworks) and green accounting may use similar inputs and analysis for many model components, but critically diverge when it comes to determining the valuation approach applied to the assessment of multiple policy impacts.

2.3 Risk and uncertainty

2.3.1 How are risk and uncertainty communicated in this report?

Communicating about risk and uncertainty is difficult because uncertainty is multi-dimensional and there are different practical and philosophical approaches to it. In this report, ‘risk’ is understood to mean the ‘combination of the probability of an event and its consequences’, as defined in the risk management standard ISO/IEC Guide 73 (2002). This definition allows a variety of ways of combining probabilities and consequences, one of which is expected loss, defined as the ‘product of probability and loss’. The fundamental distinction between ‘risk’ and ‘uncertainty’ is as introduced by economist Frank Knight (1921), that risk refers to cases for which the probability of outcomes can be ascertained through well-established theories with reliable complete data, while uncertainty refers to situations in which the appropriate data might be fragmentary or unavailable.

Dealing effectively with the communication of risk and uncertainty is an important goal for the scientific assessment of long-term environmental policies. In IPCC assessment reports, an explicit effort is made to enhance consistency in the treatment of uncertainties through a report-wide coordination effort to harmonize the concepts and vocabulary used. The Third Assessment Report common guidelines to describe levels of confidence were elaborated by Moss and Schneider (2000). The actual application of this framework differed across the three IPCC working groups and across chapters within the groups. It led to consistent treatment of uncertainties within Working Group I (focusing on uncertainties and probabilities, see Sommerville *et al*., 2007, Section 1.6) and Working Group II (focusing on risks and confidence levels, see IPCC, 2007b, Section 1.1), although consistency across these groups was not achieved. The authors of Working Group III did not systematically apply the guidelines.

Box 2.1 Risk and uncertainty vocabulary used in this report

Uncertainty cannot always be quantified, and thus the vocabulary displayed in Table 2.2 is used to qualitatively describe the degree of scientific understanding behind a finding or about an issue. See text for discussion of Table 2.2's dimensions, the amount of evidence and the level of agreement.

Tabel 2.2: *Qualitative definition of uncertainty*

	High agreement, limited evidence	High agreement, medium evidence	High agreement, much evidence
↑	Medium agreement, limited evidence	Medium agreement, medium evidence	Medium agreement, much evidence
Level of agreement (on a particular finding)	Low agreement, limited evidence	Low agreement, medium evidence	Low agreement, much evidence
	Amount of evidence (number and quality of independent sources)		→

Source: IPCC Guidance Notes on risk and uncertainty (2005).

The most important insight arising from an interdisciplinary assessment of uncertainty is its conceptual diversity. There is no linear scale going from 'perfect knowledge' to 'total uncertainty'. The literature suggests a 'pedigree' approach for characterizing the quality of information (for example the NUSAP approach by Van der Sluijs *et al.,* 2003). This involves examining at least the amount and reliability of *evidence*[6] supporting the information and the level of agreement of the information sources.

The degree of consensus among the available studies is a critical parameter for the quality of information. The *level of agreement* regarding the benefits and drawbacks of a certain technology describes the extent to which the sources of information point in the same direction. Table 2.2's vocabulary is used to qualify IPCC findings along these two dimensions. Because mitigation mostly involves the future of technical and social systems, Table 2.2 is used here to qualify the robustness of findings, and more precise expressions regarding quantified likelihood or levels of confidence are used only when there is high agreement and much evidence, such as converging results from a number of controlled field experiments.

Where findings depend on the future of a dynamic system, it is important to consider the possibility of extreme or/and irreversible outcomes, the potential for resolution (or persistence) of uncertainties in time, and the human dimensions. Rare events with extreme and/or irreversible outcomes are difficult or impossible to assess with ordinary statistics, but receive special attention in the literature.

2.3.2 Typologies of risk and uncertainty

The literature on risk and uncertainty offers many typologies, often comprising the following classes:

Randomness: risk often refers to situations where there is a well-founded probability distribution in typologies of uncertainty. For example, assuming an unchanged climate, the potential annual supply of wind, sun or hydropower in a given area is only known statistically. In situations of randomness, expected utility maximization is a standard decision-making framework.

Possibility: the degree of 'not-implausibility' of a future can be defined rigorously using the notion of acceptable odds, see De Finetti (1937) and Shackle (1949). While it is scientifically controversial to assign a precise probability distribution to a variable in the far distant future determined by social choices such as the global temperature in 2100, some outcomes are not as plausible as others (see the controversy on scenarios in Box 2.2). There are few possibility models related to environmental or energy economics.

Knightian or Deep Uncertainty: the seminal work by Knight (1921) describes a class of situations where the list of outcomes is known, but the probabilities are imprecise. Under deep uncertainty, reporting a range of plausible values allows decision-makers to apply their own views on precaution. Two families of criteria have been proposed for decision-making in this situation. One family associates a real-valued generalized expected utility to each choice (see Ellesberg, 2001), while

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[6] "Evidence" in this report is defined as: Information or signs indicating whether a belief or proposition is true or valid. See Glossary.

the other discards the completeness axiom on the grounds that under deep uncertainty alternative choices may sometimes be incomparable (see Bewley, 2002; Walley, 1991). Results of climate policy analysis under deep uncertainty with imprecise probabilities (Kriegler, 2005; Kriegler *et al.* 2006) are consistent with the previous findings using classical models.

Structural uncertainty: is characterized by « unknown unknowns ». No model (or discourse) can include all variables and relationships. In energy-economics models, for example, there can easily be structural uncertainty regarding the treatment of the informal sector, market efficiency, or the choice between a Keynesian or a neoclassical view of macro-economic dynamics. Structural uncertainty is attenuated when convergent results are obtained from a variety of different models using different methods, and also when results rely more on direct observations (data) rather than on calculations.

Fuzzyness or vagueness: describes the nature of things that do not fall sharply into one category or another, such as the meaning of 'sustainable development' or 'mitigation costs'. One way to communicate the fuzzyness of the variables determining the 'Reasons for concern' about climate change is to use smooth gradients of colours, varying continuously from green to red (see IPCC, 2001a, Figure SPM 2, also known as the 'burning embers' diagram). Fuzzy modelling has rarely been used in the climate change mitigation literature so far.

Uncertainty is not only caused by missing information about the state of the world, but also by human volition: global environmental protection is the outcome of social interactions. Not mentioning taboos, psychological and social aspects, these include:

Surprise: which means a discrepancy between a stimulus and pre-established knowledge (Kagan, 2002). Complex systems, both natural and human, exhibit behaviour that was not imagined by observers until it actually happened. By allowing decision-makers to become familiar (in advance) with a number of diverse but plausible futures, scenarios are one way of reducing surprises.

Metaphysical: describes things that are not assigned a truth level because it is generally agreed that they cannot be verified, such as the mysteries of faith, personal tastes or belief systems. Such issues are represented in models by critical parameters, such as discount rates or risk-aversion coefficients. While these parameters cannot be judged to be true or false they can have

Box 2.2 The controversy on quantifying the beliefs in IPCC SRES scenarios

Between its Second and Third Assessment Reports, the Intergovernmental Panel on Climate Change elaborated long-term greenhouse gas emissions scenarios, in part to drive global ocean-atmosphere general circulation models, and ultimately to assess the urgency of action to prevent the risk of climatic change. Using these scenarios led the IPCC to report a range of global warming over the next century from 1.4–5.8°C, without being able to report any likelihood considerations. This range turned out to be controversial, as it dramatically revised the top-range value, which was previously 3.5°C. Yet some combinations of values that lead to high emissions, such as high per-capita income growth and high population growth, appear less likely than other combinations. The debate then fell into the ongoing controversy between the makers and the users of scenarios.

Schneider (2001) and Reilly et al. (2001) argued that the absence of any probability assignment would lead to confusion, as users select arbitrary scenarios or assume equi-probability. As a remedy, Reilly et al. estimated that the 90% confidence limits were 1.1–4.5°C. Using different methods, Wigley and Raper (2001) found 1.7–4.9°C for this 1990 to 2100 warming.

Grübler et al. (2002) and Allen et al. (2001) argued that good scientific arguments preclude determining objective probabilities or the likelihood that future events will occur. They explained why it was the unanimous view of the IPCC report's lead authors that no method of assigning probabilities to a 100-year climate forecast was sufficiently widely accepted and documented to pass the review process. They underlined the difficulty of assigning reliable probabilities to social and economic trends in the latter half of the 21st century, the difficulty of obtaining consensus range for quintiles such as climate sensitivity, and the possibility of a non-linear geophysical response.

Dessai and Hulme (2004) argued that scenarios could not be meaningfully assigned a probability, except relative to other specific scenarios. While a specific scenario has an infinitesimal probability given the infinity of possible futures, taken as a representative of a cluster of very similar scenarios, it can subjectively be judged more or less likely than another. Nonetheless, a set of scenarios cannot be effectively used to objectively generate a probability distribution for a parameter that is specified in each scenario.

In spite of the difficulty, there is an increasing tendency to estimate probability distribution functions for climate sensitivity, discussed extensively in IPCC (2007a), see Chapter 9, Sections 9.6.2 and 9.6.3 and Chapter 10, Sections 10.5.2 and 10.5.4.

a bearing on both behaviour and environmental policy-making. Thompson and Raynor (1998) argue that, rather than being obstacles to be overcome, the uneasy coexistence of different conceptions of natural vulnerability and societal fairness is a source of resilience and the key to the institutional plurality that actually enables us to apprehend and adapt to our ever-changing circumstances.

Strategic uncertainty: involves the fact that information is a strategic tool for rational agents. The response to climate change requires coordination at international and national level. Strategic uncertainty is usually formalized with game theory, assuming that one party in a transaction has more (or better) information than the other. The informed party may thus be able to extract a rent from this advantage. Information asymmetry is an important issue for the regulation of firms by governments and for international agreements. Both adverse selection and moral hazards are key factors in designing efficient mechanisms to mitigate climate change.

2.3.3 Costs, benefits and uncertainties

In spite of scientific progress, there is still much uncertainty about future climate change and its mitigation costs. Given observed risk attitudes, the desirability of preventive efforts should be measured not only by the reduction in the expected (average) damages, but also by the value of the reduced risks and uncertainties that such efforts yield. The difficulty is how to value the societal benefits included in these risk reductions. Uncertainty concerning mitigation costs adds an additional level of difficulty in determining the optimal risk-prevention strategies, since the difference between two independent uncertain quantities is relatively more uncertain than related to the individual.

How can we decide whether a risk is acceptable to society? Cost-benefit analysis alone cannot represent all aspects of climate change policy evaluation, and Section 2.2 on Decision-making discusses a variety of tools. In the private sector, another practical way to deal with these risks has been to pay attention to the Value-At-Risk (VAR): in addition to using the mean and the variance of the outcome, a norm is set on the most unfavourable percentile (usually 0.05) of the distribution of outcomes at a given future date.

However, in the language of cost-benefit analysis, an acceptable risk means that its benefits to society exceed its costs. The standard rule used by public and private decision-makers in a wide variety of fields (from road safety to long-term investments in the energy sector) is that a risk will be acceptable if the expected net present value is positive. Arrow and Lind (1970) justify this criterion when the policy's benefits and costs have known probabilities, and when agents can diversify their own risk through insurance and other markets. For most of the economic analysis of climate change, these assumptions are disputable, and have been discussed in the economic literature.

First, risks associated with climate change cannot easily be diversified using insurance and financial instruments. Atmospheric events are faced by everyone at the same time in the same region. This reduces the potential benefit of any mutual risk-sharing agreement. A solution would be to share risks internationally, but this is difficult to implement, and its efficiency depends upon the correlation of the regional damages. Inability to diversify risks, combined with the risk aversion observed in most public and private decision-makers, implies that there is an additional benefit to preventive efforts coming from the reduced variability of future damages. If these monetized damages are expressed as a percentage of GDP, the marginal benefit of prevention can be estimated as the marginal expected increase in GDP, with some adjustments for the marginal reduction in the variance of damages.

Second, in most instances, objective probabilities are difficult to estimate. Furthermore, a number of climate change impacts involve health, biodiversity, and future generations, and the value of changes in these assets is difficult to capture fully in estimates of economic costs and benefits (see Section 2.4 on costs). Where we cannot measure risks and consequences precisely, we cannot simply maximize net benefits mechanically. This does not mean that we should abandon the usefulness of cost-benefit analysis, but it should be used as an input, among others in climate change policy decisions. The literature on how to account for ambiguity in the total economic value is growing, even if there is no agreed standard.

Finally, Gollier (2001) suggests that a sophisticated interpretation of the Precautionary Principle is compatible with economic principles in general, and with cost-benefit analyses in particular. The timing of the decision process and the resolution of the uncertainty should be taken into account, in particular when waiting before implementing a preventive action as an option. Waiting, and thereby late reactions, yield a cost when risks happen to be worse than initially expected, but yield an option value and cost savings in cases where risks happen to be smaller than expected. Standard dynamic programming methods can be used to estimate these option values.

2.4 Cost and benefit concepts, including private and social cost perspectives and relationships to other decision-making frameworks

2.4.1 Definitions

Mitigation costs can be measured at project, technology, sector, and macro-economic levels, and various geographical boundaries can be applied to the costing studies (see a definition of geographical boundaries in Section 2.8).

The project, technology, sector, and macro-economic levels can be defined as follows:

- **Project:** A project-level analysis considers a 'stand-alone' activity that is assumed not to have significant indirect economic impacts on markets and prices (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.
- **Technology:** A technology-level analysis considers a specific GHG mitigation technology, usually with several applications in different projects and sectors. The literature on technologies covers their technical characteristics, especially evidence on learning curves as the technology diffuses and matures. The technology analysis can use analytical approaches that are similar to project-level analysis.
- **Sector:** Sector-level analysis considers sectoral policies in a 'partial-equilibrium' context, for which other sectors and macro-economic variables are assumed to be given. The policies can include economic instruments related to prices, taxes, 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.
- **Macro-economic:** A macro-economic 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 programmes, and technology and innovation policies. Methodological frameworks include various macro-economic models, such as general equilibrium models, Keynesian econometric models, and Integrated Assessment Models (IAMs), among others.

In comparing project, technology, sector, and macro-economic cost estimates it is important to bear in mind that cost estimates based on applying taxes in a macro-economic model are not comparable with abatement costs calculated at other assessment levels. This, for example, is because a carbon tax will apply to all GHG emissions, while abatement costs at project, technology or sector level will only reflect the costs of emission reductions.

Private and social costs: Costs can be measured from a private as well as from a social perspective. Individual decision-makers (including both private companies and households) are influenced by various cost elements, such as the costs of input to a production process, labour and land costs, financial interest rates, equipment costs, fuel costs, consumer prices etc., which are key private cost components. However, the activities of individuals may also cause externalities, for example emissions that influence the utility of other individuals, but which are not taken into consideration by the individuals causing them. A social cost perspective includes the value of these externalities.

External costs: These 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.[7] In the case of GHG emissions, those who will eventually suffer from the impacts of climate change do not have a well-defined 'property right' in terms of a given climate or an atmosphere with given GHG concentrations, so market forces and/or bargaining arrangements cannot work directly as a means to balance the costs and benefits of GHG emissions and climate change. However, the failure to take into account external costs, in cases like climate change, may be due not only to the lack of property rights, but also the lack of full information and non-zero transaction costs related to policy implementation.

Private, financial, and social costs are estimated on the basis of different prices. The private cost component is generally based on market prices that face individuals. 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, because markets can be distorted by regulations and other policies as well as by limited competition that prevent prices from reflecting real resource scarcities. 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. Conversely, if market prices of polluting fuels do not include values that reflect the environmental costs, these prices will be lower than the social cost. Social costs should be based on market prices, but with eventual adjustments of these with shadow prices, to bring them into line with opportunity costs.

In conclusion, the key cost concepts are defined as follows:

- Private costs are the costs facing individual decision-makers based on actual market prices.
- Social costs are the private costs plus the costs of externalities. The prices are derived from market prices, where opportunity costs are taken into account.

Other cost concepts that are commonly used in the literature are 'financial costs' and 'economic costs'. Financial costs, in line with private costs, are derived on the basis of market prices that face individuals. Financial costs are typically used to assess

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[7] Coase, 1960, page 2 in his essay on The Problem of Social Cost, noted that externality problems would be solved in a 'completely satisfactory manner: when the damaging business has to pay for all damage caused and the pricing system works smoothly' (strictly speaking, this means that the operation of a pricing system is without cost).

the costs of financing specific investment projects. Economic costs, like social costs, assess the costs based on market prices adjusted with opportunity costs. Different from social costs, by definition they do not take all externalities into account.

2.4.2 Major cost determinants

A number of factors are critically important when determining costs, and it is important to understand their character and role when comparing mitigation costs across different studies, as occurs in Chapters 3-11 of this report, which compares costs across different models and which are based on different approaches.

The critical cost factors are based on different theoretical and methodological paradigms, as well as on specific applications of approaches. This section considers a number of factors including discounting, market efficiency assumptions, the treatment of externalities, valuation issues and techniques related to climate change damages[8] and other policy impacts, as well as implementation and transactions costs, and gives guidance on how to understand and assess these aspects within the context of climate change mitigation costing studies. For a more in-depth review of these issues see IPCC, 2001, Chapters 7 and 8.

2.4.2.1 Discount rates

Climate change impacts and mitigation policies have long-term characters, and cost analysis of climate change policies therefore involve a comparison of economic flows that occur at different points in time. The choice of discount rate has a very big influence on the result of any climate change cost analysis.

The debate on discount rates is a long-standing one. As the SAR (Second Assessment Report) notes (IPCC, 1996, Chapter 4), there are two approaches to discounting: a prescriptive approach[9] 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. Investing in a project where the return is less than the standard interest rate makes the investor poorer. This descriptive approach based on a simple arbitrage argument justifies using the after-tax interest rate as the discount rate. The SAR notes that the former leads to relatively low rates of discount (around 2-3% in real terms) and the latter to relatively higher rates (at least 4% after tax and, in some cases, very much higher rates). The importance of choosing different levels of discount rates can be seen, for example when considering the value of US$ 1 million in 100 years from now. The present value of this amount is around US$ 52,000 if a 3% discount rate is used, but only around US$ 3,000 if a discount rate of 6% is used.

The prescriptive approach applies to the so-called social discount rate, which is the sum of the rate of pure time-preference and the rate of increased welfare derived from higher per-capita incomes in the future. The social discount rate can thus be described by two parameters: a rate of pure preference for the present (or rate of impatience, see Loewenstein and Prelec (1992)) δ, and a factor γ that reflects the elasticity of marginal utility to changes in consumption. The socially efficient discount rate r is linked to the rate of growth of GDP per capita, g in the following formula:[10]

$$r = \delta + \gamma g$$

Intuitively, as suggested by this formula, a larger growth in the economy should induce us to make less effort for the future. This is achieved by raising the discount rate. In an inter-generational framework, the parameter δ characterizes our ethical attitude towards future generations. Using this formula, the SAR recommended using a discount rate of 2-4%. It is fair to consider $\delta = 0$ and a growth rate of GDP per capita of 1-2% per year for developed countries and a higher rate for developing countries that anticipate larger growth rates.

Portney and Weyant (1999) provide a good overview of the literature on the issue of inter-generational equity and discounting.

The descriptive approach takes into consideration the market rate of return to safe investments, whereby funds can be conceptually invested in risk-free projects that earn such returns, with the proceeds being used to increase the consumption for future generations. A simple arbitrage argument to recommend the use of a real risk-free rate, such as the discount rate, is proposed.

The descriptive approach relies on the assumption that credit markets are efficient, so that the equilibrium interest rate reflects both the rate of return of capital and the householders' willingness to improve their future. The international literature includes several studies that recommend different discount rates in accordance with this principle. One of them is Dimson *et al.,* 2000, that assesses the average real risk-free rate in developed countries to have been below 2% per year over the 20th century, and on this basis, suggests the use of a low discount rate. This rate is not incompatible with the much larger rates of return requested by shareholders on financial markets (which can be

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[8] Despite the fact that this report focuses on mitigation policies, many economic studies are structured as an integrated assessment of the costs of climate change mitigation and the benefits of avoided damages, and some of the issues related to valuation of climate change damages are therefore an integral part of mitigation studies and are briefly discussed as such in this chapter.

[9] The prescriptive approach has often been termed the 'ethical approach' in the literature.

[10] This formula is commonly known as the Ramsey rule.

as high as 10–15%), because these rates include a premium to compensate for risk. However, the descriptive approach has several drawbacks. First, it relies on the assumption of efficient financial markets, which is not a credible assumption, both as a result of market frictions and the inability of future generations to participate in financial markets over these time horizons. Second, financial markets do not offer liquid riskless assets for time horizons exceeding 30 years, which implies that the interest rates for most maturities relevant for the climate change problem cannot be observed.

Lowering the discount rate, as in the precriptive approach, increases the weight of future generations in cost-benefit analyses. However, it is not clear that it is necessarily more ethical to use a low (or lower) discount rate on the notion that it protects future generations, because that could also deprive current generations from fixing urgent problems in order to benefit future generations who are more likely to have more resources available.

For discounting over very long time horizons (e.g. periods beyond 30 years), an emerging literature suggests that the discount rate should decrease over time. Different theoretical positions advocate for such an approach based on arguments concerning the uncertainty of future discount rates and economic growth, future fairness and intra-generational distribution, and on observed individual choices of discount rates (Oxera, 2002). The different theoretical arguments lead to different recommendations about the level of discount rates.

Weitzman (2001) showed that if there is some uncertainty on the future return to capital, and if society is risk-neutral, the year-to-year discount rate should fall progressively to its smallest possible value. Newell and Pizer (2004) arrived at a similar conclusion. It is important to observe that this declining rate comes on top of the variable short-term discount rate, which should be frequently adapted to the conditions of the market interest rate.

It is also important to link the long-term macro-economic uncertainty with the uncertainty concerning the future benefits of our current preventive investments. Obviously, it is efficient to bias our efforts towards investments that perform particularly well in the worse states (i.e., states in which the economy collapses). The standard approach to tackle this is to add a risk premium to the benefits of these investments rather than to modify the discount rate, which should remain a universal exchange rate between current and future sure consumption, for the sake of comparability and transparency of the cost-benefit analysis. Using standard financial price modelling, this risk premium is proportional to the covariance between the future benefit and the future GDP.

Whereas it seems reasonable in the above formula to use a rate of growth of GDP per capita of g=1-2% for the next decade, there is much more uncertainty about which growth rate to use for longer time horizons. It is intuitive that, in the long run, the existence of an uncertain growth should reduce the discount rates for these distant time horizons. Calibrating a normative model on this idea, Gollier (2002a, 2002b, 2004) recommended using a decreasing term structure of discount rate, from 5% in the short term to 2% in the long term. In an equivalent model, but with different assumptions on the growth process, Weitzman (1998, 2004) proposed using a zero discount rate for time horizons around 50 years, with the discount rate being negative for longer time horizons. These models are in line with the important literature on the term structure of interest rates, as initiated by Vasicek (1977) and Cox, Ingersoll and Ross (1985). The main difference is the time horizon under scrutiny, with a longer horizon allowing considerable more general specifications for the stochastic process that drives the shape of the yield curve.

Despite theoretical disputes about the use of time-declining discount rates, the UK government has officially recommended such rates for official approval of projects with long-term impacts. The recommendation here is to use a 3.5% rate for 1-30 years, a 3% rate for 31-75 years, a 2.5% rate for 76-125 years, a 2% rate for 125-200 years, 1.5% for 201-300 years, and 1% for longer periods (Oxera, 2002). Similarly, France decided in 2004 to replace its constant discount rate of 8% with a 4% discount rate for maturities below 30 years, and a discount rate that decreases to 2% for longer maturities.[11] Finally, the US government's Office of Management and Budget recognizes the possibility of declining rates (see appendix D of US, 2003).

It is important to remember that these rates discount certainty-equivalent cash flows. This discussion does not solve the question of how to compute certainty equivalents when the project's cash flows are uncertain. For climate change impacts, the assumed long-term nature of the problem is the key issue here. The benefits of reduced GHG emissions vary according to 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. Because these benefits are only probabilistic, the standard cost-benefit analysis can be adjusted with a transformation of the random benefit into its certainty equivalent for each maturity. In a second step, the flow of certainty-equivalent cash flows is discounted at the rates recommended above.

For mitigation effects with a shorter time horizon, a country must base its decisions (at least partly) on discount rates that reflect the opportunity cost of capital. In developed countries, rates of around 4–6% are probably justified. Rates of this level

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[11] This should be interpreted as using a discount factor equaling $(1.04)^{-t}$ if the time horizon t is less than 30 years, and a discount rate equaling $(1.04)^{-30}(1.02)^{-(t-30)}$ if t is more than 30 years.

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 and the discount rates that are used by many private companies, which typically need to be considerably higher to justify investments, and are potentially between 10% and 25%.

2.4.2.2 Market efficiency

The costs of climate change mitigation policies depend on the efficiency of markets, and market assumptions are important in relation to baseline cases, to policy cases, as well as in relation to the actual cost of implementing policy options. For example, the electricity market (and thereby the price of electricity that private consumers and industry face) has direct implications on the efficiency (and thereby GHG emissions) related to appliances and equipment in use.

In practice, markets and public-sector activities will always exhibit a number of distortions and imperfections, such as lack of information, distorted price signals, lack of competition, and/or institutional failures related to regulation, inadequate delineation of property rights, distortion-inducing fiscal systems, and limited financial markets. Proper mitigation cost analysis should take these imperfections into consideration and assess implementation costs that include these imperfections (see Section 2.4.2.3 for a definition of implementation costs).

Many project level and sectoral mitigation costing studies have identified a potential for GHG reduction options with a negative cost, implying that the benefits, including co-benefits, of implementing these options are greater than the costs. Such negative cost options are commonly referred to as 'no-regret options'.[12]

The costs and benefits included in the assessment of no-regret options, in principle, are all impacts of the options including externalities. External impacts can relate to environmental side-impacts, and distortions in markets for labour, land, energy resources, and various other areas. A presumption for the existence of no-regret options is that there are:

- **Market imperfections** that generate efficiency losses. Reducing the existing market or institutional failures and other barriers that impede adoption of cost-effective emission reduction measures, can lower private costs compared to current practice (Larson *et al.*, 2003; Harris *et al.*, 2000; Vine *et al.*, 2003). This can also reduce private costs overall.
- **Co-benefits**: Climate change mitigation measures will have effects on other societal issues. For example, reducing carbon emissions will often result in the simultaneous reduction in local and regional air pollution (Dessues and O'Connor, 2003; Dudek *et al.,* 2003; Markandya and Rubbelke, 2004; Gielen and Chen, 2001; O'Connor *et al.,* 2003). It is likely that mitigation strategies will also affect transportation, agriculture, land-use practices and waste management and will have an impact on other issues of social concern, such as employment, and energy security. However, not all of these effects will be positive; careful policy selection and design can better ensure positive effects and minimize negative impacts. In some cases, the magnitude of co-benefits of mitigation may be comparable to the costs of the mitigating measures, adding to the no-regrets potential, although estimates are difficult to make and vary widely.[13]
- **Double dividend**: Instruments (such as taxes or auctioned permits) provide revenues to the government. If used to finance reductions in existing distortionary taxes ('revenue recycling'), these revenues reduce the economic cost of achieving greenhouse gas reductions. The magnitude of this offset depends on the existing tax structure, type of tax cuts, labour market conditions, and method of recycling (Bay and Upmann, 2004; Chiroleu-Assouline and Fodha, 2005; Murray, *et al.*, 2005). Under some circumstances, it is possible that the economic benefits may exceed the costs of mitigation. Contrary, it has also been argued that eventual tax distortions should be eliminated anyway, and that the benefits of reducing these therefore cannot be assigned as a benefit of GHG emission reduction policies.

The existence of market imperfections, or co-benefits, and double dividends that are not integrated into markets are also key factors explaining why no-regret actions are not taken. The no-regret concept has, in practice, been used differently in costing studies, and has usually not included all the external costs and implementation costs associated with a given policy strategy.[14]

2.4.2.3 Transaction and implementation costs

In practice, the implementation of climate change mitigation policies requires some transaction and implementation costs. The implementation costs relate to the efforts needed to change existing rules and regulations, capacity-building efforts, information, training and education, and other institutional efforts needed to put a policy into place. Assuming that these implementation requirements are in place, there might still be costs involved in carrying through a given transaction,

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[12] By convention, when assessing the costs of GHG emission reductions, the benefits do not include the impacts associated with avoided climate change damages.

[13] It should be recognised that, under a variety of circumstances, it may be more efficient to obtain air pollution reductions through controls targeted at such pollutants rather than coupling them with efforts to reduce GHG emissions, even if the latter results in some air pollution reductions.

[14] This is due to difficulties in assessing all external costs and implementation costs, and reflects the incompleteness of the elements that have been addressed in the studies.

for example related to legal requirements of verifying and certifying emission reduction, as in the case of CDM projects. These costs are termed ‘transaction costs’. The transaction costs can therefore be defined as the costs of undertaking a business activity or implementing a climate mitigation policy, given that appropriate implementation efforts have been (or are being) created to establish a benign market environment for this activity.

Implementation policies and related costs include various elements related to market creation and broader institutional policies. In principle, mitigation studies (where possible) should include a full assessment of the cost of implementation requirements such as market reforms, information, establishment of legal systems, tax and subsidy reforms, and institutional and human capacity efforts.

In practice, few studies have included a full representation of implementation costs. This is because the analytical approaches applied cannot address all relevant implementation aspects, and because the actual costs of implementing a policy can be difficult to assess *ex ante*. However, as part of the implementation of the emission reduction requirements of the Kyoto Protocol, many countries have gained new experiences in the effectiveness of implementation efforts, which can provide a basis for further improvements of implementation costs analysis.

2.4.2.4 Issues related to the valuation of non-market aspects

A basic problem in climate change studies is that a number of social impacts are involved that go beyond the scope of what is reflected in current market prices. These include impacts on human health, nature conservation, biodiversity, natural and historical heritage, as well as potential abrupt changes to ecosystems. Furthermore, complicated valuation issues arise in relation to both market- and non-market areas, since climate change policies involve impacts over very long time horizons, where future generations are affected, as well as intra-generational issues, where relatively wealthy and relatively poor countries face different costs and benefits of climate change impacts, adaptation and mitigation policies. Valuation of climate change policy outcomes therefore also involves assigning values to the welfare of different generations and to individuals and societies living at very different welfare levels today.

The valuation of inter-generational climate change policy impacts involves issues related to comparing impacts occurring at different points in time as discussed in Section 2.4.2.1 on discount rates, as well as issues in relation to uncertainty about the preferences of future generations. Since these preferences are unknown today many studies assume, in a simplified way, that consumer preferences will stay unchanged over time. An overview of some of the literature on the preferences of future generations is given by Dasgupta *et al.,* (1999).

Other limitations in the valuation of climate change policy impacts are related to specific practical and ethical aspects of valuing human lives and injuries. A number of techniques can be used to value impacts on human health – the costs of mortality, for example, can be measured in relation to the statistical values of life, the avoided costs of health care, or in relation to the value of human capital on the labour market. Applications of valuation techniques that involve estimating the statistical values of life will face difficulties in determining values that reflect people in a fair and meaningful way, even with very different income levels around the world. There are obviously a lot of ethical controversies involved in valuing human health impacts. In the Third Assessment Report the IPCC recognized these difficulties and recommended that studies that include monetary values of statistical values of life should use uniform average global per-capita income weights in order to treat all human beings as equal (IPCC, 2001, Chapter 7).

2.4.3 Mitigation potentials and related costs

Chapters 3-11 report the costs of climate change mitigation at global, regional, sectoral, and technology level and, in order to ensure consistency and transparency across the cost estimates reported in these chapters, it has been agreed to use a number of key concepts and definitions that are outlined in this section. Furthermore, the following paragraphs also outline how the concepts relate to mitigation cost concepts that have been used in previous IPCC reports, in order to allow different cost estimates to be compared and eventual differences to be understood.

A commonly used output format for climate change mitigation cost studies means reporting the GHG emission reduction in quantitative terms that can be achieved at a given cost. The potential terminology is often used in a very ‘loose’ way, which makes it difficult to compare numbers across studies. The aim of the following is to overcome such lack of transparency in cost results based on a definition of major cost and GHG emission reduction variables to be used when estimating potentials.

The term ‘potential’ is used to report the quantity of GHG mitigation compared with a baseline or reference case that can be achieved by a mitigation option with a given cost (per tonne) of carbon avoided over a given period. The measure is usually expressed as million tonnes carbon- or CO_2-equivalent of avoided emissions, compared with baseline emissions. The given cost per tonne (or ‘unit cost’) is usually within a range of monetary values at a particular location (e.g. for wind-generated electricity), such as costs less than x US$ per tonne of CO_2- or carbon-equivalent reduction (US$/tC-eq). The monetary values can be defined as private or social unit costs: private unit costs are based on market prices, while social unit costs reflect market prices, but also take externalities associated with the mitigation into consideration. The prices are real prices adjusted for inflation rates.

2.4.3.1 *Definitions of barriers, opportunities and potentials*

The terms used in this assessment are those used in the Third Assessment Report (TAR). However, the precise definitions are revised and explanations for the revisions are given in the footnotes.

A '**barrier**' to mitigation potential is any obstacle to reaching a potential that can be overcome by policies and measures. (From this point onwards, 'policies' will be assumed to include policies, measures, programmes and portfolios of policies.) An '**opportunity**' is the application of technologies or policies[15] to reduce costs and barriers, find new potentials and increase existing ones. Potentials, barriers and opportunities all tend to be context-specific and vary across localities and over time.

'**Market potential**' indicates the amount of GHG mitigation that might be expected to occur under forecast market conditions, including policies and measures in place at the time.[16] It is based on private unit costs and discount rates, as they appear in the base year and as they are expected to change in the absence of any additional policies and measures. In other words, as in the TAR, market potential is the conventional assessment of the mitigation potential at current market price, with all barriers, hidden costs, etc. in place. The baseline is usually historical emissions or model projections, assuming zero social cost of carbon and no additional mitigation policies. However, if action is taken to improve the functioning of the markets, to reduce barriers and create opportunities (e.g. policies of market transformation to raise standards of energy efficiency via labelling), then mitigation potentials will become higher.

In order to bring in social costs, and to show clearly that this potential includes both market and non-market costs, '**economic potential**' is defined as the potential for cost-effective GHG mitigation when non-market social costs and benefits are included with market costs and benefits in assessing the options[17] for particular levels of carbon prices in US\$/tCO_2 and US\$/tC-eq. (as affected by mitigation policies) and when using social discount rates instead of private ones. This includes externalities (i.e. non-market costs and benefits such as environmental co-benefits). Note that estimates of economic potential do not normally assume that the underlying structure of consumer preferences has changed. This is the proper theoretical definition of the economic potential, however, as used in most studies, it is the amount of GHG mitigation that is cost-effective for a given carbon price, based on social cost pricing and discount rates (including energy savings but without most externalities), and this is also the case for the studies that were reported in the TAR (IPCC, 2001, Chapters 3, 8 and 9).

There is also a technical potential and a physical potential that, by definition, are not dependent on policies.

The '**technical potential**' is the amount by which it is possible to reduce greenhouse gas emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. There is no specific reference to costs here, only to 'practical constraints', although in some cases implicit economic considerations are taken into account. Finally the '**physical potential**' is the theoretical (thermodynamic) and sometimes, in practice, rather uncertain upper limit to mitigation, which also relies on the development of new technologies.

A number of key assumptions are used to calculate potentials. Some of the major ones are related to:
- Transformation of economic flows to net present values (NVP) or levelised costs. It is consistent here to use the financial rate of return in the discounting of private costs, and a social discount rate in social cost calculations
- Treatment of GHG emission reductions that occur at different points in time. Some studies add quantitative units of GHG reductions over the lifetime of the policy, and others apply discount rates to arrive at net present values of carbon reductions.

The implementation of climate change mitigation policies will involve the use of various economic instruments, information efforts, technical standards, and other policies and measures. Such policy efforts will all have impacts on consumer preferences and taste as well as on technological innovations. The policy efforts (in the short term) can be considered as an implementation cost, and can also be considered as such in the longer term, if transactions costs of policies are successfully reduced, implying that market and social- and economic potentials are increased at a given unit cost.

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[15] Including behaviour and lifestyle changes.

[16] The TAR (IPCC, 2001), p. 352 defines market potential as 'the amount of GHG mitigation that might be expected to occur under forecast market conditions, with no changes in policy or implementation of measures whose primary purpose is the mitigation of GHGs'. This definition might be interpreted to imply that market potential includes no implementation of GHG policies. However many European countries have already implemented mitigation policies. It is a substantial research exercise in counterfactual analysis to untangle the effects of past mitigation policies in the current levels of prices and costs and hence mitigation potential. The proposed definition simply clarifies this point.

[17] IPCC (2001), Chapter 5 defines 'economic potential' as 'the level of GHG mitigation that could be achieved if all technologies that are cost-effective from the consumers' point of view were implemented' (p. 352). This definition therefore introduces the concept of the consumer as distinct from the market. This is deeply confusing because it loses the connection with market valuations without explanation. Who is to decide how the consumers' point of view is different from the market valuation of costs? On what basis are they to choose these costs? The definition also does not explicitly introduce the social cost of carbon and other non-market valuations necessary to account for externalities and missing markets and it is not readily comparable with the IPCC (2001), Chapter 3 definition of economic potentials. The proposed definition for this report applies to the large body of relevant literature that assesses mitigation potential at different values of the social cost of carbon, and clearly introduces non-market valuations for externalities and time preferences. The proposed definition also matches that actually used in IPCC (2001) Chapter 3, where such potentials are discussed 'at zero social cost' (e.g. p. 203).

2.5 Mitigation, vulnerability and adaptation relationships

2.5.1 Integrating mitigation and adaptation in a development context – adaptive and mitigative capacities

The TAR (IPCC, 2001) introduced a new set of discussions about the institutional and developmental context of climate change mitigation and adaptation policies. One of the conclusions from that discussion was that the capacity for implementing specific mitigation and adaptation policies depends on man-made and natural capital and on institutions. Broadly speaking, institutions should be understood here as including markets and other information-sharing mechanisms, legal frameworks, as well as formal and informal networks.

Subsequent work by Adger (2001a) further emphasizes the role of social capital in adaptation. Adger refers to a definition by Woolcock and Narayan (2000, p. 226), which states that social capital is made up of 'the norms and networks that enable people to act collectively'. According to Adger there are two different views within the main areas of the international literature that are important to climate change issues namely: 1) whether social capital only exists outside the state, and 2) whether social capital is a cause, or simply a symptom, of a progressive and perhaps flexible and adaptive society. The first issue relates to how important planned adaptation and government initiatives can be, and the second considers the macro-level functioning of society and the implications for adaptive capacity.

Adger observes that the role that social capital, networks and state-civil society linkages play in adaptive capacity can be observed in historical and present-day contexts by examining the institutions of resource management and collective action in climate-sensitive sectors and social groups, highlighting a number of such experiences in adaptation to climate change. The examples include an assessment of the importance of social contacts and socio-economic status in relation to excess mortality due to extreme heating, coastal defence in the UK, and coastal protection in Vietnam, where the adaptive capacity in different areas is assessed within the context of resource availability and the entitlements of individuals and groups (Kelly and Adger, 1999). A literature assessment (IPCC, 2007b, Chapter 20) includes a wider range of examples of historical studies of development patterns, thus confirming that social capital has played a key role in economic growth and stability.

IPCC (2001), Chapter 1 initiated a very preliminary discussion about the concept of *mitigative capacity.* Mitigative capacity (in this context) is seen as a critical component of a country's ability to respond to the mitigation challenge, and the capacity, as in the case of adaptation, largely reflects man-made and natural capital and institutions. It is concluded that development, equity and sustainability objectives, as well as past and future development trajectories, play critical roles in determining the capacity for specific mitigation options. Following that, it can be expected that policies designed to pursue development, equity and/or sustainability objectives might be very benign framework conditions for implementing cost-effective climate change mitigation policies. The final conclusion is that, due to the inherent uncertainties involved in climate change policies, enhancing mitigative capacity can be a policy objective in itself.

It is important to recognize here that the institutional aspects of the adaptive and mitigative capacities refer to a number of elements that have a 'public-good character' as well as general social resources. These elements will be common framework conditions for implementing a broad range of policies, including climate change and more general development issues. This means that the basis for a nation's policy-implementing capacity exhibits many similarities across different sectors, and that capacity-enhancing efforts in this area will have many joint benefits.

There may be major differences in the character of the adaptive and mitigative capacity in relation to sectoral focus and to the range of technical options and policy instruments that apply to adaptation and mitigation respectively. Furthermore, assessing the efficiency and implementability of specific policy options depends on local institutions, including markets and human and social capital, where it can be expected that some main strengths and weaknesses will be similar for different sectors of an economy.

As previously mentioned, the responses to climate change depend on the adaptive and mitigative capacities and on the specific mitigation and adaptation policies adopted. Policies that enhance adaptive and mitigative capacities can include a wide range of general development policies, such as market reforms, education and training, improving governance, health services, infrastructure investments etc.

The actual outcome of implementing specific mitigation and adaptation policies is influenced by the adaptive and mitigative capacity, and the outcome of adaptation and mitigation policies also depends on a number of key characteristics of the socio-economic system, such as economic growth patterns, technology, population, governance, and environmental policies.

It is expected that there may be numerous synergies and tradeoffs between the adaptive and mitigative capacity elements of the socio-economic and natural systems, as well as between specific adaptation and mitigation policies. Building more motorways, for example, can generate more traffic and more GHG emissions. However, the motorways can also improve market access, make agriculture less vulnerable to climate change, help in evacuation prior to big storms, and can support general economic growth (and thereby investments in new efficient production technologies). Similarly, increased fertiliser use in agriculture can increase productivity and reduce climate change vulnerability, but it can also influence the potential for carbon sequestration and can increase GHG emissions.

2.5.2 Mitigation, adaptation and climate change impacts

The discussion on mitigation and adaptation policy portfolios has a global as well as a national/regional dimension. It should be recognized that mitigation and adaptation are very different regarding time frame and distribution of benefits. Dang *et al.* (2003, Table 1) highlights a number of important commonalities and differences between mitigation and adaptation policies. Both policy areas can be related to sustainable development goals, but differ according to the direct benefits that are global and long term for mitigation, while being local and shorter term for adaptation. Furthermore adaptation can be both reactive (to experienced climate change) and proactive, while mitigation can only be proactive in relation to benefits from avoided climate change occurring over centuries. Dang *et al.* (2003, Table 4) also points out that there can be conflicts between adaptation and mitigation in relation to the implementation of specific national policy options. For example, installing air-conditioning systems in buildings is an adaptation option, but energy requirements can increase GHG emissions, and thus climate change.

In relation to the trade-off between mitigation and adaptation, Schneider (2004) points out that when long-term integrated assessment studies are used to assess the net benefits of avoided climate change (including adaptation options) versus the costs of GHG emission reduction measures, the full range of possible climate outcomes, including impacts that remain highly uncertain such as surprises and other climate irreversibility, should be included. Without taking these uncertain events into consideration, decision-makers will tend to be more willing to accept prospective future risks rather than attempt to avoid them through abatement. It is worth noting here that,when faced with the risk of a major damage, human beings may make their judgment based on the consequences of the damage rather than on probabilities of events. Schneider concludes that it is not clear that climate surprises have a low probability, they are just very uncertain at present, and he suggests taking these uncertainties into consideration in integrated assessment models, by adjusting the climate change damage estimates. The adjustments suggested include using historical data for estimating the losses of extreme events, valuing ecosystem services, subjective probability assessments of monetary damage estimates, and the use of a discount rate that decreases over time in order to give high values to future generations.

In this way the issues of jointly targeting mitigation and adaptation has an element of decision-making under uncertainty, due to the complexity of the environmental and human systems and their interactions. Kuntz-Duriseti (2004) suggests dealing with this uncertainty by combining economic analysis and precautionary principles, including an insurance premium system, hedging strategies, and inclusion of low-probability events in risk assessments.

A common approach of many regional and national developing country studies on mitigation and adaptation policies has been to focus on the assessment of context-specific vulnerabilities to climate change. Given this, a number of studies and national capacity-building efforts have considered how adaptation and mitigation policies can be integrated into national development and environmental policies, and how they can be supported by financial transfers, domestic funds, and linked to foreign direct investments (IINC, 2004; CINC, 2004). The Danish Climate and Development Action Program aims at a two-leg strategy, where climate impacts, vulnerabilities, and adaptation are assessed as an integral part of development plans and actions in Danish partner countries, and where GHG emission impacts and mitigation options are considered as part of policy implementation (Danida, 2005).

Burton *et al.* (2002) suggest that research on adaptation should focus on assessing the social and economic determinants of vulnerability in a development context. The focus of the vulnerability assessment according to this framework should be on short-term impacts, i.e. should try to assess recent and future climate variability and extremes, economic and non-economic damages and the distribution of these. Based on this, adaptation policies should be addressed as a coping strategy against vulnerability and potential barriers, obstacles, and the role of various stakeholders and the public sector should be considered. Kelly and Adger (2000) developed an approach for assessing vulnerabilities and concluded that the vulnerability and security of any group is determined by resource availability and entitlements. The approach is applied to impacts from tropical storms in coastal areas inVietnam.

On a global scale, there is a growing recognition of the significant role that developing countries play in determining the success of global climate change policies, including mitigation and adaptation policy options (Müller, 2002). Many governments of developing countries have started to realize that they should no longer discuss *whether* to implement any measures against climate change, but *how* drastic these measures should be, and how climate policies can be an integral part of national sustainable development paths (SAINC, 2003; IINC, 2004; BINC, 2004; CINC, 2004; MOST, 2004).

2.6 Distributional and equity aspects

This section discusses how different equity concepts can be applied to the evaluation of climate change policies and provides examples on how the climate literature has addressed equity issues. See also Chapter 20 in IPCC (2007b), and Chapters 12 and 13 of this report for additional discussions on the equity

Table 2.3: *Measures of Inter-country Equity*

	GNI *Per Capita* US$		Life Expectancy (LE) Years		Literacy (ILL) %	
	Average	C.Var	Average	C.Var	Average	C.Var
1980/90	3,764	4,915	61.2	0.18	72.5	25.3
2001	7,350	10,217	65.1	0.21	79.2	21.4
% Change Average		95%		6%		9%
% Change Co. Var.		6%		14%		-22%

Notes: Literacy rates are for 1990 and 2001. GNI and LE data are for 1980, 1990, and 2001. Ninety-nine countries are included in the sample. Coefficient of variation is the standard deviation of a series divided by the mean. The standard deviation is given by the formula:

$$s = \sqrt{\sum_{i=1}^{i=n} (x_i - \bar{x})^2 \Big/ (n-1)}$$

Where 'x' refers to the value of a particular observation, '$\bar{x}$' is the mean of the sample and 'n' is the number of observations.

Source: WB, 2005 (World Development Indicators)

dimensions of sustainable development and climate change policies.

2.6.1 Development opportunities and equity

Traditionally, success in development has been measured in economic terms – increase in Gross National Income (GNI) *per capita* remains the most common measure[18]. Likewise, income distribution has been one of the key components in equity, both within and between countries, and has been measured in terms of inequalities of income, through measures such as the 'GINI' coefficient.[19] [20] Although a great deal has been written in recent years on the components of well-being, the development literature has been slow to adopt a broader set of indicators of this concept, especially as far as equity in well-being is concerned, despite the fact that some authors have argued that absolute changes in income and other indicators of human well-being (e.g. education, mortality rates, water, sanitation etc.) are just as important as the distribution within these indicators (Maddison, 2003; Goklany, 2001).

Probably the most important and forceful critic of the traditional indicators has been Sen (1992, 1999). Sen's vision of development encompasses not only economic goods and services but also individuals' health and life expectancy, their education and access to public goods, the economic and social security that they enjoy, and their freedom to participate freely in economic interchange and social decision-making. While his criticism is widely acknowledged as addressing important shortcomings in the traditional literature, the ideas still have not been made fully operational. Sen speaks of 'substantive freedoms' and 'capabilities' rather than goods and services as the key goals of development and provides compelling examples of how his concepts can paint a different picture of progress in development compared to that of changes in GNI. It remains the case, however, that actual indicators of equity still do not cover the breadth of components identified by Sen.

The UNDP Human Development Index (HDI) is an important attempt to widen the indicators of development, and initially included *per capita* national income, life expectancy at birth and the literacy rate. However, it is important to recognize that no single all-encompassing indicator can be constructed, will be understandable or useful to either policymakers or the public, so different indexes have to be used that reflect different issues and purposes.

Rather than synthesizing these three components into a single index, as the HDI has done, we can also look at changes in the inter-country equity of the individual components. Table 2.3[21] provides data for the period 1980–2001 for per capita national income (GNI) and life expectancy at birth (LE) and from 1990 to 2001 for the literacy rate (ILL). The increase in average GNI has been much faster over this period than those of life expectancy and literacy rates. The increase in coefficient of variations for GNI per capita (by 6%) and life expectancy (by 14%) therefore show an increase in dispersion over this period, indicating a wider disparity of these parameters across countries. However, literacy rates have become more equal, with a decline in the coefficient of variation by 22% (see Table 2.3). However, a study by Goklany (2002) concluded that inequality between countries does not necessarily translate into inequality between individuals.

As Sen notes, the problem of inequality becomes magnified when attention is shifted from income inequality to inequality of 'substantive freedoms and capabilities', as a result of a 'coupling' of the different dimensions – individuals who are likely to suffer from higher mortality and who are illiterate are also likely to have lower incomes and a lower ability to convert

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[18] The Gross National Income measures the income of all citizens, including income from abroad. GDP is different to GNI as it excludes income from abroad.

[19] The GINI coefficient is a measurement standard for the total income that needs to be redistributed if all income was equally distributed. A 0 value means that all are equal, while a 1 value implies considerable inequality.

[20] When income distribution is used in equity assessments it is important to recognize that such measures do not include all aspects of justice and equity.

[21] Ideally one should use purchasing power (PPP) adjusted GNI, but data on GNI_{ppp} is much more limited for the earlier period. For LE and ILL we also looked at a larger dataset of 142 countries, and found very similar results.

incomes into capabilities and good standards of living. While this is certainly true at the individual level, at the country level the correlation appears to be declining.

This wider analysis of equity has important implications for sharing the costs of mitigation and for assessing the impacts of climate change (see Chapter 1 for a more detailed discussion of climate change impacts and the reference to the UNFCCC Article 2). As generally known, the impacts of climate change are distributed very unequally across the planet, hurting the vulnerable and poor countries of the tropics much more than the richer countries in the temperate regions. Moreover, these impacts do not work exclusively, or even mainly, through changes in real incomes. The well-being of future generations will be affected through the effects of climate change on health, economic insecurity and other factors. As far as the costs of actions to reduce GHGs are concerned, measures that may be the least costly in overall terms are often not the ones that are the most equitable – see Sections 2.6.4 and 2.6.5 for a further discussion of the links between mitigation policy and equity.

2.6.2 Uncertainty as a frame for distributional and equity aspects

Gollier, 2001 outlines a framework for assessing the equity implications of climate change uncertainty, where he considers risk aversion for different income groups. The proposition (generally supported by empirical evidence) is that the relative risk aversion of individuals decreases with increasing wealth (Gollier, 2001), implying that the compensation that an individual asks for in order to accept a risk decreases relative to his income with increasing income. However, the absolute risk aversion – or the total compensation required in order to accept a risk – increases with wealth. It means that a given absolute risk level is considered to be more important to poorer people than to richer, and the comparatively higher risk aversion of poorer people suggests that larger investments in climate change mitigation and adaptation policies are preferred if these risks are borne by the poor rather than the rich.

A similar argument can be applied in relation to the equity consequences of increased climate variability and extreme events. Climate change may increase the possibility of large, abrupt and unwelcome regional or global climatic events. A coping strategy against variability and extreme events can be income-smoothing measures, where individuals even out their income over time through savings and investments. Poorer people with a lower propensity to save, and with less access to credit makers, have smaller possibilities to cope with climate variability and extreme events through such income-smoothing measures, and they will therefore be more vulnerable.

2.6.3 Alternative approaches to social justice

Widening our understanding of equity does not provide us with a rule for ranking different outcomes, except to say that, other things being equal, a less inequitable outcome is preferable to a more inequitable one. But how should one measure outcomes in terms of equity and what do we do when other things are not equal?

The traditional economic approach to resource allocation has been based on utilitarianism, in which a policy is considered to be desirable if no other policy or action is feasible that yields a higher aggregate utility for society. This requires three underlying assumptions:

(a) All choices are judged in terms of their consequences, and not in terms of the actions they entail.
(b) These choices are valued in terms of the utility they generate to individuals and no attention is paid to the implications of the choices for aspects such as rights, duties etc.
(c) The individual utilities are added up to give the sum of utility for society as a whole.

In this way the social welfare evaluation relies on the assumption that there is a net social surplus if the winners can compensate the losers and still be better off themselves. It should be recognized here that philosophers dispute that efficiency is a form of equity.

This approach has been the backbone of welfare economics, including the use of cost-benefit analysis (CBA) as a tool for selecting between options. Under CBA all benefits are added up, as are the costs, and the net benefit – the difference between the benefits and costs – is calculated. The option with the highest net benefit is considered the most desirable.[22] If utilities were proportional to money benefits and 'disutilities' were proportional to money costs, this method would amount to choosing to maximize utilities. Since most economists accept that this proportionality does not hold, they extend the CBA by either (a) asking the decision-maker to take account of the distributional implications of the option as a separate factor, in addition to the calculated net benefit; or (b) weighting costs or benefits by a factor that reflects the relationship between utility and the income of the person receiving that cost or benefit. For details of these methods in the context of climate change, see Markandya and Halsnaes (2002b).[23]

An alternative approach to allocating resources, which is derived from an ethical perspective and has existed for at least as long as the utilitarian approach described above (which has its modern origins in the late 18th century by Jeremy Bentham), is based on the view that social actions are to be judged by whether or not they conform to a 'social contract' that defines the rights and duties of individuals in society. The view was

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[22] This is considerably simplified; ignoring the time dimension and market imperfections in valuing costs and benefits but the principle remains valid.

[23] The ability of CBA to combine equity and utility through these means has been challenged by philosophers who argue that there could be serious ethical problems with combining the two when benefits and costs are as hugely disaggregated, as is the case with climate change. See Brown, 2002.

inspired by the work of Kant and Hegel and finds its greater articulation in the writing of Rousseau and the French 19th century philosophers.[24] In this position, for example, a society may predetermine that an individual has the right to be protected from serious negative health damage as a result of social actions. Hence no action, even if it increased utility, could be tolerated if it violated the rights and duties of individuals.

Modern philosophers who have developed the 'rights' view include Rawls, who argued that it is not utilities that matter but the distribution of 'primary goods, which include, in addition to income, "rights, liberties and opportunities and… the social basis of self respect"' (Rawls, 1971). Rawls argued further that social justice demanded that society be judged in terms of the level of well-being of its worst-off member. At the other end of the political spectrum, Nozick and the modern libertarians contend that personal liberties and property rights have (with very few exceptions) absolute precedence over objectives such as the reduction of poverty and deprivation (Nozick, 1974).

More recently, however, some ethical philosophers have found fault with both the 'modified' utilitarian view and the rights-based approach, on a number of grounds. Sen, for example, has argued that options should be judged not only in terms of their consequences, but also in terms of procedures. He advocates a focus on the capabilities of individuals to choose a life that one has reason to value. A person's capability refers to the alternative combinations of 'functionings', where functionings can be more popularly described as 'lifestyles' (Sen, 1999, pp. 74-75). What matters are not only the realized functionings, but also the capability set of alternatives, differently from a utilitarian-based approach that focuses only on the outcomes. In particular, the freedom to make the choices and engage in social and market transactions is worth something in its own right.

Sen criticizes the 'rights-based' equity approaches for not taking into consideration the fact that individuals are different and the actual consequences of giving them specific rights will vary between individuals, so rights should be seen in the context of capabilities. Both apply, because individuals have different preferences and thereby value primary inputs, for example, differently, and because their capability to use different rights also differ. Along these lines, Sen further argues that his capability-based approach can facilitate easier inter-personal comparisons than utilitarianism, since it does not suggest aggregating all individuals, but rather presenting information both on the capability sets available to individuals and their actual achievements.

What implications does this debate have in the context of climate change? One is that rights and capabilities need to be viewed in an international context. An example of an approach based on global equity would be to entitle every individual alive at a given date an equal per capita share in the intrinsic capacity of the earth to absorb GHGs. Countries whose total emissions exceeded this aggregate value would then compensate those below the value. In accordance with a utilitarian approach this compensation would be based on an estimate of the aggregate economic welfare lost by countries due to climate change, seen in relation to their own emissions. In contrast, the capability-based approach would argue for reduced capabilities associated with climate change.

As suggested above, societies do not (in practice) follow a strict utilitarian view of social justice and they do indeed recognize that citizens have certain basic rights in terms of housing, medical care etc. Equally, they do not subscribe to a clear 'rights' view of social justice either. Social choices are then a compromise between a utilitarian solution that focuses on consequences and one that recognizes basic rights in a more fundamental way. Much of the political and philosophical debate is about which rights are valid in this context – a debate that shows little sign of resolution. For climate change there are many options that need to be evaluated, in terms of their consequences for the lives of individuals who will be impacted by them. It is perfectly reasonable for the policymakers to exclude those that would result in major social disruptions, or large number of deaths, without recourse to a CBA. Equally, choices that avoid such negative consequences can be regarded as essential, even if the case for them cannot be made on CBA grounds. Details of where such rules should apply and where choices can be left to the more conventional CBA have yet to be worked out, and this remains an urgent part of the agenda for climate change studies.

As an alternative to social-justice-based equity methods, eco-centric approaches assign intrinsic value to nature as such (Botzler and Armstrong, 1998). This value can be specified in terms of diversity, avoided damages, harmony, stability, and beauty, and these values should be respected by human beings in their interaction with nature. In relation to climate change policies the issue here becomes one of specifying the value of nature such that it can be addressed as specific constraints that are to be respected beyond what is reflected in estimates of costs and benefits and other social impacts.

2.6.4 Equity consequences of different policy instruments

All sorts of climate change policies related to vulnerabilities, adaptation, and mitigation will have impacts on intra- and inter-generational equity. These equity impacts apply at the global, international, regional, national and sub-national levels.

Article 3 of the UNFCCC (1992, sometimes referred to as 'the equity article') states that Parties should protect the

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[24] For a discussion of this debate in an economic context, see Phelps, 1973.

climate system on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof. Numerous approaches exist in the climate change discourse on how these principles can be implemented. Some of these have been presented to policymakers (both formally and informally) and have been subject to rigorous analysis by academics, civil society and policymakers over long periods of time.

The equity debate has major implications for how different stakeholders judge different instruments for reducing greenhouse gases (GHG) and for adapting to the inevitable impacts of climate change.

With respect to the measures for reducing GHGs, the central equity question has focused on how the burden should be shared across countries (Markandya and Halsnaes, 2002b; Agarwal and Narain, 1991; Baer and Templet, 2001; Shukla, 2005). On a *utilitarian basis*, assuming declining marginal utility, the case for the richer countries undertaking more of the burden is strong – they are the ones to whom the opportunity cost of such actions would have less welfare implications. However, assuming constant marginal utility, one could come to the conclusion that the costs of climate change mitigation that richer countries will face are very large compared with the benefits of the avoided climate change damages in poorer countries. In this way, utilitarian-based approaches can lead to different conclusions, depending on how welfare losses experienced by poorer people are represented in the social welfare function.

Using a '*rights' basis* it would be difficult to make the case for the poorer countries to bear a significant share of the burden of climate change mitigation costs. Formal property rights for GHG emissions allowances are not defined, but based on justice arguments equal allocation to all human beings has been proposed. This would give more emissions rights to developing countries – more than the level of GHGs they currently emit. Hence such a rights-based allocation would impose more significant costs on the industrialized countries, although now, as emissions in the developing world increased, they too, at some point in time, would have to undertake some emissions reductions.

The literature includes a number of comparative studies on equity outcomes of different international climate change agreements. Some of these studies consider equity in terms of the consequences of different climate change policies, while others address equity in relation to rights that nations or individuals should enjoy in relation to GHG emission and the global atmosphere.

Equity concerns have also been addressed in a more pragmatic way as a necessary element in international agreements in order to facilitate consensus. Müller (2001) discusses fairness of emission allocations and that of the burden distribution that takes all climate impacts and reduction costs into consideration and concludes that there is no solution that can be considered as the right and fair one far out in the future. The issue is rather to agree on an acceptable 'fairness harmonization procedure', where an emission allocation is initially chosen and compensation payments are negotiated once the costs and benefits actually occur.

Rose *et al.* (1998) provide reasons why equity considerations are particularly important in relation to climate change agreements. First, country contributions will depend on voluntary compliance and it must therefore be expected that countries will react according to what they consider to be fair,[25] which will be influenced by their understanding of equity. Second, appealing to global economic efficiency is not enough to get countries together, due to the large disparities in current welfare and in welfare changes implied by efficient climate policies.

Studies that focus on the net costs of climate change mitigation versus the benefits of avoided climate change give a major emphasis to the economic consequences of the policies, while libertarian-oriented equity studies focus on emission rights, rights of the global atmosphere, basic human living conditions etc. (Wesley and Peterson, 1999). Studies that focus on the net policy costs will tend to address equity in terms of a total outcome of policies, while the libertarian studies focus more on initial equity conditions that should be applied to *ex ante* emission allocation rules, without explicitly taken equity consequences into consideration.

Given the uncertainties inherent in climate change impacts and their economic and social implications, it is difficult to conduct comprehensive and reliable consequence studies that can be used for an *ex ante* determination of equity principles for climate change agreements. Furthermore, social welfare functions and other value functions, when applied to the assessment of the costs and benefits of global climate change policies, run into a number of crucial equity questions. These include issues that are related to the asymmetry between the concentration of major GHG emission sources in industrialized countries and the relatively large expected damages in developing countries, the treatment of individuals with different income levels in the social welfare function, and a number of inter-generational issues.

Rights-based approaches have been extensively used as a basis for suggestions on structuring international climate change

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[25] What countries consider as 'fair' may be in conflict with their narrow self-interest. Hence there is a problem with resolving the influence of these two determinants of national contributions to reducing GHGs. One pragmatic element in the resolution could be that the difference between the long-term self interest and what is fair is much smaller than that between narrow self-interest and fairness.

agreements around emission allocation rules or compensation mechanisms. Various allocation rules have been examined, including emissions per capita principles, emissions per GDP, grandfathering, liability-based compensation for climate change damages etc. These different allocation rules have been supported with different arguments and with reference to equity principles. An overview and assessment of the various rights-based equity principles and their consequences on emission allocations and costs are included in Rose *et al.* (1998), Valliancourt and Waaub (2004), Leimbach (2003), Tol and Verheyen (2004) and Panayotou *et al.* (2002).

While there is consensus in the literature about how rules should be assessed in relation to specific moral criteria, there is much less agreement on what criteria should apply (e.g. should they be based on libertarian or egalitarian rights-based approaches, or on utilitarian approaches).

A particular difficulty in establishing international agreements on emission allocation rules is that the application of equity in this *ex ante* way can imply the very large transfer of wealth across nations or other legal entities that are assigned emission quotas, at a time where abatement costs, as well as climate change impacts, are relatively uncertain (Halsnæs and Olhoff, 2005). These uncertainties make it difficult for different parties to assess the consequences of accepting given emission allocation rules and to balance emission allocations against climate damages suffered in different parts of the world (Panayotou *et al.*, 2002).

Practical discussions about equity questions in international climate change negotiations have reflected, to a large extent, specific interests of various stakeholders, more than principal moral questions or considerations about the vulnerability of poorer countries. Arguments concerning property rights, for example, have been used by energy-intensive industries to advocate emission allocations based on grandfathering principles that will give high permits to their own stakeholders (that are large past emitters), and population-rich countries have, in some cases, advocated that fair emission allocation rules imply equal per capita emissions, which will give them high emission quotas.

Vaillancourt and Waaub (2004) suggest designing emission allocation criteria on the basis of the involvement of different decision-makers in selecting and weighing equity principles for emission allocations, and using these as inputs to a multi-criteria approach. The criteria include population basis, basic needs, polluter pays, GDP intensity, efficiency and geographical issues, without a specified structure on inter-relationships between the different areas. In this way, the approach primarily facilitates the involvement of stakeholders in discussions about equity.

2.6.5 Economic efficiency and eventual trade-offs with equity

For more than a decade the literature has covered studies that review the economic efficiency of climate change mitigation policies and, to some extent, also discuss different emission allocation rules and the derived equity consequences (IPCC, 1996, Chapter 11; IPCC, 2001, Chapters 6 and 8). Given that markets for GHG emission permits work well in terms of competition, transparency and low transaction costs, trade-offs between economic efficiency and equity (resulting from the distribution of emission rights) do not need to occur. In this ideal case, equity and economic efficiency can be addressed separately, where equity is taken care of in the design of emission allocation rules, and economic efficiency is promoted by the market system.

In practice, however, emission markets do not live up to these ideal conditions and the allocation of emission permits, both in international and domestic settings, will have an influence on the structure and functioning of emission markets, so trade-offs between what seems to be equitable emission allocations and economic efficiency can often occur (Shukla, 2005). Some of the issues that have been raised in relation to the facilitation of equity concerns through initial emission permit allocations include the large differences in emission permits and related market power that different countries would have (Halsnæs and Olhoff, 2005).

2.7 Technology

The cost and pace of any response to climate change concerns will also depend critically on the cost, performance, and availability of technologies that can lower emissions in the future. These technologies include both end-use (demand) as well as production (supply) technologies. Technological change is particularly important over the long time scales characteristic of climate change. Decade or century-long time scales are typical for the lags involved between technological innovation and widespread diffusion and of the capital turnover rates characteristic for long-lived energy capital stock and infrastructures (IPCC, 2001, 2002).

The development and deployment of technology is a dynamic process involving feedbacks. Each phase of this process may involve a different set of actors and institutions. The state of technology and technology change can differ significantly from country to country and sector to sector, depending on the starting point of infrastructure, technical capacity, the readiness of markets to provide commercial opportunities and policy frameworks. This section considers foundational issues related to the creation and deployment of new technology.

'Technology' refers to more than simply devices. Technology includes hardware (machines, devices, infrastructure networks etc.), software (i.e. knowledge/routines required for the production and use of technological hardware), as well as organizational/institutional settings that frame incentives and deployment structures (such as standards) for the generation and use of technology (for a review, compare Grubler, 1998).[26] Both the development of hybrid car engines and the development of Internet retailing mechanisms represent technological changes.

Many frameworks have been developed to simplify the process of technological change into a set of discrete phases. A common definitional framework frequently includes the following phases:

(1) Invention (novel concept or idea, as a result of research, development, and demonstration efforts).
(2) Innovation (first market introduction of these ideas).
(3) Niche markets (initial, small-scale applications that are economically feasible under specific conditions).
(4) Diffusion (widespread adoption and the evolution into mature markets, ending eventually in decline) (see Figure 2.3 below).

While the importance of technology to climate change is widely understood, there are differing viewpoints on the feasibility of current technology to address climate change and the role of new technology. On the one hand, Hoffert *et al.* (2002) and others have called for a major increase in research funding now to develop innovative technological options because, in this view, existing technologies cannot achieve the deep emission cuts that could be needed to mitigate future change. On the other hand, Pacala and Socolow (2004) advance the view that a range of known current technologies could be deployed, starting now and over the next 50 years, to place society on track to stabilize CO_2 concentrations at 500 ± 50 parts per million. In their view, research for innovative technology is needed but only to develop technologies that might be used in the second half of the century and beyond. Still a third viewpoint is that the matter is better cast in terms of cost, in addition to technical feasibility (e.g. Edmonds *et al.*, 1997; Edmonds, 2004; Nakicenovic and Riahi, 2002) From this viewpoint, today's technology is, indeed, sufficient to bring about the requisite emissions reductions, but the underlying question is not technical feasibility but the degree to which resources would need to be reallocated from other societal goals (e.g. health care, education) to accommodate emissions mitigation. The role of new technology, in this view, is to lower the costs to achieve societal goals.

From the perspective of (commercial) availability and costs it is important to differentiate between the short-term and the long-term, and between technical and economic feasibility. A technology, currently at a pilot plant development stage and thus not available commercially, has no short-term potential to reduce emissions, but might have considerable potential once commercialized. Conversely, a technology, currently available commercially, but only at high cost, might have a short-term emission reduction potential in the (unlikely) case of extremely strong short-term policy signals (e.g. high carbon prices), but might have considerable potential in the long-term if the costs of the technology can be reduced. Corresponding mitigation technology assessments are therefore most useful when they differentiate between short/medium-term and long-term technology options, (commercial) availability status, costs, and the resulting (different) mitigation potentials of individual technology options. Frequently, the resulting ranking of individual technological options with respect to emissions reduction potentials and costs/yields emission abatement 'supply curves' illustrate how much emission reductions can be achieved, at what costs, over the short- to medium-term as well as in the longer-term.

2.7.1 Technology and climate change

Recognizing the importance of technology over the long-term introduces an important element of uncertainty into the climate change debate, as direction and pace of future technological change cannot be predicted. Technological innovation and deployment are responsive to climate policy signals, for example in form of carbon taxes, although the extent and rate of this response can be as uncertain as the timing and magnitude of the policy signal. Reducing such uncertainties, for instance through long-term, predictable policy frameworks and signals, are therefore important. The usual approach consists of formulating alternative scenarios of plausible future developments. These, however, are constrained by inherent biases in technology assessment and uncertainties concerning the response of technological change to climate policy. There is also widespread recognition in the literature that it is highly unlikely that a single 'silver bullet' technology exists that can solve the climate problem, so the issue is not one of identifying singular technologies, but rather ensembles, or portfolios of technologies. This applies to both mitigation and adaptation technologies. These technologies have inter-dependencies and cross-enhancement ('spillover') potentials, which adds another important element of uncertainty into the analysis. Despite these problems of uncertainty and ignorance, insights are available from multiple fields.

Extensive literature surveys on the importance of technological change on the extent of possible climate change and on feasibility and costs of climate policies are provided by Clarke and Weyant (2002), Grubb *et al.* (2002), Grübler *et al.* (1999), Jaffe *et al.* (2003) and Löschel (2002) among others.

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[26] It is also important to note that important linkages exist between technological and behavioural change. A frequently discussed phenomenon is so-called 'take-back' or 'rebound' effects, e.g. a change in consumption behaviour after the adoption of energy efficiency improvement measures (e.g. driving longer distances after purchasing a more energy-efficient car). Compare the review by Schipper and Grubb, 2000.

Quantitative illustrations have been published in a number of important scenario studies including the IPCC SAR (IPCC, 1996) and SRES (IPCC, 2000), the scenarios of the World Energy Council (WEC, Nakicenovic *et al.*, 1998a) as well as from climate policy model inter-comparison projects such as EMF-19 (Energy Modelling Forum) (Weyant, 2004b), the EU-based Innovation Modeling Comparison Project (IMCP) (Edenhofer *et al.*, 2006) and the multi-model calculations of climate 'stabilization' scenarios summarized in the TAR (IPCC, 2001). In a new development since the TAR, technology has also moved to the forefront of a number of international and national climate policy initiatives, including the Global Energy Technology Strategy (GTSP, 2001), the Japanese 'New Earth 21' Project (RITE, 2003), the US 21 Technology Roadmap (NETL, 2004), or the European Union's World Energy Technology Outlook (WETO, 2003).

The subsequent review first discusses the importance of technological change in 'no-climate policy' (or so-called 'reference' or 'baseline') scenarios, and hence the magnitude of possible climate change. The review then considers the role of alternative technology assumptions in climate policy ('stabilization') scenarios. The review continues by presenting a discussion of the multitude of mechanisms underlying technological change that need to be considered when discussing policy options to further the availability and economics of mitigation and adaptation technologies.

2.7.1.1 Technological change in no-climate policy (reference) scenarios

The importance of technological change for future GHG emission levels and hence the magnitude of possible climate change has been recognized ever since the earliest literature reviews (Ausubel and Nordhaus, 1983). Subsequent important literature assessments (e.g. Alcamo *et al.,* 1995; Nakicenovic *et al.*, 1998b; Edmonds *et al.*, 1997; SRES, 2000) have examined the impact of alternative technology assumptions on future levels of GHG emissions. For instance, the SRES (2000) report concluded technology to be of similar importance for future GHG emissions as population and economic growth combined. A conceptual simple illustration of the importance of technology is provided by comparing individual GHG emission scenarios that share comparable assumptions on population and economic growth, such as in the Low Emitting Energy Supply Systems (LESS) scenarios developed for the IPCC SAR (1996) or within the IPCC SRES (2000) A1 scenario family, where for a comparable level of energy service demand, the (no-climate-policy) scenarios span a range of between 1038 (A1T) and 2128 (A1FI) GtC cumulative (1990-2100) emissions, reflecting different assumptions on availability and development of low- versus high-emission technologies. Yet another way of illustrating the importance of technology assumptions in baseline scenarios is to compare given scenarios with a hypothetical baseline in which no technological change is assumed to occur at all. For instance, GTSP (2001) and Edmonds *et al.* (1997, see also Figure 3.32 in Chapter 3) illustrate the effect of changing reference case technology assumptions on CO_2 emissions and concentrations based on the IPCC IS92a scenario by holding technology at 1990 levels to reveal the degree to which advances in technology are already embedded in the non-climate-policy reference case, a conclusion also confirmed by Gerlagh and Zwaan, 2004. As in the other scenario studies reviewed, the degree to which technological change assumptions are reflected in the scenario baseline by far dominates future projected emission levels. The importance of technology is further magnified when climate policies are considered. See for example, the stabilization scenarios reviewed in IPCC TAR (2001) and also Figure 2.1 below.

Perhaps the most exhaustive examination of the influence of technological uncertainty to date is the modelling study reported by Gritsevskyi and Nakicenovic (2000). Their model simulations, consisting of 130,000 scenarios that span a carbon emission range of 6 to 33 GtC by 2100 (Figure 2.1), provided a systematic exploration of contingent uncertainties of long-term technological change spanning a comparable range of future emissions as almost the entirety of the no-climate policy emissions scenario literature (see Chapter 3 for an update of the scenario literature). The study also identified some 13,000 scenarios (out of an entire scenario ensemble of 130,000) regrouped into a set of 53 technology dynamics that are all 'optimal' in the sense that they satisfy the same cost minimum in the objective function, but with a bimodal distribution in terms of emissions outcomes. In other words, considering full endogenous technological uncertainty produces a pattern of 'technological lock-in' into alternatively low or high emissions futures that are equal in terms of their energy systems costs.

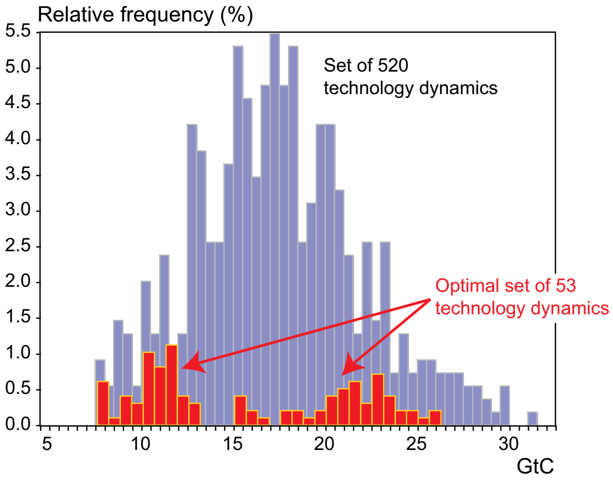

Figure 2.1: *Emission impacts of exploring the full spectrum of technological uncertainty in a given scenario without climate policies. Relative frequency (percent) of 130,000 scenarios of full technological uncertainty regrouped into 520 sets of technology dynamics with their corresponding carbon emissions by 2100. Also shown is a subset of 13,000 scenarios grouped into 53 sets of technology dynamics that are all 'optimal' in the sense of satisfying a cost minimization criterion in the objective function. See text for further discussion. 1 Gt C = 3.7 Gt* CO_2

Source: Adapted from Gritsevskyi and Nakicenovic, 2000.

This finding is consistent with the extensive literature on technological 'path dependency' and 'lock-in phenomena' (e.g. Arthur, 1989) as also increasingly reflected in the scenario literature (e.g. Nakicenovic *et al.*, 1998b and the literature review in Chapter 3). This casts doubts on the plausibility of central tendency technology and emissions scenarios. It also shows that the variation in baseline cases could generate a distribution of minimum costs of the global energy system where low-emission baseline scenarios could be as cheap as their high-emission counterparts.

The results also illustrate the value of technology policy as a hedging strategy aiming at lowering future carbon emissions, even in the absence of directed climate policies, as the costs of reducing emissions even further from a given baseline are *ceteris paribus* proportionally lower with lower baseline emissions.

2.7.1.2 Technological change in climate policy scenarios

In addition to the technology assumptions that enter typical 'no-climate policy' baselines, technology availability and the response of technology development and adoption rates to a variety of climate policies also play a critical role. The assessment of which alternative technologies are deployed in meeting given GHG emission limitations or as a function of *ex ante* assumed climate policy variables, such as carbon taxes, again entails calculations that span many decades into the future and typically rely on (no-climate policy) baseline scenarios (discussed above).

Previous IPCC assessments have discussed in detail the differences that have arisen with respect to feasibility and costs of emission reductions between two broad categories of modelling approaches: 'bottom-up' engineering-type models versus 'top-down' macro-economic models. Bottom-up models usually tend to suggest that mitigation can yield financial and economic benefits, depending on the adoption of best-available technologies and the development of new technologies. Conversely, top-down studies have tended to suggest that mitigation policies have economic costs because markets are assumed to have adopted all efficient options already. The TAR offered an extensive analysis of the relationship between technological, socio-economic, economic and market potential of emission reductions, with some discussion of the various barriers that help to explain the differences between the different modeling approaches. A new finding in the underlying literature (see, for example, the review in Weyant, 2004a) is that the traditional distinction between 'bottom-up' (engineering) and 'top down' (macro-economic) models is becoming increasingly blurred as 'top down' models incorporate increasing technology detail, while 'bottom up' models increasingly incorporate price effects and macro-economic feedbacks, as well as adoption barrier analysis, into their model structures. The knowledge gained through successive rounds of model inter-comparisons, such as implemented within the Energy Modeling Forum (EMF) and similar exercises, has shown that the traditional dichotomy between 'optimistic' (i.e. bottom-up) and 'pessimistic' (i.e. top-down) views on feasibility and costs of meeting alternative stabilization targets is therefore less an issue of methodology, but rather the consequence of alternative assumptions on availability and costs of low- and zero-GHG-emitting technologies. However, in their meta-analysis of post-SRES model results, Barker *et al.* (2002) have also shown that model structure continues to be of importance.

Given the infancy of empirical studies and resulting models that capture in detail the various inter-related inducement mechanisms of technological change in policy models, salient uncertainties continue to be best described through explorative model exercises under a range of (exogenous) technology development scenarios. Which mitigative technologies are deployed, how much, when and where depend on three sets of model and scenario assumptions. First, assumptions on which technologies are used in the reference ('no policy') case, in itself a complex result of scenario assumptions concerning future demand growth, resource availability, and exogenous technology-specific scenario assumptions. Second, technology deployment portfolios depend on the magnitude of the emission constraint, increasing with lower stabilization targets. Finally, results depend critically on assumptions concerning future availability and relative costs of mitigative technologies that determine the optimal technology mix for any given combination of baseline scenarios with alternative stabilization levels or climate policy variables considered.

2.7.1.3 Technological change and the costs of achieving climate targets

Rates of technological change are also critical determinants of the costs of achieving particular environmental targets. It is widely acknowledged that technological change has been a critical factor in both cost reductions and quality improvements of a wide variety of processes and products.[27] Assuming that technologies in the future improve similarly to that observed in the past enables experts to quantify the cost impacts of technology improvements in controlled modeling experiments. For instance, Edmonds *et al.* (1997, compare Figure 3.36 in Chapter 3) analyzed the carbon implications of technological progress consistent with historical rates of energy technology change. Other studies have confirmed Edmonds' (1997) conclusion on the paramount importance of future availability and costs of low-emission technologies and the significant economic benefits of improved technology

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[27] Perhaps one of the most dramatic historical empirical studies is provided by Nordhaus (1997) who has analyzed the case of illumination since antiquity, illustrating that the costs per lumen-hour have decreased by approximately a factor of 1,000 over the last 200 years. Empirical studies into computers and semiconductors indicate cost declines of up to a factor of 100,000 (Victor and Ausubel, 2002; Irwin and Klenov, 1994). Comparable studies for environmental technologies are scarce.

that, when compounded over many decades, can add up to trillions of dollars. (For a discussion of corresponding ‘value of technological innovation’ studies see Edmonds and Smith (2006) and Section 3.4, particularly Figure 3.36 in Chapter 3). However, to date, model calculations offer no guidance on the likelihood or uncertainty of realizing ‘advanced technology’ scenarios. However, there is an increasing number of studies (e.g. Gerlagh and Van der Zwaan, 2006) that explore the mechanisms and policy instruments that would need to be set in place in order to *induce* such drastic technological changes.

The treatment of technological change in an emissions and climate policy modeling framework can have a huge effect on estimates of the cost of meeting any environmental target. Models in which technological change is dominated by experience (learning) curve effects, show that the cost of stabilizing GHG concentrations could be in the range of a few tenths of a percent of GDP, or even lower (in some models even becoming negative) – a finding also confirmed by other modelling studies (e.g. Rao *et al.*, 2005) and consistent with the results of the study by Gritsevskyi and Nakicenovic (2000) reviewed above, which also showed identical costs of ‘high’ versus ‘low’ long-term emission futures. This contrasts with the traditional view that the long-term costs[28] of climate stabilization could be very high, amounting to several percentage points of economic output (see also the review in IPCC, 2001).

Given the persistent uncertainty of what constitutes ‘dangerous interference with the climate system’ and the resulting uncertainty on ultimate climate stabilization targets, another important finding related to technology economics emerges from the available literature. Differences in the cost of meeting a prescribed CO_2 concentration target across alternative technology development pathways that could unfold in the absence of climate policies are more important than cost differences between alternative stabilization levels *within* a given technology-reference scenario. In other words, the overall ‘reference’ technology pathway can be equally, if not more, important in determining the costs of a given scenario as the stringency of the ultimate climate stabilization target chosen (confer Figure 2.2).

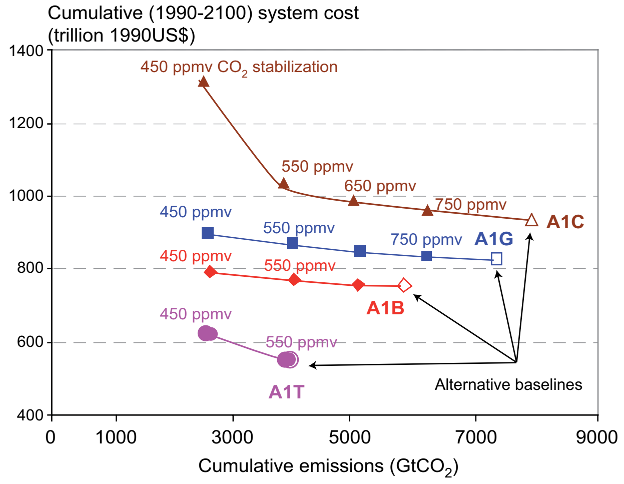

Figure 2.2: *The impacts of different technology assumptions on energy systems costs and emissions (cumulative 1990–2100, systems costs (undiscounted) in trillion US$) in no-climate policy baseline (reference) scenarios (based on the SRES A1 scenario family that share identical population and GDP growth assumptions) and in illustrative stabilization scenarios (750, 650, 550 and 450 ppm respectively). For comparison: the total cumulative (undiscounted) GDP of the scenarios is around 30,000 trillion US$ over the 1990–2100 time period.*

Source: Roehrl and Riahi (2000).

In a series of alternative stabilization runs imposed on the SRES A1 scenarios, chosen for ease of comparability as sharing similar energy demands, Roehrl and Riahi (2000) confer also IPCC (2001) have explored the cost differences between four alternative baselines and their corresponding stabilization targets, ranging from 750 ppmv all the way down to 450 ppmv. In their calculations, the cost differences between alternative baselines are also linked to differences in baseline emissions: advanced post-fossil fuel technologies yield both lower overall systems costs as well as lower baseline emissions and hence lower costs of meeting a specified climate target (confer the differences between the A1C and A1T scenarios in Figure 2.2). Their findings are consistent with the pattern identified by Edmonds *et al.* (1997) and Gerlagh and Van der Zwaan (2003). Cost differences are generally much larger between alternative technology baselines, characterized by differing assumptions concerning availability and costs of technologies, rather than between alternative stabilization levels. The IEA (2004) World Energy Outlook also confirms this conclusion, and highlights the differential investment patterns entailed by alternative technological pathways.[29] The results from the available literature thus confirm the value of advances in technology importance in lowering future ‘baseline’ emissions in order to enhance feasibility, flexibility, and economics of meeting alternative stabilization targets, in lowering overall systems costs, as well as in lowering the costs of meeting alternative stabilization targets.

A robust analytical finding arising from detailed technology-specific studies is that the economic benefits of technology improvements (i.e. from cost reductions) are highly non-linear, arising from the cumulative nature of technological change, from interdependence and spillover effects, and from potential

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[28] Note here that this statement only refers to the (very) long term, i.e. a time horizon in which existing capital stock and technologies will have been turned over and replaced by newer vintages. In the short term (and using currently or near-term available technologies) the costs of climate policy scenarios are invariably higher than their unconstrained counterparts.

[29] The IEA (2004) ‘alternative scenario’, while having comparable total systems costs, would entail an important shift in investments away from fossil-fuel-intensive energy supply options towards energy efficiency improvements, a pattern also identified in the scenario study of Nakicenovic *et al.* (1998b).

increasing returns to adoption (i.e. costs decline with increasing market deployment of a given technology).[30] (A detailed review covering the multitude of sources of technological change, including the aforementioned effects, is provided in Chapter 11, Section 11.5, discussing so-called 'induced technological change' models).

2.7.2 Technological change

Changes in technology do not arise autonomously – they arise through the actions of human beings, and different social and economic systems have different proclivities to induce technological change. The range of actors participating in the process of technological change spans the full range of those that use technology, design and manufacture technology, and create new knowledge.

The process of technological change has several defining characteristics. First, the process is highly uncertain and unpredictable. Firms planning research toward a well-defined technical goal must plan without full knowledge regarding the potential cost, time frame, and even the ultimate success. Further, the history of technological development is rife with small and large examples of serendipitous discoveries, (e.g. Teflon) whose application is far beyond, or different, than their intended use.

A second defining characteristic of technological change is the transferable, public-good nature of knowledge. Once created, the value of technological knowledge is difficult to fully appropriate; some or all eventually spills over to others, and in doing so the knowledge is not depleted. This characteristic of knowledge has both benefits and drawbacks. On the one hand, an important discovery by a single individual, such as penicillin, can be utilized worldwide. Knowledge of penicillin is a public good and therefore one person's use of this knowledge does not preclude another person from using this same knowledge – unlike for capital or labour, where use in one task precludes use in an alternative task. On the other hand, the understanding by potential innovators that any new knowledge might eventually spill over to others limits expected profits and therefore dampens private-sector innovative activity. Thus intellectual property rights can serve both as a barrier and an aid in technology change. A final, third feature of technological change is its cumulativeness, which is also frequently related to spillover effects.

There are numerous paradigms used to separate the process of technological change into distinct phases. One approach is to consider technological change as roughly a two-part process, which includes:

(1) The process of conceiving, creating, and developing new technologies or enhancing existing technologies – the process of advancing the 'technological frontier'.
(2) The process of diffusing or deploying these technologies.

These two processes are inextricably tied. The set of available technology defines what might be deployed, and the use of technology affords learning that can guide R&D programmes or directly improve technology through learning-by-doing. The two processes are also linked temporally. The set of technologies that find their way into use necessarily lags the technological frontier. The useful life of technologies – their natural turnover rate – helps to drive the time relationship. Car lifespans can be in the order of 15 years, but the associated infrastructure – roads, filling stations, vehicle manufacturing facilities – have significantly longer lifespans, and electric power plants may be used for a half-century or more; hence, the average car is substantially younger than the average coal-fired power plant and much of its associated infrastructure. The nature of the capital stock (e.g. flexifuel cars that can use both conventional petrol and ethanol) is also important in determining diffusion speed.

2.7.2.1 The sources of technological change

New technology arises from a range of interacting drivers. The literature (for a review see, for example, Freeman, 1994, and Grubler, 1998) divides these drivers into three broad, overlapping categories: R&D, learning-by-doing, and spillovers. These drivers are distinctly different[31] from other mechanisms that influence the costs of a given technology, such as. through economies of scale effects (see Box 2.3 below). Each of these entails different agents, investment needs, financial institutions and is affected by the policy environment. These are briefly discussed below, followed by a discussion of the empirical evidence supporting the importance of these sources and the linkages between them.

Research and Development (R&D): R&D encompasses a broad set of activities in which firms, governments, or other entities expend resources specifically to improve technology or gain new knowledge. While R&D covers a broad continuum, it is often parsed into two categories: applied R&D and fundamental research, and entails both science and engineering (and requires science and engineering education). Applied R&D focuses on improving specific, well-defined technologies (e.g. fuel cells). Fundamental research focuses on broader and more fundamental areas of understanding. Fundamental research may be mission-oriented (e.g. fundamental biological research

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[30] This is frequently referred to as a 'learning-by-doing' phenomenon. However, the linkages between technology costs and market deployment are complex, covering a whole host of influencing factors including (traditional) economics of larger market size, economies of scale in manufacturing, innovation-driven technology improvements, geographical and inter-industry spillover effects, as well as learning-by-doing (experience curve) phenomena proper. For (one of the few available) empirical studies analyzing the relative contribution of their various effects on cost improvements see Nemet (2005). A more detailed discussion is provided in Chapter 11.

[31] However, there are important relations between economies of scale and technological change in terms that scaling up usually also requires changes in manufacturing technologies, even if the technology manufactured remains unchanged.

intended to provide a long-term knowledge base to fight cancer or create fuels) or focus on new knowledge creation without explicit consideration of use (see Stokes (1997) regarding this distinction). Both applied R&D and fundamental research are interactive: fundamental research in a range of disciplines or research areas, from materials to high-speed computing, can create a pool of knowledge and ideas that might then be further developed through applied R&D. Obstacles in applied R&D can also feed research priorities back to fundamental research. As a rule of thumb, the private sector takes an increasingly prominent role in the R&D enterprise the further along the process toward commercial application. Similar terms found in the literature include: Research, Development, and Demonstration (RD&D), and Research, Development, Demonstration, and Deployment (RDD&D or RD^3). These concepts highlight the importance of linking basic and applied research to initial applications of new technologies that are an important feedback and learning mechanism for R&D proper.

R&D from across the economic spectrum is important to climate change. Energy-focused R&D, basic or applied, as well as R&D in other climate-relevant sectors (e.g. agriculture) can directly influence the greenhouse gas emissions associated with these sectors (CO_2, CH_4). At the same time, R&D in seemingly unrelated sectors may also provide spillover benefits to climate-relevant sectors. For example, advances in computers over the last several decades have enhanced the performance of the majority of energy production and use technologies.

Learning-by-doing: Learning-by-doing refers to the technology-advancing benefits that arise through the use or production of technology, i.e. *market deployment.* The more that an individual or an organization repeats a task, the more adept or efficient that organization or individual becomes at that task. In early descriptions (for example, Wright, 1936), learning-by-doing referred to improvements in manufacturing labour productivity for a single product and production line. Over time, the application of learning-by-doing has been expanded to the level of larger-scale organizations, such as an entire firm producing a particular product. Improvements in coordination, scheduling, design, material inputs, and manufacturing technologies can increase labour productivity, and this broader definition of learning-by-doing therefore reflects experience gained at all levels in the organization, including engineering, management, and even sales and marketing (see, Hirsh, 1956; Baloff, 1966; Yelle, 1979; Montgomery and Day, 1985; Argote and Epple, 1990).

There are clearly important interactions between learning-by-doing and R&D. The production and use of technologies provides important feedbacks to the R&D process, identifying key areas for improvement or important roadblocks. In addition, the distinction between learning-by-doing and R&D is blurred at the edges: for example, everyday technology design improvements lie at the boundary of these two processes.

Spillovers: Spillovers refer to the transfer of knowledge or the economic benefits of innovation from one individual, firm, industry, or other entity to another. The gas turbine in electricity production, 3-D seismic imaging in oil exploration, oil platform technologies and wave energy, and computers are all spillovers in a range of energy technologies. For each of these obvious cases of spillovers there are also innumerable, more subtle instances. The ability to identify and exploit advances in unrelated fields is one of the prime drivers of innovation and improvement. Such advances draw from an enabling environment that supports education, research and industrial capacity.

There are several dimensions to spillovers. Spillovers can occur between:

(1) Firms within an industry in and within countries (intra-industry spillovers).
(2) Industries (inter-industry spillovers).
(3) Countries (international spillovers).

The latter have received considerable attention in the climate literature (e.g. Grubb *et al.*, 2002). Spillovers create a positive externality for the recipient industry, sector or country, but also limit (but not eliminate) the ability of those that create new knowledge to appropriate the economic returns from their efforts, which can reduce private incentives to invest in technological advance (see Arrow, 1962), and is cited as a primary justification for government intervention in markets for innovation.

Spillovers are not necessarily free. The benefits of spillovers may require effort on the part of the receiving firms, industries, or countries. Explicit effort is often required to exploit knowledge that spills over, whether that knowledge is an explicit industrial process or new knowledge from the foundations of science (see Cohen and Levinthal, 1989). The opportunities created by spillovers are one of the primary sources of knowledge that underlies innovation (see Klevorick, *et al.*, 1995). There are different channels by which innovativions may spillover. For instance, the productivity achieved by a firm or an industry depends not only on its own R&D effort, but also on the pool of general knowledge to which it has access. There are also so-called ‘rent spillovers’, such as R&D leading to quality changes embodied in new and improved outputs which not necessarily yield higher prices. Finally, spillovers are frequent for products with high market rivalry effects (e.g. through reverse engineering or industrial espionage). However it is inherently difficult to distinguish clearly between these various channels of spillovers.

Over the last half century, a substantial empirical literature has developed, outside the climate or energy contexts, which explores the sources of technological advance. Because of the complexity of technological advance and the sizable range of forces and actors involved, this literature has proceeded largely through partial views, considering one or a small number of sources, or one or a small number of technologies. On the whole, the evidence strongly suggests that all three of the

Box 2.3 Economies of scale

Economies of scale refer to the decreases in the average cost of production that come with an increase in production levels, assuming a constant level of technology. Economies of scale may arise, for example, because of fixed production costs that can be spread over larger and larger quantities as production increases, thereby decreasing average costs. Economies of scale are not a source of technological advance, but rather a characteristic of production. However, the two concepts are often intertwined, as increased production levels can bring down costs both through learning-by-doing and economies of scale. It is for this reason that economies of scale have often been used as a justification for using experience curves or learning curves in integrated assessment models.

sources highlighted above – R&D, learning-by-doing, and spillovers – play important roles in technological advance and there is no compelling reason to believe that one is broadly more important than the others. The evidence also suggests that these sources are not simply substitutes, but may have highly complementary interactions. For example, learning from producing and using technologies provides important market and technical information that can guide both public and private R&D efforts.

Beginning with Griliches's study of hybrid corn (see Griliches, 1992), economists have conducted econometric studies linking R&D to productivity (see Griliches, 1992, Nadiri, 1993, and the Australian Industry Commission, 1995 for reviews of this literature). These studies have used a wide range of methodologies and have explored both public and private R&D in several countries. As a body of work, the literature strongly suggests substantial returns from R&D, social rates well above private rates in the case of private R&D (implying that firms are unable to fully appropriate the benefits of their R&D), and large spillover benefits. Griliches (1992) writes that '… there have been a significant number of reasonably well done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates'.

Since at least the mid-1930s (see Wright, 1936), researchers have also conducted statistical analyses on 'learning curves' correlating increasing cumulative production volumes and technological advance. Early studies focused heavily on military applications, notably wartime ship and airframe manufacture (see Alchian, 1963 and Rapping, 1965). From 1970 through to the mid-1980s, use of experience curves was widely recommended for corporate strategy development. More recently, statistical analyses have been applied to emerging energy technologies such as wind and solar power. (Good summaries of the experience curve literature can be found in Yelle, 1979; Dutton and Thomas, 1984. Energy technology experience curves may be found in Zimmerman, 1982; Joskow and Rose, 1982; Christiansson, 1995; McDonald and Schrattenholzer, 2001).

Based on the strength of these correlations, large-scale energy and environmental models are increasingly using 'experience curves' or 'learning curves' to capture the response of technologies to increasing use (e.g. Messner, 1997; IEA, 2000; Rao *et al.*, 2005; and the review by Clarke and Weyant, 2002). These curves correlate cumulative production volume to per-unit costs or other measures of technological advance.

An important methodological issue arising in the use of these curves is that the statistical correlations on which they are based do not address the causal relationships underlying the correlations between cumulative production and declining costs, and few studies address the uncertainties inherent in any learning phenomenon (including negative learning). Because these curves often consider technologies over long time frames and many stages of technology evolution, they must incorporate the full range of sources that might affect technological advance or costs and performance more generally, including economies of scale, changes in industry structure, own-industry R&D, and spillovers from other industries and from government R&D. Together, these sources of advance reduce costs, open up larger markets, and result in increasing cumulative volume (see Ghemawat, 1985; Day and Montgomery, 1983; Alberts, 1989; Soderholm and Sundqvist, 2003). Hence, the causal relationships necessarily operate both from cumulative volume to technological advance and from technological advance to cumulative volume.

A number of studies have attempted to probe more deeply into the sources of advance underlying these correlations (see, for example, Rapping, 1965; Lieberman, 1984; Hirsh, 1956; Zimmerman, 1982; Joskow and Rose, 1985; Soderholm and Sundqvist, 2003, and Nemet, 2005). On the whole, these studies continue to support the presence of learning-by-doing effects, but also make clear that other sources can also be important and can influence the learning rate. This conclusion is also confirmed by recent studies following a so-called 'two-factor-learning-curve' hypothesis that incorporates both R&D and cumulative production volume as drivers of technological advance within a production function framework (see, for example, Kouvaritakis *et al.*, 2000). However, Soderholm and Sundqvist (2003) conclude that 'the problem of omitted variable bias needs to be taken seriously' in this type of approach, in addition to empirical difficulties that arise, because of the absence of public and private sector technology-specific R&D statistics and due to significant co-linearity and auto-correlation of parameters (e.g. Miketa and Schrattenholzer, 2004).

More broadly, these studies, along with related theoretical work, suggest the need for further exploration of the drivers behind technological advance and the need to develop more explicit models of the interactions between sources. For example, while the two-factor-learning-curves include both R&D and cumulative volume as drivers, they often assume a substitutability of the two forms of knowledge generation that is at odds with the (by now widely accepted) importance of feedback effects between 'supply push' and 'demand pull' drivers of technological change (compare Freeman, 1994). Hence, while modelling paradigms such as two-factor-learning-curves might be valuable methodological steps on the modelling front, they remain largely exploratory. For a (critical) discussion and suggestion for an alternative approach see, for example, Otto *et al.*, 2005.

A range of additional lines of research has explored the sources of technological advance. Authors have pursued the impacts of 'general-purpose technologies', such as rotary motion (Bresnahan and Trajtenberg, 1992), electricity and electric motors (Rosenberg, 1982), chemical engineering (Rosenberg, 1998), and binary logic and computers (Bresnahan and Trajtenberg, 1992). Klevorick *et al.* (1995) explored the sources of technological opportunity that firms exploit in advancing technology, finding important roles for a range of knowledge sources, depending on the industry and the application. A number of authors (see, for example, Jaffe and Palmer 1996; Lanjouw and Mody 1996; Taylor *et al.,* 2003; Brunnermier and Cohen, 2003; Newell *et al.* 1998) have explored the empirical link between environmental regulation and technological advance in environmental technologies. This body of literature indicates an important relationship between environmental regulation and innovative activity on environmental technologies. On the other hand, this literature also indicates that not all technological advance can be attributed to the response to environmental regulation. Finally, there has been a long line of empirical research exploring whether technological advance is induced primarily through the appearance of new technological opportunities (technology-push) or through the response to perceived market demand (market pull). (See, for example, Schmookler, 1962; Langrish *et al.,* 1972; Myers and Marquis, 1969; Mowery and Rosenberg, 1979; Rosenberg 1982; Mowery and Rosenberg, 1989; Utterback, 1996; Rycroft and Kash 1999). Over time, a consensus has emerged that 'the old debate about the relative relevance of "technology push" versus "market pull" in delivering new products and processes has become an anachronism. In many cases one cannot say with confidence that either breakthroughs in research "cause" commercial success or that the generation of successful products or processes was a predictable "effect" of having the capability to read user demands or other market signals accurately' (Rycroft and Kash, 1999).

2.7.2.2 Development and commercialization: drivers, barriers and opportunities

Development and diffusion or commercialization of new technology is largely a private-sector endeavour driven by market incentives. The public sector can play an important role in coordination and co-funding of these activities and (through policies) in structuring market incentives. Firms choose to develop and deploy new technologies to gain market advantages that lead to greater profits. Technological change comprises a whole host of activities that include R&D, innovations, demonstration projects, commercial deployment and widespread use, and involves a wide range of actors ranging from academic scientists and engineers, to industrial research labs, consultants, firms, regulators, suppliers and customers. When creating and disseminating revolutionary (currently non-existent) technologies, the path to development may proceed sequentially through the various phases, but for existing technology, interactions can occur between all phases, for example, studies of limitations in currently deployed technologies may spark innovation in fundamental academic research. The ability to identify and exploit advances in unrelated fields (advanced diagnostics and probes, computer monitoring and modelling, control systems, materials and fabrication) is one of the prime drivers of innovation and improvement. Such advances draw from an enabling environment that supports education, research and industrial capacity.

The behaviour of competing firms plays a key role in the innovation process. Especially in their efforts to develop and introduce new non-commercial technology into a sustainable commercial operations, firms require not only the ability to innovate and to finance costly hardware, but also the managerial and technical skills to operate them and successfully market the products, particularly in the early stages of deployment and diffusion. The development of proprietary intellectual property and managerial know-how are key ingredients in establishing competitive advantage with new technology, but they can be costly and difficult to sustain.

Several factors must therefore be considered prominently with respect to the process of technology development and commercialization. A detailed review of these factors is included in the IPCC Special Report on Technology Transfer (SRTT) and the discussion below provides a summary and update, which draws on Flannery and Khesghi (2005) and OECD (2006). Factors to consider in development and commercialization of new technologies include:

- First, the lengthy timescale for deployment of advanced energy technologies.
- Second, the range of barriers that innovative technologies must successfully overcome if they are to enter into widespread commercial use.

- Third, the role of governments in creating an enabling framework to enhance the dissemination of innovative commercial technology created by private companies.
- Fourth, absorptive capacity and technological capabilities are also important determinants of innovation and diffusion.

New technologies must overcome a range of technical and market hurdles to enter into widespread commercial use. Important factors include:

- Performance.
- Cost.
- Consumer acceptance.
- Safety.
- Financial risks, available financing instruments.
- Enabling infrastructure.
- Incentive structures for firms (e.g. licensing fees, royalties, policy environment, etc.).
- Regulatory compliance.
- Environmental impacts.

The diffusion potential for a new technology depends on all above factors. If a technology fails even in one of these dimensions it will not achieve significant global penetration. While reducing greenhouse gas emissions should be an important objective in technological research, it is not the only factor.

Another factor is that the lengthy timescale for deployment of advanced energy technologies has a substantive impact on private-sector behaviour. Even with successful innovation in energy technology, the time necessary for new technology to make a widespread global impact on emissions will be lengthy. Timescales are long, both due to the long lifespan of existing productive capital stock, and the major investment in hardware and infrastructure that is required for significant market penetration. During the time that advanced technology is being deployed, both incremental and revolutionary changes may occur in the technologies under consideration, and in those that compete with them.

One consequence of the long time scales involved with energy technology is that, at any point in time, there will inevitably be a significant spread in the efficiency and performance of the existing equipment deployed. While this presents an opportunity for advanced technology to reduce emissions, the overall investment required to prematurely replace a significant fraction of sunk capital can be prohibitive. Another consequence of the long time scale and high cost of equipment is that it is difficult to discern long-term technological winners and losers in evolving markets.

A third factor is enabling infrastructure. Infrastructure can be interpreted broadly. Key features have been described in numerous studies and assessments (e.g. IPIECA, 1995), and include: rule of law, safety, secure living environment for workers and communities, open markets, realization of mutual benefits, protection of intellectual property, movement of goods, capital and people, and respect for the needs of host governments and communities. These conditions are not unique for private companies. Many of them also are essential for successful public investment in technology and infrastructure.[32]

2.7.2.3 The public-sector role in technological change

Given the importance of technology in determining both the magnitude of future GHG emission levels as well as feasibility and costs of emission reduction efforts, technology policy considerations are increasingly considered in climate policy analyses. Ongoing debate centers on the relative importance of two differing policy approaches: technology-push (through efforts to stimulate research and development) and demand-pull (through measures that demand reduced emissions or enhanced efficiency). Technology-push emphasizes the role of policies that stimulate research and development, especially those aimed at lowering the costs of meeting long-term objectives with technology that today is very far from economic in existing markets. This might include such measures as public-funded R&D or R&D tax credits. Demand-pull emphasizes the use of instruments to enhance the demand for lower-emission technologies, thereby increasing private incentives to improve these technologies and inducing any learning-by-doing effects. Demand-pull instruments might include emissions taxes or more direct approaches, such as renewable portfolio standards, adoption subsidies, or direct public-sector investments (see Figure 2.3).

Two market failures are at issue when developing policies to stimulate technology development. The first is the failure to internalize the environmental costs of climate change, reducing the demand for climate-friendly technologies and thereby reducing private-sector innovation incentives and learning-by-doing. The second is a broad suite of private-sector innovation market failures that hold back and otherwise distort private-sector investment in technological advance, irrespective of environmental concerns (confer Jaffe *et al.*, 2005). Chief among these is the inability to appropriate the benefits of knowledge creation. From an economic standpoint, two market failures require two policy instruments: addressing two market failures with a single instrument will only lead to second-best solutions (see, for example, Goulder and Schneider, 1999). Hence, it is well understood that the optimal policy approach should include both technology-push and demand-pull instruments. While patents and various intellectual property protection (e.g. proprietary know-how) seeks to reward innovators, such protection is inherently imperfect, especially in global markets where such protections are not uniformly enforced by all governments.

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[32] These and other issues required for successful dissemination of technology were the subject of an entire IPCC Special Report (IPCC, 2000)

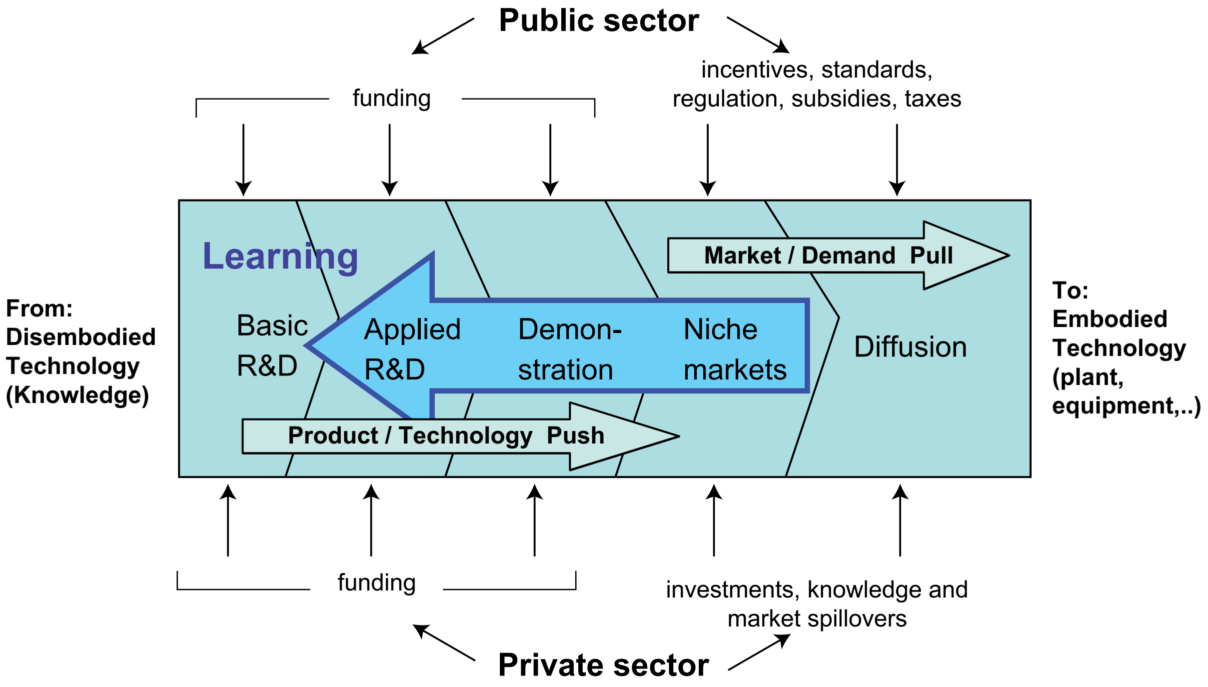

Figure 2.3 : *Technology development cycle and its main driving forces. Note that important overlaps and feedbacks exist between the stylized technology life-cycle phases illustrated here and therefore the illustration does not suggest a 'linear' model of innovation.*

Source: Adapted from Foxon (2003) and Grubb (2005).

Similarly, in the early adoption of technology learning-by-doing (by producers) or learning-by-using (by consumers) may lower the cost to all future users, but in a way that may not fully reward the frontrunners.[33] Similarly, lack of information by investors and potential consumers of innovative technologies may slow the diffusion of technologies into markets. The 'huge uncertainties surrounding the future impacts of climate change, the magnitude of the policy response, and thus the likely returns to R&D investment' exacerbate these technological spillover problems (Jaffe *et al.*, 2005).

The outstanding questions revolve around the relative combinations of instruments and around how effective single-policy approaches might be. Within this context, a number of authors (e.g. Montgomery and Smith, 2005) have argued that fundamental long-term shifts in technology to mitigate greenhouse gas emissions cannot be achieved through emissions-constraining policies alone, and short-term cap and trade emission-reduction policies provide insufficient incentives for R&D into long-term technology options. Conversely, Popp (2002) demonstrated how energy R&D is responsive to price signals, suggesting that without emissions constraints R&D into new low-emission technologies may face a serious lack of incentives and credible policy signals. The argument that emissions-based policies will induce long-term technology innovation relies primarily on two lines of reasoning (Goulder 2004; Grubb, 2005). The first is that the anticipation of future targets, based on a so-called announcement effect, will stimulate firms to invest in research and development and ultimately to invest in advanced, currently non-commercial technology (the credibility and effectiveness of this effect, however, being challenged by Montgomery and Smith, 2005). The second is that early investment, perhaps through incentives, mandates, or government procurement programmes, will initiate a cycle of learning-by-doing that will ultimately promote innovation in the form of continuous improvement, which will drive down the cost of future investments in these technologies. This issue is especially critical in the scaling up of niche-market applications of new technologies (e.g. renewables) where mobilizing finance and lowering investment risks are important (see, for example, IEA, 2003, or Hamilton, 2005). In their comparative analysis of alternative policy instruments Goulder and Schneider (1999) found that when comparing a policy with only R&D subsidies to an emissions tax, the emissions-based policies performed substantially better.

Irrespective of the mix between demand-pull and technology-push instruments, a number of strong conclusions have emerged with respect to the appropriate policies to stimulate technological advance. First, it is widely understood that flexible, incentive-

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[33] However, there are many other factors, in addition to appropriating returns from innovation, that influence the incentive structure of firms, including 'first mover' advantages, market power, use of complementary assets, etc. (for a review see Levin *et al.*, 1987).

oriented policies are more likely to foster low-cost compliance pathways than those that impose prescriptive regulatory approaches (Jaffe *et al.*, 2005). A second robust conclusion is the need for public policy to promote a broad portfolio of research, because results cannot be guaranteed since it is impossible to *ex ante* identify

technical winners or losers (GTSP, 2001). A third conclusion is that more than explicit climate change or energy research is critical for the development of technologies pertinent to climate change. Spillovers from non-energy sectors have had enormous impacts on energy-sector innovation, implying that a broad and robust technological base may be as important as applied energy sector or similar R&D efforts. This robust base involves the full 'national systems of innovation'[34] involved in the development and use of technological knowledge. Cost and availability of enabling infrastructure can be especially important factors that limit technology uptake in developing countries.[35] Here enabling infrastructure would include management and regulatory capacity, as well as associated hardware and public infrastructure.

2.7.3 The international dimension in technology development and deployment: technology transfer

Article 4.5 of the Convention states that developed country Parties 'shall take all practicable steps to promote, facilitate, and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention', and to 'support the development and enhancement of endogenous capacities and technologies of developing country Parties'.

Similarly Article 10(c) of the Kyoto Protocol reiterated that all Parties shall: 'cooperate in the promotion of effective modalities for the development, application, and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies'.

Technology transfer is particularly relevant because of the great interest by developing countries in this issue. This interest arises from the fact that many developing countries are in a phase of massive infrastructure build up. Delays in technology transfer could therefore lead to a lock-in in high-emissions systems for decades to come (e.g. Zou and Xuyan, 2005). Progress on this matter has usually been linked to progress on other matters of specific interest to developed countries. Thus Article 4.7 of the Convention is categorical that 'the extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and the transfer of technology'.

The IPCC Special Report on Methodological and Technological Issues on Technology Transfer (SRTT) (IPCC, 2000) defined the term 'technology transfer' as a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders. A recent survey of the literature is provided in Keller (2004) and reviews with special reference to developing countries are included in Philibert (2005) and Lefevre (2005). The definition of technology transfer in the SRTT and the relevant literature is wider than implied by any particular article of the Convention or the Protocol. The term 'transfer' was defined to 'encompass diffusion of technologies and technology cooperation across and within countries'. It also 'comprises the process of learning to understand, utilize and replicate the technology, including the capacity to choose and adapt to local conditions and integrate it with indigenous technologies'.

This IPCC report acknowledged that the 'theme of technology transfer is highly interdisciplinary and has been approached from a variety of perspectives, including business, law, finance, micro-economics, international trade, international political economy, environment, geography, anthropology, education, communication, and labour studies'.

Having defined technology transfer so broadly, the report (IPCC, 2000, p. 17) concluded that 'although there are numerous frameworks and models put forth to cover different aspects of technology transfer, *there are no corresponding overarching theories*' (emphasis added). Consequently there is no framework that encompasses such a broad definition of technology transfer.

The aforementioned report identified different stages of technology transfer and different pathways through which it is accomplished. These stages of technology transfer are: identification of needs, choice of technology, and assessment of conditions of transfer, agreement and implementation. Evaluation and adjustment or adaptation to local conditions, and replication are other important stages. Pathways for technology

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[34] The literature on national innovation systems highlights in particular the institutional dimensions governing the feedback between supply-push and demand-pull, and the interaction between the public and private sectors that are distinctly different across countries. A detailed review of this literature is beyond the scope of this assessment. For an overview see, for example Lundvall, 2002, and Nelson and Nelson, 2002.

[35] In this context, the concept of technological 'leapfrogging' (Goldemberg, 1991), and the resulting requirements for an enabling environment for radical technological change, is frequently discussed in the literature. For a critical review see, for example, Gallagher (2006).

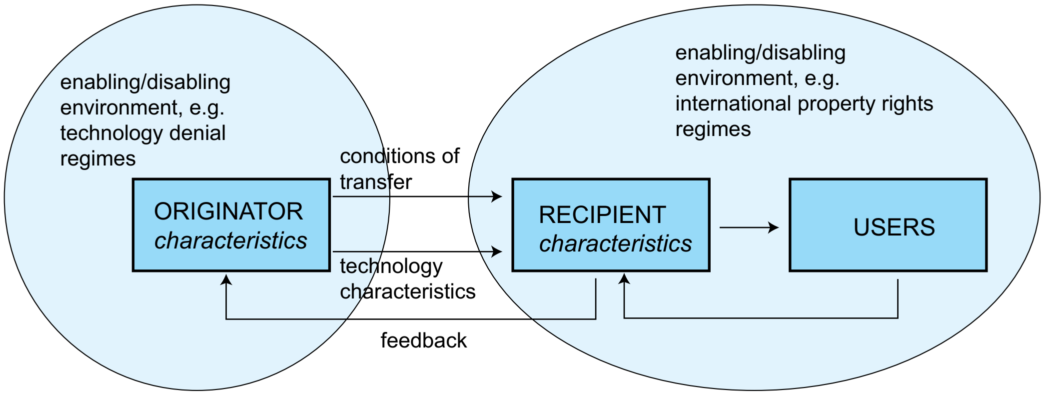

Figure 2.4: *A general framework for factors affecting technology transfer and subsequent innovation.*

transfer vary depending on the sector, technology type and maturity and country circumstances. Given this variety and complexity, the report concluded that there is no pre-set answer to enhancing technology transfer.

There is no international database tracking the flow of ESTs (environmentally sound technologies). Little is known about how much climate-relevant equipment is transferred, and even less about the transfer of know-how, practices and processes, and most international analyses rely on proxy variables. It is well known that the nature of financial flows from OECD countries to developing countries has changed over the last 15 years. Overseas development assistance (ODA) has declined and been overtaken by private sources of foreign direct investments (WDI, 2005). International financial statistics only reflect the quantity and not the quality of FDI. They also say nothing about what fraction is a transfer of ESTs. Despite its decline, ODA is still critical for the poorest countries, particularly when it is aimed at developing basic capacities to acquire, adapt, and use foreign technologies.

IPCC (2000, p. 22) summarized the historical experience as a 'failure of top-down, technology-focused development'. Some developing country policymakers believe that payments for technology are beyond their means and that international technology transfer contributes little to technological development in the recipient country (UNDP, 2000). Many failures of technology transfer have resulted from an absence of human and institutional capacity (IPCC, 2000, p. 118).

There are several modes to encourage technology transfer to developing countries, from technical assistance and technology grants, to capacity building and policy development cooperation. The priorities for these modes shift as host countries develop economically. Technology demonstration projects can play an important role early in the industrialization process. As the economy grows, policy development cooperation, such as assistance to develop energy-efficiency standards or to create an enabling environment for technology diffusion, becomes more important. Ohshita and Ortolano (2003) studied past experiences of demonstration projects using cleaner energy technologies in developing countries through assistance by international organizations as well as developed countries. They found that demonstration projects raised awareness of cleaner energy technologies in the technology transfer process, but were not very successful in diffusing the technologies more widely in the target developing countries. For China in particular, demonstration projects played an important role in the past, when the economy began shifting from a centrally planned system to a more open, market-based system. There is increasing recognition that other modes of technology diffusion may now be more suitable for China. Given the continued high growth of the Chinese economy, donors have been shifting their assistance programmes from technology demonstration to policy development assistance (Ohsita, 2006).

Figure 2.4 shows one attempt to create a framework for all forms of technology transfer. In all forms technology transfer, especially across countries, at least seven characteristics are important. These are:

1. The characteristics of the technology.
2. The characteristics of the originator of the transfer.
3. The enabling (or disabling) environment in the country of origin.
4. The conditions of the transfer.
5. The characteristics of the recipient.
6. The enabling (or disabling) environment in the host country.
7. The ultimately valuable post-transfer steps, i.e. assimilation, replication and innovation.

Each of these characteristics are discussed below.

Characteristics of the originator of the transfer. Initially, there was a widespread tendency to think of technology transfer in supply-side terms – the initial choice and acquisition of technology (Brooks, 1995) and a lack of corresponding focus on the other factors that influence the successful outcome of technology transfer, such as enabling environment, institutions and finance.

The environment in the country of origin can be conducive or disabling for technology transfer. The public sector continues to be an important driver in the development of ESTs. Of the 22 barriers listed in the technical summary of the IPCC Report (2000) as barriers to technology transfer, 21 relate to the enabling environment of recipient countries. Many governments transfer or license the patents arising out of publicly funded efforts to the private sector as a part of their industrial policy, and then the transferred patents follow the rules of privately owned technologies (IPCC, 2000, p. 25).

One should also consider the 'imperfect' nature of technology markets:

(1) While some of the components of technology are of a public-good nature, others have an important tacit nature.
(2) Technology markets are normally very concentrated on the supply side, and bargaining power is unevenly distributed.
(3) The strategic nature of technologies normally includes limiting clauses and other restrictions in transfer contracts (for a discussion see Arora *et al.*, 2001; Kumar, 1998).

Technology Denial Regimes[36] in the country of origin also sometimes constitute a barrier to technology transfer, especially for multiple-use technologies. Thus supercomputers can be used for climate modelling and global circulation models and also to design missiles.

The conditions of the transfer. Most technologies are transferred in such a way that the originators also benefit from the transfer and this helps to establish strong incentives for proper management and maintenance of the technologies. The conditions of the transfer will primarily depend on the transfer pathway used, as mentioned above. Common pathways include government assistance programmes, direct purchases, trade, licensing, foreign direct investment, joint ventures, cooperative research agreements, co-production agreements, education and training and government direct investment. Developing countries have argued for the transfer of ESTs and corresponding know-how, on favourable, concessional and preferential terms (Agenda 21, 1992, Chapter 34). There have been instances in the pharmaceutical industry when certain drugs benefiting developing countries have been licensed either free or on concessionary terms.

The characteristics of the recipient. The recipient must understand local needs and demands; and must possess the ability to assess, select, import, adapt, and adopt or utilize appropriate technologies.

The enabling (or disabling) environment in the host country. Many of the barriers to technology transfer that are listed in the IPCC Report (IPCC, 2000, p. 19) relate to the lack of an enabling (or a disabling) environment in the recipient country for the transfer of ESTs. A shift in focus, from technology transfer per se to the framework represented in Figure 2.4, leads to an equal emphasis on the human and institutional capacity in the receiving country. A crucial dimension of the enabling environment is an adequate science and educational infrastructure. It must be recognized that capacity building to develop this infrastructure is a slow and complex process, to which long-term commitments are essential.

A recipient's ability to absorb and use new technology effectively also improves its ability to develop innovations. Unfortunately, the capacity to innovate and replicate is poorly developed in developing countries (STAP, 1996). However, the engineering and management skills required in acquiring the capacity to optimize and innovate are non-trivial. The technology-importing firm needs to display what has been called 'active technological behaviour'. Firms that do not do this are left in a vicious circle of technological dependence and stagnation (UNDP, 2000).

2.8 Regional dimensions

Climate change studies have used various different regional definitions depending on the character of the problem considered and differences in methodological approaches. Regional studies can be organized according to geographical criteria, political organizational structures, trade relations, climatic conditions, stage of industrialization or other socio-economic criteria relevant to adaptive and mitigative capacity (Duque and Ramos, 2004; Ott *et al.*, 2004; Pan, 2004a).

Some classifications are based on so-called 'normative criteria' such as membership of countries in UN fora and agreements. Differentiation into Annex-1 and non-Annex-1 countries is specified in the UNFCCC, although the classification of certain countries has been a matter of some dispute. Annex-1 countries are further sub-divided into those that are undergoing a transition to market economies. Figure 13.2 in Chapter 13 shows the current country groupings under the Climate Convention, OECD and the European Union. Some Economies in Transition (Rabinovitch and Leitman, 1993) and developing countries are members of the OECD, and some developing countries have income levels that are higher than developed nations (Baumert *et al.*, 2004; Ott *et al.*, 2004). Given the complexities of the criteria used in country groupings, in this report the terms 'developed countries', 'economies in

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[36] Regulatory criteria denying access to certain technologies to individual countries or groups of countries.

transition' (together forming the industrialized countries) and 'developing countries' are commonly used; categories that are primarily of a socio-economic nature.

In climate mitigation studies, there are often two types of regional breakdowns used – physio-geographic or socio-economic. Data on insolation (relevant to solar power), rainfall (relevant to hydrower), temperature, precipitation and soil type (relevant to the potential for carbon sequestration) are examples of physio-geographic classifications useful in climate change mitigation studies.

The multitude of possible regional representations hinders the comparability and transfer of information between the various types of studies implemented for specific regions and scales. Data availability also determines what kinds of aggregation are possible. Proxies are used when data is not available. This report has generally chosen a pragmatic way of analyzing regional information and presenting findings. Readers should bear in mind that any regional classification masks sub-regional differences.

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