Title:	Framing Issues	
Chapter:	2	
(Sub)Section:	All	
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Remarks:	Second Order Draft	
Version:	CH2_SOD_200706_MK_SB_Th.doc	
File name:	Chapter 2_Text.doc	
Date:	20/07/2006 14:22	Time-zone: CET

Contents

EXECUTIVE SUMMARY

The chapter frames climate change mitigation policies in the context of general development issues and recognises that there is a two-way relationship between climate change and sustainable development. On one hand development pathways influence climate change vulnerability, adaptation and mitigation. On the other hand, climate change itself, adaptation and mitigation policies could have significant impacts on 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. Forming and maintaining stable international coalitions to agree and implement climate policies raises complex issues of strategic behaviour and frameworks which enhance or inhibit negotiation. However, many new initiatives emerge from NGO's, the business sector, and governmental cooperation efforts, 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 human voluntary or involuntary limits to information management, from difficulties in incorporating some variables in formal analysis, as well as from the inherently unpredictable elements of complex systems. While science aims to produce the highest standard of proof available, it is a contingent human production and in time scientific truth can change based on new empirical data. An increasing international literature considers how the limits of the evidence basis and other sources of uncertainties can be disclosed. Some of the work in this context emphasise the expected values of outcomes, precautionary approaches, insurance, and crisis management.

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 multi-national levels. Inputs can include financial, economic, ecological and social factors. In formal cost-benefits analysis one major determinant of the present value of costs and benefits is the discount rate since climate change, and mitigation and adaptation measures all involve impacts spread over very long time periods. The literature includes both prescriptive approaches, which argue for discount rates reflecting one or other ethical rule, and descriptive approaches, which attempt to reflect assessment of actual human behaviour and choices – observed in the market and through experimental approaches. Much of the literature use constant discount rates at a level estimated to reflect time preference rates as used in assessment of typical large investments. Some recent literature also includes recommendations about using time decreasing discount rates reflecting uncertainty about future economic growth, fairness and intra generational distribution, and observed individual choices. Based on this some countries officially recommend to use time decreasing discount rate for long time horizons.

Recent literature has explored the potential linkages between climate change mitigation and adaptation policies. 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 access to resources, credit, social capital, and the decision making capacity in itself. There are also policy options that can simultaneously support adaptation and mitigation including biomass energy options, landuse policies, infrastructure planning and management, renewable energy options, and agricultural irrigation and other management approaches.

Climate change has large implications for inter-regional and intergenerational equity, and the application of different equity approaches has major implications for policy recommendations as well as on the proposed distribution of costs and benefits of climate policies. Different approaches to social justice can be applied to the evaluation of 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 defined rights of individuals. The climate policy focus of economic assessment would be to assess welfare losses and gains to different groups and the society at large, while a rights based approach rather can focus on specific states of the climate that should be maintained in the interests of the most vulnerable individuals or groups of individuals. Alternatively, the literature also includes the capability approach that argues that climate policy both should ensure that opportunities and freedom are maintained and that the distribution of the welfare impacts of the policies is fair.

The cost and pace of any response to climate change concerns will strongly depend critically on the cost, performance, and availability of technologies that can lower emissions in the future. Technological change is particularly important over the long-term time scales characteristic of climate change. Decade or longer 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. 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. 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.

2.1 Chapter Scoping

This chapter builds up on the framing issues mentioned in Chapter 1. It covers the relationships between climate change and sustainable development, decision making frameworks, risk and uncertainty, cost and benefit concepts, climate change vulnerability and mitigation and adaptation relationships, distributional and equity aspects, regional dimensions, and technology research and development deployment diffusion and transfer. This chapter provides conceptual frameworks of these issues that are important for the discussion of specific climate change mitigation aspects in subsequent chapters.

Section 2.2 introduces a pragmatic approach to the definition of sustainable development (SD) and a number of issues on how SD and climate change policy impacts can be assessed jointly are introduced. It explores the two-way relationship between sustainable development and climate change. On one hand, climate change is influencing key natural and human living conditions and thereby also the basis for social and economic development, on the other hand society's priorities on sustainable development influence both the vulnerability and the GHG emissions that are causing climate change. It includes the identification of indicators that can be used to establish linkages between Millennium Development Goals (MDG) and climate change, and well as an overview of how SD development indicators have been defined and assessed for OECD countries.

Section 2.3 discusses a number of issues related to the specific character of climate change decision making. It highlights a number of social decision making issues related to the long term nature of climate change and uncertainties. It is pointed out that there is no single decision maker in international climate change policies and stakeholders assign different values to climate change impacts and to the costs and benefits of policy actions. Since climate change also is characterised by large uncertainties, decision making becomes a very complex and demanding task. An overview is provided of various analytical approaches that can be used to support decision making.

Section 2.4 defines various kinds of risk and uncertainty, and how they matter for the climate change issues. The section addresses approaches to determining uncertainties, developing expert judgments, and communicating uncertainty and confidence in findings that arise in the context of the assessment process.

The next section 2.5 describes costs and benefit concepts. It also covers major cost determinants such as discount rates, market efficiency, transaction and implementation costs, ancillary and joint costs, and valuation techniques. Concepts of GHG emission mitigation costs and mitigation potential are also covered.

Section 2.6 outlines a framework for how mitigation and adaptation options can be looked at in an integrated manner, and discusses the relationship between specific mitigation and adaptation policies. Adaptive and mitigative capacities reflect the institutional structure and the social conditions of society for dealing with climate change. A number of examples of policies that both support adaptation and mitigation goals are given.

Section 2.7 on distributional and equity aspects describes how different equity concepts can be applied to the evaluation of climate change policies. The equity issues involve intra- and intergenerational dimensions. In the short term, key issues are the distributions of mitigation costs among individuals and nations and emerging consequences of climate change. In the longer-term the distributional issues that arise from how damages face different individuals and nations become very pertinent. The section discusses how different approaches can be applied to the evaluation of equity consequences of climate change policies.

The cost and pace of any response to climate change will depend critically on the cost, performance, and availability of technologies that can lower emissions in the future. Technological change is particularly important over the long-term time scales characteristic of climate change. Section 2.8 goes through some of the major elements of technological development and deployment. The role of technological change in business-as-usual scenarios is examined and factors driving technological change including research and development, leaning-by-doing, and spillovers are considered. The roles of markets, policies, and technology transfer are finally discussed in relation to public policies and various markets actors.

Climate change studies have used various different regional definitions depending on the character of the problem considered and differences in methodological approaches. This is discussed in 2.9. Analytical or functional regions are defined according to analytical requirements: functional regions are grouped using physical criteria or socio-economic criteria.

2.2 Climate Change and Sustainable Development

2.2.1 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 related to short- and long term mitigation issues are addressed in Chapters 3 (section 3.1.1.1 and 3.1.2) and 11 (section 11.7.3). Sectoral issues are coved in Chapters 4-11 (sections 4.5.4, 5.4.3.1, 6.5.1, 7.7, 8.4.5, 9.7, and in 10.6 Long-term considerations and AMSD.

2.2.2 Background

The Third Assessment of the IPCC (TAR) included considerations about SD and climate change. The issues were addressed particularly by WGs II and III and the Synthesis report. One of the outcomes of the SD and climate change discussions was a figure in the Synthesis Report that jointly illustrate climate change, human and natural systems, and socio-economic development paths, see Figure 2.1 below.

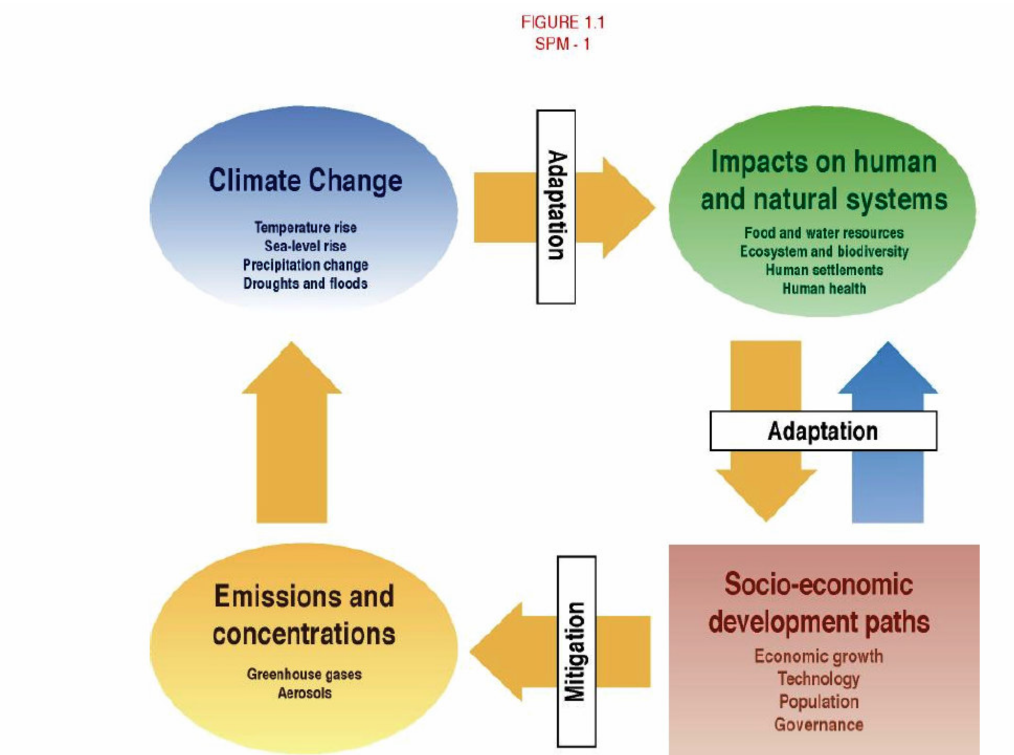

Figure 2.1 *TAR figure on SD, adaptation and mitigation interactions*

Figure 2.1 is a schematic and simplified representation of an integrated assessment framework for considering anthropogenic climate change. The yellow arrows show a full clockwise cycle of cause and effect among the four quadrants shown in the figure, while the blue arrow indicates the societal response to climate impacts. Each socio-economic development path has driving forces which give rise to emissions of greenhouse gases, aerosols and precursors – with carbon dioxide (CO_2) being the most important. The greenhouse gas emissions accumulate in the atmosphere, changing concentrations and disturbing the natural balances, depending on physical processes such as solar radiation, cloud formation, and rainfall. The aerosols also give rise to air pollution (e.g.) acid rain that damage human and the natural systems (not shown). The enhanced greenhouse effect will initiate climate changes well into the future with associated impacts on the natural and human systems.

The Third Assessment Report had 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 (Chapter 1, TAR). It noted the advantages of a portfolio approach to mitigation policy and analysis rather than one that relies on a narrow set of policy instruments or analytical tools. The TAR introduced the concept of mitigative capacity as a mean to integrate results related to the aforementioned three perspectives (see a more through discussion of this concept in section 2.6). The report noted that global future scenarios that show falling GHG emissions tend to show improved governance, increased equity and political participation, reduced conflicts, and improved environmental quality (Chapter 2, TAR). They also tend to show increased energy efficiency, shifts to non-fossil energy sources, and/or shifts to a post-industrial economy, stabilization of population at a low level, and expanded provision of family planning, and improved rights and opportunities for women. The TAR noted that it may be possible to significantly reduce GHG emissions by pursuing climate objectives through general socio-economic policies. Further, adoption of state-of-the-art environmentally sound technologies may offer particular opportunity for sustainable development while reducing GHG emissions. The preparation of the TAR was supported by IPCC Expert Group Meetings that were specially targeted at sustainable development and social dimensions of climate change, which noted the various ways that the TAR's treatment of SD could be improved (Munasinghe and Swart 2000; Jochem et al. 2001).

Since the TAR, an emerging 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; Demeritt et al., 1998; Munasinghe and Swart 2000; Schneider, Easterlig et al. 2000; Banuri et al., 2001; Morita, Robinson et al. 2001; Halsnæs and Verhagen, 2005, Markandya and Halsnæs 2002; Metz et al. 2002; Munasinghe and Swart, 2005; Najam, Rahman et al. 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 that influence development pathways and the capacity for climate change adaptation and mitigation. See also Chapter 12 of this report and Chapter 18 of the IPCC WGII report for a more extensive discussion about these issues.

When addressing climate change mitigation and adaptation, it should be recognised, that GHG emissions as well as climate change vulnerability are influenced by the development path and the institutions embedded in this. At the same time, development paths and institutions facilitate and can also constrain adaptation and mitigation policies. This also means that policies that influence the development path and institutions have indirect impacts on climate change adaptation and mitigation despite they are targeted towards broader development goals. These impacts can be positive or negative, and several studies have therefore suggested to integrate climate change adaptation and mitigation perspectives into development policies in order to make development paths more sustainable (Beg et al., 2002; Davidson, 2003; Munasinghe and Swart, 2005; Halsnæs and Verhagen, 2006).

Rather than starting with a broad sustainable development agenda, climate change adaptation and mitigation can also be the focal policy perspectives and sustainable development can be considered as an issue that indirectly is influenced. Such climate policies will 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 policy implementation in practice can meet some barriers that are not captured in the analysis in terms of conflicts between general development goals and 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 dikes and flood control, climate information systems, and introduction of carbon taxes[1]. 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 support 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 the IPCC WGII report for a more extensive discussion about these issues).

2.2.3 The Dual Relationship: CC → SD and SD →CC

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, on the other hand society's priorities on sustainable development influence both the GHG emissions that are causing climate change and the vulnerability.

Several conceptual discussions about the relationship between SD and climate change were initiated by the Third Assessment of IPCC. The Synthesis report (IPCC, 2002) recognises the importance of understanding the relationship between sustainable development and climate change and concludes that "the climate change issue is part of the larger challenge of sustainable development. As a result, 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

[1] The costs of the mentioned options depend on the context so the options mentioned are not equally relevant in all places.

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 (IPCC 2001a)." (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 programs including the Development and Climate project (Halsnæs and Verhagen, 2005), and an OECD development and environment directorate program (Beg 2002) explores 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 as previously stated the international literature also include work by Cohen, Demeritt et al., 1998; Banuri et al., 2001; Morita et al., 2001; Munasinghe and Swart 2000; Metz et al., 2002; Munasinghe and Swart, 2005; Schneider et al., 2000; Najam et al., 2003; Smit et al., 2001; Swart et al., 2003; and Wilbanks, 2003).

2.2.4 The Sustainable Development Concept

Sustainable development 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 agenda 21, and by many local governments and private sector actors. The sustainable development literature to a large extent emerged as a reaction to a growing interest in considering the interactions and potential conflicts between economic development and the environment. Sustainable development 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" (World Commission on Environment and Development, 1987).

The literature includes many alternative theoretical and applied definitions of sustainable development. The theoretical work spans hundreds of different studies that are based on economic theory, complex systems approaches, ecological science and other approaches that derive conditions for how development paths can meet sustainable development criteria.

Since a comprehensive discussion of the theoretical literature about sustainable development is beyond the scope of this report, a pragmatic approach limits us to consider how development can be made more sustainable. Before we move into a practical operationalisation of such a pragmatic approach a brief overview is provided about a few issues of divergence between different concepts of sustainable development in the theoretical literature.

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, 1988). However, the interpretation and valuation of these dimensions have given raise 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, is, by its nature, transdisciplinary and synthetic, it does not fit well within the disciplinary and analytical model of knowledge that is the backbone of modern education systems (Kay and Foster, 1999). Systems Thinking attempts at formulating a network of interlocking concepts and models, none of them claiming more fundamental than others but all of them mutually consistent, using whatever language becomes appropriated to describe different aspects of the multileveled, interrelated fabric if reality. It attempts to integrate fragmented and dispersed ideas into a broader body of concepts that emphasises basic principles of organisation, structure and process, and in which the manifestations of (un)sustainability are seen as resulting from the interplay of essential phenomena like co-evolution, change, adaptation, self-organisation, resilience, among others.

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). These transformation cycles take place in nested sets of space and time scales. It is the functioning of those cycles, and the communication between them, that determines the system’s sustainable development. In this sense, the term sustainable development acquires a clear connotation and meaning: ‘sustainability is the capacity to create, test, and maintain adaptive capability. Development is the process of creating, testing, and maintaining opportunities. The concept that combines the two, sustainable development, given this framework, therefore refers to the goal of fostering adaptive capabilities while simultaneously creating opportunities (Gunderson and Holling, 2002).

A core element in the economic literature on sustainable development is the focus on growth and the use of manmade, 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 to some extent can be used to substitute each other in a sustainable solution. Strong sustainability on the other hand, 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 states that renewables 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 presents an approach for evaluating alternative criteria for consumption[2] over time seen in a sustainable development perspective. Intertemporal consumption and utility are here introduced as measurement 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.

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

Although institutions often are understood as part of the capital assets, Arrow et al. (2004) only considers 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, interpersonal networks, and the rules and norms that guide their behaviour. Seen from a sustainable development perspective, the issue is then, how and to which extent policies and institutional frameworks for these can 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 are no yet at a stage of practical application, 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 OECD (1998) that addresses aspects like demography, health, employment, equity, information, training, and a number of governance issues as an example of a pragmatic approach to the inclusion of social elements in sustainability studies.

Arrow et al (2004) summarizes 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 rather have focused on the ability of the economy to maintain living standards. It is here concluded that the sustainability criteria implies that intertemporal welfare should be optimized in order to ensure that current consumption is not excessive[3]. However, the optimal level of current consumption cannot be determined i.e. due to various uncertainties, and theoretical considerations are therefore focusing on factors that could be predicted to make current consumption unsustainable. 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 authors have argued that the term 'sustainable development' can be used to support cosmetic environmentalism, sometimes called green washing or simply hypocrisy (Najam 1999, Athanasiou, 1996). One response to such practices has been the development of greatly improved monitoring, analytical techniques, and standards, in order to be able to verify claims about sustainable practices (Hardi and Zdan, 1997; OECD, 1998; Bell and Morse, 1999; Parris and Kates, 2003).

It has been argued that the term "sustainable development" is itself an oxymoron because biophysical limits constrain the amount of future development that is sustainable (Dovers and Handmer, 1993; Mebratu, 1998; Sachs, 1999). This leads some to argue for a 'strong sustainability' approach in which natural capital must be preserved since it cannot be substituted for by any other form of capital (Pearce et al., 1989; Cabeza Gutes, 1996). Others point out that the concept of sustainable development is anthropocentric, thereby avoiding a reformulation of values that may be required to pursue true sustainability (Suzuki and McConnell, 1997).

[3] 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."

Despite these criticisms, basic principles are emerging from the international sustainability literature, which help 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; World Commission on Environment and Development, 1987).

In the more specific context of climate change policies, the controversy between different sustainability approaches has shown up in relation to discussion about key vulnerabilities; see Section 2.6.3 for more details on these issues.

2.2.5 Development Paradigms

Assessment of SD and climate change assessments in the context of this report is to consider how current development can be made more sustainable. This assessment gives a focal attention to how development goals like health, education, and energy, food, and water access can be achieved in the context of good governance and without compromising the global climate. In this way, SD issues are considered in relation to current development goals and to challenges in meeting these.

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 depend 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.

When considering linkages between development and climate change, it is important to recognize that the concept of development is understood very differently in various scientific paradigms, and these different understandings have important implications for the scope of integrated development and climate change studies. This is illustrated by a number of examples in the following.

A large number of the models that have been used for mitigation studies are applications of economic paradigms. Studies of development 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 like 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 state if these costs exceed the benefits of avoided climate change. However, there is a very rich literature about the costs of climate change mitigation that has revealed 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 even without taken the benefits of avoided climate change into consideration make the mitigation policies economically attractive (IPCC, 1995, Chapters 8 and 9; IPCC, 2001, Chapters 7 and 8). The character of such market imperfections are discussed further in section 2.4.

Other development paradigms based on institutional economics are more focused on how markets and other information 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 here understood 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).

This understanding of institutions has wide policy implications. The policy implications that are formulated by Douglas North are that there is no greater challenge than forming a dynamic theory of social change that enables an understanding of an economy's "adaptive efficiency", by which North means a flexible institutional matrix that adjusts to technical and demographic change as well as to shocks to the system (after Peet and Hartwick, 1999).

In this context, climate policy issues can include considerations about how climate change mitigation can be integrated in 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 the 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 the role of the State, Market, Civil Society and Partnerships.

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 successful implementation of GHG emission reduction options in most cases 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 and the like), introduction of new actors (institutional and human capacity efforts), and reducing the risks of participating (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 about political science and sociological literature in this area.

Key theoretical contributions in the economic growth and development debate also include work by A. Sen (1999) and P. Dasgupta (1993) about capabilities and human wellbeing. Dasgupta, 1993 in his inquiry into well-being and destitution concludes that "citizens' achievements are the wrong things to look at. We should instead 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 which citizens make use of income and basic needs." (Dasgupta, 1993, pp. 54). Following that, Dasgupta recommends to study 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 2.7 where the equity dimensions of basic needs and wellbeing approaches are discussed in more detail.

Climate change mitigation policies in the context of capabilities and human wellbeing can then include considerations about the extent to which mitigation policies can support the access of individuals to specific resources and freedoms recognising the associated impacts of avoided climate change at a global level.

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

2.2.6 International Frameworks for Evaluating SD and Climate Change Links

Studies that assess sustainable development impacts of climate change and vice versa when they are considering short to medium term perspective will be dealing with a number of key current development challenges. This section will give a short introduction to international policy initiatives and decisions that currently are offering a framework for addressing development goals, and will discuss how climate change can be addressed jointly based on these frameworks.

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, where the parties of the WSSD meeting selected to emphasize that particular actions were needed in order to implement Agenda 21. The WEHAB background document highlights a number of policy actions in the different sectors, and some examples that must be considered to have major linkages to climate change are listed in the following:

- **Water.** Providing and expanding safe water supply, water management, efficiency in agriculture, human health, disaster preparedness, and financial resources, institutional and technical capabilities, protecting aquatic ecosystems.
- **Energy.** Accessibility, efficiency, renewables, advanced fossil fuels[5], transportation.
- **Health.** Reducing poverty and malnutrition, health service access, reduced infant-, child-, and maternal mortality, controlling and eradicating major diseases, planning, environmental linkages, capacities to conduct risk management, and disaster preparedness.
- **Agriculture.** Increase productivity and sustain natural basis, knowledge generation and information transfer, public-private partnerships, policies and institutional reforms.
- **Biodiversity.** Integration in SD, economic and sectoral plans, reverse and restoration if possibility of biodiversity loss.

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.

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

[5] Advanced fossil fuels are not further specified in the framework, but are only referred to as cleaner and sustainable energy sources.

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

A recent report by the CSD includes a practical plan for how to achieve the Millennium Development Goals (CSD, 2005). The report emphasizes that the goals matter because they "are the world's time-bound and quantified targets for addressing extreme poverty in its many dimensions – income poverty, hunger, disease, lack of adequate shelter, and exclusion – while promoting gender equality, education and environmental sustainability" (CSD, 2005, Chapter 1, page 1). 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 MDG's. Furthermore, CSD (2005) suggests adding a number of energy goals to the MDG's, 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 MDG's and climate change mitigation.

Several international studies and agency initiatives have assessed how the MDG's 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 MDG's can be further developed to include both adaptation and mitigation is shown in table 2.1 (based on Davidson et al, 2003). A linkage between MDG's and development goals is also described very specifically by Shukla, 2003 and Shukla et al., 2003 in relation to the official Indian 10^{th} plan for 2002-2007.

Table 2.1. *Relationship between MDG's, 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 worlds 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 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 can help adaptation
To halve between 1990 and 2015, the proportion of people who suffer from hunger	Energy: Energy for machinery and irrigation in agriculture Food/water: More efficient production processes that increases production and reduces waste Distribution of land and food	Energy: GHG emissions. Food/water: Increased GHG emissions from some agricultural activities but partly offset by more carbon sequestration and improved waste management. Adaptive capacity of farmers depend on income and land ownership.

MDG Goals	Sectoral Themes	Climate Change Links
To ensure that, by 2015, children everywhere will be able to complete a full course of primary schooling	Energy: Reduce time spent by children on energy provision. Lighting for reading Energy for educational media including TV and computers Food/water: Reduced time spend in this sector enables children to spend more time on education Improved health increases children's capacity to read	Energy: Education can support adaptive and mitigative capacity. Food/water: Education can support adaptive and mitigative capacity
Ensuring that girls and boys have equal access to primary and secondary education, preferably by 2005, and to all levels of education no later than 2015	Energy: Modern energy services free girls and young women's time spend on energy provision New electronic educational media makes it easier for girls to get information from home Food/water: Modern production practices in agriculture and improved water supply free girls and young women's time spend on energy.	Energy: Education can support adaptive and mitigative capacity Food/water: Education can support adaptive and mitigative capacity
5. 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 spend on fuel collection can increase the time spend on children's health care Food/water: Improved health due to increased supply of high quality food and clean water Reduced time spend on food and water provision can increase the time spend on children's health care	Energy: GHG emissions Food/water: Health improvements will decrease vulnerability to climate change and the adaptive capacity
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 spend on children's health care	Energy: GHG emissions Food/water: Health improvements will decrease vulnerability to climate change and the adaptive capacity

MDG Goals	Sectoral Themes	Climate Change Links
6 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 reduces 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 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

To measure progress towards sustainable development requires the development and systematic use of robust set of indicators and measures. Agenda 21 explicitly recognizes in chapter 40 that a pre-requisite for action is 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. As pointed out by Farsari and Prastacos (Farsari and Prastacos 2002), indicators have evolved as a useful tool for making development more sustainable, evaluating progress made and illustrating the complexity of this task and concepts and parameters involved. A plethora of indicators and indexes has been developed including the Human Development Index, Index of Sustainable Economic Welfare, Genuine Progress Indicator, Measure of Domestic Progress, Index of Economic and Social Well-Being, Human Well-Being index, Environmental Sustainability Index, Ecosystem Wellbeing Index, etc. A brief introduction to some of these indexes is given in the following.

The OECD Ministerial Council decided in 2001 that the regular Economic Surveys of OECD countries should include an evaluation of sustainable development dimensions and a process for agreeing on SD indicators to be used in regular OECD peer reviews of government policies and performance was initiated. 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 management of waste
- 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 small attention in this first attempt.

One of the general conclusions of the environmental evaluation was that protection costs are rising in OECD, and that countries with high standards spend around 2% of GDP in this area. It was here recommended that environmental taxes and other economic instruments as well as international agreements should be used in order to ensure cost effectiveness in pollution control. The evaluation of living standards in developing countries emphasized trading opportunities and ODA. It was here concluded that export of agricultural products in particular meet significant barriers in terms of domestic support to agriculture in OECD countries. Furthermore, it was recommended that ODA programs should be more targeted. Finally, a more specific sustainability issue facing OECD countries was that a number of countries had made substantial progress in containing the fiscal pressures of aging in coming decades.

Another approach to operationalisation of SD dimensions is the methodologies, guidelines and indicators of sustainable development, that the UN Commission for Sustainable Development, CSD has developed (CSD, 2001). The approach includes social, environmental, economic, and institutional themes.

Focussing on the ecological dimensions Farsari and Prastacos, 2002 have developed the barometer of sustainability and ecological footprint approaches. In line with this, a "global entropy model" incorporates the conditions for sustainability (Ruebbelke 1998) by employing available entropy data to demonstrate up to what extent improvements in entropic efficiency should be accomplished to compensate the effects of increasing economic activity and population growth.

Boulanger (Boulanger, 2004) observes that the various indicators can be classified according to four main approaches: (1) the socio-natural sectors (or systems) approach, which focuses on sustainability as an equilibrium between the three pillars of sustainable development but which overlooks development aspects, (2) the resources approach, which concentrates on sustainable use of natural resources and ignores development issues, (3) a human approach based on human well being, basic needs, and (4) the norms approach, which foresees sustainable development in normative terms. Each of the approaches has its own merit and weaknesses. Despite these various efforts at measuring sustainability, few of them offer an integrated approach to measuring environmental, economic and social parameters (Corson 1996; Farsari and Prastacos 2002; Swanson *et al.* 2004). Additionally, few of these macro-indicators expressly include measures of progress with respect to climate change.

Since the Earth Summit in Rio in 1992 and in the process of preparation of the World Summit on Sustainable Development (WSSD), important worldwide initiatives have been developed to promote sustainable development. The various United Nations regions along with individual nations have elaborated their action plan for sustainable development taking into account their specificities. It is at the national level that efforts have been undertaken in order to track progress toward implementation of actions directed at achieving national sustainable development strategy objectives. Swanson *et al.* (Swanson et al., 2004) have compiled country case studies with clear mechanisms and responsibilities for process monitoring of sustainable development related strategies. At the sectoral level, several initiatives are being implemented to measure and monitor progress to-wards sustainable development (see Section 12.3.1 for further discussion of sectoral indicators).

The use of SD indicators for policy evaluations have been applied in technical studies of SD and climate change (Munasinghe, 2002, Atkinson et al., 1997, Markandya et al., 2002). The 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 Action Impact Matrix (AIM) has been used to identify, prioritize, and address climate and development synergies and tradeoffs (Munasinghe and Swart, 2005).

2.2.7 Implementation of SD and Climate Change Policies

SD and climate change are influenced by a number of key policy decisions related to economic, social and environmental issues as well as by business sector initiatives, private households and many other stakeholders, and these decisions again are framed by government policies, markets, information sharing, culture, and a number of other factors. Some of the decisions that are critically import in this context are investments, natural resources use, energy consumption, land use, technology choice, and consumption and lifestyle, and they can both lead to increasing and decreasing GHG emission intensities, which again will have implications for the scope of the mitigation challenge. Seen in a longer term perspective these decisions are critical determinants for development pathways.

There has been an evolution in our understanding of how sustainable development and climate change mitigation decisions are taken by societies. In particular, this includes a shift from government defined strictly by the nation-state to a more inclusive concept of governance, which recognizes various levels of government (global, transnational/regional, and local) as well as the roles of the private sector, non-governmental actors and civil society. Chapter 12 includes a comprehensive assessment of how state, market, civil society and partnerships play a role in sustainable development and climate change policies.

2.3 Decision Making

2.3.1 Irreversibility and the Implications for Decision Making

Human impacts on the climate system through greenhouse gas emissions may change 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). However, the speed and nature of these changes, the tipping point at which change may accelerate and become irreversible and the cost and effectiveness of mitigation and adaptation responses are all to a greater or lesser extent uncertain. The combination of environmental irreversibility 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 possibly subject to thresholds or other non-linear effects d) whether the irreversible damages are clustered in particular parts of the world or have 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 greenhouse emissions can require actions that are essentially irreversible. For example, large-scale investments in low emission technologies, once made, 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 associated with irreversibility of this nature further complicate decision making on abatement action (Keller *et al.*, 2004; Pindyck, 2002; Kolstad, 1996).

2.3.2 The Public Good Character of Climate Change

Climate benefits arising from mitigation action are a global public good since they are spatially indivisible, are freely available to all (non-excludability), and their consumption by one individual (nation) does not diminish their availability to others (non-rivalry). This does not mean that climate impacts are the same for all. Some countries may actually benefit temporarily from climate change (Reilly *et al.*, 2003).

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 (mitigation is largely additive) 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 (a) climate benefits from mitigation action (skewed towards the least-developed countries) and (b) the ability to pay and marginal cost of abatement (both greater in general for developed countries) increase the difficulty in 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 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 (environment, business and labor) to the negotiation processesi. *Case studies* of many MEAs have provided insights particularly consideration of institutional, cultural, political and historical dimensions that influence outcomes. A weakness of this approach is that the conclusions can differ depending on the choice of cases and the way analysis is done. However, such ex-post analysis of the relevant policies often provides deep insights which are more accessible to policy makers since they are based on experience rather than theoretical thinking or numeric models.

2.3.3 Inertia

Without special actions by governments to overcome their natural inertia economic and social systems might delay too long in reacting to climate risks 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 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 the risks associated with irreversibility 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

2.3.4 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 (Budyko, 1999; Higgins *et al.*, 2002; NRC, 2002; Alley *et al.*, 2003). Potential examples include the disintegration of the West Antarctic Ice sheet (Oppenheimer and Alley, 2005) which, if it occurred, could raise sea level by 4-6 meters over several centuries, a shutdown of the North Atlantic Thermohaline circulation (Rahmstorf and Zickfeld, 2005) with far reaching, adverse ecological and agricultural consequences (Vellinga and Wood, 2002; Higgins and Vellinga, 2004; Higgins and Schneider, 2005). Although some studies raise the possibility that isolated, economic costs of such a shutdown might not be as high as assumed (Link and Tol 2004); increases in the frequency of droughts (Salinger, 2005) or a higher intensity of tropical cyclones (Knutson and Tuleya, 2004; Emanuel, 2005; Trenberth, 2005). Positive feedback from warming may cause the release of carbon or methane from the terrestrial biosphere (Shindell *et al.*, 2004; Jones et al., 2005) and oceans (Archer *et al.*, 2004; Archer and Buffett, 2005) which would add to the mitigation required.

Much conventional decision making analysis is based on assumptions that it is possible to model and compare the outcomes of the full range of alternative climate policies. Each of these policy alternatives is likely to result in a range of different costs and environmental benefits and damages – each with probability distribution around the outcomes. Conventional analysis assumes that there can be a smooth trade-off between these different dimensions of each policy outcome (each modified by the probability of its happening to provide an "expected" value) so that there is a unique "solution" of what is the "best" strategy – that is the one with the "highest expected value" (usually expressed in monetary terms). For example it could suggest that a policy which risked a catastrophically bad outcome but with a very low probability of occurrence might be valued more positively than one which avoided the possibility of catastrophe and produced a merely bad outcome but with a very high probability of occurrence. Similarly it assumes 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 is there is always a price at which we are comfortable to "dispense with" a species an ecological community (e.g. polar bears), or indigenous cultures. Equally it assumes that we value economic (and other) gains and losses symmetrically – a dollar gained is always assumed to be valued equally to one that is lost.

Recent literature drawing on experimental economics and the behavioral sciences suggest that these assumptions are an incomplete description of the way that humans really make decisions. This literature suggests 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, eco-systems or communities), that attitudes to gains and losses might not be symmetrical (losses valued more highly than gains of an equivalent magnitude). This literature suggests that under these circumstances the conventional decision axiom of choosing the policy set that maximizes the expected value (monetary) of the outcomes might not be appropriate. Non-conventional decision criteria (for example 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 2002, Lempert and Schlesinger, Kriegler et al 2006).

2.3.5 Uncertainty

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 so important that it is explored fully in Section 2.4 Risk and Uncertainty below. Uncertainties of differing types exist in relation key socio-economic factors (e.g., population growth, economic growth, technology development and diffusion) and scientific phenomena (e.g., the carbon cycle, climate sensitivity and the vulnerability of sensitive ecosystems).

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 near-term abatement options are with long-term objectives. There is an increased focus on non-conventional (robust) decision rules which preserve future options by avoiding unacceptable risks while allowing learning to occur. (Chichilnisky 2002, Lempert and Schlesinger, Kriegler et al 2006).

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 process. This is also referred to as "act then learn, then act again" (Valverde et al 1999).

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

2.3.6 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).

But traditionally studies 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 privileged over those of succeeding generations 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 programs, research and assessments, and various frameworks that can facilitate collective decision-making recognizing 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 2.5.4.1 below.

2.3.7 Dealing with Risks and Uncertainty in Decision making

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

The UNFCCC Article 3 (Principles) states that: *3. 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 so as to ensure global benefits at the lowest possible cost.*

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 have to be considered first.

First, 'precaution' relates to decision making in situations of deep uncertainty. It applies in the absence of precise probabilistic descriptions of the risks. In this context the legitimacy of expected utility maximization and the Rational Actor Paradigm is contested by a large body of literature in law, sociology, history, psychology, communication, management and decision sciences or philosophy.

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).

Third, the precautionary principle cuts both ways because in many cases, as J. Graham and J. Wiener (1995) noted, environmental choices are trade-offs between a risk and another risk. For example, mitigating climate change may involve more extensive use of nuclear power.

Hunyadi (2004) frames the issue of precaution by defining three schools: The **imperative of responsibility** school. The **prudential** school emphasizes proportionality over catastrophism, and reminds that there is no such thing as zero risk. The **dialogic** school promotes dialogue and public debates. It stresses the need for hybrid forums, involving not only policymakers and experts but also citizens and industrial stakeholders.

There is no consistent formal definition of precautionary decision-making in the scientific literature.

During the last decade, insured property losses due to extreme weather events have continued to increase. The trend towards higher losses can be attributed only in part to rising population densities and value concentrations as well as to the growing urbanization of exposed areas. Climate change is shifting the distribution of actuarial tables(see WGII 7.2).

A major share of the risk of catastrophes falls upon reinsurers, that is large companies whose business is to sell insurance to insurance companies. In the context of globalization and consolidation, many reinsurers are actively developing new instruments to trade some of their risk to the deeper financial markets. These instruments include:

Options. The Chicago Board of Trade was the first in 1995 to offer options indexed on catastrophe losses (options on the index compiled regionally by ISO's Property Claim Services). Low reinsurance prices until 1999 contributed to the suspension of trade of these options. Since that year the reinsurance market has turned up, especially after 9/11/2001.

Swaps. The CATEX market, for example, allows insurers and reinsurers from different geographic areas to reduce their risk by exchanging standardized units of exposure.

Catastrophe bonds are corporate bonds that require the bondholders to forgive or defer some or all payments of principal or interest if actual catastrophe losses exceed a specified amount. When that happens, an insurer or reinsurer that issued catastrophe bonds can pay claims with funds that would otherwise have gone to bondholders.

At the same time, governments are also developing new kinds of public – private partnership to cope with market failures, uncertainties and really big (>5 billion dollars) cataclysms. At the 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.

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.

2.3.8 Decision Support Tools

- Decisions about 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 bio-physical 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., 2002). In particular Integrated Assessment Models have improved greatly in the richness with which they represent the bio-physical and socio-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 the negotiation of 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. Projections are hypothetical trends in driving variables; scenarios are plausible and consistent images about the future chosen among a very large number (a continuum) of possible futures, essentially for their illustrative purpose. Scenario analysis is a methodology to assess alternative future development. Usually a scenario includes description of process, representing sequences of events over a certain period of time. Elements, including the drivers and barriers, of a scenario are chosen with respect to importance, desirability and/or probability.

There are some subdivisions of scenario analyses. First, a scenario can be either normative or descriptive. Secondly, it can be narrative or quantitative. Thirdly, it can be a trend or with surprise. Making distinction between these subdivisions is important when a scenario analysis is used for making a decision.

Among many scenario analyses, there are three important schools of activities relevant to IPCC. (i) Greenhouse gas emissions scenarios (IS92a). (ii) Scenarios to assess the risks and identify robust actions in corporate planning. Shell Co. Ltd. was the pioneer in the use of scenario analysis for corporate decision-making and this practice has been adopted by many companies and governments (Schwartz 1991). (iii) Governmental scenarios as a base for long-term planning and actions. Increasing number of governmental agencies and international organizations have developed scenarios. For a review of the scenarios for global environmental issues, see (Greeuw 2000)

A large number of analytical approaches can be used as a support to decision making. The IPCC TAR, Chapter 10 provided an extensive overview of decision making approaches and reviewed their applicability at geopolitical levels and in climate policy domains. The review included 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.

Some of the most commonly used general approaches that are used for climate change decision making are economic analysis including cost benefit- and cost effectiveness analysis, multi-attribute analysis, integrated assessment, safe landing/tolerable windows/guard rail approaches, and green accounting.

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 like air pollution, health and biodiversity. The benefits and costs of climate change policies by definition 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. The approach can use quantitative data, qualitative information or a mixture of both. By developing an overall score or ranking for each option alternative policies can be assessed even under conditions of weak comparability. Different functional forms for the aggregation process can be used.

Policy optimization models aim to support the selection of policy/decision strategies follow 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); and
- 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;
- stochastic projection approaches, in which at least some inputs and outputs take on a range of value; and
- exploratory modeling.

Integrated assessment models (IAMs) aim to combine key elements of biophysical and economic systems into a decision making framework with various levels of detail about the different subcomponents 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; and
- 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 consideration 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 socioeconomic costs of mitigation measures they would be prepared to accept to avoid that damage (e.g.

Toth 2004). Modeling effort (in an integrated assessment model linking climate and economic variables, and with explicit assumptions about burden sharing through emissions allocations and trading) is then directed at identifying the sets of feasible mitigation paths - known as 'emissions corridors' - consistent with these constraints. To the extent that there is overlap between the acceptable "emissions corridors" the conditions for agreement on mitigation action exist.

Green accounting attempts to integrate a broader set of social welfare measures into macroeconomic 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 like local air pollution, GHG emissions, waste generation, and other polluting substances in macroeconomic studies. Green accounting approaches both include monetary valuation approaches that attempt to calculate a "green national product", where the economic value of pollutants are subtracted from the national product, as well as accounting systems that include quantitative non-monetary pollution data.

Halsnæs and Markandya, (2002) recognize that decision analytical approaches 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.

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, multicriteria-analysis as well as cost benefit analysis (as for example applied in integrated assessment optimization modeling frameworks) and green accounting may use similar inputs and analysis for many model components but critically diverge when it comes to the determination of valuation approach applied to the assessment of multiple policy impacts.

2.4 Risk and Uncertainty

Since IPCC's First Assessment Report, the essential message remains the same: uncertainties are here to stay. It is necessary to report about them when assessing the literature, and to manage them when elaborating action plans to mitigate or adapt to climate change.

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 as the "combination of the probability of an event and its consequences." following the standard practice in risk management (ISO/IEC(2002) Guide 73) This is consistent with, but more general than, defining "risk" as an expected 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; and uncertainty to situations in which the appropriate data are not available or are fragmentary.

This section discusses first the specific terminology on risk and uncertainty used this report. Next the framing of "kinds of uncertainties" is divided in two parts. The first deals with uncertainty from missing, incomplete or imperfect data, the second with the human dimensions including surprise, values, taboos and strategic uses of information. Finally, the final sections on risk management frames key concepts about precaution, insurance, and crisis.

2.4.1 How are risk and uncertainty communicated in this report?

Dealing effectively with the communication of risk and uncertainty is an important goal for the scientific assessment of long-term environmental policies. This section examines the previous reports' record on the matter, and the steps taken to improve it in this report.

In IPCC assessment reports, an explicit effort is made to enhance consistency in the treatment of uncertainties. This is 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 WG I 8) and Working Group II (focusing on risks and confidence levels, see WG II 1.1), although consistency across these groups was not achieved. The guidelines were not systematically applied by the authors of Working Group III.

With this assessment report, the coordination effort to improve the treatment of risk and uncertainties within IPCC was jumpstarted with a concept paper written by Manning and Petit (2004), then discussed at the Maynooth (Manning et al., 2004) interdisciplinary workshop. That process led to formal "Guidance notes for lead authors of the IPCC AR4 on addressing uncertainties" and explicit coordination meetings involving all this report's writing teams. As a consequence, in this report:

- The vocabulary described in Table 2.2 is used to summarize the scientific understanding relevant to an issue, or to express uncertainty in a finding where there is no basis for making a more quantitative statement. This table 2.2 is based on two dimensions of uncertainy presented above, the *amount of evidence* and the *level of agreement*.
- Where the level of confidence is "high agreement, much evidence", or where otherwise appropriate, uncertainties are described using Table 2.3 for levels of confidence or 2.4.3. for likelihoods (see also table 2.5 for quantitatively defined likelihood scale). While in most cases the subjective levels of confidence will be used, because mitigation mostly involves the future of technical and social systems, there are mitigation situations, for example in the Forestry chapter, where objective probabilities from controled experiments can be reported.

Table 2.2. *A simple typology of uncertainties*

Type	Indicative examples of sources	Typical approaches and considerations
Unpredictability	Projections of human behaviour not easily amenable to prediction (e.g. evolution of political systems). Chaotic components of complex systems.	Use of scenarios spanning a plausible range, clearly stating assumptions, limits considered, and subjective judgments. Ranges from ensembles of model runs.
Structural uncertainty	Inadequate models, incomplete or competing conceptual frameworks, lack of agreement on model structure, ambiguous system boundaries or definitions, significant processes or relationships wrongly specified or not considered.	Specify assumptions and system definitions clearly, compare models with observations for a range of conditions, assess maturity of the underlying science and degree to which understanding is based on fundamental concepts tested in other areas.
Value uncertainty	Missing, inaccurate or non-representative data, inappropriate spatial or temporal resolution, poorly known or changing model parameters.	Analysis of statistical properties of sets of values (observations, model ensemble results, etc); bootstrap and hierarchical statistical tests; comparison of models with observations.

Source: reproduced from Table 2 in IPCC Guidance Notes (2005).

Table 2.3. *Qualitatively defined levels of understanding*

consensus →	*High agreement limited evidence*	...	*High agreement much evidence*
agreement or	...	...	...
Level of	*Low agreement limited evidence*	...	*Low agreement much evidence*
	Amount of evidence (theory, observations, models) →		

Source: reproduced from Table 2 in IPCC (2005)

Table 2.4. *Qualitatively calibrated levels of confidence*

Terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Source: reproduced from Table 3 in IPCC Guidance Notes (2005)

Table 2.5. *Qualitatively defined likelihood scale*

Terminology	Likelihood of the occurrence/outcome
Virtually certain	> 99% probability of occurrence
Very likely	> 90% probability
Likely	> 66% probability
About as likely as no	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Exceptionally unlikely	< 1% probability

Source: reproduced from Table 4 in IPCC Guidance Notes (2005)

2.4.2 The multi-dimensionality of risk and uncertainty

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 (see for example the NUSAP approach, van der Sluijs et al. 2003). This would involve examining at least the amount of evidence supporting the information, the level of agreement of the information sources and their reliability. Where information is dependant on the future of a dynamic system, it is also 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 of the system.

The *amount of evidence* available about a given technology is linked to the quality and number of independent sources of information. For example, geological carbon storage has only been implemented in a few industrial-scale storage projects, so there is limited information available with respect to costs, acceptability and efficiency. On the other hand, a technology such as landfill gas recovery is being used in several distinct countries, so there is much evidence that it is feasible, even if there remain financial and institutional barriers in places.

Independent of the number of observations, the degree of consensus among experts on the interpretation of the existing data is also a critical parameter on the quality of information. The *level of agreement* on the benefits and drawbacks of a certain technology describes whether the sources of information point in the same direction or not.

Rare events with extreme and/or irreversible outcomes should receive special attention because they are difficult or impossible to assess with ordinary statistics. Extreme events also raise an issue because there is evidence that people may adjust their interpretation of likelihood language according to the magnitude of perceived potential consequences. One practical way to deal with this issue has been to pay attention to the Value-At-Risk (VAR): in addition to using the mean and the variance, a norm is set on the most unfavorable percentile (usually 0.05) of the distribution of outcomes at a given date in the future.

2.4.3 Levels of confidence versus levels of likelihood

In practical applications, probability numbers are used to measure two distinct but related variables. One is levels of likelihood or more generally degrees of truth. In this case, they are called objective probabilities, and can be seen as the physical propensity of an event to happen. The other variable is confidence or belief. In this case, probabilities are called subjective or Bayesian.

Approaches to determine objective probabilities based on the observation of relative frequencies are called frequentist. This works best when a statistically significant body of historical observations is available. When there is a low amount of evidence (a small number of observations, missing data, or correlation between experiments), the accuracy of numbers determined by relative frequencies is low.

Approaches to determine subjective probabilities include asking people to directly quantify their strength of opinion, degree of belief or level of confidence. For example, in formal expert surveys, one method to elicit a probability distribution involves asking the expert to dispatch a stake of 100 items over the alternative outcomes considered. In a less formal setting such as the IPCC writing teams, experts agree verbally.

Another subjective approach is based on the idea that the beliefs of a rational agent can be determined through observing its choices. For example, if people buy shares in oil companies, it is generally a sign that they expect higher oil prices. Over the last decade, this has been formalized by creating prediction markets (Wolfers and Zitzewitz, 2004). These are speculative markets designed for the purpose of making predictions. Participants bet by trading assets whose final cash value is tied to a particular event or parameter. The current market prices can then be interpreted as predictions of the probability of the event or of the expected value of the parameter. Real-money prediction markets are available for many economic and energy indicators. Regarding energy and environmental questions, there are several public play-money prediction markets but there is certainly an incentive problem with claims that are to be adjudicated in the distant future6.

2.4.4 Typologies of risk and uncertainty

The literature on risk and uncertainty offers many typologies. The following categories can be found.

Risk is when there is a well founded probability distribution). Scientific predictions are not always deterministic. For example, assuming an unchanged climate, the potential annual supply of wind, sun or hydro power in a given area is known only statistically. In situations of randomness, expected utility maximization is a standard decision-making framework, but in situations of deeper uncertainty there is no such standard, see the costs and decision-making sections.

Possibility: A level of possibility expresses a degree of 'not-implausibility' of a future to a decision maker (it can be defined rigorously using the notion of acceptable odds, a method first proposed by De Finetti). Possibility is important for climate mitigation because, while it is scientifically controversial to assign a precise probability distribution to a variable in the far distant future, especially when it is determined by social choices such as the global temperature in 2100, clearly some outcomes are not as plausible as others.

There are very few possibility models related to environmental or energy economics. In the debates in the early 50s on rational decision making, Shackle (1949) was a precursor of possibility theory by arguing that economic decisions were based more on 'degree of surprise' or plausiblity than degrees of probability. However, these views remained a minority and the standard paradigm turned out to be subjective expected utility.

Knightian or Deep Uncertainty: Knight (1921) seminal work describes a class of situations where the list of outcomes is known, but the probabilities are imprecise. Imprecise probability theory suggests to represent such deep uncertainty using a set of equally admissible probabilities. The notion

6 Consider for example the claim CO2LVL - CO_2 Level 2030 at the foresight exchange prediction market (www.ideosphere.com) : *This claim is based on the ambient CO2 level in December of 2030. The claim pays $0.01 for each PPM by volume (PPMV) of CO_2 in excess of 400 PPMV, up to 500 PPMV. For instance, 0.0 for <400.5 PPMV, 0.5 for 450 PPMV, and 1.0 for >499.5 PPMV. If available, data from the Mauna Loa Observatory will be used to judge the claim.* This claim opened in may 2002 at around \$0.40 (corresponding to 440 ppmv), increased, stabilized around \$0.70 between mid 2003 to mid 2005, and dropped to around \$0.56 in early 2060, showing an expected value of 456 ppmv.

of expected utility then becomes interval-valued. Two families of criteria have been proposed for decision making in this situation. Both are models of partial, rather than full, rationality. The first type of criteria, discussed in Ellesberg (2001), aims at establishing a complete ordering among choices, and associate somehow a real-valued expected utility to each choice. The second type of criteria, discussed in Bewley (1986 and 2002) and Walley (1991), discards the completeness axiom on the grounds that under deep uncertainty alternative choices may sometime be incomparable. In this situation, the concept of a globally optimal choice is replaced by a set of equally admissible but incomparable choices.

Fuzzyness or vagueness describes the kind of uncertainty of natural language, and more generally the nature of things that don't fall sharply in one category or another. In the marble bag example, the number of 'dark' marbles would better be represented using a fuzzy number. While fuzzy modeling is used to integrate experts' knowledge with precise quantitative information in other domains, it is rarely used in the climate change mitigation literature. Major integrated assessment models of energy and climate problems have not used much these techniques so far.

In the previous report, the ‘burning embers’ diagram (IPCC TAR, 2001a fig. SPM 2) used a fuzzy graphical representation of ‘Reasons for concern’ to assign a fuzzy quantitative meaning to the word “dangerous” of the UNFCC article 2.

Structural uncertainty relates to « unknown », while analysts try to have a frame of reference appropriate for the problem at hand, no model (or discourse) can include all variables and relationships. In the energy-economics model used to assess the implications of emission mitigation, for example, there can easily be structural uncertainty regarding, the informal sector, biomass fuels, or the choice between a Keynesian or a neo-classical view of macroeconomic 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 calculations.

Box 2.1. The controversy on quantifying the beliefs in IPCC SRES scenarios

Between SAR and TAR, the Intergovernmental Panel on Climate Change elaborated long-term greenhouse gases 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 to 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 which 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 sempiternal 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 equiprobability. As a remedy, Reilly et al. estimated that the 90% confidence limits were 1.1 to 4.5°C. Using different methods, Wigley and Raper (2001) found 1.7 to 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 `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 socioeconomic trends in the latter half of the 21st century, the difficulty of obtaining consensus range for quintiles like climate sensitivity, and the possibility of a nonlinear 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.

2.4.5 Human dimensions of uncertainty

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. This section extends the discussion to these psychological and social aspects of uncertainty.

Surprise means a discrepancy between a stimulus and pre-established knowledge (Kagan, 2002). Complex systems, both natural and human, exhibit behavior that were not imagined by observers until they actually happened. Surprise is a subjective psychological state, it depends on the observer. It can occur in a situation of structural uncertainty, but also in a situation of randomness if a small probability event realizes. Causes of surprise could include rapid technological breakthroughs or social upheaval affecting oil prices or GHG emissions. While the word « surprise » frequently stands for « unexpected extreme event », no climate change at all would be a surprise too. By allowing decision makers to get familiar in advance with a number of diverse but plausible futures, scenarios are one way of reducing surprises.

Metaphysical. Some things are not assigned a truth level because it is generally agreed that they can not be verified, such as the mysteries of Faith, personal tastes or belief systems. This is represented in models by critical parameters like discount rates or risk aversion coefficients. While these cannot be judged to be true or false they can have bearing on both behavior and environmental policymaking. Thompson and Rayner (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 rational agents, who are aware of information can use uncertainty as a strategic tool. Strategic uncertainties are an important human dimension of the response to climate change, since this response requires coordination at the international and national level.

Strategic uncertainty is usually formalized with game theory using the hypothesis of information asymmetry, that is assuming that one party in a transaction has more or better information than the other party. The informed party may therefore 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 hazard are key factors in the design of efficient market-based mechanisms to mitigate climate change.

2.4.6 Uncertainties and Costs

In spite of the scientific progress, there is still much uncertainty about the consequences of the increasing concentration of greenhouse gases in the atmosphere on the welfare of current and future generations. Given observed risk attitudes, the desirability of preventive efforts should be measured not only by the reduction of the expected socio-economic 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 of these risk reductions, which include. In addition, abatement costs are most often uncertain, which yields one additional level of complexity in determining the optimal risk-prevention strategy.

How can we decide whether a risk is acceptable to society? Using the language of cost-benefit analysis, we can say that the risk is acceptable if its benefits to society exceed its costs. But to say this is merely to re-state the problem, for by assumption the benefits and costs are uncertain. Furthermore it must be recognized that a number of climate change impacts involve some assets like health, biodiversity, and intergenerational impacts that are difficult to capture fully by estimates of economic costs and benefits (see the subsequent discussion about valuation techniques). In this way, cost benefit analysis cannot represent all aspects of climate change policy evaluation.

Where the included benefit and costs of climate change policies have known probabilities, and where individuals can diversify away their own risk through insurance and other markets, we know from the work of Arrow and Lind (1970) that such a risk will be acceptable if its expected net present value is positive. This criterion is a 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. However, this result cannot be applied for most of the economic analysis of global warming, for at least two reasons.

First, risks associated with global warming cannot easily be diversified using insurance and financial instruments. An increase in the temperature is faced by everyone at the same time in the same region. The positive correlation of individual risks reduces the potential benefit of any mutual risk-sharing agreement. A solution would be to share global warming risks internationally, but this strategy is difficult to implement, and its efficiency depends upon the correlation of the regional damages. Our inability to diversify risks combined with the observed risk aversion implies that there is an additional benefit to our preventive efforts coming from the reduced variability of future damages. If these monetized damages are expressed in 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 by experts. Where we cannot measure risks precisely, we cannot simply apply this technique mechanically. But this does not mean we should abandon the usefulness of cost-benefit analysis as an input among others to decisions about climate change policies. Gollier (2001) suggests that a sophisticated interpretation of the Precautionary Principle is compatible with general economic principles in general, and with cost-benefit analyses in particular. This principle is applicable to contexts in which probabilities cannot be assessed with precision.

Third, the timing of the decision process and of the resolution of the uncertainty should be taken into account, in particular when waiting before implementing a preventive action is an option. Waiting and thereby late reactions yields a cost when risks happen to be worse than initially expected, but yields an option value and cost savings in case that risks happen to be smaller than expected. Standard dynamic programming methods can be used to estimate these option values.

2.5 Cost and Benefits Concepts Including Private and Social Cost Perspectives and Relationship to Other Decision Making Frameworks

2.5.1 Definitions

Mitigation costs can be measured at project, technology, sector, and macroeconomic levels, and various geographical boundaries can be applied to the costing studies (see a definitional of geographical boundaries in section 2.8).

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

- **Project.** A project level analysis considers a "standalone" 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 similar analytical approaches as project level analysis.
- **Sector.** Sector level analysis considers sectoral policies in a "partial-equilibrium" context, for which other sectors and the macroeconomic variables are assumed to be as given. The policies can include economic instruments related to prices, 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.
- **Macroeconomic.** A macroeconomic analysis considers the impacts of policies across all sectors and markets. The policies include all sorts of economic policies, such as taxes, subsidies, monetary policies, specific investment programmes, and technology and innovation policies. Methodological frameworks include various macroeconomic models such as general equilibrium models, Keynesian econometric models, and Integrated Assessment Models (IAMs), among others.

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 cost components such as the costs of input to a production process, labour and land costs, financial interest rates, equipment costs, fuel costs etc. However, the activities of individuals may also cause externalities like for example emissions that influence the utility of other individuals, but which are not taken into consideration by the individuals causing them.

External costs

External costs typically arise when markets fail to provide a link between the person who creates the "externality" and the person who is affected by it, or more generally when property rights for the relevant resources are not well defined[7]. In the case of GHG emissions, those who eventually will 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 mean to balance the costs and benefits of GHG emissions and climate change. The failure to take into account external costs, in cases like climate change, however, may be a product not only of a lack of property rights, but also the result of a lack of full information and non-zero transaction costs 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 markets can be distorted by some subsidies and taxes or by other policies 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. 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 typically are used to assess 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 they by definition do not take all externalities into account.

2.5.2 Major Cost Determinants

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

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[7] Coase, 1960, page 2 in his essay about 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 this means that the operation of a pricing system is without cost).

The critical cost factors are based on different theoretical and methodological paradigms as well as on specific applications of approaches. This section will consider 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, and implementation and transactions costs, and will give guidance on how to understand and assess these aspects in the context of climate change mitigation costing studies. For a more in depth review of these issues see IPCC, 2001, Chapter 7 and 8.

2.5.2.1 Discount rates

Climate change impacts as well as mitigation policies have a long-term character, and cost analysis of climate change policies therefore will 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 SAR notes (IPCC, 1996, Chapter 4), there are two approaches to discounting; an ethical, or prescriptive, approach based on what rates of discount should be applied, and a descriptive approach based on what rates of discount people (savers as well as investors) actually apply in their day-to-day decisions. SAR notes that the former leads to relatively low rates of discount (around 2%–3% in real terms) and the latter to relatively higher rates (at least 6% and, in some cases, very much higher rates). The importance of choosing different levels of discount rates for example can be seen when considering the value of $ 1 mill. arriving 100 years from now. The present value of this amount is around $ 52,000 if a 3% discount rate is used, but only about $ 3,000 if a discount rate of 6% is used.

The ethical approach applies the so-called social discount rate, which is the sum of the rate of pure time-preference and the rate of increase of welfare derived from higher per capita incomes in the future. The social discount rate in this way can be described by two parameters: a rate of pure preference for the present (or rate of impatience) 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[9]:

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

Intuitively, as suggested by this formula, a larger growth of the economy should induce us to do less effort for the future. This is done by raising the discount rate. In an intergenerational framework, the parameter δ characterizes our ethical attitude towards future generations. Using this formula, the SAR recommended on this basis to use a discount rate of 2-4%. For ethical reasons, it is fair to consider δ =0 and a growth rate of GDP per capita of 1-2% per year for developed countries and a higher rate for developing countries which anticipate larger growth rates.

[8] Despite that the scope of this report is focussed 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 and integral of mitigation studies and are briefly discussed as such in this chapter.

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

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

The descriptive approach takes into consideration the market rate of return to safe investments, whereby conceptually funds can be 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 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 households' 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 returns requested by shareholders on financial markets (which can be as high as 10-15%), because these rates include a premium compensating for risk. The descriptive approach has however several drawbacks. First, it relies on the assumption of efficient financial markets, which is not a credible assumption, both because 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 risk less assets for time horizons exceeding 30 years, which implies that the interest rates for most maturities relevant for the global warming problem are not observable.

For discounting over very long time horizons like periods beyond 30 years, an emerging literature suggests that the discount rate should be decreasing with time. Different theoretical positions advocate for such an approach based on arguments about uncertainty about the future discount rate 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) based on a survey of the suggestions by 1700 professional economists suggested that the year-to-year discount rate should fall progressively from 4% to 0% as the perspective shift from being up to 5 years to be the far distant future of beyond 300 years. Newell and Pizer, 2004 obtained 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. If, for example, the short-term interest rate goes up from 4% to 7%, the discount rate curve should be shifted upwards.

It is also important to link the long-term macroeconomic uncertainty and the uncertainty about 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 the existence of an uncertain growth in the long run 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 run to 2% in the long run. In an equivalent model but with different assumption on the growth process, Weitzman (1998, 2004) proposes to use a zero discount rate for time horizons around 50 years, 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 considering more general specifications for the stochastic process that drives the shape of the yield curve.

Despite theoretical dispute about the use of time declining discount rates, the UK government officially has recommended to use 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% to a 4% discount rate for maturities below 30 years, and a discount rate that decreases to 2% for larger maturities.[10] Finally, the Office of Management and Budget of the U.S. government both recognizes the possibility of declining rates (see appendix D of US, 2003).

It is important to remind 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 long-term nature of the problem is the key issue. The benefits of reduced GHG emissions vary with the time of emissions reduction, with the atmospheric GHG concentration at the reduction time, and with the total GHG concentrations more than 100 years after the emissions reduction. 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, the country must base its decisions at least partly on discount rates that reflect the opportunity cost of capital. In developed countries rates around 4%–6% are probably justified. Rates of this level are in fact used for the appraisal of public sector projects in the European Union (EU) (Watts, 1999). In developing countries the rate could be as high as 10%–12%. The international banks use these rates, for example, in appraising investment projects in developing countries. It is more of a challenge, therefore, to argue that climate change mitigation projects should face different rates, unless the mitigation project is of very long duration. These rates do not reflect private rates of return and the discount rates that are used by many private companies, which typically need to be considerably higher to justify investments, potentially between 10% and 25%.

2.5.2.2 Market Efficiency

[10] 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 larger than 30.

The costs of climate change mitigation policies depend on the efficiency of markets and market assumptions are important both 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 faces private consumers and industry have direct implications on the efficiency and thereby GHG emissions related to appliances and equipment in use. Relatively low prices will here tend to imply that the technology stock is relatively old and inefficient since the cost of energy is low.

Markets, in practice 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 given these imperfections, see section 2.4.5.3 for a definition of implementation costs.

Many project level and sectoral mitigation costing studies have identified a potential of GHG reduction options with a negative cost implying that the benefits, including co-benefits, of implementing the options are greater than the costs. Such negative cost options are commonly referred to as no regret options[11].

The costs and benefits included in the assessment of no regret options, in principle, are all internal and external impacts of the options[12]. 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 exists:

- **Market imperfections** that generate efficiency losses. Reduction of 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.
- **Ancillary or co-benefits**. Climate change mitigation measures will have effects on other societal issues. For example, reducing carbon emissions in many cases will 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 Chan, 2001, O'Connor et al. 2003). It is likely that mitigation strategies will also affect transportation, agriculture, landuse 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 the effects will be positive; careful policy selection and design can better ensure positive effects and minimize negative impacts. In some cases, the magnitude of ancillary 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.
- **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

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[11] By convention, the benefits in an assessment of the costs of GHG emissions reductions do not include the impacts associated with avoided climate change damages.

[12] This is both due to difficulties in assessing all externals costs and implementations costs and reflects imcompleteness of the elements that have been addressed in the studies.

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.

The existence of market imperfections, ancillary or co-benefits, and double dividends that are not integrated in markets also are 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 in most cases not included all the external costs and implementation costs associated with a given policy strategy[13].

2.5.2.3 Transaction and Implementation Costs

In practice, the implementation of climate change mitigation policies requires some transaction and implementation cost. The implementation costs relate to the efforts needed to change existing rules and regulation, capacity building efforts, information, training and education, and other institutional efforts needed to put a policy into place. Given, that these implementation requirements are in place, there might still be costs of carrying through a given transaction as 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 in this way can 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 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 as far as possible should include a full assessment of the cost of implementation requirements like market reforms, information, establishment of legal systems, tax and subsidy reforms, and institutional and human capacity efforts.

Few studies, in practice have included a full representation of implementation costs. This is both the case 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, many countries have as part of the implementation of the emission reduction requirements of the Kyoto Protocol gained new experiences in the effectiveness of implementation efforts, which can provide a basis for further improvements of implementation costs analysis.

2.5.2.4 Ancillary and Joint Costs and Benefits

Policies aimed at mitigating GHGs, as stated earlier, can yield other social benefits and costs, and a number of empirical studies have made a preliminary attempt to assess these impacts. At the same time, policies that aim at other economic, social or environmental problems than GHG emission reduction in many cases will have impacts on GHG emissions. Dependent on the structure of the analysis and the specification of policy goals, the literature includes studies that consider GHG emission reduction either as a primary, secondary, or joint policy goal. It should here be recognised

[13] This is both due to difficulties in assessing all externals costs and implementations costs and reflects imcompleteness of the elements that have been addressed in the studies.

that the perspective of the study can vary according to stakeholder interests and can vary from country to country. This means for example that a GHG emission reduction effort implemented in a developing country seen from an industrialised country project developer mainly can aim at emission reductions, while the local government primarily can appreciate local benefits on air quality, employment, and energy access that arrive from the project.

Studies of indirect impacts of GHG emission reduction and of joint impacts on mulitiple policy goals in principle can include all sorts of impacts that are considered to be important given the boundary of the analysis.

It is apparent that the actual magnitude of the ancillary benefits or co-benefits assessed critically depends on the scenario structure of the analysis, in particular on the assumptions about policy management in the baseline case (IPCC, 2001b; Krupnick et al.,1996; Krupnick et al., 2000; O'Connor et al., 2003).

2.5.2.5 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, and also potential abrupt changes of 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 intergenerational 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 intragenerational climate change policy impacts involves issues related to comparing impacts occurring at different points in time as discussed in section 2.4.5.1 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 in a simplified way assumes that consumer preferences will stay unchanged over time. An overview of some of the literature about 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 aspect 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 estimates of statistical values of life will face difficulties in the determination of values that in a fair and meaningful way reflect people with very different income levels around the world. In this way there is a lot of ethical controversies involved in valuing human health impacts. The IPCC, TAR recognising these difficulties 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 equal (IPCC, 2001, Chapter 7).

2.5.3 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, it is outlines how the concepts relate to mitigation cost concepts that have been used in previous IPCC reports in order to facilitate that different cost estimates can be compared and eventual differences can be understood.

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

The measure "**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 in million tonnes carbon- or CO_2-equivalent emissions avoided 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) e.g. costs less than $ per tonne of CO_2- or carbon-equivalent reduction ($/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.

2.5.3.1 Definitions of barriers, opportunities and potentials

The terms that used in this assessment are those used in the TAR, with the addition of "enhanced market potential" for reasons explained below. However, the precise definitions are revised and explanations for the revisions are given in footnotes.

A **"barrier"** to mitigation potential is any obstacle to reaching a potential that can be overcome by policies and measures. (From here on, "policies" will be assumed to include policies, measures, programmes and portfolios of policies.) An **"opportunity"** is the application of technologies or policies 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[14]. It is based on private unit costs and discount rates, as they appear in the base year and as they are expected to change

[14] TAR WGIII (IPCC, 2001) gives the definition of 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".(p. 352) 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 e.g. the Climate Change Levy in the UK. 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.

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 working 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. The improved prospects might be called **"enhanced market potential"**[15] i.e. baseline market potential enhanced by policies designed to promote market efficiency, provide information to market participants, reduce or remove anti-competitive practices, and reduce transactions and other hidden costs[16]. The gap between market and enhanced market potential is likely to widen through time as the enhancing policies take effect. These potentials are both based on private costs, although the policies may well involve costs themselves. The implicit assumption is that both market and enhanced market potentials are cost effective in that the mitigation actions can be carried out with the expectation of no net costs, including the costs of the policies.

The market-transformation literature takes the market potential as the baseline. However, the mitigation literature also includes many assessments using bottom-up energy-engineering models that assume efficient markets and no hidden costs. The cost-effective options given by such models, assuming no carbon constraint, zero social cost or shadow price of carbon, correspond to these enhanced market potentials, provided policies can be implemented to remove the barriers. Here the baseline might be historical emissions, model solutions with frozen technologies or without a shift to more efficient use of technology. The business-as-usual scenarios of the top-down models assuming perfect markets also in principle provide estimates of this potential, but since they are calibrated to actual emissions, they can only be used for this purpose if they include market imperfections.

In order to bring in social costs, and to show clearly that this potential includes both market and non-market costs, "**economic potential"** is cost-effective GHG mitigation when non-market social costs and benefits are included with market costs and benefits in assessing the options[17] for particu-

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[15] The best name for this concept is under discussion. Jaffe and Stavins (1994a and b) discuss the various potentials and other literature has used this term although not systematically.

[16] Many of these enhancements were included in "economic potential" in the TAR WGIII Report. The TAR notes that the literature uses the term "economic potential" to indicate both market potential with the elimination of market failures and the broader potential including the effects of introducing social costs and benefits. Since the concepts of externalities and social costs and benefits are essentially economic concepts developed extensively in the economic welfare literature, it is justifiable to use "economic potential" in AR4 to indicate potential for the whole economy, including social costs. The proposed terminology clarifies the issue by separating market and non-market effects on potentials, with market effects being included in market and enhanced market potentials.

[17] TAR WGIII (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? And 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 TAR Chapter 3 definition of economic potentials. The proposed definition for AR4 applies to the large body of relevant literature which assesses mitigation potential at different values of the social cost of carbon, and is clearly introducing non-market valuations

lar levels of carbon prices in $/t$CO_2$ and $/t C-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 and ancillary benefits. This potential will then include the effects of additional policies to specifically address the externalities associated with emissions of GHGs and mitigation technologies, namely carbon taxes, emission trading schemes, incentive schemes for low-carbon products and processes and other policies. Such policies are designed to address a particular type of market failure, i.e. the absence of markets involving common resources, in particular the resource of an atmosphere without anthropogenic emissions. Note that these estimates do not normally assume that the underlying structure of consumer preferences is changed. This definition of potential is the one used for the main sets of quantitative estimates of potentials in the TAR (Chapters 3, 8 and 9 WGIII).

The market potential, enhanced market potential, and economic potential are policy dependent, as their definitions also indicate. The transition from a lower to a higher potential level assumes the implementation of additional policies. The market potential level assumes no additional policies above the ones in place. To reach the enhanced market potential level, the barriers that impede private actors to take benefit from economically efficient opportunities need to be removed, which requires additional policy instruments and interventions. The third level – economic potential – is calculated for different CO_2-equivalent or C-equivalent prices, reflecting maximization of social welfare by internalization of climate change externalities. The economic potential is calculated by applying social rather than private discount rates.

There are also a technical potential and a physical potential, which 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.

A number of key assumptions are used in the calculation of potentials. Some of the major ones are related to:

- Transformation of economic flows to net present values (NVP) or levelised costs. It is here consistent to use the financial rate of return to discount private cost units, and a social discount rate to discount social costs.
- 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, others calculate annual levelized GHG emission reductions, and some studies apply discount rates to arrive at net present values of carbon reduction.

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

for externalities and time preferences. Furthermore the proposed definition fits with that actually used in TAR WGIII Chapter 3, where such potentials are discussed "at zero social cost" (e.g. p. 203).

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 in the longer term be considered so if transactions costs of policies successfully are reduced imply that market and socioeconomic potentials at a given unit cost are increased.

2.6 Mitigation, Vulnerability and Adaptation Relationships

2.6.1 Integrating Mitigation and Adaptation in a Development Context - Adaptive and Mitigative Capacities

The TAR introduced a new set of discussions about the institutional and developmental context of climate change mitigation and adaptation policies. One of the conclusions of that discussion was, that the capacity for implementing specific mitigation and adaptation policies depends on manmade and natural capital and on institutions. Institutions here in a broad sense should be understood as including markets and other information sharing mechanisms, legal frameworks, and formal and informal networks. Following that, the TAR introduced a discussion about the concepts of mitigative and adaptive capacity and their commonalities and links to development and institutional policies.

Yohe and Moss (2000) suggested the following determinants of *adaptive capacity*, that became a key conceptual inspiration for the IPCC WG II conclusions on climate change vulnerability and adaptation policies (IPCC, 2001a):

- The range of available technological options for adaptation.
- The availability of resources and their distribution across the population.
- The structure of critical institutions and the derivative allocation of decision-making authority.
- The stock of human capital, including education and personal security.
- The stock of social capital including the definition of property rights.
- The systems access to risk spreading processes.
- The ability of decision makers to manage information, the process by which these decision makers determine which information is credible, and the credibility of the decision-makers themselves.
- Public perception of attribution.

Subsequent work by Adger (2001a) further emphasises the role of social capital in adaptation. Adger refers to a definition by Woolcock and Naryan, 2000 p. 226 that 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 in main areas of the international literature of importance to climate change issues namely 1) Whether social capital exists only 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 issue 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, and a number of such experiences in adaptation to climate change are highlighted. 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 where vested interests have to be subjugated, and coastal protection in Vietnam, where the adaptive capacity in different areas are assessed in the context of resource availability and the entitlements of individuals and groups (Kelly and Adger, 1999). A literature assessment of AR4 WGII, Chapter 20 includes a wider range of examples on historical studies of development patterns which confirm that social capital has played a key role in economic growth and stability (Yohe et al, 2005).

The TAR IPCC WG III as a parallel effort to the discussion about adaptive capacity initiated a very preliminary discussion about the concept of *mitigative capacity* (IPCC, 2001, Chapter 1). 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, like in the case of adaptation, to a large extent is reflecting 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 the implementation of cost effective climate change mitigation policies. The final conclusion is that, due to the inherit uncertainties involved in climate change policies, enhancing mitigative capacity can be a policy objective in itself.

It is here important to recognise that the institutional aspects of the adaptive and mitigative capacities refer to a number of elements that have a "public good character" and to 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 nations policy implementing capacity exhibits many similarities across different sectors, and that capacity enhancing efforts in this area will have many joint benefits. Examples of national policy implementation capacity with a strong linkage to mitigation and adaptation are:

- Land property rights and capital access for rural farmers are key framework conditions for adaptation policies such as irrigation, improved fertiliser use, and crop switching. GHG emissions and carbon sequestration similarly are influenced by these conditions.
- Electricity markets and capital access influence the structure of future power supply and thereby GHG emissions. The same factors influence the energy sector's vulnerability to climate change for example from changing hydropower resources.
- Implementation of adaptation and mitigation policies in developing countries require financial transfers, and the ability of a country to attract such resources depends on local governance, decision makers management of information, and on the market environment.

There might be major differences in the character of the adaptive and mitigative capacity in relation to sectoral focus and the range of technical options and policy instruments that apply to adaptation and mitigation respectively. The assessment of the efficiency and implementability of specific policy options, however, depend 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. A country with well functioning capital markets and information sharing systems more easily can implement energy efficiency measures and introduce new power production technologies. In the same way, food security policies, based on improved land management and mechanisation of agricultural production, work better, when supported by capital access, education and information systems.

As already said, 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 like market reforms, education and training, improving governance, health services, infrastructure investments and so on.

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. Examples of such context related interactions include:

- The cost and GHG emission reduction of implementing wind turbines as a substitute to newly installed coal power depend on the power market, grids, land costs, financial markets etc. Many of these context specific issues also influence how adaptation measures like irrigation and improved management practices can be implemented in agriculture.
- The GHG emission reduction and costs of energy efficiency policies related to households and industry is influenced by structural economic changes including the development of energy intensive industries, investments in new production facilities, and the lifestyle of households. Similarly the vulnerability of resource dependent sectors to climate change and the impacts for the economy at large will depend on the industrial sector and a number of lifestyle issues.

It is to be expected that there can 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 highways, for example, can generate more traffic and more GHG emissions. However, the highways 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, and can also indirectly influence land use structures and the potential for carbon sequestration and can increase GHG emissions.

2.6.2 Mitigation , Adaptation and Climate Change Impacts

The discussion about mitigation and adaptation policy portfolios has a global- and a national/regional dimension. It must be recognized that mitigation and adaptation are very different regarding time frame and distribution of benefits, which must be taken into consideration in a balanced approach. 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 which are global and long term for mitigation, and 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 in building is an adaptation option, but energy requirements can increase GHG emissions and thereby 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 like 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. Schneider concludes that it is not clear that climate surprises have a low probability, they are just at present very uncertain, and he suggests to take 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 discount rate that decreases over time in order to give high values to future generations.

So 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 assessment.

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 in 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 be focused on an assessment of 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 and 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. It is argued that particularly least developed countries urgently have to cope with climate change vulnerability, which is a necessary step in order to take care of immediate risks that cannot be mitigated by GHG emission reduction policies (Burton et al, 2002).

At the 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 as well as adaptation policy options (Müller, 2002). Many governments of developing countries have started to realize that they now should not 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).

The actual development of national adaptation strategies in developing countries, National Adaptation Programmes of Actions NAPAs are supported by GEF and a guidebook for these is the UNDP Adaptation Policy Frameworks for Climate Change (UNDP, 2005).

2.6.3 Examples of Interactions between Climate Change Impacts, Adaptation and Mitigation

After years of being treated as a marginal option by scientists and decision makers worldwide, adaptation is currently receiving more attention as a crucial part of a comprehensive global climate policy along with mitigation (Smith, 1997; UNEP/IVM, 1998; Kates, 2000; IPCC, 2001a; Adger, 2001b; Burton et al., 2002; Huq, 2002.

There are some specific national studies that highlight linkages between climate change adaptation and mitigation policies (SAINC, 2003; IINC, 2004; Shukla et al., 2003). A few studies also provide a framework to assist policymakers in developing future strategies to harmonize climate change mitigation and adaptation policies (Burton et al., 2002; Kapshe et al., 2003; Dang et al., 2003), and to highlight opportunities for the development and improvement of efficiency and skills, especially in the sphere of technology transfer which can be used in local programmes to promote sustainable development. Some examples of mitigation and adaptation policies with considerable interactions and synergies are discussed in more detail in the following. A particular emphasis is here given to developing countries and to policy options related to:

- Biomass and land-use
- Infrastructure
- Energy use in buildings
- Renewable energy potentials
- Tourism
- Agriculture

Biomass and land use

Biomass and land use are one of the areas where large potential synergies and tradeoffs can emerge in climate change mitigation and adaptation policies. Modern biomass, when used to supply bioenergy services, has a role to play in each one of these environmental drivers at both the large and small scales. Biomass use for energy offers opportunities as a carbon sink and a carbon offset, and at the same time climate change influences both the potential for specific biomass growth and create several spill over impacts from agricultural markets, forestry, infrastructure, and human settlements. Whether or not a bioenergy project is economically viable, as well as being truly renewable, sustainable, environmentally sound, and contribute to a net reduction in GHG's is determined by the source of biomass, the end use, and the substituted landuse activities.

The social impacts from using biomass are also important, but are often given very little attention in the assessment of new and existing bioenergy projects even though social impacts like employment rates per unit of energy often exceed those when using fossil fuel supplies to provide the same energy service (PC, 2002; Moreira, 2005). Bioenergy crops can also offer opportunities for farmers to increase their revenue, which is an important benefit in rural areas of developing countries (Moreira, 2005).

In this way bioenergy has a significant global role to play in linking mitigation and adaptation. However some bioenergy technologies have not reached commercialization, and need more development to improve efficiency, reliability and cost to become commercial. Many developed countries have an opportunity for development, usage and transfer of such technologies (Faninger, 2003).

The forestry sector offers opportunities for linking mitigation with adaptive capacity enhancement options. The options include both afforestation/ reforestation, such as commercial, bioenergy and restoration plantations, agroforestry systems, and forest conservation, through sustainable management of native forests and forest protection (Masera et al., 2001). Projects that help contain deforestation and reduce frontier expansion can play an important role in climate change mitigation. In addition, these projects have other environmental and social benefits, such as decreasing migration of young rural population to cities, protecting biodiversity and conserving watershed and soils, and these factors are also indirectly important components in the adaptive capacity.

There are many country specific case studies highlighting these options (Fearnside, 2001; Ravindranath et al., 2001; Asquith et al., 2002). For example Amazonia contains more carbon (C) than a decade of global, human-induced CO_2 emissions (60–80 billion tons C). Projected increases in Amazon deforestation associated with investments in road paving and other types of infrastructure may increase C emissions, counterbalancing nearly half of the reductions in C emissions that would be achieved if the Kyoto Protocol were implemented (Carvalho et al., 2004).

Infrastructure

Huge investments are being committed in new infrastructure projects in developing countries. Development of infrastructure enhances the scope of utilizing underemployed resources, and supports industrialization and trade. Following that, infrastructure development will also be a major driver for GHG emissions and mitigation policies. At the same time, climate change impacts can be important in the planning of infrastructures since infrastructures are long-life assets that traditionally are designed to withstand normal variability in the climate regime. The recent incidents of cyclones on the east and west coast of India and landslides caused by heavy rainfall in Konkan region indicate that the infrastructures are vulnerable to extreme climatic changes has been assessed in a paper by Kapshe et al. (2003). The paper suggests a framework for assessing the likely climate change impacts on long-life assets using a methodology of reverse matrix for climate change impact analysis.

Energy use in buildings

Future energy consumption is highly dependent on temperature conditions for example in relation to cooling and heating demands and mitigation and adaptation policies will in this area be closely interlinked, and there can be strong tradeoffs. Studies of health impacts in terms of excess mortality induced by extreme heating has assessed the role of air-conditioning and thereby increased energy consumption and GHG emissions in adapting to climate change (Davies et al. (2003). Other studies conclude that heat warning system that does not rely on increased air-conditioning and associated GHG emissions can also make significant contributions to increased mortality during heat waves (Ebi et al, 2004).

A study for India projects major changes in energy demand projection for space cooling and heating in the residential and building sectors (Kapshe et al., 2003). The air-conditioning and refrigeration load is closely related to the ambient air temperature and thus will have a direct relation to temperature increase. Temperature increase in the northern Himalayan region, where space heating is required during winter, might result in some saving in heating energy. This will be more than compensated by the increased energy requirement for space cooling in the plains, thus resulting in a net increase.

Tourism

The tourist sector will also be vulnerable to various climate change impacts such as extreme events, heating, and sea level rise, and adaptation options i.e. include air-conditioning, improved building structures, protection and against sea level rise and flooding, replanting of trees, and mangroves. Many of these options can have direct and indirect impacts on energy consumption and GHG emissions, and there is a potential for exploiting synergies between the areas by integrated policies as illustrated in a study for Fiji (Becken, 2005). Even that host countries with key tourist activities are not having mitigation as a main priority, policies like energy efficiency will imply cost savings that can be attractive both from an adaptation and an economic policy perspective.

Agriculture

Agriculture in most of the developing countries is rain-fed. This exposes farming communities to climate change. The farmers' vulnerability to increased water stress can be reduced through their participation in improved management of irrigation, by adopting local rainwater-harvesting systems, implementing watershed development projects, low-cost drip irrigation systems, zero tillage, bed planting, multiple-cropping system, crop diversification, agro-forestry, animal husbandry (sheep-rearing), and so on. The strategies may range from change in land use to cropping patterns, from water conservation to flood warning systems to crop insurance, etc. (Kurukulasuriya, 2004).

Changing precipitation patterns and enhanced evaporation (due to temperature increase) across regions could affect the water requirement for agriculture. For areas dependent on ground water for irrigation, this would result in a higher demand of energy for irrigation. Enhancing tree cover, watershed development, micro-irrigation systems, and using renewable electricity for irrigation pump-sets would offer another possible linkage between mitigation and adaptation.

The many examples of potential linkages between mitigation and adaptation policies call for more integrated implementation strategies and for the design of international cooperative mechanisms that can support the policies. These mechanisms go beyond the present separation of adaptation and mitigation policies in the UNFCCC and subsequent international agreements. See a more detailed assessment of cooperative mechanisms in Chapter 13.

2.7 Distributional and Equity Aspects

This section will discuss how different equity concepts can be applied to the evaluation of climate change policies and provide examples on how the climate literature has addressed equity issues. See also IPCC WGII AR4 Chapters 20 and Chapters 12 and 13 of this report for additional discussions about equity dimensions of sustainable development and climate change policies.

The equity issues have intra generational as well as intergenerational dimensions. In the short term the issue of particular interest is on the distributions of mitigation costs among individuals and nations, while in the longer term more and more climate change impacts will occur. Studies of distributional issues need to address how damages face different individuals and nations. Climate change has a very asymmetric character in terms of the present distribution of GHG emissions and of climate change impacts and vulnerabilities. It should also be noted that there are important intergenerational aspects related to the timing of mitigation policies, since the timing affects the costs of transition.

2.7.1 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, has been measured in terms of inequalities of income, through measures such as the 'Gini' coefficient[19]. 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.

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 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.

An important attempt to widen the indicators of development is the UNDP Human Development Index (HDI), which initially included *per capita* national income, life expectancy at birth and the literacy rate.

An important attempt to widen the indicators of development is the UNDP Human Development Index (HDI), which initially included *per capita* national income, life expectancy at birth and the literacy rate. 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 2.6[20] 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 in 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 on these parameters across countries. Literacy rates, however, have become more equal, with a decline in the coefficient of variation by 22 percent (see table 2.6).

Table 2.6 *Measures of Inter-country Equity*

	GNI *Per Capita* $USD	Life Expectancy (LE) Years	Literacy (ILL) %

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

[19] 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.

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

	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%

Source: WB, 2005 (World Development Indicators)
Notes: Literacy Rates are for 1990 and 2001. GNI and LE data are for 1980, 1990, and 2001. 99 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.

As Sen notes, the problem of inequality becomes magnified when attention is shifted from income inequality to inequality of "substantive freedoms and capabilities" because 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 incomes into capabilities and living well. 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 the sharing of the costs of mitigation and for assessing the impacts of climate change (see Chapter 1 for a more detailed discussion about climate change impacts and the reference to the UNFCCC Article 2). As is well known, the impacts of climate change are very unequally distributed across the planet, hurting the vulnerable and poor countries of the tropics much more than better off 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 2.7.5 and 2.7.6 for a further discussion of the links of mitigation policy to equity.

Table 2.7 provides several examples of the likely effects on equity as measured across the wider set of development indicators. As the table shows, climate change impacts, adaptation and mitigation can raise inequality both between countries and within a country, which is also in line with the conclusions of the TAR of the IPCC (2001a; 2001; 2002). It is expected that particularly significant will be the effects on health and economic and social security.

Table 2.7. *Impacts of Climate Change on Different Dimensions of Equity*

Dimension of Equity	Effect of Climate Change	
	Within a Country	Across Countries
Economic	Increased vulnerability of agricultural practices that are undertaken by poor people will increase inequality	With greater negative impacts in developing countries, inequality will increase
Health	Poorer people suffer from lower general health standard and less access to health services and can therefore be more impacted, although some impacts will affect all sections	Major impacts of flooding, vector borne diseases etc. will be in developing countries
Economic and Social Security	Probably affects all sections, but those more dependent on natural resources will be hurt more.	Bigger effects will be in developing countries
Gender	As major users of natural resources e. g firewood for wood fuel and as contributors to subsistence agriculture, women will be severely affected by climate change	Economic disparity along gender lines will increase
Access to Public Goods	Cuts in government expenditure to cope with climate change will affect all, but could fall disproportionately on the poor.	Costs of adaptation will be greater in poor countries, making them less able to maintain provision of other public goods.
Political and Social Freedoms	With possible social disruptions, freedoms could be eroded.	Effects of migration and could be felt in all countries, including the more well-to-do ones, affecting traditional liberties.

2.7.2 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) but the absolute risk aversion 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. The more climate change is taking place, the more the surprises will occur on a time scale that will have immediate human and ecological consequences. Diamond, 2004 has shown that while not every social collapse has an environmental origin, there are many historical examples, where an ecological meltdown met by an inappropriate response from society to a coming disaster has led to the collapse of whole cultures (Easter Island, Classical Mayan civilization, and the Greenland Norse).

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 climate variability and extreme events through such income smoothing measures, and they will therefore be more vulnerable.

2.7.3 Alternative Approaches to Social Justice

Widening our understanding of equity does not provide us with a rule for ranking different outcomes, except in a general sense 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? A number of these issues were discussed in the TAR; what follows is a summary of the previous discussion plus reference to some of the more recent literature on the subject.

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) that all choices are to be 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 things such as rights, duties etc., and (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 losers and still be better off themselves.

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[21]. If utilities were proportional to money benefits and 'disutilities' 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 (2002)[22].

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

[22] 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.

An alternative approach to allocating resources that is derived from an ethical perspective, and that 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 the defines rights and duties of individuals in society. The view goes back to Kant and Hegel and finds its greater articulation in the writing of Rousseau and the French 19th Century philosophers[23]. 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 society be judged in terms of the level of wellbeing 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).

A number of utilitarians (e.g. Singer, 2002 Shraeder-Frachette, 1991) do now support rules that acknowledge rights to some not to be harmed by others without their consent. Their support, however, derives not from the inherent rights theories as deontolgogists would, but on consequences.

More recently, however, some ethical philosophers have found fault with both the 'modified' utilitarian view and rights based approach on a number of grounds. Sen, for example, has argued that options cannot be judged only in terms of their consequences, but procedures also matter. He advocates a focus on the capabilities of individuals to choose a life that one has reasons to value. A person's capability refers to the alternative combinations of 'functionings', where functionings in a more popular way can be described as lifestyles (Sen, 1999, pages 74-75). What matters are not only the realized functionings, but also the capability set of alternatives, differently from a utilitarian based approach that focus 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 criticises the "rights based" equity approaches for not taken into consideration that individuals are different and the actual consequences of giving them specific rights will vary across individuals. This is both the case, because individuals have different preferences and thereby value for example primary inputs 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 interpersonal comparisons than utilitarianism, since it does not suggest to aggregate all individuals but rather to present 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 here have to be viewed in an international context, with a distinction between national particularism (i.e. global justice based on cooperation between nations) and grand universialism(i.e. global justice based on individuals perspectives without regard to their citizenship, Sen, 1999). The

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

latter is the more relevant concept for measuring the equity impacts of climate policies, although it is less applied in practice than the concept of national particularims.

An example of a right based approach based on global equity would be 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. The capability-based approach in contrast would argue for both the loss of freedom and opportunities.

As suggested above, societies do not in practice follow slavishly a utilitarian view of social justice and they do indeed recognize that citizens have certain basic rights in terms of housing, medical care and the like. 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 what rights are valid in this context – a debate that shows little signs 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 policy makers 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 to be worked out, and this is remains a 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 in a way, where it can be addressed as specific constraints that are to be respected beyond what is reflect in estimates of costs and benefits and other social impacts.

2.7.4 Equity Consequences of Different Policy Instruments

All sorts of climate change policies related to vulnerabilities, adaptation, and mitigation will have impacts on intra- and intergenerational equity. The equity impacts both apply at the global, international, regional, national and sub-national level.

Article 3 of the UNFCCC (1992, sometimes referred to as "the equity article") states that parties should protect the climate system on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. 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.

Taking the measures for reducing GHGs, the central equity question has been 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 would lead to the conclusion that the costs of climate change mitigation that will face richer countries 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 dependent on how welfare losses experienced by poorer people are represented in the social welfare function.

In 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 a sense of justice would suggest equal allocation to all human beings, as proposed above. 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, 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 the studies consider equity in terms of the consequences of different climate change policies, while other studies 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 initially is 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, countries contributions will depend on voluntary compliance and it must therefore be expected that countries will react according to what they consider to be fair[24] which will be influenced by their understanding of equity. Second, appeal 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 focuses on the net costs of climate change mitigation versus the benefits of avoided climate change give a major emphasis to welfare consequences of the policies, while libertarian oriented equity studies focus on emission rights, rights of the global atmosphere, basis human living conditions etc. (Wesley and Peterson, 1999). Studies that focus on the net policy costs will tend to

[24] 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.

address equity in terms of a total outcome of policies, while the libertarian studies rather focus 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 to 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 runs 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 about structuring international climate change 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 equity principles. While there is consensus in the literature about which how rules should be ranked with regard 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 the establishment of international agreements about emission allocation rules is that the application of equity in this *ex ante* way can imply 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. These uncertainties both 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. Equity arguments, 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 implies equal per capita emissions.

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 included span population basis, basic needs, polluter pays, GDP intensity, efficiency and geographical issues without a specified structure about interrelationships between the different areas. In this way, the approach primarily facilitates the involvement of stakeholders in discussions about equity.

An overview and assessment of different rights based equity principles and their consequences on emission allocations and costs i.e. are included in Rose et al. (1998), Valliancourt and Waaub (2004), Leimbach (2003), Tol and Verheyen (2004) and Panayotou (2002).

2.7.5 Economic Efficiency and Eventual Tradeoffs with Equity

The literature over more than a decade 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, tradeoffs 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 tradeoffs between what is seemed 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).

2.8 Technology

The cost and pace of any response to climate change concerns will 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-term 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 cf. Grubler, 1998).[25] Both the development of hybrid automobiles automobile 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), innovation (first market introduction of these ideas), niche markets (initial, small-scale applications that are economically feasible under specific conditions), and, finally, diffusion (widespread adoption and the evolution into mature markets, ending eventually in decline).

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 can not achieve the deep emissions 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 than in terms of technical feasibility. 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.

2.8.1 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 and the response of technological innovation and deployment to climate policy signals, e.g. in form of carbon taxes, is also highly uncertain. The usual approach consists in the formulation of alternative scenarios of plausible future developments. These, however, are constrained by inherent biases in technology assessment and uncertainties on the response of technological change to climate policy. There is also widespread recognition in the literature that it is highly unlikely that there exists a single "silver bullet" or "backstop" technology 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 interdependencies and cross-enhancement ("spillover") potentials, which adds

[25] It is also important to note that there exist important linkages between technological and behavioural change. A frequently discussed phenomenon are 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 purchase of a more energy efficient car), cf. the review by Schipper and Grubb, 2000).

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. 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., 1998) as well as from climate policy model inter-comparison projects such as EMF-19 (Weyant, 2004), the EU-based Innovation Modeling Comparison Project (IMCP) model inter-comparison project (Edenhofer et al., 2006) and the multi-model calculations of climate "stabilization" scenarios summarized in IPCC TAR (IPCC, 2001). Technology has also moved to the forefront of a number of international and national climate policy initiatives including the Global Energy Technology Strategy (GETS, 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 literature review first discusses the importance of technological change in "no-climate policy" (or so-called "reference" or "baseline") scenarios illustrating the importance of alternative technology developments on future GHG emissions, and hence magnitude of possible climate change in absence of climate policies. The review then considers the role of alternative technology assumptions in climate policy ("stabilization") scenarios with a focus on the cost implications of alternative assumptions on availability and costs of low-carbon-emitting technologies. A common thread of both sections is that uncertainties on pace and direction of overall technological change ("baseline uncertainty") dominate uncertainties on technology deployment rates in scenarios of varying degrees of stringency of climate policy ("stabilization" uncertainty). The review then briefly discusses calculations identifying the economic value of improved technology and concludes with open research issues (particularly on the question of how technological change responds to climate policy signals) and terminological clarifications to better represent technologies at their varying degrees of maturity and hence temporal availability for climate mitigation.

2.8.1.1 Technological Change in No-Climate Policy (Reference) Scenarios

The importance of technological change for future GHG emission levels and hence magnitude of possible climate change has been recognized and illustrated in scenario studies for the last 20 years. The earliest literature is summarized in Ausubel and Nordhaus (1983) and since then a number of scenario literature assessments (e.g. Alcamo et al. 1995, Nakicenovic et al., 1998, Edmonds et al., 1997; SRES, 2000) have examined the impact of alternative technology assumptions on future levels of GHG emissions. Nakicenovic et al (1998) report the results of a sensitivity analysis of changing three component drivers of global carbon emissions (global economic output, global energy intensities and carbon intensities) according to the entire range of the scenario literature reviewed in comparison to the IS92a reference (no climate policy) scenario. In terms of impacts on global carbon emissions the two technology indicators of energy and carbon intensity exert a comparable impact each by 2020 and 2050 when compared to the impact of varying scenario assumptions of global economic output. By 2100, Gross World Product is the largest influencing component variable compared to the two technology indicators, but when combined, the two technology can surpass Gross World Product as explanatory variable for scenario differences. This conclusion was echoed in the SRES (2000) report, which concluded technology to be of similar importance for future GHG emissions as population and economic growth combined.

A conceptually simpler illustration is provided by comparing individual GHG emissions scenarios that share comparable assumptions on population and economic growth. For instance, the Low Emitting Energy Supply Systems (LESS) scenarios developed for the IPCC SAR (1996) illustrate alternative combinations of technology that all lead to comparable output in terms of energy services and low carbon emissions (below some 500 GtC cumulative emissions over the 1990-2100 period) but in exploring four alternative technology systems (plus an additional "high demand" variant). In the IPCC SRES (2000) scenarios one scenario family (A1) was also used to illustrate the importance of alternative technology developments. For a comparable level of energy service demand, the SRES A1 (no-climate-policy) scenarios span a range of between 1038 GtC cumulative (1990-2100) emissions in the A1T scenario group that illustrates the impacts of rapid development and deployment on low-emitting and zero-carbon energy technologies all the way up to 2128 GtC cumulative emissions in its "fossil fuel-intensive" A1FI scenario group counterpart. 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, cf. Figure 2.3 below) illustrated 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 et al., 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 emissions 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 2.3 below.

Perhaps the most exhaustive examination of the influence of technological uncertainty to date is the modeling 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 2.2), 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 (but based on a single central tendency demand baseline without climate policies). 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 all are "optimal" in the sense that they satisfy the same cost minimum in the objective function with, however, 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. 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., 1998). 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 emissions counterparts.

The results also illustrate the value of technology policy as a hedging strategy aiming at lowering future carbon emissions even in 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.

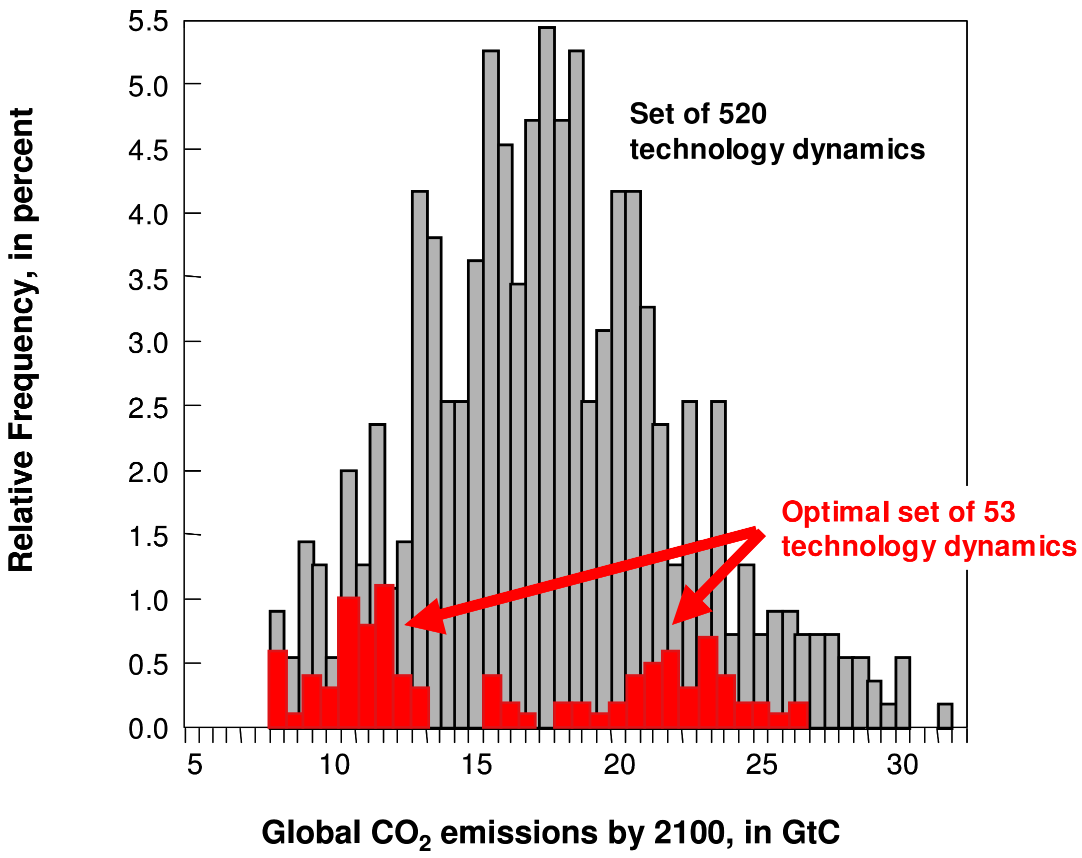

Figure 2.2. *Emissions impacts of exploring the full spectrum of technological uncertainty in a given scenario without climate policies. Relative frequency (percent) of 130,000 scenarios of full technological uncertainty regrouped into 520 sets of technology dynamics with their corresponding carbon emissions (GtC) by 2100 obtained through numerical model simulations for a given scenario of intermediary population, economic output, and energy demand growth. Also shown is a subset of 13,000 scenarios grouped into 53 sets of technology dynamics that are all "optimal" in the sense of statisfying a cost minimization criterion in the objective function. The corresponding distribution function is bi-modal, illustrating "technological lock-in" into low or high emissions futures respectively that arise from technological interdependence and spillover effects. Baseline emissions are an important determinant for the feasibility and costs of achieving particular climate targets that are ceteris paribus cheaper with lower baseline emissions. Source: Adapted from Gritsevskyi and Nakicenovic, 2000.*

2.8.1.2 Technological change in climate policy scenarios

Next 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). The assessment is in most cases based on model calculations using a cost minimization framework and requires a minimum degree of detail in the technology representation, which is evidently dependent on the type of model used in the policy analysis.

Previous IPCC assessments have discussed in detail the differences that have arisen with respect to feasibility and costs of emission reductions between two broad category 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. Top-down studies conversely 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, socioeconomic, 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 is that the traditional distinction between “bottom-up” (engineering type) and “top down” (macro-economic type) models is becoming increasingly blurred as “top down” models incorporate increasing technology detail, whereas “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 intercomparisons such as done 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 instead 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 is also of importance.

Given the infancy of empirical studies and resulting models that capture in detail the various interrelated 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 on 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.

2.8.1.3 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.[26] As-

[26] Perhaps one of the most dramatic historical empirical studies is provided by Nordhaus (1998) who has analyzed the case of illumination since antiquity illustrating that the costs per lumen-hour have decreased by approximately a fac-

suming that technologies in the future improve similarly as was observed in the past enables us to quantify the cost impacts of technology improvements in controlled modeling experiments. Figure 2.3 illustrates such a calculation reported by Edmonds et al., (1997) and since then replicated in a number of other studies. For three illustrative stabilization scenarios (750, 650, and 550 ppmv respectively) three alternative technology cost scenarios are analyzed (otherwise based on the IS92a reference scenario): a (unlikely) scenario in which technologies remain static at 1990 levels (BAU1990 in Figure 2.3), a scenario in which costs decline at roughly historically observed rates (BAUTech+) and an accelerated ("advanced technology") scenario. The alternative technology cost assumptions matter significantly more than the stringency of the stabilization target analyzed, a finding echoed also in other studies. These studies therefore confirm the paramount importance of future availability and costs of low-emission technologies and hence the significant economic benefits of improved technology that, when compounded over many decades, can add up to trillions of dollars. (For a discussion of corresponding "value of technological innovation" studies see Section 3.4 in Chapter 3). However, to date, model calculations offer no guidance on likelihood or uncertainty of the realization of "advanced technology" scenarios or on the mechanisms and policy instruments that would need to be set in place in order to *induce* such drastic technological changes.

tor of 1000 over the last 200 years. Empirical studies in 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.

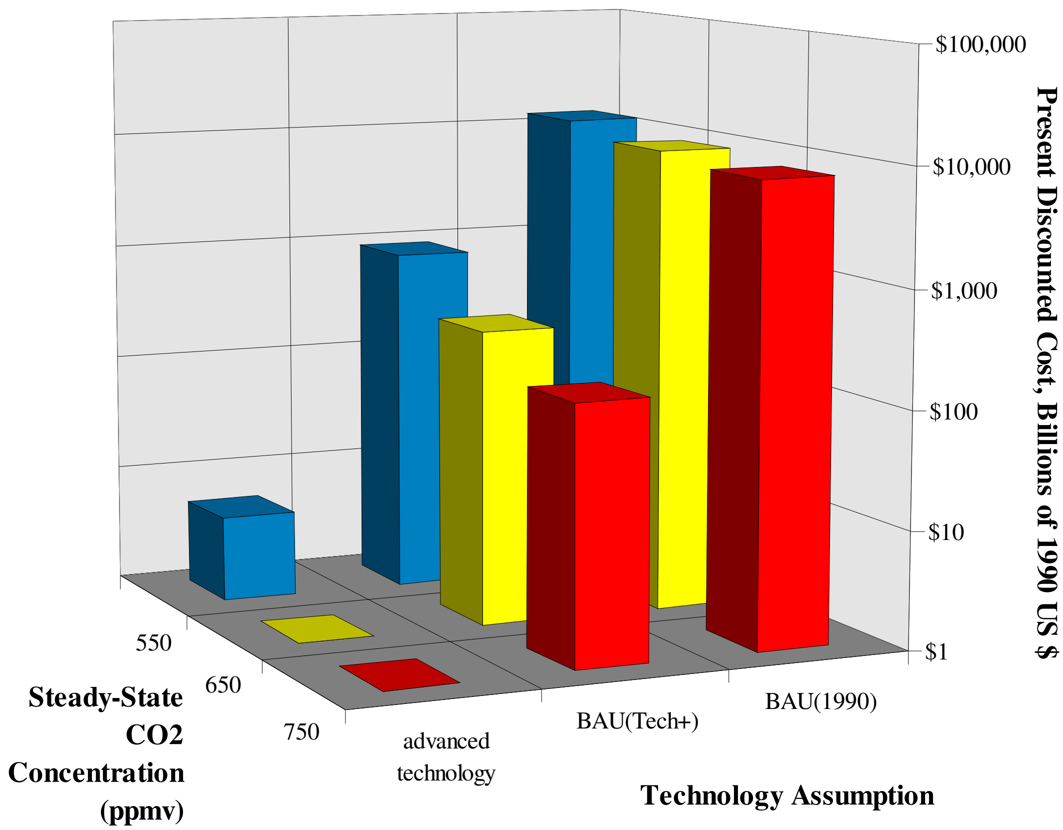

Figure 2.3. *Impact of technological change assumptions on costs of alternative stabilization (750, 650, and 550 ppmv) scenarios. Costs are total discounted (at XX percent) systems costs over the period 1990 to 2100. For each of the three stabilization targets, three alternative technology scenarios are shown. Two reference (BAU) scenarios one with frozen 1990 technologies (BAU-1990), one with "business as usual" rates of technological change (BAU-Tech+) and one scenario assuming accelerated development and deployment of low emissions and carbon capture technologies ("advanced technology" scenario). The results confirm the critical importance of technological change in determining future costs of energy supply and of climate stabilization that emerge as robust finding from a number of scenario and modeling studies). While feasibility and costs of future technologies remain inherently uncertain, modeling studies help to assess the relative importance for costs and for emissions reduction of new technologies that can guide technology development strategies and subsequent niche market deployment strategies that are important preconditions for subsequent improvements in economics and for large-scale diffusion. Source: adapted from Edmonds et al. (1997).*

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 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 of Gritsevskyi and Nakicenovic (2000) reviewed above that also showed identical costs of "high" versus "low" long-term emission futures. This contrasts with the traditional view that the long-term costs[27] of climate stabilization could be very high, amounting to several percentage points of economic output (cf. the review in TAR, 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 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 as, if not more, important in determining the costs of a given scenario as the stringency of the ultimate climate stabilization target chosen (cf. Figure 2.4).

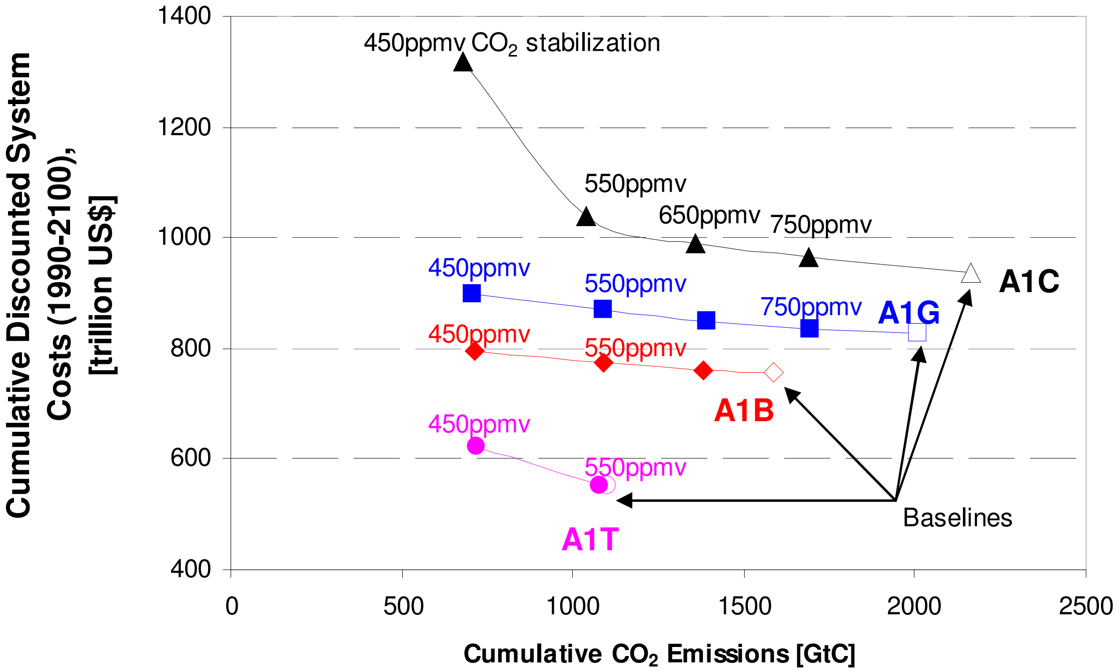

Figure 2.4. *The impacts of different technology assumptions on energy systems costs on emissions (cumulative 1990-2100 CO_2 emissions in GtC) in no-climate policy baseline (reference) scenarios and on the costs of alternative stabilization targets. Total cumulative (1990-2100) undiscounted total energy systems costs (in trillion 1990$) in four scenario based on the SRES A1 scenario family, shown here for better comparability as sharing identical assumption concerning future population and economic growth. Also shown are corresponding total cumulative costs of scenarios meeting increasingly stringent stabilization targets (at 750, 650, 550 and 450 ppmv respectively). For comparison: the total cumulative (undiscounted) GDP of the scenarios is around 30,000 trillion US$ over the 1990-2100 time period. The cost difference across the scenarios are dominated by baseline uncertainties. Compared to that the cost differences between alternative stabilization tar-*

[27] 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.

gets (with exception of the A1C-450 stabilization scenario) is much smaller. Costs of stabilization increase also non-linearly with the stringency of the stabilization target adopted. Ceteris paribus, the higher the rates of technological change particularly in low-carbon technologies are in any particular scenario, the lower future emissions even in absence of climate policies and the lower the costs of achieving any given stabilization target. These results suggest the importance of technology policies in lowering future "baseline" emissions in order to enhance feasibility, flexibility, and economics of meeting alternative stabilization targets that due to persistent uncertainty cannot be determined at the present. Source: Roehrl and Riahi (2002).

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, cf. also TAR, 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. Their findings are consistent with the pattern identified by Edmonds et al. (1997) and Gerlagh and Zwaan (2003). Cost differences are generally much larger between alternative technology baselines, characterized by differing assumptions concerning availability and costs of technologies, than between alternative stabilization levels. In the Roehrl and Riahi (2000) calculations the cost differences between alternative baselines are also linked to differences in baseline emissions (illustrated by the cumulative 1990-2100 carbon emissions); advanced post-fossil fuel technologies yield both lower overall systems costs as well as lower emissions as illustrated in the A1T scenario, whose unconstrained baseline emissions are already close to a 550 ppmv stabilization pathway as opposed to the fossil fuel (coal) intensive scenario baseline A1C that approaches 850 ppmv by 2100 in the scenario baseline that exponentially increases the costs of meeting any stabilization level below 550 ppmv. The IEA (2004) World Energy Outlook also confirms this conclusion, highlighting in addition the differential investment patterns entailed by alternative technological pathways.[28] The results from the available literature thus confirm the value of advances in technology in lowering overall systems costs as well as the costs of meeting alternative stabilization targets, shedding new light on the policy rationale of technology strategies aiming at lowering future emission baselines and increasing the ease of adoption of (yet unknown) environmental targets such as GHG stabilization levels.

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 nonlinear, arising from the cumulative nature of technological change, from interdependence and spillover effects, and from potential increasing returns to adoption (i.e. costs declines with increasing market deployment of a given technology[29]). (A detailed review of the multitude of sources of technological change including above-mentioned effects is provided in Chapter 11 of this assessment discussing so-called "induced technological change" models).

[28] 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. (1998).

[29] This is frequently referred to as a "learning-by-doing" phenomenon. However, the linkages between technology costs and market deployment are complex including 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 there various effects on cost improvements see Nemet (2005). A more detailed discussion is provided in Chapter 11.

2.8.2 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, timeframe, 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; it cannot be used up in the same way that labor or capital can be used up, implying that the benefits arising from a single advance can be enormous. 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.

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"—and (2) the process of diffusion or deployment of these technologies.

These two processes are inextricably tied. The set of available technology defines what might be deployed, and use of technology affords learning that can guide R&D programs 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. Automobile lifetimes can be on the order of 15 years, but the associated infrastructure—roads, fueling stations, vehicle manufacturing facilities—have significantly longer lifetimes 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. Similarly, technologies in use in the economies of origin, can lag technologies used in other economies due to capital stock impacts.

2.8.2.1 The Sources of Technological Change

New technology arises from a range of interacting drivers. It is instructive to divide these drivers into three broad, overlapping categories: R&D, learning-by-doing, and spillovers. These drivers are distinctly different[30] from other mechanisms that influence the costs of a given technology, e.g. through economies of scale effects (see Box 2.2 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 the improvement of specific, well-defined technologies (e.g., fuel cells).[31] Fundamental research focuses on broader and more fundamental areas of understanding. Fundamental research may be mission oriented (e.g., fundamental biological research intended to provide a long-term knowledge base to fight cancer or create fuels) or focused on new knowledge creation without explicit consideration of use (see Stokes 1997 regarding this distinction). 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. And obstacles in applied R&D can feed back research priorities to fundamental research. As a rule of thumb, the private sector takes an increasingly prominent role in the R&D enterprise the further in 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 highlights 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. The more that an individual or an organization repeats a task, the more adept or efficient the organization or individual becomes at that task. In early descriptions (for example, Wright 1936), learning-by-doing referred to improvements in manufacturing labor productivity for a single product and production line. Workers on an assembly line become more and more efficient over time with repetition of their individual tasks. Design and material input improvements may also arise from feedback from workers on the production line or from end-users. 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 coordi-

30 There are however 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.

31 For an applied analysis see Hayashi et al., (2005).

nation, scheduling, design, material inputs, and manufacturing technologies can increase labor 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 & Day 1985, and Argote & 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 the 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 in a range of energy technologies are all spillovers. For each of these obvious cases of spillovers are 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 (1) between firms within an industry in and within countries (intra-industry spillovers), (2) between industries (inter-industry spillovers), and (3) between 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 limits (but does 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 & 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 of an industry depends not only on its own R&D effort, but also on the pool of general knowledge which is accessible to it. There are also socalled rent spillovers, e.g. 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 industrial espionage). However it is inherently difficult to distinguish clearly between these various channels of spillovers.

Box 2.2 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 costs in production 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. The two concepts are often intertwined however, 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.

Over the last half century, a substantial empirical literature has developed, outside of the climate or energy contexts, exploring 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 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, the 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 research (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 the mid 1980's, 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 & Thomas 1984. Energy technology experience curves may be found in Zimmerman 1982, Joskow & Rose 1982, Christiansson 1995, and Mcdonald & Schrattenholzer 2001.) Taken in total, these studies indicate an irrefutable relationship between technological advance (typically measured in per-unit costs) and cumulative production volume over time.

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. 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 & Montgomery 1983, Alberts 1989, Soderholm & Sundqvist 2003). Hence, the causal relationship 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; and Soderholm and Sundqvist, 2003). 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 confirmed also 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 & 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 autocorrelation 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 of advance and 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 (cf. 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 e.g. Otto et al., 2005).

A range of additional lines of research have 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 & Mody 1996, Taylor et al. 2003, Brunnermier & Cohen 2003, and 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, implying that market forces stimulate private innovative activity. On the other hand, this work 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, and 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 can not 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 & Kash, 1999).

2.8.2.2 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. 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. In the creation and dissemination of 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, e.g. 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.

In the process of innovation the behaviour of competing firms plays a key role. Especially in the effort 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, especially 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. The cost and pace of any market response to climate change concerns will depend critically on the state of existing technology, anticipated rates of growth in energy demand and turnover of existing capital stock, and the cost, performance and availability of technologies with lower emissions in the future. 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 and technical capacity and the readiness of markets to provide commercial opportunities.

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 below discussion provides a summary and up-date drawing on Flannery & Khesghi (2005). 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.

For one, 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
- Enabling infrastructure
- Incentive structures for firms (e.g. licensing fees, royalties, etc.)
- Regulatory compliance
- Environmental impacts.

The diffusion potential for a new technology depends on all of 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.

A second factor is 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 for new technology to make a widespread global impact on emissions will be lengthy. Timescales are long both because of the long lifetime of existing productive capital stock, and because of the major investment in hardware and infrastructure that is required for significant market penetration. During this 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 deployed slate of existing equipment. While this presents an opportunity for advanced technology to reduce emissions, the overall investment required prematurely to 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, safe, 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]

2.8.2.3 The Public-Sector Role in Technological Change

Given the importance of technology in determining both 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 to lower the costs of meeting long-term objectives with technology that today are very far from economic in existing markets. This might include such measures as publicly-funded R&D or R&D tax credits. Demand-pull emphasizes the use of instruments to enhance the demand for lower-emissions 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 2.5).

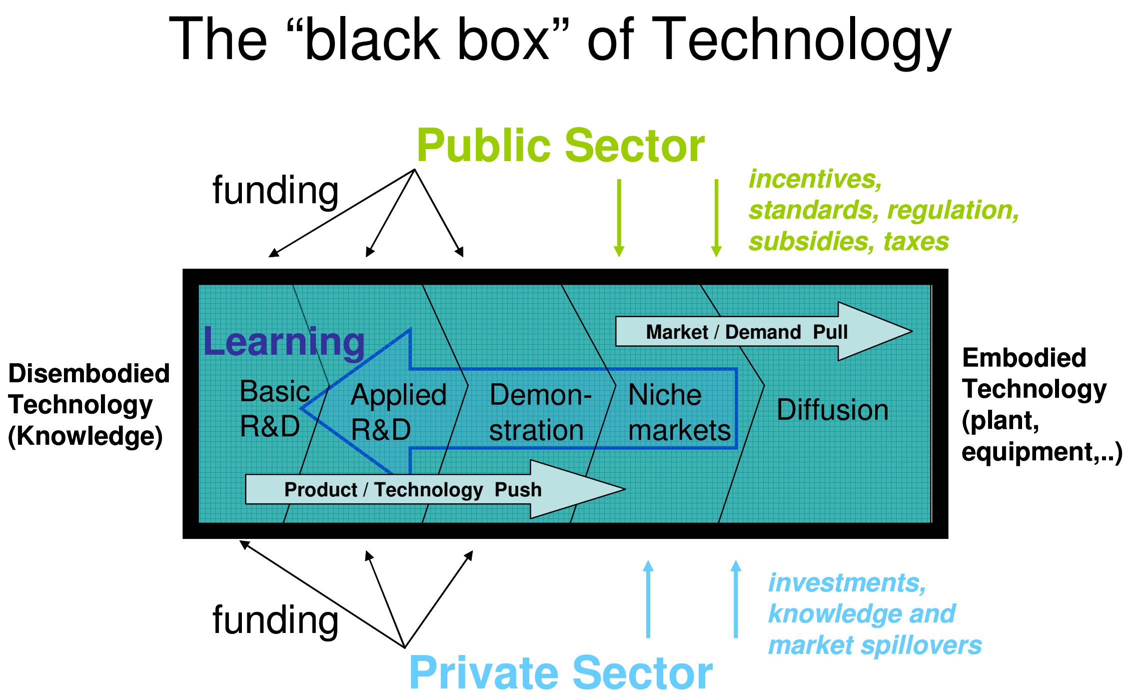

Figure 2.5. *Describing the technology development cycle and its main driving forces. Note that important overlaps and feedbacks exist between the stylized technology life-cycle phases illustrated here and therefore the Figure does not suggest a "linear" model of innovation. It is important to recognize the need for finer terminological distinction of "technology", particularly when discussion different mitigation and adaptation options. Source: Adapted from Foxon (2003) and Grubb (2005).*

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

At issue in the development of policies to stimulate technology development are two market failures. 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 (cf. Jaffe et al., 2005). Chief among these is 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 lead only to second-best solutions (see, for example, Goulder and Schneider, 1999). Hence, it is well understood that the optimal policy approach would include both technology-push and demand-pull instruments. While patents and various protections of intellectual property, e.g. proprietary know-how, seek to reward innovators, such protection is inherently imperfect, especially in global markets where such protections are not uniformly enforced by all governments. Similarly, in the early adoption of technology learning by doing (by producers) or learning by using (by consumers) may lower cost to all future users but in a way that does not adequately reward first movers. 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 might single policy approaches be. Within this context, a number of authors (e.g., Montgomery and Smith, 2005) have argued that fundamental, long-term shifts in technology for mitigation of greenhouse gas emissions cannot be achieved through emissions-constraining policies alone. Instead, they suggest that to induce the necessary long-term technological advances requires focussing directly on approaches aimed at stimulating research and development. While they believe that emissions-based policies, such as cap and trade approaches, can be successful in some settings, they do not believe that these apply to the challenge of deep, long-term reductions in greenhouse gasses. For successful inducement of technical change they argue that emissions objectives must be such that they are readily achievable with foreseeable technology that is affordable. They argue that existing short term targets do not provide sufficient incentive to invest in revolutionary transforming technologies with the potential to dramatically lower greenhouse gas emissions, because they are simply too costly compared with politically viable or plausible policies. Montgomery and Smith (2005) argue that the economic challenge of such investments makes it impossible for firms to have confidence that long-term political emissions targets, even if announced, would be credible. They believe that cap and trade approaches can only be effective when set to promote the more rapid entry into markets of successfully demonstrated, nearly affordable technical solutions. Thus they argue for mitigation policy to focus on tools to promote research for transforming technologies.

On the other hand, the argument that technical change induced by emissions-based policies will deliver technology innovation relies primarily on two arguments (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 second is that early investment, perhaps through incentives, mandates, or government procurement programs, will initiate a cycle of learning-by-doing that will ultimately promote innovation in the form of continuous improvement that will drive down the cost of future investments in these technologies. 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 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 both because results cannot be guaranteed because governments have a poor track record when picking 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"[33] involved in the development and use of knowledge.

Inherent in technology innovation management are many dynamic choices that can be difficult for public sector entities to efficiently manage. For example, it may be difficult to know when to cut back or promote various elements of the portfolio and, because the supply of scientists and engineers is finite such approaches may raise wages without generating commensurate more research leads. This can pose major challenges to those who recommend mandates, subsidies or procurement programs to accelerate the introduction of currently uneconomic technology. Such programs can become very costly because they are at odds with underlying market pressures.

Policy incentives or penalties aimed at stimulating certain technical directions that focus only on CO_2 emissions may not achieve desired outcomes unless the technology succeeds in all dimensions. Cost and the availability of enabling infrastructure can be especially important factors that limit technology uptake in developing countries. Here enabling infrastructure would include management and regulatory capacity as well as associated hardware and public infrastructure that might be required.

2.8.3 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: "co-operate 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, environ-

[33] The literature on national systems of innovation 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 e.g. Lunvall et al., 2002, and Nelson and Nelson, 2002.

mentally 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 of developing countries on this issue. Progress on this matter has been usually 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 Philbert (2004) and Levebre (2005). The definition of technology transfer in 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." Further, it "comprises the process of learning to understand, utilise 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, microeconomics, 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 Report identified different stages of technology transfer and different pathways through which it is accomplished. Stages of technology transfer are the following: 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 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. Little is known about the how much climate-relevant equipment is transferred, and even less about the transfer of know-how, practices and processes. 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 in the last 15 years. Overseas development assistance (ODA) has declined and been overtaken by private sources of foreign direct investments (FDI). 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 county policy makers 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, and the priorities shift as the host countries develop. Technology demonstration projects play important role for the economy before taking off. As the economy grows, policy development assistance, such as technically assisting efficiency standard setting process, to create enabling environment for technolgy transfer become more important. (Ohshita and Ortolano, 2003) studied past experiences of technology demonstration projects of clean coal and energy efficiency improvement in developing countries through the assistance by international organization as well as developed countries. They found that the most demonstration programs were not very successful in diffusing the technologies themselves, but they were successful in building engineering capacity in the target developing countries, in particular in the countries such as China in 1980s, where economy began shifting from centrally planned systems to market systems. While the demonstration programs played the roles in the history, there is increasing recognition that they are not the priority in China anymore. Given the latest high growth of the Chinese economy, the donors have been shifting their assistance programs from demonstration to policy development assistance (GEF, 2004).

Figure 2.6 shows one attempt to create a framework for 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; and
7. The ultimately valuable post-transfer steps, i.e., assimilation, replication and innovation.

We discuss each in turn.

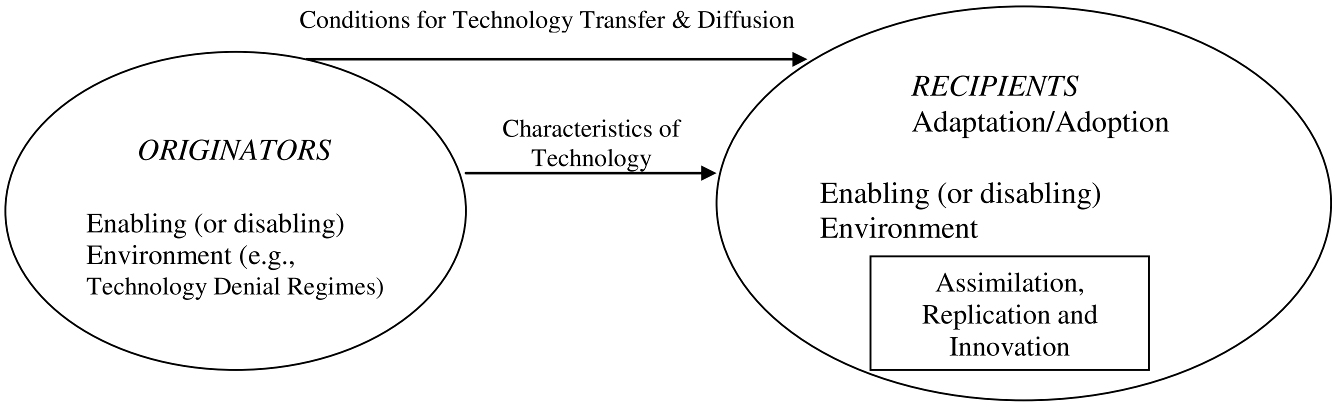

***Figure 2.6**. A General Framework for Technology Transfer and Diffusion*

2.8.3.1 The 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. 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). 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: a) while some of the components of technology are of a public-good nature, some other have an important tacit nature; b) technology markets are normally very concentrated on the supply side, and bargaining power unevenly distributed; c) the strategic nature of technologies normally includes limiting clauses and other restrictions in transfer contracts (for a discussion see Arora et al., 2001, and Kumar, 1998).
Technology Denial Regimes in the country of origin also sometime constitute a barrier to technology transfer, especially for multiple-use technologies. Thus super computers can be used for climate modelling and global circulation models and also to design missiles.

2.8.3.2 The conditions of the transfer

Most technologies are transferred in such a way so that the originators also benefit from the transfer and this helps to establish strong incentives for propor management and maintenance of the technologies. The conditions of the transfer will primarily depend on the pathway of transfer, 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 favorable, concessional and preferential terms (Agenda 21, 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 (reference).

2.8.3.3 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.

2.8.3.4 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 2.6 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 optimise 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)

2.9 Regional Dimensions

This section addresses how the world can be disaggregated into units or regions that are relevant to studies of specific aspects of climate change.

For many problems that can be considered global common goods with a value to all human beings, such as species extinction or the responses of the earth's climate system to long-lived greenhouse gases, the reasonable and relevant unit of analysis is the earth. The analyses of atmospheric radiative forcing (in IPCC Working Group I) use this level of aggregation. Analysis of what should be done globally to stabilise concentrations below a certain level are also done at that level. However, for climate change mitigation in many cases the regional or national level is much more relevant, because there the actual decision*s* are taken. What is the most relevant diaggregation for such purposes?

Climate change studies have used various different regional definitions depending on the character of the problem considered and differences in methodological approaches. Regional studies in this way can be organized according to geographical criteria, political organisational structures, trdade relations, climatic conditions, socioeconomic criteria as for example of relevance to adaptive and mitigative capacity and other criteria (Duque and Ramos, 2004).

The Human Development Report (www, xx) provides data that can be used to classify countries into different regions based on GDP per capita and various living standard indicators. There can also be several classifications based on the so-called normative criterion of membership of countries in the UN. Differentiation into Annex-1 and non-Annex-1 countries is determined during treaty negotiations, although the classification of certain countries has been a matter of some dispute. Annex –I countries are further sub-divided into those that are undergoing a transition to market economies. Figure 13.6 (WG III, chapter 13) shows the current country groupings under the Climate Convention, OECD and the European Union (Hohne et al., 2005). Besides classification of Parties into Annex-1, Annex-II, and non-Annex-1, the UNFCCC recognizes the categories of developed countries, developing countries and least developed countries (in Article 12). It further recognizes in Article 4.8 countries that are small island countries, countries with low-lying coastal areas, etc. Several voluntary associations of the countries are formed for different purposes, such as G-4, G-5, G-7, G-8, G-19, G-77, etc. The Convention also recognized countries whose economies are highly dependent upon the production, processing and export, and consumption of fossil-fuels (Article 4.8(h)).

In climate studies, there are of two types of regional breakdowns —physio-geographic or socio-economic. Physio-geographic ways of dividing the world are mainly, but not exclusively used in analyses of impacts and adaptation common in IPCC Working Group II.

When we are interested to study coastal areas at risk for inundation from sea level rise caused by any reason, the appropriate classifying criterion is the height of a region above mean sea level. For global circulation models that study evolution of climate systems on computers, the most pragmatic division is by grids formed by latitudes and longitudes. Because most grid cells are relatively large (100 km by 100 km or 50 km by 50 km) problems do arise in appropriate representation when a particular grid cell has both land and sea in it.

In IPCC Working Group III, socio-economic criteria are more frequently used for classifying regions. Data on solar insolation, while being primarily physio-graphic is also useful in climate change mitigation studies. An example of socio-economic criterion is per capita income. While national per capita income is almost continuously varying, appropriately choosing certain cut-offs can result in a classification of countries into least developed, developing, and developed. Any national classification, however, will hide or mask sub-regional differences.

Data availability is a factor that determines what kinds of aggregation are possible. Proxies are used when data are not available. Classifying regions by their population density will not give a perfect rural-urban division as some parts of Netherlands, while rural, have high population densities. In the example in the preceding paragraph, when per-capita income is used as a proxy for the stage of development, the resulting classification will be by and large accurate, but some countries will be misclassified, e.g., say, Qatar. If per-capita income were used to study consumption patterns, this should be corrected by the savings rate.

So far, we have considered division of the world based on one classifying criterion. Some studies will call for classification based on two or more variables. In order to study the impact of climate on agriculture or on forests, we need a classification of the world based on biomes, which in turn are determined by temperature, precipitation and soil type. A better classification of the average stage of development is provided by the Human Development Index, which includes besides per-capita income, life expectancy and an index of education comprised of adult literacy rate and the gross enrollment ratio.

Many climate change impact studies traditionally have been related to geographical regions, since climate models are structured to make projections for given areas. IN relation to mitigation studies regional boundaries primarily are relevant in relation to policy options that are related to specific natural resources like hydropower or land use for agriculture or forestry. Climate Change Mitigation studies will often use regional definitions that can both be related to geographical areas and socio-economic and political structures. An assessment of for example power systems can be structured around regional power connections and markets, while a CO_2 tax analysis can reflect political unions like the EU and various countries. Furthermore, studies of specific GHG's as for example industrial emissions can be structured in order to present major companies and emission sources around the world.

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