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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. Furthermore, climate change and the effects of mitigation and adaptation policies are characterised by uncertainties, some irreducible. A large number of analytical approaches can be used to support decision making. They range from formalised modelling optimisation approaches, to the generation of multidimensional qualitative inputs to policy dialogues.

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. It is important to disclose the limits of the evidence basis and other sources of uncertainty when providing results to support the policy process. Decision making approaches dealing with risks and uncertainties include emphasising 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 multinational 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. Other major determinants of net costs are assumptions about the existence and extent of no regret options, ancillary benefits, and double dividends. Finally, climate change mitigation costs are highly influenced by implementation and transaction costs, which are not fully integrated in all studies.

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 that assess equity 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 by whether the conform to a social contract that defines 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 would 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 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 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. 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 applied for 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 examples 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. The approach presented in this section 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 the need for coordinated international efforts given uncertainties and vulnerability of specific groups and countries. 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 can be used to support decision making. They range from formalised modelling optimisation approaches, to the generation of multidimensional qualitative inputs to policy dialogues.

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 and their relationship to other decision-making frameworks. It also covers major cost determinants such as discount rates, market efficiency, transaction and implementation costs, ancillary and joint costs, valuation of non-market impacts, and valuation techniques. Concepts of GHG emission mitigation costs and mitigation potential are also covered. Closely related with this section is the section on decision-making, policy instruments and implementation.

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, and the more general framework conditions for implementing policies. These framework conditions can be addressed in terms of adaptive and mitigative capacities that reflect the institutional structure and the social conditions of society for curbing with climate change. A number of examples of policies that both support adaptation and mitigation goals are given.

The section on distributional and equity aspects describes how different equity concepts can be applied to the evaluation of climate change policies with suitable examples. The equity issues involve intra- and inter-generational dimensions. In the short term, the issue of particular interest is the distributions of mitigation costs among individuals and nations, while in the longer-term the distributional issues also need to address how damages face different individuals and nations. The section discusses how different approaches to social justice can be applied to the evaluation of equity consequences of climate change policies. They span traditional economic approaches that assess equity 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 by whether the conform to a social contract that defines rights of individuals. Equity approaches that emphasis human wellbeing and capabilities are also discussed in the context of climate change policies.

Comment: Why do short term impacts have intergenerational effects?

Climate change studies have used various different regional definitions depending on the character of the problem considered and differences in methodological approaches. Some regional definitions also follow normative criteria related to officially established geographical units such as towns, provinces, countries, etc. Analytical or functional regions are defined according to analytical requirements: functional regions are grouped using physical criteria such altitude or soil type or socio-economic criteria such as per capita income and economic regions. Section 2.8 gives some examples of how the world can be classified into different regions based on the analytical interest of the study.

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. Technological change is particularly important over the long-term time scales characteristic of climate change. Section 2.9 goes through some of the major elements of technological development and deployment, and considers how these might involve a different set of actors and institutions. 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.

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.

Furthermore, a pragmatic approach to the definition of SD is presented and a number of examples on how SD and climate change policy impacts can be assessed jointly are introduced. The approach includes the identification of indicators that can be used to establish linkages between development goals and climate change. The discussion addresses linkages between Millennium Development

Goals (MDG), national development programmes and climate change, as well as SD goals for OECD countries.

2.2.2 Background

The Third Assessment of the IPCC (TAR) included considerations about SD and climate change. The issues in particularly were addressed 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 2.2.1 below.

[INSERT **Figure 2.2.1** here]

Figure 2.2.1 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. For both developed and developing countries each socio-economic development path explored in the Special Report on Emissions Scenarios 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.

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; Halsnæs and Verhagen, 2005). These have included discussions about how a clear distinction 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

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. 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).

Arrow et al., 2004 in a joint authorship between leading economists and ecologists presents an approach for evaluating alternative criteria for consumption 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.

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 suggest to include social capital in society's productive base, as well as corresponding policy options that aim at influencing social capital in order to meet sustainable development objectives. 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 usefull methafors, 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.

Rather than starting with a broad sustainable development agenda, climate change adaptation and mitigation can also be the major policy perspectives and sustainable development can be considered as an indirect policy impact. Such an approach will tend to focus on sectoral policies, projects and climate 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 not are captured in the analysis in terms of conflicts between 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 relatively expensive renewable energy technologies. It is worth noticing that the actual impact of all these policy examples on sustainable development and climate change adaptation and mitigation is 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.

The following Figure 2.2.2 illustrates the interactions between the climate system, natural systems and society and the scope for policy interactions.

[INSERT **Figure 2.2.2** here]

The figure includes three systems shown by ellipses namely the Climate system, the Natural system, and the Socio-economic system. GHG emissions are forcing the climate system and result in climate change that again becomes a stress to natural systems. Climate change influences the natural system and the final impacts depend on the resilience of the system. As a result, the ecological services provided to society such as resources for agriculture and fishery, aesthetic values and water resources are influenced. It should here be recognised that all the system interactions have a complex and non-linear character, and it is beyond the capability of a stylised representation like applied in figure 2.2.2 to capture all these aspects.

The responses to climate change depend on society's productive base including capital assets and institutions and the adaptive and mitigative capacities. Policies that enhance the society's productive base and the adaptive and mitigative capacities are in the figure kept together in one box in order to emphasize the many commonalities between these elements. Furthermore, policies in this area are supposed to have many synergetic impacts that at the same time influence the natural system and the socio-economic system. This is in particular the case, if the policies are targeted towards the achievement of general SD goals (Halsnæs and Verhagen, 2005). See also section 2.6.2 for a more detailed discussion about adaptive and mitigative capacities.

Adaptation and mitigation policies are in this conceptual framework assumed to be more isolated policy efforts that directly addresses climate change and indirectly influence society's productive base, but which do not directly aim at changing the assets. The actual outcome of implementing specific mitigation and adaptation policies is influenced by the adaptive and mitigative capacity that is part of the state of the Socio-economic- and Natural systems. At the same time the outcome of adaptation and mitigation policies depends on the drivers of socio-economic development (investments, consumption, technology, population, governance, and environmental priorities).

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

There is a dual relationship between sustainable development and climate change. On 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 vulnerability and the GHG emissions that are causing climate change.

A number of 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 on this background 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. In particular, the socio-economic and technological characteristics of different development paths will strongly affect emissions, the rate and magnitude of climate change, climate change impacts, the capability to adapt, and the capacity to mitigate." The major findings of IPCC at the more conceptual level accordingly were, that sustainable development can be used as a framework for understanding society's ability to respond to climate change impacts, but more work is needed to understand and assess the capacity for policy implementation.

Climate change, at the same time, influences SD since negative climate impacts on ecosystem services, human health, agricultural production and many other areas will make it more difficult to meet social and environmental goals. Climate change impacts on development prospects have been described in an interagency project on poverty and climate change as "Climate Change will compound existing poverty. Its adverse impacts will be most striking in the developing nations because of their dependence on natural resources, and their limited capacity to adapt to a changing climate. Within these countries, the poorest, who have the least resources and the least capacity to adapt, are the most vulnerable (IPCC 2001a). Projected changes in the incidence, frequency, intensity, and duration of climate extremes, as well as more gradual changes in the average climate, will notably threaten their livelihoods – further increasing inequities between the developing and developed world. Climate change is therefore a serious threat to poverty eradication." (African Development Bank et al, 2003).

Recognizing the dual relationship between SD and climate change point to a need for 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 center (Heller and Shukla, 2003).

2.2.4 Development Goals and SD Objectives

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. Hundreds of different definitions of sustainable development have been suggested in the literature, and it is not possible in the context of this section to provide an overview or a discussion of these. The approach taken here rather is very pragmatic, and sustainable development will be considered as a framework for assessing how human well being can be achieved in the short and long term.

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).

Since this report, various international organizations and government have developed approaches for how SD can be applied as a framework for evaluation development pathways and specific policies. The OECD Ministerial Council started in 2001 a process for agreeing on indicators of SD that can be used in its regular peer reviews of government policies and performance. From this menu, a few areas will be selected for each country peer review based on specific country relevance (OECD, 2003). Similarly, the UN Commission for Sustainable Development, CSD has developed guidelines and methodologies for indicators of sustainable development (CSD, 2001)

Several authors have suggested that sustainable development can be addressed as a framework for jointly assessing social, human, environmental and economic dimensions (Munasinghe, 2002, Atkinson et al., 1997, Markandya et al., 2002). One way to address these dimensions is to use a number of economic, environmental, human and social indicators to assess SD impacts of policies including both quantitative and qualitative measurement standards.

The CSD, 2001 SD development indicator framework operates with a social, environmental, economic, and institutional theme. The sub-themes in these areas are:

Social

- Equity
- Health

- Education
- Housing
- Security
- Population.

Environmental
- Atmosphere
- Land
- Oceans, Seas, and Coasts
- Fresh water
- Biodiversity.

Economic
- Economic structure
- Consumption and production patterns.

Institutional
- Institutional framework
- Institutional capacity.

The starting point for SD and climate change assessment in the context of this report is to consider how current development can be made more sustainable. This assessment will give a focal attention to how basic 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 worth recognizing that major conceptual understandings and assumptions rely on the underlying development paradigms and analytical approaches that are applied in studies. The understanding of development goals and the tradeoffs between different policy objectives depend on the development paradigm applied, and the following sections will provide a number of examples on how policy recommendations about SD and climate change depend on alternative understandings of development as such.

2.2.5 Alternative Development Paradigms

The basic aim of development is understood differently in various paradigms both within and across different scientific disciplines. The actual specification of development in the paradigms constitute the background for considering what should be examined in order to understand development and climate change linkages, and development paradigms therefore are a key framing element of the studies. A number of examples in the following are given on different development paradigms and the implications for the scope of climate change mitigation studies.

Development paradigms that are based on economic theory typically specify a number of goals that are considered as important inputs to human wellbeing. In this way, the development goals can be understood as elements in a sort of a value function. The value function represents the outcome of the individual utility of enjoying various goods and services.

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. 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 net benefits (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.

Differently, other economic based development paradigms like 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 in a broad sense being understood as the core allocation mechanism and as the structure of society that organizes markets and other institutions (Peet and Hartwick, 1999).

This understanding of institutional mechanisms has wide policy implications. The policy implication is i.e. formulated by Oliver North as there is no greater challenge than forming a dynamic theory of social change than 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, the policy issue is how climate change mitigation eventually can be integrated in the institutional structure of an economy. An institutional approach to climate change mitigation analysis therefore will involve the assessment of how current institutions work and how they can be improved recognizing weak markets and capacity limitations. Furthermore, the institutions also include governance and political systems that are major factors in the determination of development paths. See a more elaborate discussion about these elements in Chapter 12, section 12.2.2.

Key theoretical contributions in the economic growth and development debate also include work by A. Sen (1999) and P. Dasgupta (1993). 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, p. 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.

Seen in the context of climate change mitigation, the issue will then be to assess to which degree the policies infringe on or eventually can support the access of individuals to specific resources and freedoms. In some cases it might be concluded that a climate change mitigation policy can be costly if more expensive energy forms are introduced, in other cases policies can enhance energy access if for example energy saving measures are introduced and energy becomes more affordable.

This approach is in line with social science paradigms that are based on libertarian or egalitarian ethics that emphasize the rights of the individual to participate in decisions and pursue their goals. The focus is here often on establishing a process that facilitates the rights of the individuals (Raynor and Malone, 1998). Issues like risks and justice related to climate change will be focal areas for the studies about local participatory processes.

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

2.2.6 Development Pathways

In discussions about development pathways it is important to recognize that several different definitions of sustainable development is possible as discussed previously in section 2.2.4, but given that a pragmatic approach is taken, the issue can be formulated like how can policies support that development paths become more sustainable.

A society's development path is influenced by policies as well as institutional frameworks and structures that shape economic structures and resource consumption and thereby climate change. Given these framework conditions a number of key decisions related to investments, use of natural resources, consumption and lifestyle, technology choice, influence development pathways and these specific policy elements as well as institutional structures in principle can be sought addressed by sustainable development policies.

Despite sustainable development policies cannot be defined in a clear cut way, various specific policy recommendations that addresses different components have been discussed in the literature. They include a broad number of policies related to nature conservation, legal frameworks that support the management of common access resources, environmental taxes, promotion of organic food and non-material lifestyles, human and institutional capacity building efforts, R&D, financial schemes, technology transfer, energy efficiency, and renewable energy options. These policies, typically are not derived and implemented as part of a general sustainable development policy package, but are rather targeted towards more individual policy goals like air pollution standards, food security and health issues, GHG emission reduction, income generation to specific groups, or development of industries for green technologies. In this way a development path evolves as a result of many economic and social transactions that are governed by government policies, private sector initiatives, and by the preferences and choices of consumers

The development path that arrives from various policy initiatives and framework conditions have been discussed in the literature including theoretical studies of conditions for sustainable development as well as in qualitative and quantitative scenario studies including the IPCC SRES scenarios and other scenario studies (IPCC, WGIII, TAR, Chapter 2, SRES report).

The theoretical work spans hundreds of different studies that based on economic theory, complex systems approaches, ecological science and other approaches derive conditions for how development paths can meet sustainable development criteria. It is beyond the scope of this report to provide an overview of this rich literature, so only a few issues of divergence between ecologists and economists in the theoretical literature will here be introduced.

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[1]. However, the optimal level of current consumption cannot be determined, 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 contemporaneous goods (including capital goods) and the social costs of these commodities.

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

Weak institutions in developing countries have a lot of implications for the capacity to adapt or mitigate to climate change as well as in relation to the implementation of broader development policies. A review of the social capital literature 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). The measures all depend on the nature of the formal institutions, the social groups of society, and the interactions between them (Halsnæs, 2002).

Social and cultural processes influence the future in a myriad of ways. They shape the institutions and how they function and can also create new demands, which in terms of energy consumption and GHG emissions can be larger than the gains from technological efficiency improvements. Social norms of ownership and distribution have a vital influence on the structure of production and consumption. And most vitally, the social and culture processes determine the quality and extent of the so-called social "infrastructure" sectors, such as education, which are paramount to capacity building and technological progress. Unlike institutions, social and culture processes are often more inflexible and difficult to influence. However, specific sectors like education are amenable to interventions. Barring some negative features, such as segregation for instance, there is no consensus as to the interventions that are necessary or desirable to alter social and cultural processes. On the other hand, understanding their role is crucial for assessing the evolution of the social infrastructures that underlie technological progress and human welfare (Jung et al, 2000). [2]

2.2.7 Climate Change Policy Impacts on Development Policies

Studies that aim at the assessment of sustainable development impacts of climate change and vice versa will be addressing 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 with the development goals. Following that, a number of examples on how countries have formulated development goals that aim at meeting similar policy objectives will be given.

A number of international initiatives including the decisions of the World Summit on Sustainable Development (WSSD) in 2002, and subsequent activities by the UN Committee for Sustainable

[1] Arrow et al. (2004) states 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.

Development (CSD) are considering the definition of goals for a number of sectors that will have important linkages to climate change policies. A short overview of these initiatives is given in the following.

A key decision of the WSSD was the adoption of the so called WEHAB[2] framework that links sustainable development and water, energy, health, agriculture and biodiversity policy issues (WSSD, 2002). The WEHAB sectors reflect the areas, where the parties of the WSSD meeting wanted 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, financial resources, institutional and technical capabilities, protecting aquatic ecosystems.
- **Energy.** Accessibility, efficiency, renewables, advanced fossil fuels, 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 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 and the SD-Climate linkages included in Figure 2.2.3, 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 and tourism.

Climate change policy aspects can also be linked to the MDG's that also 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 Millenium 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 suggests to add a number of energy goals to the MDG's, which indirectly 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 2.2.7 (based on Davidson et al, 2003).

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

Another example of how climate change, MDG's and development goals can be linked is shown in Table 2.2.8. It is here illustrated how climate change policy objectives, and MDG's can be linked to official development policies of India as formulated in the official Indian 10th plan for 2002-2007 (Shukla, 2003; Shukla et al., 2003).

[INSERT **Table 2.2.7** here]

[INSERT **Table 2.2.8** here]

The OECD Ministerial Council decided in 2001 that the regularly Economic Surveys of OECD countries should include an evaluation of sustainable development dimensions. The first 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, and in particular the 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 and that countries with high standards spend around 2% of GDP in this area. It is 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 in particular export of agricultural products 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, the retirement income policy evaluation found that a number of countries have made substantial progress in containing the fiscal pressures of aging in coming decades. Among the conclusions were recommendations about stronger incentives for savings and private pensions as well as removing incentives for early retirement from the labor market.

2.2.8 Conditions for Implementing SD and Climate Change Policies

The basis for implementing SD and climate policies is as illustrated in Figure 2.2.2 both determined by the general state of nature and the socio-economic system, and by policy priorities.

A recent development in the international governance structure of SD and climate change policies is that a wider spectrum of stakeholders currently is beginning to be engaged in the areas. These stakeholders include international agencies, global forums like the WSSD, private companies, and NGO's. The participation of a broader set of stakeholders creates a new potential for linking formal international agreements and commitments with voluntary actions, and market driven processes.

A number of companies have as part of their corporate strategy voluntary defined a number of goals that reflect social responsibilities and environmental concerns that go beyond traditional company obligations (Halsnæs, 2005). Following this line of thinking, an increasing number of companies are defining targets for GHG emissions and sinks. Several international coordination networks are promoting such activities including the World Business Council on Sustainable Development (WBCSD), the Climate Biz network, and the Climate Group (WBCSD, 2004). These initiatives work as platforms for cooperation between companies, NGO's, governments and other stake-holders.

The WBCSD states in its objectives of the energy and climate change programme that "increas-ingly, companies will need to understand and manage their GHG risks in order to:

- Maintain their license to operate
- Ensure long-term success in a competitive business environment
- Comply with national or regional policies aimed at reducing corporate GHG emissions
- Identify risks and cost-effective reduction opportunities in the value chain
- Set internal targets and measure and report progress
- Develop process/product innovations."

In this way the WBCSD takes the approach that in future expectations about mandatory GHG emis-sion policies it is prudent to identify risks and to start a process of monitoring GHG's. The monitor-ing of GHG's by the companies are supported by a guidebook for accounting that in accordance with IPCC standards of GHG emission inventories sets very detailed standards for company ac-counting (WBCSD and WRI, 2004). In addition to this, the WBCSD also emphasize that GHG emission accounting is important in showing eco-efficiency and in creating an image of transpar-ency and accountability. Another benefit that companies can get out of following the standard for GHG accounting according to WBCSD is that they can get access to GHG trading markets.

Also the insurance sector has developed company profiles and activities that aim at SD and climate change. An example of this is Zanetti et al. (2005) that considers climate change as a core element in the company's long term risk management strategy. Several factors are in this context identified as being important to the insurance industry including property and casualty, life and health, asset management, finance, operational risk.

An example of an initiative from NGO's that links climate change and SD implications is the Gold Standard developed by the WWF. The Gold Standard is specifically developed in order to assess how CDM projects can support a broader set of SD goals that goes beyond their capacity to reduce GHG emissions (WWF, 2003).

2.3 Decision Making

2.3.1 Introduction

Decision making must be considered in the context of a large number of real world limitations and complexities, where various formalized approaches can be used as a support to decision making, but cannot provide definite answers or ultimate policy recommendations. The literature offers no ideal or optimal solution to balancing the risks between climate change and the costs of adaptation and mitigation policies, but important insights can be provided by the use of analytical tools and other approaches. This section discusses a number of critical issues related to decision making and evaluates how various approaches can be used to address such issues.

The evaluation of decision making approaches in the context of this chapter will be based on new literature that have been assessed in the context of the conclusions in the SAR (IPCC, 1996, Chapter 2) and the TAR (IPCC, 2001, Chapter 10) that arrived from an extensive review of the literature. Those reviews encompassed techniques including decision analysis, cost benefit analysis, cost-effectiveness analysis, safe-landing approaches, robust decision making, game theory, portfolio theory, public finance theory, ethical and cultural prescriptive rules, and various policy dialogue exercises. Some key conclusions from the SAR and the TAR reports that constitute the background for the current section can be summarized by:

- There is no single decision maker in climate change, and because of differences in values and objectives, parties participating in a collective decision-making process do not apply the same criteria to the choice of alternatives.
- Decision analysis that aims to produce a single optimum policy or a unique and stable ordering of options requires a complete and consistent utility valuation of decision outcomes. In climate change, many outcomes are difficult to value and a global welfare function does not exist, so quantitative comparisons of options as the only decision making basis is not meaningful.
- Decision analysis may help keep the information content of the climate change problem within the cognitive limits of the decision maker.
- The treatment of uncertainty in decision analysis is quite powerful, but in climate change objective probabilities have not been established for many outcomes.
- Because of the large uncertainties and differences between parties, there may be no "globally" optimal climate change strategy; nevertheless, the factors that affect optimal single-decision-maker strategies will still have relevance to individual partners.

2.3.2 General Elements of the Decision Making Problem

Climate change decision making involves a number of complex problems that can be addressed in different ways in decision making processes and more formalized analytical approaches. Climate change emerges over very long time horizons, so decisions about implementing GHG emission reductions or adaptive measures have to balance the near time costs against the benefits of reduced future climate change impacts as well as the risks of un managed changes. Furthermore there are large asymmetries between the geographical location of GHG emission sources, and climate change impacts and vulnerability. Climate change vulnerability is particularly large among poorer people, which at the same time have only contributed very little to atmospheric GHG concentrations, so climate change and related policies have large equity impacts.

Decision making processes can be supported by expert advice including various technical inputs such as general climate change research, applied policy studies, and formalized decision analytical tools. One of the key interfaces between climate change decision making and experts has to do with the choice of major impact variables that are considered in the evaluation of the costs, benefits and other impacts of climate change policies. Such impacts can include various economic parameters, local and global environmental change, social issues like employment generation, health, education, equity, and many other areas. The selection and representation of different impact areas in climate change decision analysis will in the following be discussed in relation to different decision analytical tools. Furthermore, a number of approaches for dealing with uncertainty in decision making will also be discussed in the section.

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, safe-landing approaches, game theory, Portfolio theory, public finance theory, ethical and cultural prescriptive rules, and various policy dialogue exercises. Despite differences in scope and valuation paradigms, there are a number of common elements and critical assumptions built into all the decision making approaches that create a number of particular complexities due to the specific character of climate change.

Halsnæs and Markandya, (2002) recognizes that various decision analytical approaches that are considering GHG emission reduction options in the context of multiple policy objectives exhibit a number of commonalities in assumptions and valuation issues that goes across several different analytical approaches. The standard approach goes through the selection of GHG emission reduction options, selection of focal impact areas that are considered to be influenced by the 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.

The point to be made in relation to this list of elements in decision analysis is that all analytical approaches explicitly or implicitly have to consider the described elements, whether this is done in order to collect quantitative information that are used in formalised approaches or if the focus is on qualitative information and policy dialogues. Furthermore, it seems to be the case that many different decision making approaches will 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 opmization modelling frameworks) are similar in many areas, but finally diverge when it comes to the determination of valuation approach applied to the assessment of multiple policy impacts. Another area, where there is significant differences between the approaches is in their handling of uncertainty issues.

The following section will go through a number of critical social decision making aspects related to climate change and review how these are tackled in different decision making analytical approaches. Furthermore the treatment of uncertainty is considered.

2.3.3 Key methodological issues related decision analysis

This section will discuss some of the generic methodological problems that are core elements in climate change analytical approaches and studies, followed by providing a short overview of some major tools that have been used as a support to decision making.

The methodological issues that will be discussed include choice of variables and valuation approaches applied in climate studies, handling of the time dimension, and risks and uncertainties.

2.3.3.1 Choice of Focal variables for Climate Change Studies

Any climate change policy study involves a selection of focal variables that are considered to be important "measurement" points for the evaluation in case. These variables can more or less be built into the methodological approach, as for example the welfare function of an economic model or the objective function of a sectoral energy model that minimises energy system costs. The variables to some extent can also reflect a specific focus of policy makers, that in a sort of an interactive process with modellers or other experts request information about specific aspects like employment generation, energy security, and other economic and social development issues.

There are various different approaches that can be applied to the valuation of a range of chosen impact variables. The literature for example includes utilitarian approaches where monetary values or other welfare proxies are assigned, and multi criteria frameworks, where utility more is expressed in terms of amounts of satisfaction in relation to different attributes (Keeney and Raiffa, 1993). Examples of the first mentioned approach are economic optimisation models and cost benefit analysis, while the last mentioned approach is applied in various multicriteria assessment approaches.

Some approaches suggest to combine welfare measures, and other quantitative and qualitative measures with specifically defined constraints or policy targets. In this way, the analysis is structured around an assessment of the impacts on a set of variables in the objective function of meeting specific goals and targets. An example of this is cost effectiveness analysis that considers the costs of meeting stabilisation targets, temperature limits, GHG emission reductions and other targets.

Within welfare economic based approaches as well as in relation to other approaches there are also important differences in the value function applied to the objective function. In a CBA approach, for example, the objective can be to maximise benefits over costs, while different applications of cost effectiveness analysis can be specified in relation to the objective of maximizing the utility of multiple attributes or to maximise the minimum value of specific variables in any policy outcome (IPCC, 1995, page 63).

2.3.3.2 Issues related to the time dimension

Climate policy raises questions of inter-generational equity[i] and changing preferences due to the long term character of the impacts (for a survey see Bromley, D.W, and J. Paavola, 2002). Conventional economic analysis discounts future benefits and costs, and will often at least in one major policy case assume that tastes and preferences remain unchanged since no information exist about how these eventually might change in the future.

In this way, the preferences (individual and social) of present generations are one of the key determinants of the expected values of economic outcomes. The literature as yet does not include any alternative approach, so this means that current distributions of wealth and income which are key determinants of current preferences a dominant role in estimates of the welfare of future generations.

It is clear that preferences will not be stable over the long time frames involved in the assessment of climate policy options. Among other factors, individual preferences will be affected by information, education, social and organizational affiliation, income distribution and a number of cultural values (Ignacios Palacios-Huerta and Tano Santos, 2002).

Since climate change is a long term global issue, it must be expected that a number of institutional arrangements are necessary in order to help 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.

Potential institutions that can support collective decision making has been considered in a wide range of literature about climate change policy regimes. See a detailed discussion of this literature in Chapter 13. Two important broad conceptual approaches to analysing the prospects and conditions for securing stable global agreements to reduce emissions are game theory and political science,

Three streams of game theory have progressively emerged in the analysis of the conditions under which stable and effective coalitions can be built to reduce greenhouse emissions. These are non-cooperative models, cooperative approaches and the “new coalition theory” (Eyckmans and Finus, 2003).

Non cooperative models suggest that difficulties arise in forming and maintaining stable coalitions to reduce emissions since for many of the participants there is a possibility - if they take no action to limit emissions - of benefiting from the efforts taken by others to mitigate climate change without incurring the costs (the free rider problem) or even to profit from these efforts through increased economic activity resulting from the movement of energy intensive jobs and industry away from the countries taking action (carbon leakage). Conversely those who act unilaterally to reduce emissions cannot expect to capture all the climate benefits (if any) flowing from their action, while the costs they face could be higher than under a cooperative scheme. Non-cooperative game theory applies conditions for internal and external stability of coalitions. In general the literature suggests that the “conditions” for achieving large scale stable coalitions means that they achieve relatively modest emissions reductions. (e.g., Barrett, 1994; Carraro and Siniscalco, 1993; Hoel and Schneider, 1997).

Cooperative game theory emphasises the prospect of building stable coalitions if a transfer scheme (for example by emissions trading) can allocate the gains from cooperation in proportion to the benefits from reduced climate impacts (e.g., Chander and Tulkens, 1995; Chander and Tulkens, 1997; Germain et al., 1998; Germain et al., 2003). Eykmans and Finus (2003) note that “a conceptual drawback of the cooperative approach is that it only tests stability of the “grand” (all party) coalition, analyses stability in terms of the aggregate payoff to coalitions and rests on very strong assumptions about implicit punishment of any free-riding countries. However, there a large number of empirical studies (e.g., Eyckmans and Tulkens 2003, Germain et al. 1998 and Kaitala, et al., 1995).

“New coalition theory” builds from these streams by modifying assumptions in relation to responses to payoffs from cooperation, including spillover benefits, to allow for the development of multiple coalitions and to draw a conceptual line between the rules of coalition formation and stability (Finus, 2002). Eyckmans and Finus. (2003, p1) suggest through the application of these decision rules in the context of an Integrated Assessment Model (IAM) that “Most of the regional agreements are superior to single agreements. Moreover, our findings confirm those derived from simpler theoretical models that a cleverly designed transfer scheme can foster cooperation and that from the number of participants the success of a treaty cannot be inferred. They also support a conjecture of theory that in the case of greenhouse gases stable coalition structures (partial cooperation) can close the gap between the global optimum (full cooperation) and the Nash equilibrium (no cooperation) by a substantial amount.

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 processesii. The role of domestic political pressures, constraints and opportunities and competing priorities (for example security) might be seen as having been influential in the decisions made by parties in relation to the ratification or otherwise of the Kyoto Protocol.

2.3.4 Decision making under uncertainty

Uncertainties surrounding 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) remain the subject of debate. The climate issue is a long-term problem requiring long-term-solutions. Policymakers nevertheless need to know how compatible near-term abatement decisions are with long-term objectives. That is, are we currently on an emissions trajectory that is consistent with our long-term goals? This is a particularly difficult question given the uncertainties regarding stabilization targets.

The assumption that desired stabilization targets can be known with certainty is, of course, an over-simplification. But fortunately, policy makers are not required to make once-for-all decisions binding their successors over the entire century. There will be ample opportunities for mid-course adjustments. Climate negotiations are best viewed as an ongoing process of "act-then learn" and today's decisions makers can aim at evolving an acceptable hedging strategy -- one that balances the risks of acting too aggressively with one of acting not aggressively enough.

Several studies have attempted to identify the optimal near-term hedging strategy based on the uncertainty regarding the long-term objective. These studies find that the desirable amount of hedging depends upon one's assessment of the stakes, the odds, and the cost of mitigation. The risk premium – the amount that society is willing to pay to avoid risk – ultimately is a political decision that differs among countries.

It is difficult and perhaps counterproductive to explore the payoffs from various types of investments without a conceptual framework for thinking about their interactions. Decision analysis provides a framework for exploring the payoffs from various types of climate policies and their interactions in different time frames. The next several decades will require a series of decisions on how best to reduce the risks from climate change. Again, there will no doubt be opportunities for learning and midcourse corrections. The immediate challenge facing policy makers is what actions make sense today in the face of the many long-term uncertainties.

[INSERT **Figure 2.3.1** here]

Figure 2.3.1 provides a caricature of the climate policy "decision tree". In the parlance of decision analysis, the squares represent points at which decisions are made, the circles represent the reduction of uncertainty, and the arrows indicate the wide range of possible decisions and outcomes. The diagram is by no means exhaustive. Nor do we intend to search for the optimal set of near-term decisions. Such a quest is beyond the scope of this report. Indeed, it is questionable whether such an analysis is even possible given the diversity of decisions required at the international, domestic, and local levels. Our goal is much more modest: to stimulate debate on the trade-offs and synergies among major options for reducing the risks of climate change. Perhaps most importantly, the development of the diagram is not meant to be a once-and-for-all exercise, but rather a dynamic process. One in which the tree is continually pruned and new branches added.

In its current manifestation, the first node summarizes some of today's investment options. How much should we invest in mitigation? In adaptation? In expanding mitigative and adaptive capacity? And in research to reduce scientific uncertainty? Once we act, we have an opportunity to learn and make mid-course corrections. *There is no implied meaning to the order of the uncertainty nodes*. They are intended to represent the some of the types of learning that will occur between now and the next set of decisions. Nor do we mean to imply that uncertainty will be resolved, only that there will be new information which may influence future actions. Hence, the expression "acts, then learn, and then act again".

Although the diagram may give the impression that learning and decision making takes place at discrete intervals, we emphasize that it is only a caricature: learning and decision making is, of course a continuous process. We must take advantage of important new knowledge as it unfolds and act accordingly.

The first uncertainty node in the diagram relates to the efficacy of investments in the initial period. How effective is each action in meeting its respective goal and what have we learned to facilitate the achievement of future goals? For example, in the area of mitigation, are countries achieving their targets? What have we learned about the ability of existing institutions to implement reductions mandated at the international, domestic, and local level? What are the marginal and total costs of implementation and the impact on market and non-market systems? Although the set of questions will vary by investment category, their ultimate goal will be the same: to inform future investment decisions in the quest to reduce risks.

The issue of development paths is particularly complex. Climate change mitigation and adaptation will both be affected by, and have impacts on, broader socio-economic policies and trends, such as those related to development, sustainability and equity. In the present context, it is unclear whether development should be characterised as a decision node, an uncertainty node, or both.

Demographic trends are also hard to predict. What will the population be in 2050, 2100, and beyond? Where will the greatest increases take place? What will be the significance of increasing life spans? Will there be shortfalls in the size and capacity of the workforce? These are but a few of the demographic-related uncertainties that can impact future climate change and society's ability to cope with it.

Climate change decision-making is not a once-and-for-all event. Rather it is a process that is likely to take place over decades if not centuries. Furthermore, it does not occur at discrete intervals but is driven by the pace of the scientific and political process. There are also likely to be changes in the nature of the decisions over time.

2.3.5 Decision Analytical Tools

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, multicriteria analysis, integrated assessment, safe landing approaches, green accounting etc. A number of structural differences in these approaches in the following will be highlighted.

Cost–benefit analysis measures all negative and positive policy impacts and resource uses in the form of monetary costs and benefits based on social costs. The idea is to assess the ratio between benefits and costs as an indicator of how a given investment or other policy effort pays off seen from the society's point of view. A special case of cost–benefit analysis in which all the costs of a portfolio of projects are assessed in relation to a policy goal is termed cost effectiveness analysis. The policy goal in this case represents the benefits of the projects and all the other impacts are measured as positive or negative costs. The policy goal can, for example, be a specified goal of emissions reductions for GHGs. The result of the analysis can then be expressed as the costs (US$/t) of GHG emissions reductions (Sathaye et al., 1993; Markandya, 1998).

The Multi-attribute analysis is constructed around a framework for integrating different decision parameters and values in a quantitative analysis without assigning monetary values to all parameters (Keeney and Raiffa, 1993). Examples of parameters that can be controversial or difficult to measure in monetary values are human health impacts, equity, and environmental damages. Multi-attribute analysis can also be used to combine quantitative and qualitative information.

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. The basic philosophy behind the use of economic values is that these can be used to represent welfare impacts of given climate change policies. The most straight-forward is to assign monetary values to impacts that are related to markets like employment, use of production inputs, and investment costs. It is more difficult to assign monetary values to non-market impacts like air pollution, health, biodiversity, and long term impacts of an intergenerational nature. 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.

What differentiates multi-attribute analysis from benefit cost analysis is that instead of using values derived from markets or from non-market valuation techniques, the impacts evaluated in a multi-attribute framework are assigned weights – which are usually selected by the analyst or through a stakeholder consultation process. An overall score or ranking for each option is calculated by multi-plying each criterion by its weight and aggregating across all criteria. Different functional forms for the aggregation process can be used. Multi-attribute analysis is explicitly subjective in the alloca-tion of weights to impacts (which conceptually can cover the same range of factors as in a benefit cost assessment). This is its strength (ie the explicitness of the value assumptions) and its weakness (ie the privileging of the values of the analyst or the particular group of stakeholders consulted to derive the weights), (Bennet, 2000).

Integrated assessment approaches aim at combining key elements of biophysical and economic sys-tems into a decision making framework with various levels of detail about the different sub-components and systems. These models include all different variations on the extent to use mone-tary values, the integration of uncertainty, and on the formulation of the policy problem with regard to optimization, policy evaluation and stochastic projections.

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

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

Policy evaluation approaches include:

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

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

- computer-aided IAMs to analyze the behaviour of complex systems;

- simulation gaming in which complex systems are represented by simpler ones with relevant behavioural similarity;
- scenarios as tools to explore a variety of possible images of the future; and
- qualitiative integrated assessments based on a limited, heterogenous 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 cost–benefit approaches, where it is particularly difficult to estimate a marginal benefit curve — where 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.

Toth (2004) has proposed a “tolerable windows” approach (also known as the inverse or guide rails approach). This approach emphasizes 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. 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.

A number of decision making approaches have tried to integrate specific climate change aspects in a broader menu of environmental, social, and economic issues. These approaches include green accounting and studies of sustainable development and climate change.

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.

Climate change cost analysis has in a number of studies been extended to integrate a broader menu of sustainable development aspects covering development, social- and environmental dimensions in one integrated framework (Munasinghe and Swart, 2005, Halsnæs and Verhagen, 2005). The studies have defined specific focal points that have been considered as important aspects of sustainable development, and have in some cases suggested indicators of these reflecting areas like energy-, water, and food access, employment, income distribution, local and global pollution, education, health aspects, and local participation. Some of these impacts have been represented by monetary values and others by quantitative or qualitative information as part of a sort of a multi-attribute decision making approach. See a more elaborate discussion about sustainable development aspects in section 2.2 and Chapter 12.

Following these lines of thoughts Geoffrey Heal (1998) characterized the challenge of sustainable development issues seen from an economic perspective as to establish an approach that makes it economic rational to pursue sustainable development objectives (Heal, 1998, p. 2). This challenge according to Heal (1998, p. 14) is related to three areas, namely:

1) A treatment of the present and the future that places a positive value on the long run. 2) Recognition of all the ways in which environmental assets contribute to economic well-being. 3) Recognition of the constraints implied by the dynamics of environmental assets.

Issues related to each of these areas are considered in more detail in other sections. The first mentioned area regarding values on the present versus the future involves issues like uncertainty and discounting, the second involves a discussion about valuation of non-market assets and other costing issues, and the third i.e. deals with abrupt changes, uncertainties and risks.

2.4 Risk and Uncertainty

2.4.1 Introduction

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.

This section introduces the “Risk and Uncertainty” guidelines that IPCC authors were asked to consider when writing this report. This is followed by a discussion of the `pedigree' approach to characterize the quality of informations, the epistemic difference between the frequentist and the bayesian approach, and the difference of degree between precise and imprecise probabilities. A typology of “kinds of uncertainties” is introduced in order to show that the human dimensions of uncertainty include suprise, values, taboos and strategic uses of information that are issues beyond the epistemic differences and technical degrees of imperfect understanding of the world,

Finally, the third section on risk management frames key concepts about insurance, precaution and crisis.

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’. A `pedigree' approach for characterizing the quality of information would involves 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 technologyis linked to the quality and number of independent sources of information. For example, geologic carbon storage has only been studied through experiments, so there is limited information available about large scale implementation. 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.

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. It reflects the degree of consensus among experts on the interpretation of the existing data, independent of the number of observations.

Rare events with extreme and/or irreversible outcomes should receive special attention because they are difficult to assess with ordinary statistics. Some geophysical, ecological or social processes exhibit hysteresis, chaos, and positive feedback loops which contradict the assumptions that perturbations are small and independent and that change is continuous. Extreme events also raise an issue regarding the theoretical separation between the probability and the utility of outcomes: 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 constraint is set on the most unfavorable percentile (usually 0.05) of the distribution of outcomes at a given date in the future.

Some risks and uncertainties can be expected to increase or decrease with time. In a sequential decision making process, when one expects to be better informed in the near future, it is important that early choices preserve some flexibility so that future decisions can adapt. Commiting too early to irreversible options destroys the value of future information (see the section on decision making). Finally, it is also important to distinguish uncertainties that involve human and social processes from those that do not: Games of strategy play differently from games of chance. Most energy and environmental policies involve group decision making and collective actions. Socially constructed uncertainty by and about other group members is unavoidable. Yet, many risk assessment and forecasting models assume probabilistic risks and neglect strategic game-theoretic response.

2.4.3 How is risk and uncertainty measured?

This section explores answers to the question « where do the probability numbers come from ? ». This leads to a short discussion of the different philosophical stands on “the foundations of statistics”. Note that this section, along with the sections on decision-making and costs, only frames the issue. The actual assessment of the literature on uncertainty analysis methods in integrated assessment models is to be found in Chapter 3 of this report.

Where do probability numbers come from? The classical answer is that mathematical probability theory is founded on the notion of equiprobability. Equiprobability is a mathematical idealization of physical situations of perfect symmetry. But in practical applications involving probabilities, the numbers rarely come from such ideal models. Instead, there is a variety of procedures for measuring levels of uncertainty:

Frequentist approaches determine the level of probability by observation of relative frequencies. This works best when a statistically significant body of historical observations is available. On the other hand, when there is a low amount of evidence (a small number of observations, missing data, or correlation between experiments), the accuracy of numbers that are determined by relative frequencies is low.

Personal approaches involve asking people to directly quantify their strength of opinion 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. Personal strength of opinons are what neuroeconomists observe on their brain-scan machines when they study experimentally human decision making under uncertainty.

Subjective approaches are 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. Many constructed experiments about public decisions that are related to technological choice and environmental issues have been conducted.

Different viewpoints on the relative merits of the approached mentioned above lead to a variety of philosophical schools on "the foundations of statistics". The most obvious division existsbetween the objective and the bayesian views on probability. Objective probabilities are seen as a physical entity, defined as using a frequentist approach. Bayesian probabilities are seen as degrees of beliefs, defined on the basis of subjective or personal approaches.

An important distinction is often made between situations when information can legitimately be represented using precise probabilities, and situations where the information is imprecise. This distinction is elaborated upon in the section on missing, incomplete or imperfect data. As an example of imprecise information, consider for example the chance of drawing a black marble from a bag containing 100 marbles, knowing that only between 30 and 60 marbles are black.

Imprecision can occur in both the frequentist and the bayesian settings, when the sample size is small, when experts are uncertain or when the bid/ask spread is large (in a subjective market-based setting).

A growing body of empirical and theoretical literature in Economics and Psychology question the view that only precise probabilities are useful. The literature emphasises the fundamental distinction between situations with and without well-founded precise probabilites. The former are called cases of Risk, and opposed to cases of Uncertainty. Under uncertainty, there are theoretical and practical alternatives to the standard decision-making criteria based on the maximisation of expected utility (also called the Rational Actor Paradigm). These alternatives do not assume that it is always coherent or even possible to optimize expected utility.

2.4.4 How is risk and uncertainty communicated in the IPCC ?

Dealing effectively with the communication of risk and uncertainty is an important goal for the IPCC. This section examines the previous reports' record on the matter, and the steps taken to improve it.

Communicating about risk and uncertainty is difficult for several reasons. As discussed above, uncertainty is multi-dimensional and there are different practical and philosophical approaches to it. There are also terminology issues. Words such as "risk", "uncertainty" and "probabilities" are used with very different meanings by different communities of practice. Meanings of the word risk include probability levels, consequences, and expected values. In the theoretical literature, one point of contention is whether "uncertainty" should be used exclusively or inclusively, i.e. if "risk" should be considered a kind of "uncertainty". There is also a frequent verbal confusion between a general kind of uncertainty and the mathematical formalism appropriate to describe it, for example between vagueness and fuzzy logic.

In IPCC assessment reports, an effort is made to enhance consistency in the treatment of uncertainties. This is not only by leading a reflexive inquiry on the treatments of uncertainties in its reports (IPCC TAR WG II 2.6 and the text below), but also through an explicit report-wide coordination effort.

As for the reflexive inquiry, IPCC Third Assessment Report did discuss uncertainties related to climate impacts (TAR WG I 13.5, WG I 10.2, WG II 1.5.1), as well as those related to mitigation costs (TAR WG II 1.5.2, WG III 7.4.3.1, 10.1.2.1). The « uncertainty explosion » effect arising from the composition of uncertainties along the causal chain is described in this report, figure 3.23 and was previously discussed in (TAR WG II 2.6.4, WG I 5.4.2, 8.5.4.3, WG I 9.2.2.4, WG II 3.5.5, WG III 2.4.3). Methods to describe uncertainties were presented in (TAR WG III 7.3.6, WG II 3.6.6.3, 2.5.4, WG I 13.5), and those related to decision making in (TAR WG II 2.7, WG III 1.2.4, 10.1.4.1).

However, the actual application of this framework differed across the various IPCC working groups and chapters within the groups. The common guidelines to describe levels of confidence in the Third Assessment Report elaborated by Moss and Schneider (2000) 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 fourth 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. The guidance notes suggest to:

- Use a systematic typology of uncertainties such as the simple one reproduced Table 2.4.4.
- Use the vocabulary described in Table 2.4.5 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 2.4.5 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, describe uncertainties using Table 2.4.6 or 2.4.7. These tables offer a calibrated langage to translate quantitative levels of confidence or likelihood.
- Within the Working Group III, it was noted that stages of development of a technology correlate with degrees of certainty. Vocabulary on stages of technology development is discussed.

2.4.5 Kinds of uncertainties: a typology

Many typologies have been proposed in the literature based on the multiple dimensions of uncertainty. Different classifications are possible since there is some unavoidable arbitrariness in choosing which criteria is more fundamental than another. Any classification is founded in the concept of ideal classes, whereas real life situations of uncertainty may exhibit several aspects belonging to different classes.

The following discussion cconsiders three kinds of uncertainty. First, we examine uncertainties that result from the imperfect understanding of the world by an ideal observer, from randomness to structural uncertainty. Secondly, we examine epistemic uncertainty such as the provisory nature of scientific theories, incompleteness and some deeper issues with inference. Thirdly, we examine the human dimensions of uncertainty: surprise, metaphysical issues, taboos and strategic use of information.

2.4.6 Missing, incomplete or imperfect data

This section refers to situations of uncertainty that do not involve the will of other agents. It can be illustrated by the classical metaphor of statistics: drawing a colored marble from a bag containing 100 such marbles. The different kinds of uncertainty are ordered by increasing imprecision, that is from situations of more information about the bag to situations of less information.

Randomness: The composition of the bag is known, so there is a well founded probability distribution. For example, assuming an unchanged climate, the potential annual supply of wind, sun or hydro power in a given area is a statistically known variable. In situations of randomness, the standard expected utility theory gives a strong theoretical justification to cost-benefit analysis.

Scientific predictions are not always deterministic. This is not only caused be the fundamental indeterminacy in quantum theory, but also arrives since even deterministic systems can follow chaotic dynamics: the imperfect knowledge about the present state of the world may limit the ability of science to provide predictions at the relevant timescale given. For example, the best available socio-economic description of the consequences of most mitigation measures are very likely not a deterministic model, because the global society is a complex system that may be very sensitive to initial conditions. In other words, small perturbations possibly lead to large changes in the human response to the climate issue.

Possibility: The list of outcomes is known, and there is an upper bound on the number of some colors. For example, the bag contains three colors, less than 30 black, less than 60 red and less than 100 white marbles. Ha-Duong (2003) argued that possibility theory (Dubois et al. 1998) is more relevant than probability to quantify the plausibility of far-distant futures (see also Box 2.4.1 on the SRES scenario controversies). Stating a possibility level amounts to state an upper bound on the admissible probability of a future, knowing on the other hand that the lower bound is infinitesimal (for example, because there is an infinity of futures that could happen).

Box 2.4.1. *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 quantiles 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

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. This generalizes both kinds of uncertainty above. An extreme case would be that nothing is known about the proportion of each color in the bag. However, less unspecific statements could be made that still leave deep uncertainty about the drawing's outcome. For example: the bag contains between 30 and 60 black marbles, and the other marbles are white, so that *p*(black) is between 0.3 and 0.6.

Imprecise probability theory suggests to represent such deep uncertainty using a set of equally admissible probabilities. The notion 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 go back somehow to the real-valued expected utility. The second type of criteria, discussed for example in Bewley (1986 and 2002) and Walley (1991), disgards 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.

Kriegler (2005) made an integrated assessment of climate change using imprecise probabilities and concluded that it was very unlikely that the warming in the 21st century would remain below 2 °C in the absence of policy intervention. Moreover, he found that it would require a very stringent stabilisation level of around 450 ppm CO2 equivalent in the atmosphere to obtain a non-negligible value for the lower probability of limiting the warming to 2 °C.

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, given the full spectrum of colors the number of 'dark' marbles would better be represented using a fuzzy number. While fuzzy modeling could potentially be used to integrate experts' knowledge with precise quantitative informations, major integrated assessment models of energy and climate problems have not used much these techniques so far.

Recognizing the unavoidability of the natural language vagueness, the guidance note to IPCC authors is explicit that categories defined in the tables 2.4.6 and 2.4.7 should be considered as having “fuzzy” boundaries. 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 things that can not be talked about in a given frame of reference, such as concepts missing from a language, variables not included in a formal model, or relationships between variables that are not known. There would be structural uncertainty in the bag example if the list of possible colors was not completely known. A way to deal with structural uncertainty is to recognize that propositions are always implicitly dependant on the context. This outlines the importance of clearly stating assumptions, systems definitions and limits considered.

2.4.7 The nature of scientific knowledge

This section introduces a few basic concepts of Epistemology, which is the discussion of the nature and the limits of scientific knowledge : rationalism, empiricism, the provisional nature of scientific theories, and the problem of induction.

Two of the most fundamental epistemological attitudes are Rationalism and Empiricism. Rationalism holds that some ideas or concepts are independent of experience and that some truth is known by reason and logic alone. Empiricism holds that knowledge depends foremost on evidence. Empiricism is central to experimental sciences, and remains a component in most modern philosophies of science. This approach suggests that theories are provisional at best, and argue that scientific attitude is to be ready to adjust the worldview based on new empirical data. Scientific truth is not unquestionable in the sense of theology or ideology (that point of view could be called scientism).

Thus, it is expected that at times new experimental results will shed doubt on established theories. The consequence is that the progress of science sometimes increases, rather than decreases uncertainty. Schlesinger and Andronova (2005, fig. 3) suggest that the 95% confidence interval for climate sensitivity enlarged in the 60s and the 70s, apparently as the result of a temperature oscillation over the North Atlantic Ocean.

An issue with scientific empiricism is that for any set of observations, it's generally the case that several alternative theoretical explanations are possible. Tensions on the oil market, for example, could be explained equally well by long-term reserve exhaustion (the peak oil explanation) or by a conjectural underinvestment in exploration due to a cycle of low oil prices. A pragmatic answer to this is to see scientific activity as essentially a model-building activity, where the goal of models is to represent the environment without looking at perfect full knowledge. The preferred theory is the one that explains most of the available observations « relative to others », that is the theory that makes predictions that maximally simplify problem-solving.

This working of science can be problematic for policy making. Before closure, there can not be probability distributions on the various theories. It's difficult to know when normal scientific controversies are over, since there is a qualitative human dimension to the process of finding scientific truth. And even after closure, it remains that the valid alternative explanations are still compatible with the observations and can be picked up to defend minority views; or new explanations may be introduced to explain future observations.

As science is about making general rules from specific observations, it is subject to the fundamental problem of induction: how many specific cases are needed to infer a general pattern? The problem of induction is a major source of epistemic uncertainty in situations with limited data. In this IPCC report, it was left to the chapter writing teams to determine what constitutes « much evidence » versus « limited evidence » in Table 2.4.5, with the additional constraint to avoid trivializing statements just to increase their confidence.

The problem of induction is philosophically and mathematically not solved. In particular, scientific inquiries cannot be based solely on formal logic as most people learn it, because that logic is only deductive (see Box 2.4.2). The most influential scientific approach to use induction is Bayesianism.

When limited to precise probabilities, it does not resolve the deeper kinds of uncertainties discussed above, such as the difference between an even chance and no information.

Box 2.4.2. *Epistemic uncertainty and kinds of logical inference*

Inference is usually classified in three kinds: *deductive*, *inductive* and *abductive*.

Deductive inference derives a specific result from general premises (A implies B, A holds, therefore B). It is the safest way to make a conclusion. Example: Increasing the CO_2 concentration increases radiative forcing, this planet's CO_2 concentration has increased, therefore this planet's radiative forcing has increased. A weakness in deductive inference is that it depends on *ceteris paribus* conditions. For example, the demand curve concept for normal goods suggests that a higher price leads to a lower demand. If one observes a higher price of oil, can deductive infererence be used to conclude that the oil consumption declines ? In fact it is quite possible that the quantity used increases too, because there are other factors (i.e. the supply curve) that affect the equilibrium level.

Inductive inference learns general rules from specific cases. Induction is less powerful that deduction, as the truth of the premises make it only likely that the conclusion is also true. Example: The historical rate of decrease in energy intensity per unit of value appears to have averaged about 1 percent per year since the mid-nineteenth century, therefore it is reasonable to include an autonomous rate of energy efficiency improvement in energy policy models.

Abductive inference allows one to learn a general hypothesis by observing a particular case using a general rule (A causes B, observing B, therefore suspecting A). This is also known as the « detective logic ». It is even weaker than the previous kinds of inference, as it runs contrary to deduction. Example: There is coral bleach all over the world. Global climatic change would explain that better than anything else. Therefore, there (probably) is global climatic change.

2.4.8 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 behaviors 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, social upheaval affecting oil prices or GHG emissions, or abrupt change to a cooler climatic trend. 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, or critical utility function parameters with respect to risk, time and equity. While these cannot be judged to be true or false they can have bearing on both behaviour and environmental policymaking. See the section on Decision Making (in 2.3.3).

Taboos are what people must not know or even inquire about (Smithson 1988, p. 8). These actively created areas of uncertainty exist in any social group. The IPCC community is no exception. Since IPCC's purpose is to assess the science only, aspects outside the scientific sphere (artistic, cultural, military or political developments, to name a few) which also influence climate policymaking are not discussed. There are also some issues that a purely academic or a purely political body in principle could consider, but which fall outside the IPCC mandate due to specific co-constructions between science and policy in some areas.

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. The following aspects of strategic uncertainty have been recognized as important in the literature.

Adverse selection is a consequence of uncertainty that degrades the quality of the participants in a market. Adverse buyers selection occurs in insurance markets : agents who know they have a higher risk will buy more insurance than those who have a below-average risk. This yields insurance pools with disproportionately high risk members, raising premiums and eroding the value of insurance. The classical example of adverse sellers selection is the used cars market described by Akerlof (1970): owners of good cars will be more likely to keep them for themselves. This leads to a vicious situation in which buyers presume that most used cars are bad ("lemons"), which may depress the price to the point where good car owners are not interested to sell at all.

Moral hazard occurs when the presence of a contract can affect the behaviour of one or more parties (Mirrlees 1999). For example in the insurance industry, coverage of a loss may increase the risk-taking of the insured. Wiener (1999) argued that because global environmental agreements occur in a participatory framework, subsidies to attract participation can yield high costs with some policy instruments.

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.

The literature on the interaction between risk, deep uncertainty and the free riding problem suggests that strategic use of uncertainty is not always negative. Na and Shin (1998) and others argued that in some cases, reaching an agreement may be easier under a "veil of uncertainty". Cooperation is more likely to emerge ex-ante, before uncertainty is resolved, than ex-post, because more agents potentially gain from the agreement before the uncertainty is resolved.

2.4.9 Techniques for dealing with risks and uncertainty

Given the multi-dimensionality of risk and uncertainty discussed above, this section is not restricted to the statistically known risks which are adequately described by probabilities. It also includes less precisely known deep, structural or human related uncertainties. This is the usual meaning of the word `risk' in risk management. Godard et al. (2002, p. 21) argued that the governance of these deep uncertainties rests on three pillars: precaution, large-scale insurance, and crisis prevention and management.

2.4.9.1 Precaution

To frame the discussions on precaution, three key points have to be considered first.

First, 'precaution' is frequently distinguished from 'prevention' by stating that the later relates to statistically known precise risks (there is a well founded probability distribution), while the former relates to deep uncertainties.

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.

In the context of deep uncertainty 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. Hunyadi (2004) frames the issue by defining three schools:

The **imperative of responsibility** school. von Hans Jonas (1979) writes that “Care for the future of mankind is the overruling duty of collective human action in the age of a technical civilization that has become ‘almighty’, if not in its productive then at least in its destructive potential. ... We live in an apocalyptic situation, that is, under the threat of a universal catastrophe if we let things take their present course. ... The danger derives from the excessive dimensions of the scientific-technological-industrial civilization. ... ”

The **prudential** school emphasizes proportionality over catastrophism, and reminds that there is no such thing as zero risk. For example, the European Commission (CEC, 2000) stresses that measures based on the precautionary principle should be proportional to the chosen level of protection and be based on an examination of the potential benefits and costs. Finding the correct balance requires a structured decision making process with detailed scientific and other objective information.

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.

The precautionary principle is a component of contemporary international law's doctrine. The UNFCCC, for example, explicitly mentions precaution. From a scientific perspective however, the concept of precaution is thus subject to a plurality of interpretations. In particular, there is no consistent formal definition of precautionary decision-making in the scientific literature.

2.4.10 Insurance

During the 1998-2004 period, insured property losses due to extreme weather events have continued to increase (see also WGII 7.2). Swiss Re (2005) states that : ...with insurance claims of around USD 42 billion, 2004 will go down as one of the most expensive in recent history. By way of comparison: in 1992, losses adjusted for inflation were in the region of USD 38 billion (including Hurricane Andrew); in 2001 they reached USD 37 billion (including the 11 September terrorist attack); and in 1999, they totalled USD 36 billion (including the Lothar and Martin winter storms). Thus 2004 reinforces the trend towards higher losses, which can be attributed in part to rising population densities and value concentrations as well as to the growing urbanisation of exposed areas.

A major share of the risk of catastrophes is born by 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 PCS 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.

2.4.11 Crisis

When precaution and insurance do not succeed, the social response to risk is not likely to grow linearly over time. There are phases of under concern, but also phases of over concerns and strong political demands. The social amplification of issues may lead to crises that rush decisions towards unwise choices or block climate change mitigation innovations, such the CO2 sequestration experiment off the shores of Hawaï that was rejected by local communities. After defining kinds of crises, this section highlights a few known crisis management pitfalls.

Quarantelli (2005) argues that there are different scales of crisis: emergency, disaster, and catastrophe. They can be distinguished as follows: An emergency, like a downed electric pylon, does not require intervention from outside. In a disaster, like a national blackout or the 2003 heat wave in Europe, the physical and institutional support infrastructure of the impacted communities remain active. In a catastrophe, they are destroyed.

These three scales of crisis require qualitatively different planning because they are structurally different. For an organisation, a disaster is structurally different from a technical emergency, in the four following ways: in a disaster, organisations have to relate with groups they may not be familiar with, they must adjust to losing part of their autonomy, to different performance standards, and to a thinner public/private boundary (there can be requisitions for the common good).

A growing body of knowledge from a stream of literature connected with research in international relations, sociology and management sciences, suggests that there are indeed some regularities in the dynamics of crises, beyond the fundamental remark that the gravity of difficulties is a direct function of the lack of individual and collective preparation. Known pitfalls, which are not limited to risk communication, include:

Denial: Early detection and mobilisation are critical, but bureaucracies naturally tend to fall back into defensive negation. This may prevent early action or limit it to reactively engaging the necessary first emergency responses. Literature suggests that early action should proactively search for information and establish a journal to keep the history of replies to the crisis.

Trust loss: While it may be tempting in the short run to try to reinsure and assert that things are under control, or to delay explanations until things are well understood, it is dangerously counterproductive. While it is important to demonstrate seriousness (that someone at the top is in charge) and to recognize the existence of the problem, it is also essential to acknowledge the other stakeholders with a special attention to some groups such as the victims or the professionals implied in the response.

Defer to the experts: Experts are there to give some insights, but they are not used to working under pressure, and given that decisions always have many facets, it is up to the decision-maker to conduct the ultimate integrated assessment. Policymakers' relation with experts often need to be clarified: in many cases the best experts can do is to state precisely their uncertainty and shoot down false solutions rather than offer an optimal response within the political time constraints.

Social dynamics issues: Confusion and groupthink are common organisational pitfalls for human groups in a crisis situation. The former has the advantage of being comfortable for each individual member since nobody is responsible. The later allies an illusion of invulnerability, faith into the group's own morality, closed loop thinking with disconnection from reality.

To a lesser extent, climate change and policy modeling teams around the world interact, and views and estimates tend to become anchored to previous versions or values. In order to mitigate this issue, IPCC guidance notes to the authors warn them that there is a tendency for a group to converge on an expressed view and become overconfident with that. They ask that authors try to recognize when individual views adjust as a result of group discussion, and to allow adequate time for such changes in viewpoint to be reviewed.

In conclusion, whether they involve windmills, nuclear plants, power lines or pipelines, most actions related to climate change mitigation have intrinsic uncertainties and may lead to local or national crisis. As a reply it is not given to the actors to choose between precaution, insurance and crisis management. The situation is more complex, since climate change is but a slow part of global change, and mitigation is inextricably linked with other human activities such as finance, health, energy or transportation.

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

2.5.1 Introduction

The section introduces costs and benefit concepts and their relationship to other decision-making frameworks. It also covers major cost determinants such as discount rates, market efficiency, transaction and implementation costs, ancillary and joint costs, valuation of non-market impacts, and valuation techniques. Concepts of GHG emission mitigation costs and mitigation potential are also covered, and specific definitions are given, which provides the framework for the detailed reporting of cost results that are included in Chapters 3-11 of this report. Closely related with this section is the section on decision-making, policy instruments and implementation.

2.5.2 Definitions

Mitigation costs can be measured at the, 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, post-Keynesian econometric models, and Integrated Assessment Models (IAMs), among others.

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

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 practice, it can be difficult to determine the proper shadow princes since these relate to different theoretical states of market functioning that is not currently observable in current market performance. A fuller discussion of shadow pricing is given in Ray (1984) and Squire and van der Tak (1975).

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.

2.5.3 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 includes the preservation of irreplacable, unique, and vital natural ecosystems. 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 recognised that a number of climate change impacts involve some assets like health, biodiversity, and intergenerational impacts that cannot be captured 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 to 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. This formula is based on the Arrow-Pratt approximation of the risk premium combined with a relative risk aversion (Pratt, 1964). It is widely accepted that the representative consumer of our economy has a degree of risk aversion between two and four (Drèze, 1981).

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) shows how a sophisticated interpretation of the Precautionary Principle is compatible with general economic principles in general, and with cost-benefit analyses in particular.

When faced with choices involving consequences with ambiguous probabilities, as in the Ellsberg (1961) game, it is observed that most people tend to express preferences in favour of choices involving the least ambiguous probability distribution of consequences. Gilboa and Schmeidler (1989) have proposed a methodology to tackle with scientific uncertainties. To keep it simple, they suggest to bias the probabilities used in the cost-benefit analysis towards the more pessimistic view compatible with scientific knowledge. By how much should we bias our collective beliefs towards pessimist remains a heavily debated question.

Finally, option values should be included in the cost-benefit analysis when (1) waiting before implementing a preventive action is an option, and (2) better information is expected to come in the future. Standard dynamic programming methods can be used to estimate these option values. They require using a description of the possible scenarios for the future.

2.5.4 Major Cost Determinants

A number of factors are critically important as determinants for costs. These 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[3] and

[3] 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

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, WG III SAR and TAR.

2.5.4.1 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 lead 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) □, and a factor □that reflects the elasticity of marginal utility to changes in consumption. SAR presented a formula linking the socially efficient discount rate *r* to the rate of growth of GDP per capita *g*:

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

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, parameter   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   =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.

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 investments, whereby conceptually funds can be invested in projects that earn such returns, with the proceeds being used to increase the consumption for future generations.

This descriptive approach proposes a simple arbitrage argument to recommend the use of a real risk-free rate as the discount rate. This 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 house-

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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.

holds' 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 (Dimson et al., 2000), 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 trade. Second, financial markets do not offer liquid riskless assets for time horizons exceeding 30 years, which implies that the interest rates for most maturities relevant for the 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 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.

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 to use 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 (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 compatible with the important literature on the term structure of interest rates, as initiated by Vasicek (1977) and Cox, Ingersoll and Ross (1985).

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.

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, which typically need to be considerably higher to justify the project, potentially between 10% and 25%.

2.5.4.2 Market Efficiency

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. If climate change mitigation policies promote the introduction of new technologies, the financial cost and implementation requirements depend on institutional issues, capital markets, information, human capacity etc. Serious limitations in such enabling factors will tend to increase the mitigation costs.

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.

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

- **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 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). 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 noregrets 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 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.

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

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.

2.5.4.3 Transaction and Implementation Costs

In practice, the implementation of climate change mitigation policies requires some transaction and implementation cost. The implementation costs relates 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, as shown in table 2.4.5.3.

[INSERT **Table 2.4.5.3** here]

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 as listed in Table 2.4.5.3.

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.

2.5.4.4 Ancillary and Joint Costs and Benefits

Policies aimed at mitigating GHGs, as stated earlier, can yield other indirect social benefits and costs (herein called ancillary 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 indirect impacts on GHG emissions. So 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 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. A broad application of the concepts then brings studies of ancillary and joint impacts close to the approaches considered in section 2.2 on sustainable development, where Millennium Development Goals and other chosen indicators of sustainable development are discussed as integrated components of climate change mitigation 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).

2.5.4.5 Issues Related to the Valuation of Non-Market Impacts

A basic problem in climate change studies is that a number of impacts are involved that go beyond the scope of what is reflected in current market systems. 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 difficult “valuation” issues surrounding the various climate change impacts that are beyond market sectors include several sub-aspects such as irreversibility of impacts, unique values related to natural and historical heritage, loss of livelihoods of indigenous populations, human health and mortality, and other impacts on assets that cannot be substituted. Some studies have suggested to handle issues related to abrupt change and irreversible impacts by specifying constraints as safe minimum standards in climate change studies, which for example in the “safe landing” analytical approach have been addressed as targets for maximum decadal change in temperature or atmospheric GHG concentrations (Toth, 2004).

Issues related to natural and historical heritage have been considered in economic valuation studies (Navrud and Ready, 2002). In particular valuation of non-substitutable unique values constitute difficulties, as for example if values are sought applied to historical monuments with a past and future lifetime of thousands of years.

Other limitations in the application of monetary values to these impacts are related to specific practical and ethical issues related to valuation of human life 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.

It is a particular problem that health impacts from climate change as well as from many other environmental impacts typically are asymmetrical in a way where the polluter and the "victim" are very separate. It is expected that poor people in developing countries will be particularly vulnerable to climate change due to their dependence on natural assets and a weak coping capacity, and this implies that an assessment of the costs and benefits of climate change mitigation policies will involve comparison of the costs of mitigation in various countries with the impacts of avoided climate change including poor peoples livelihoods.

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).

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. 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).

2.5.4.6 Valuation Techniques

External effects that occur beyond markets can be valued with indirect valuation methods. Values have to be inferred from individual decisions in related markets or from indirectly elicited as through questionnaires on willingness to pay (WTP) for environmental goods. In the WTP approaches the welfare estimates both take care of the income effect and substitution effect of changes in specific environmental goods. An alternative approach is the willingness to accept (WTA) that estimates the welfare changes arriving from substitution between different goods without taking income changes by environmental externalities into consideration. In this way the WTP will imply higher welfare loss estimates related to environmental externalities than WTA.

An argument for using WTP approaches rather than WTA can be that WTP recognises the right of individuals to enjoy specific environmental qualities as for example clean air and a climate that do not change too much from the current state.

Values of environmental goods are broadly divided into use values and non-use values. Use values result from some direct or indirect use of the environment, while non-use values arise when individuals have a WTP or WTA due to the option value of using the environmental good or just the existence of the good as such.

Various techniques can be used to elicit values for environmental goods that are related to use values. The hedonic method values external effects based on statistical surveys of markets that are related to environmental assets. The value of nature for example can be studied based on differences in property prices between houses located near attractive areas compared with the prices of houses in other areas. Another commonly used approach is the travel cost method, where consumers value of a specific areas is assessed based on the time and travel cost they are willing to spend on getting to the location.

The approach of the contingent valuation method is to ask people directly about how much they are willing to pay for the provision of a particular environmental good including use values as well as non use values. Since the method is not based on revealed preferences, contingent valuation might incur various biases from strategic answers to lack of information. The literature has extensively addressed how to understand and reduce these biases.

2.5.5 Mitigation Potentials and Related Costs

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 intransparencies 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 CO2-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 \$0 per tonne of CO2- 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.

2.5.5.1 Definitions of barriers, opportunities and potentials

The terms proposed 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[4]. It is based on private unit costs and discount rates, as they appear in the base year and as they are expected to change in the absence of any additional policies and measures. In other words, as in the TAR, market potential is the conventional assessment of the mitigation potential at current market price, with all barriers, hidden costs, etc in place. The baseline is usually historical emissions or model projections assuming zero social cost of carbon and no additional mitigation policies.

However, if action is taken to improve the 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"**[5] 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[6]. 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[7] for particu-

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[4] 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.

[5] 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.

[6] 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.

[7] 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)

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.

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 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).

The implementation of climate change mitigation policies will involve the use of various economic instruments, information efforts, technical standards, and other policies and measures. Such policy efforts will all have impacts on consumer preferences and taste as well as on technological innovations. The policy efforts in the short term can be considered as an implementation cost, and can also 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.

2.5.6 Overview of Major Input Assumptions

The major assumptions in energy sector mitigation analysis are shown in Table 2.5.6, which is a further development of table 7.4 from IPCC TAR WG3 (2001).

[INSERT **Table 2.5.6** here]

2.6 Mitigation, Vulnerability and Adaptation Relationships

2.6.1 Introduction

This section outlines a framework for how mitigation and adaptation options can be looked at in an integrated way, and discusses the relationship between specific mitigation and adaptation policies, and the more general framework conditions for implementing policies. These framework conditions can be addressed in terms of adaptive and mitigative capacities that reflect the institutional structure and the social conditions of society for curbing with climate change.

The relationship between climate change of mitigation and adaptation is discussed in the context of key vulnerabilities and the aim of Article 2 of the UNFCCC to avoid dangerous anthropogenic interference with the climate system. Uncertainty and short term vulnerabilities are here recognized as important issues to address in integrated studies of mitigation and adaptation.

The section finally, presents a number of case examples of integrated mitigation and adaptation policies including biomass options, cooling demand, renewable energy, infrastructure, and agricultural options.

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

The TAR of the IPCC 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 capital assets and 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 consider 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 capital assets 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 on 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.

The only areas, where there might be major differences in the character of the adaptive and mitigative capacity are 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. Adaptation and mitigation policies here can be assumed to be more individual policy efforts such as investments in protective measure like dikes, new crops, low carbon emitting technologies, carbon taxes etc, that are implemented given the institutional structure of the society and the state of nature (see also a discussion about the relationship between capacities and policies in the sustainable development section).

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 thereby also depends on a number of key characteristics of the socio-economic system such as economic growth patterns, technology, population, governance, and environmental priorities. 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 will depend on 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.

It is important to recognize that it is complicated to project the future role of institutional and social capital aspects[8], despite these are major determinants for the costs and effectiveness of climate policies. This is the case because institutional and social capacities only manifest themselves in relation to policy implementation processes as such, and this is also the case why studies of social capital typically address experiences from the past. Another complexity in relation to addressing institutional issues and social capital is the "public good" character of the capacity. Social and human capitals render general benefits to the whole society, and cannot be singled out as separate components that can be measured as a cost in relation to the implementation of specific policies. These complexities also partly explain, why the concepts of adaptive and mitigative capacity have only been implemented in very few studies, so the literature is in a very preliminary state.

2.6.3 Mitigation and Adaptation, and Key Vulnerabilities

The UNFCCC provides the legal framework conditions for mitigation and adaptation policies in its Articles 2 and 4: Article 2 of the UNFCCC states that "The ultimate objective …is to achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." Further Article 4, 2. a of the UNFCCC states that Annex I parties "shall adopt national policies and take corresponding measures on the mitigation of climate change by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs."

These general statements have not yet been developed into more precise definitions of what *dangerous* anthropogenic interference means or what would be a *sufficient timeframe* to allow adaptation of human, social and natural systems. These issues are both major subjects of climate negotiations and of the scientific literature. A basic common understanding is here, that mitigation as well as adaptation will be part of a climate change policy portfolio due to the time lags of the climate system and the inherent uncertainties surrounding the issues and the decision making processes.

The discussion about the mitigation and adaptation policy portfolio has a global- and a national/regional dimension. It must be recognised 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.

In relation to the global dimension, 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

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8 The same limitations characterise the more general literature on sustainable development, where studies of social and human capital are still not as well developed and operational as studies of manmade and natural capital.

outcomes, including impacts that remain highly uncertain like surprises and other climate irreversibilities 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 to deal with this uncertainty by combining economic analysis and precautionary principle and discusses three different precautionary principles including an insurance premium system, hedging strategies, and inclusion of low-probability events in risk assessment. It is concluded that, cost benefit analysis should be supplemented with values that take care of climate change uncertainty and goes beyond risk aversion parameters.

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 actual development of national adaptation strategies in developing countries, NAPAS is supported by GEF and a guidebook for these is the UNDP Adaptation Policy Frameworks for Climate Change (UNDP, 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 experiences with climate variability and extremes, economic and non-economic damages and the distribution of these.
- Expected trends in variability and extremes.
- Adaptation policies as a coping strategy against vulnerability and potential barriers and obstacles.
- The role of public policies and different stakeholders.

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). This conclusion is supported by the UNFCCC Article 3.2 that states that "The specific needs and special circumstances of developing country Parties especially those that are particularly vulnerable to adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration."

The UNFCCC negotiations have implied that a Special Climate Change Fund (SCCF) was adopted in December 2003 and guidelines for the management of this fund is currently being developed by GEF (GEF, 2004a). Adaptation will have a top priority of this fund together with technology transfer and associated capacity building activities. The specific scope of the SCCF is defined as a sort of a complementary system to the GEF Trust Fund. The GEF Council guidelines state that "The SCCF may be called upon to support climate change adaptation activities that generate benefits by alleviating barriers to development caused by the effects of climate change and which may be primarily local benefits whereas the GEF Trust Fund may be called upon to support adaptation activities primarily linked to producing global environmental benefits through its various focal areas." (GEF 2004a, p. 11). In this way, the GEF defines the SCCF to be in particular oriented towards adaptation options with a strong national development component.

A more detailed GEF document on assistance to adaptation elaborates more on the linkages between general development policies, and climate change vulnerabilities and adaptation (GEF, 2004b). It is emphasized that adaptation should be mainstreamed into development planning and that linkages between adaptation and sustainable development should be addressed at local, sectoral, national, regional, and global level, which both include references to national development plans and to global challenges like the Millennium Development Goals.

2.6.4 Examples of Interactions between Climate Change, Adaptation and Mitigation

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, highlight *what* measures they are already taking for a climate friendly development and *how* to design integrated climate policies that can go hand in hand with national sustainable development paths (SAINC, 2003; IINC, 2004; BINC, 2004; CINC, 2004; MOST, 2004).

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). However, climate policy sets, which include both options - mitigation and adaptation, still receive little attention within the planning process of national sustainable development agendas in many countries. This could be due to the perception that commonalities are small, jurisdictions are different, and the costs and benefits are differentially distributed.

There are some specific national studies that highlight these linkages (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, and unmanaged ecosystems
- Heating and cooling degree days
- Renewable energy potential
- Infrastructure
- Agriculture.

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 useful 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. At the same time climate change will influence 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 and environmentally sound, is determined 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).

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).

Huge investments are being committed in new infrastructure projects in developing countries. Development of infrastructure enhances the scope of utilizing underemployed resources, and supports industrialisation and trade. Following that, infrastructure development will also be a major driver for GHG emissions and mitigation policies. However, climate change impacts can be important in the planning of infrastructures since they are long-life assets that traditionally are designed to withstand normal variability in climate regime. The recent incidents of cyclones on 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. A bi-directional impact matrix that includes the impact of project on the environment as well as impact of environmental changes on the project is proposed.

The likely damages to long-life assets and dependent economic activities from climate change could be enormous in particularly if these issues have not been given proper attention in the original design of the activities. The damages can be mitigated by integrating climate change impacts in the overall assessment of investment decisions and design of infrastructure projects and by developing insurance markets for spreading the risks of extreme climate impacts.

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. 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.

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.

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

2.7.1 Introduction

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 involve intra generational as well as intergenerational dimensions. In the short term the issue of particular interest is the distributions of mitigation costs among individuals and nations, while in the longer term more and more climate change impacts will occur and the distributional issues need to address how damages face different individuals and nations. Climate change has a very asymmetric character, both in terms of the present distribution of GHG emissions and of

Comment: **Why do short term impacts have intergenerational effects?**

the distribution 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. From a short-term perspective, mitigation is constrained by the existing capital stock, infrastructure, and the institutional framework of technology implementation. A time profile for mitigation that requires early retirement of capital stock increases the costs of achieving any target (IPCC, 2001b, WGIII, Chapter 8).

Comment: What asymmetry are we getting at?

All together, climate change therefore has very important equity dimensions, and the application of different equity approaches has major implications on policy recommendations and on the distribution of costs and benefits of climate policies.

2.7.2 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[9]. Likewise, income distribution as 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[10]. Although a great deal has been written in recent years on the components of well-being, the development literature has been slow to adopt wider measures of this concept, especially as far as equity in well-being is concerned.

Probably the most important and forceful critic of the traditional measures 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 measures 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. Rather than synthesising 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 2.7.2[11] 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.

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

[10] 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.

[11] 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.

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.

[INSERT **Table 2.7.2**. here]

This wider analysis of equity has important implications for assessing the impacts of climate change (see Chapter 1 of this report for a more detailed discussion about climate change impacts and the reference to the UNFCCC Article 2). As is well known, these impacts 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.
Africa is an example of a continent that is expected to suffer particularly from climate change. The under-developed state of African economies exposes the continent to extreme climate related events such as droughts and floods and their attendant consequences such as famine, diseases, infrastructure damages, loss of economic opportunities and livelihoods, etc. Moreover, the majority of the populations in Africa still live on less than US$1 per day (UNDP, 2003b). With the frequency and intensity of extreme weather related events presently being experienced, Africa's development opportunity will be even further compromised, making it difficult for the region to achieve the United Nations Millennium Development Goals (MDGs), the objectives of the New Partnership for Africa's Development (NEPAD) as well as the United Nations World Summit on Sustainable Development - Johannesburg Plan of Implementation (UNWSSD-JPI).

Table 2.7.3 summarises the likely effects on equity as measured across this wider set of indicators. As the table shows, climate change will raise inequality in most dimensions both between countries and within a country, which is also in line with the conclusions of the TAR of the IPCC (2001a; 2001; 2002). Particularly significant will be the effects on health and economic and social security. In addition to these equity dimensions, there will also be significant intergenerational issues since the impacts of climate change occur over very long time horizons. The time dimension is discussed in more details in Section 2.7.5.

[INSERT **Table 2.7.3** here]

2.7.3 Uncertainty as a Frame for Distributional and Equity Aspects

Uncertainty in relation to climate change has implications for equity through several channels. First is the effect of not knowing how able future generations will be to cope with climate change, and what kinds of impacts they will have to cope with. We discuss this in section 2.7.5, where the time dimension of equity is analyzed. Second, the effects of climate change risks depend on the wealth of the agent that is influenced by future climate change as well as by costs of climate change mitigation policies. Finally, specific equity issues arise related to increased climate variability and extreme events.

It does not take a lot of study to realise that if climate change increases the frequency of extreme events, the impact will be felt more acutely by the poor and vulnerable than by the rich. Adaptation and coping actions do exist, some of which are in the nature of public goods – they benefit everybody in the community – but others are in the nature of private goods, such as insurance, relocation etc. Those who are living close to subsistence often do not have the means to undertake private coping measures, thus reducing their capabilities. The following are some pathways by which the poor are more affected by uncertainty

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 appropriate 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.

Of course, no society need accept such a situation, and measures can be taken to address these unfavourable impacts on equity. These are discussed further in Section 2.7.6 below.

2.7.4 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?

Comment: The discussion of Sen does not provide us with a rule for ranking different situations with respect to equity.

The traditional economic approach to social justice has been based on utilitarianism, in which a policy was considered to be socially just if no other policy or action was feasible that yielded a higher aggregate utility for society. This required 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 in the aggregate utility function.

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 computed. The option with the highest net benefit is the most desirable[12]. If utilities are proportional to money benefits and 'disutilities' proportional to money costs this method amounts to choosing to maximise utilities. Since most economists accept that this proportionality does not hold, they extend the CBA by (a) weighting costs or benefits by a factor that reflects the relationship between utility and income of the person receiving that cost or benefit, or (b) 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. For details of these methods in the context of climate change, see Markandya and Halsnaes (2002).

An alternative approach to social justice that has existed for at least as long as the utilitarian approach (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[13]. 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 this right.

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 well-being of its worst-off member. At the other end of the political spectrum, Nozick and the modern libertarians contend that personal liberties and property rights have (with very few exceptions) absolute precedence over objectives such as the reduction of poverty and deprivation (Nozick, 1974).
More recently some ethical philosophers have found fault with both the 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 to 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 is 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

[12] This is massively simplified, ignoring the time dimension and market imperfections in valuing costs and benefits but the principle remains valid.
[13] For a discussion of this debate in an economic context, see Phelps, 19XX.

comparisons than utilitarianism, since it does not suggest to aggregate all individuals and suggest to present information both on the capability set available to individuals and their actual achievements.

What implications does this debate have in the context of climate change? An example of a right based approach in this context could be to determinate a sort of a threshold value for temperature change taking probabilities into consideration. Passing this value will result in economic compensations to particularly vulnerable countries. In accordance with a utilitarian approach it could be argued that countries should be compensated based on an estimate of the aggregate economic welfare lost. The capability based approach in contrast could argue for both taking the loss of freedom and opportunities, and the actual economic welfare impact into consideration.

In practice societies do not 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 ‘efficient’ solution and one that recognizes such rights. Much of the political and philosophical debate is about what rights are valid in this context – a debate which shows little signs of resolution. In terms of 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 approaches eco-centric approaches assign inherit 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 to specify the value of nature in way, where they be addressed as specific constraints that are to be respected beyond what is reflect in estimates of costs and benefits and other social impacts.

2.7.5 The Time Dimension

In climate change policy a central question is how much action should be taken now, to avoid or reduce impacts on future generations, and a key variable in making such decisions is the discount rate[14]. The higher the rate applied in CBA or other decision-making tools, the lower will be the value attached to future damages and the fewer will be the actions taken today. Hence intergenerational equity is substantially a question of what discount rate to adopt. Substantially but not exclusively, as we will argue below.

The climate change literature has discussed the discount rate extensively (IPCC, 1996; Portney and Weyant, 1999; Weitzman, 2001, 2004) and is also covered in the cost section of this chapter. Hence the discussion here is limited to the issues raised in the context of the distributional and equity issues raised in this section.

[14] See also a broader discussion in Chapter 10 of the IPCC WGIII, TAR (IPCC, 2001) about the time dimension and equity, including issues related to the allocation of emission allowances over time and scale.

The discount rate adopted is partly justified on the grounds of economic growth making future generations better off and hence also more able to cope with the impacts of climate change. But sustained growth over hundreds of years has not been historically observed. At best the growth experience of the industrialised world has encompassed the last two hundred years and there is no guarantee that this will continue over the next two hundred. Hence a conservative view would adopt a 'zero growth' scenario over the long term, which would imply much lower discount rates than those traditionally used in policy-making.

Second there is the uncertainty about climate change impacts. The range of possible impacts is very large; at the lower end they could probably be addressed by future generations with modest cost, but at the upper end they would mean disaster for those alive fifty or one hundred years from now. This uncertainty implies that some risk aversion should be built into the decision-making criteria and only the present generation can do that – it will be too late for future generations to accommodate such risks. This, however, argues for increasing the expected damages in the future by a 'risk premium' rather than 'adjusting' with the discount rate.

Finally, there is the point raised in the previous section about 'rights' as opposed to utilities. Although intergenerational equity is substantially a question of the discount rate it should not be solely viewed in that light. Based on the wider concepts of social justice governments may well take the view that it is unethical to impose certain impacts on future generations and override the decisions based on discount rates. How and when this is justified, however, still needs to be discussed and formalised.

2.7.6 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 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. An example is the Brazilian Contraction and Convergence proposals. The contraction and convergence proposal talks of reducing GHG emissions to a level that stabilises concentrations in the atmosphere at a scientifically agreed safe level, converging GHG emissions entitlements to an equal per capita distribution with a globally agreed timeframe, establishing a global market in tradeable emissions entitlements which would promote efficiency, transfer of resources to poor countries whose emissions quotas exceed their needs and creating sustainable livelihoods through international cooperation, capacity building and transferring of low carbon technologies. The Brazilian proposal refers not to GHG emissions per se, but to contributions to temperature increases, noting that different levels of GHG emissions should result in differentiated responsibilities for future GHG emission reductions.

Comment: I am not sure I have interpreted this correctly. In any case the original was confusing.

The equity debate has major implications for how we 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). On a utilitarian basis, assuming declining marginal utility, the case for the richer countries undertaking more of the burden is strong – they are the ones to whom the opportunity cost of such actions would have less welfare implications. However, assuming constant marginal utility, one could 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.

On 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 natural justice would suggest equal allocation to all human beings. 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 industrialised countries, although now, as emissions in the developing world increased, they, too, would have to undertake some emissions reductions.

As far as adaptation measures are concerned, we have already noted how the major part of these will fall on developing countries. Again a utilitarian approach would compare the costs of mitigation and the costs of adaptation, and if concerns are taken about the responsibility of climate change due to past emissions, it will suggest that the industrialised countries provide them with assistance in meeting these costs and there is no reason, except perhaps under an extreme libertarian view, that such transfers would not be justified under the rights approaches to social justice[15].

The literature includes a number of comparative studies on equity 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 addresses 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 far out in the future. The issue is rather to agree on an acceptable "fairness harmonisation procedure" where an emission allocation initially is chosen and compensation payments are negotiated once the costs and benefits actually occur.

Rose et al, 1998 provides reasons for 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 will to be fair. Second, appeal to global economic efficiency is not enough to get countries together due to the large disparities in current welfare and the costs and benefits of climate change among countries.

Comment: Why does this make equity an important consideration?

Studies that focuses on the net costs of climate change mitigation policies versus the benefits of avoided climate change give a major emphasis to policy consequences, while libertarian oriented

Comment: Better explain what consequential studies are – this is ont a generally understood term.

[15] Even libertarians such as Nozick accept that individual entitlements though property rights may be overridden if necessary to prevent 'catastrophic moral horrors' (see Sen, 1999). Where possible, however, the libertarian view would prefer such transfers to be made by individuals acting in their private capacity, rather than through governments. The recent Tsunami disaster indicates that private contributions to disasters can be significant. The problem is that contributions for preventive purposes are much less substantial and it is preventive action that need to make up the bulk of the response to climate change.

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 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.

Right 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 emission 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, but there is no consensus in the literature about which ones that are superior with regard to specific moral criteria.

A particular difficulty in the establishment of international agreements about emission allocation rules is, that the application of equity in this way ex ante 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 asses the consequences of accepting given emission allocation rules and make it difficult to balance emission allocations against climate damages suffered in different parts of the world (Panayotou et al., 2002).

An emerging literature suggests to build equity rules for international climate change policies from legal principles in international or domestic laws. Tol and Verheyen, 2004, page 1110 state that the Rio Declaration in line with other international laws includes a "no-harm rule" that implies that states have their sovereign right to exploit their natural resources and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment or other States or of areas beyond the limits of national jurisdiction. The international climate change agreements as yet developed do not include any compensation mechanisms or other legal measures that cope with failures to meet these principles.

Many countries have adopted domestic laws that in a similar way include legal principles to apply to environmental externalities. Examples of this include urban air pollution control mechanisms in India. Most environmental legislation in India is based on active State intervention to preserve, protect and improve the environment. Some important acts related to protection of air pollution are Air (Prevention and control of pollution) Act (1981), Environment (Protection) Act (1986), and Public Liability Insurance Act (1991) (IINC, 2004). The Supreme Court of India, responding to a public interest litigation on deteriorating urban air quality in Delhi, ruled in favor of compulsory phasing out of diesel use for public transport. Consequently compressed natural gas (CNG) was introduced as the fuel for public transport by 2001 in Delhi due to legal intervention at the highest level, reducing GHG and local pollutant emissions. Subsequently, the Indian Government came out with the Auto Fuel Policy (Mashelkar et al., 2002) and CNG has now been introduced in Mumbai as well. Legal interventions have also resulted in drastic lowering of sulfur contents in diesel used for road transportation.

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. When equity based arguments are used in this way, rights based equity arguments become very similar to utilitarian based reasoning, where the consequences on stakeholders are the dominant concern.

Comment: I could not understand this.

Vaillancourt and Waaub, 2004 suggest to design emission allocation criteria on the basis of the invitation of different decision makers to select and weigh equity principles for emission allocations and use these as inputs to a multi-criteria approach. The criteria included spans 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).

2.7.7 Economic Efficiency and Eventual Tradeoffs with Equity

The literature over more than a decade has included 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 promoted by the market system.

In practice, however, 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. 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), and issues related to the uncertainty of future baseline emissions in countries that makes it difficult to ensure environmental effectiveness (hot air).

Bohn and Carlen, 2002 suggest to overcome difficulties related to the construction of a broad international emission market, where developing countries are given equity based compensations in the form of large emission permits, by offering financial compensations to the countries instead of large emission quota. It is concluded that the financial transfers are more attractive to developing countries than emission quotas since the transfers offer an economic benefit that is more certain than emission quotas.

2.7.8 Legal Issues Including Liability and Compensation Aspects

The ultimate objective of the UNFCCC is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Developed countries possess financial and technological resources required in order to mitigate climate change. These resources are not at the disposal of developing countries, and suggestions have therefore been forwarded about including legal clauses in climate change agreements that will ensure compensation for damages incurred by GHG emissions from industrialised countries.

The Financial Services of the United Nations Environment Programme (UNEP) estimates that the extra economic costs of disasters attributed to climate change have been running at more than US$300 billion from 1991 to 2000. The insurance industry is therefore facing very hard times and are of the opinion that climate change may bankrupt the industry (Simms, 2001). Development groups are of the opinion that climate change could cost developing countries up to US$9 trillion over the next 20 years, several times the anticipated international aid flows.

Comment: Is this an estimate of costs today? It seems unlikely….

With the prospects of developing countries looking so bleak, deteriorating terms of trade, share of development aid nearly halved during the 1990s and Foreign Direct Investment mainly focusing on natural resource exploitation, getting resources to tackle climate change seems impossible. It may therefore not be long before the world sees legal issues surrounding climate change coming into reality.

At least some Small Island States are already thinking along these lines. Examples of a successful court case which they may base their litigation on include that of the Canadian smelter plant polluting Washington state in the U.S.A. The court ruling was that states had a duty to protect other states, and that no state had the right to act in a way that might cause injury by fumes to another (Simms, 2001).

Responsibility for climate change and ability to pay would require that industrialised countries should commit significant new resources and technology to help poor countries affected by the increasingly volatile and uncertain global environment instead of waiting until legal and compensation measures are instituted (African Development Bank et al., 2003).

2.8 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 mitigation.

Since climate change is a global common good that originates from long term GHG emissions and accumulated atmospheric GHG concentrations, the resonable unit of analysis is the globe. Thus, for many problems, such as species extinction (that can be considered like common goods with a value to all human beings) or the responses of the earth's climate system to long-lived greenhouse gases, the relevant unit of analysis is the earth.

Climate change studies have used various different regional definitions depending on the character of the problem considered and differences in Methodological approaches. Some regional definitions also follow normative criteria related to officially established geographical units such as towns, provinces, countries, etc.) and two, to apply analytical criteria to design geographical units directly related to the analysed phenomena. Analytical or functional regions are defined according to analytical requirements: functional regions are grouped using physical criteria (e.g., altitude or soil type) or using socio-economic criteria such as per capita income (Duque and Ramos, 2004).

In climate change studies many climate change impact studies traditionally have been related to geographical regions, since climate models are structured to make projections for given areas. When such studies also include the assessment of impacts on specific ecosystems, water systems or landuse activities, the regions in a different way can be defined to included regions in different parts of the world that have similar production activities as for example wheat crop land. 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, 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.

Table 2.8.1 gives examples of some ways of classifying the world into different regions based on the analytical interest of the study. There can 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 some countries continue to dispute their classification (e.g., Turkey). Similarly, the UN Charter determines which countries are permanent members, and General Assembly voting determines which of the countries rotate as non-permanent members. 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 Table also shows ways of classifying the world based on analytic criteria. The first of these is based on 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 developing, developing, economies in transition and developed. While this classification will be by and large accurate, several regions will be mis-classified, e.g., parts of Brazil and China and Qatar. If per-capita income were used to study consumption patters, this should be corrected by the savings rate.
Data availability is a factor that determines what kinds of aggregation are possible. Proxies are used when data are not available. Thus for example, when data on night time light pollution are not available, data on population density may be used as a proxy, which itself is a measure of urbanization. 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.

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.

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.. Similarly, the study of global oil security requires a division of the world into oil producing, exporting and importing countries (all countries are oil consuming).

2.9 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. 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[16]. 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).[17] Both the development of hybrid automobiles automobile engines and the development of internet retailing mechanisms represent technological changes.

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 these costs.

[16] Many frameworks have been developed to simplify this process into a set of discrete phases. A common framework puts forward a sequential process involving the following phases: (1) invention (first demonstration of a novel concept or idea), innovation (first market introduction of these ideas), niche markets (initial, small-scale applications of an innovation), and, finally, diffusion (widespread adoption)

[17] 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).

2.9.1 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 there exists no single "silver bullet" or "backstop" technology that can solve the emissions mitigation problem, so the issue is not one of identifying singular technologies, but rather ensembles, or portfolios of technologies. These technologies have interdependencies and cross-enhancement ("spillover") potentials, which adds another important element of uncertainty into the analysis. Despite these problems of uncertainty and ignorance, insights are available from multiple fields.

Extensive literature surveys on the importance of technological change on the extent of possible climate change and on feasibility and costs of climate policies are provided by Clarke and Weyant (2002), Grubb et al. (2002), Grübler et al. (1999), 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 IMCP model inter-comparison project (Edenhofer et al., 2005) 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.

2.9.1.1 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 (Gross World Product or GWP). By 2100, GWP is the largest influencing component variable compared to the two technology indicators, but when combined, the two technology can surpass GWP 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 an illustration based on the SRES-A1 scenarios cf. Figure 2.9.2 below). For instance, GETS (2001) and Edmonds et al. (1997) 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. 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) (cf. also Figure 2.9.2 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 2.9.1), provided a systematic exploration of all 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). 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 casts both doubts on the plausibility of central tendency technology and emissions scenarios as well as the customary assumption that low emission futures are inevitable more costly than 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.

[INSERT **Figure 2.9.1** here]

2.9.1.2 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 cased 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. 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 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.

Given the infancy of attempts to model in detail various 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. The impact of these various influencing factors is illustrated in Figure 2.9.2 below.

[INSERT **Figure 2.9.2** here]

Figure 2.9.2 illustrates the importance of technological change assumptions in both reference and mitigation scenarios for an illustrative 550 ppmv concentration target based on four SRES scenarios. Actual projected scenario values in the original SRES no-climate policy scenarios are compared to a hypothetical case with frozen 1990 structures and technologies for both energy supply and end-use. The difference (denoted by a grey shaded area in Figure 2.9.2) illustrates the impact of technological change leading to improved efficiency and "decarbonization" in energy systems, already incorporated into the baseline emission scenario (cf. discussion in Section 2.9.1.1. above). The impacts of technological options leading to emission reductions is illustrated by colour shaded areas in Figure 2.9.2 regrouped into three categories: demand reductions (e.g. through deployment of more efficient end-use technologies such as lighting or vehicles), fuel switching (substitution of high GHG emitting technologies by low- or zero-emitting technologies such as renewables or nuclear), and finally, carbon capture and sequestration technologies. The mix in the mitigative technology portfolio required to reduce emissions from the reference scenario level to that consistent with the illustrative 550 ppmv stabilization target varies as a function of the baseline scenario underlying the model calculations (shown in Figure 2.9.2) as well with the degree of stringency of the stabilization target adopted (not shown in Figure 2.9.2). An interesting finding from a large number of modeling studies is that scenarios with higher degrees of technology diversification (e.g. scenario A1B in Figure 2.9.2) also lead to a higher degree of flexibility with respect of meeting alternative climate (e.g. stabilization) targets and generally also to lower overall costs compared to less diversified technology scenarios (cf. Figure 2.9.4 below).

2.9.1.3 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.[18] Assuming 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 2.9.3 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 2.9.3), 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 (cf. Figure 2.9.4 below). 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. 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.

[INSERT **Figure 2.9.3** here]

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

[18] 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 factor 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.

technological change is dominated by experience (learning) curve effects, show that the social cost of stabilizing GHG concentrations could in the range of a few tenths of a percent or even lower, 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[19] 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 social costs of a given scenario as the stringency of the ultimate climate stabilization target chosen (cf. Figure 2.9.4).

[INSERT **Figure 2.9.4** here]

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). 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 study reported by Philibert and Podkanski (2005) based on the IEA (2004) World Energy Outlook also confirms this conclusion, highlighting in addition the differential investment patterns entailed by alternative technological pathways.[20] 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.

[19] 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.

[20] The “alternative scenario” reviewed by Philibert and Podkanski (2005), 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).

2.9.1.4 Value of technology calculations

Model calculations also enable economists to quantify the value of improved technologies as illustrated for two technologies in Figure 2.9.5.

[INSERT **Figure 2.9.5** here]

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[21]). (A detailed review of the multitude of sources of technological change including above mentioned effects is provided in Chapter 11 of this assessment).

Generally, economic benefits from improved technology increase non-linearly with: a) the distance to current economic characteristics (or the ones assumed to be characteristic of the scenario baseline), b) the stringency of environmental targets, as well as c) the comprehensiveness and diversity of a particular technology portfolio considered in the analysis. Thus, the larger the distance between future technology characteristics compared to current ones, the lower the stabilization target, and the more comprehensive the suite of available technologies (as illustrated by the various carbon capture and sequestration options analyzed in Figure 2.9.5), the larger will be the economic value of improvements in technology.

These results lend further credence to technology R&D and deployment incentives policies as "hedging" strategies addressing climate change. However, given the current insufficient understanding of the complexity of driving forces underlying technological innovation and cost improvements, cost-benefit or economic "return on investment" calculations have to date not been attempted in the literature, due at least in part to a paucity of empirical technology-specific data on R&D and niche market deployment expenditures and the deep uncertainties involved in linking "inputs" (R&D and market stimulation costs) to "outputs" (technology improvements and cost reductions).

2.9.2 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.

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[21] 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.

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 U.S. 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.

2.9.2.1 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 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. Applied R&D focuses on the improvement of specific, well-defined technologies (e.g., fuel cells). Fundamental research focuses on broader and more fundamental areas of understanding. Fundamental research may be mission oriented (e.g., fundamental biological research 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.

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 coordination, 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, 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 limit 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).

Box 2.9.1 *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.

2.9.2.2 Empirical Evidence

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" model that incorporates both R&D and cumulative production volume as drivers of technological advance (see, for example, Kouvaritakis et al., 2000). Soderholm & Sundqvist (2003) concluded that “the problem of omitted variable bias needs to be taken seriously”.

More broadly, these studies, along with related theoretical work, suggest the need for further exploration of the drivers of advance and more interactive 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). Further, there are difficulties that arise largely because of the absence of public and private sector technology specific R&D statistics and also due to significant co-linearity and auto-correlation of parameters (e.g. Miketa and Schrattenholzer, 2004). Hence, while modelling paradigms such as two-factor learning curves are valuable methodological steps on the modelling front, they remain largely exploratory.

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 & 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, the 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).

2.9.2.3 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.

Several factors must be considered prominently with respect to this process (Flannery & Khesghi, 2005). These include:

> First, the lengthy timescale for deployment of advanced energy technologies.
>
> Second, the range of barriers that 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
- Regulatory compliance
- Environmental impacts.

A weakest link paradigm exists in the context of technology penetration: all of these conditions can be considered necessary conditions. 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.[22]

2.9.2.4 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 or adoption subsidies.

[INSERT **Figure 2.9.6** here]

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. 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

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

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, Newell, Stavins, 2004).

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 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, support for the concept 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, Newell and Stavins, 2004). 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 (GETS, 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” [cite] 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 CO2 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 migbt be required.

2.9.2.5 Modelling technology development and diffusion

There have been substantial additions to the literature since the TAR in the modelling of endogenous and induced technological change across all sectors of the economy in the context of reducing GHG emissions, with an edited book (Grübler et al, 2002) and four special issues of journals addressing the topic (Resource and Energy Economics, see Heal, 2003; Energy Economics, see Weyant 2004; Ecological Economics, see Herman et al., 2005; and Energy Journal, see Weyant, 2006). Further reviews and studies have been done by Grubb et al. (2002), Goulder (2004), Barker, et al, (2006), One feature that emerges from the studies is the great variety in the treatment of technological change and its relationship with economic growth. Figure 2.11.3.1 from Edenhofer et al. (2005) in the International Modelling Comparison Project (IMCP) lists the treatment relating to technological change in energy and carbon intensities in other areas in 13 models covering a wide range of approaches. (The GDP cost and carbon-price estimates of stabilisation from these models are discussed in section 11.4).

2.9.3 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, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies."

Technology transfer is particularly relevant because developing countries have made their enthusiastic participation in the Convention partly contingent upon technology transfer. 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 (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. This definition of technology transfer was 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.

The historical legacy of top-down technology focussed development has been one of failure (IPCC, 2000, p. 22). 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 oragnization 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 2.9.7 shows one attempt to create a framework for technology transfer. In all forms technology transfer, especially across countries, at least six characteristics are important. These are:

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

We discuss each in turn.

[INSERT **Figure 2.9.7** here]

2.9.3.1 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.

2.9.3.2 The enabling (or disabling) environment in the country of origin

The environment in the country of origin can also 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), only one pertained to the environment in the countries of origin - a “reluctance to identify and make available ESTs that are in the public domain.” 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).

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.

2.9.3.3 The conditions of the transfer

Whereas spillovers in referred to unintended technology transfer, most technology is transferred in such a way so that the originators also benefit from the transfer. The conditions of the transfer will primarily depend on the pathway of transfer, as mentioned in section 2.9.3. 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.

2.9.3.4 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.

2.9.3.5 The enabling (or disabling) environment in the host country

Of the 22 barriers listed in the IPCC Report (IPCC, 2000, p. 19) 21 barriers pertain 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 2.9.3 leads to an equal emphasis on the insufficient human and institutional capacity in the receiving country. The crucial barrier then is the inadequate 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.

2.9.3.6 Post-transfer Value Addition

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)

Finally, we must emphasize that technology transfer is a process of incremental and cumulative learning by which the results of the initial choice are internalised or assimilated. Just like research and development, it is an essential component of social learning (Brooks, 1995).

References

Adger, W.N., 2001a: Social Capital and Climate Change. *Working Paper*, **8**

Adger, W.N., 2001b: Scale of governance and environmental justice for adaptation and mitigation of climate change. *J. Int. Dev*, **13**, pp. 921-931.

African, D.B., A.D. Bank, U.K. Department for International Development, E.C. Directorate-General for Development, G. Federal Ministry for Economic Cooperation and Development, T.N. Ministry of Foreign Affairs - Development Cooperation, O.f.E.C.a. Development, U.N.D. Programme, U.N.E. Programme, and T.W. Bank, 2003: *Poverty and Climate Change. Reducing the Vulnerability of the Poor.*

Agarwal, A., and S. Narain, 1991: *Global Warming in an Unequal World: A case of Ecocolonialism.* Centre for Science and Environment, New Delhi.

Agenda 21, 1992: *The Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests.* Rio de Janerio, Brazil.

Akerlof, G.A., 1970: The market for lemons: Quality uncertainty and the market mechanism. *Quarterly Journal of Economics*, **84**(3), pp. 488-500.

Alberts, W., 1989: The experience curve doctrine reconsidered. *Journal of Marketing*, **53**, pp. 36-49.

Alcamo, J., A. Bouwman, J. Edmonds, A. Grübler, T. Morita, and A. Sugandhy, 1995: An evaluation of the IPCC IS92 emission scenarios. In: *Climate Change 1994: Radiative forcing of climate change and an evaluation of the IPCC IS92 emission scenarios*. Cambridge University Press, Cambridge, pp. 247-304.

Alchian, A., 1963: Reliability of progress curves in airframe production. *Econometrica*, **31**(4), pp. 679-693.

Allen, M., S. Raper, and J. Mitchell, 2001: Uncertainty in the IPCC's third assessment report. *Science*, **293**(July 20), pp. 430-433.

Argote, L., and D. Epple, 1990: Learning curves in manufacturing. *Science*, **247**(4945), pp. 920-924.

Arrow, K., 1962: The Economic Implications of Learning by Doing. *The Review of Economic Studies*, **29**(3), pp. 155-173.

Arrow, K., P. Dasgupta, L. Goulder, G. Daily, P. Ehrlich, G. Heal, S. Levin, K.-G. Mäler, S. Schneider, D. Starret, and B. Walker, 2004: Are We Consuming Too Much? *Journal of Economic Perspectives*, **18**(3), pp. 147-172.

Arrow, K., and Lind, 1970: Uncertainty and the evaluation of public investment decision. *American Economic Review*, **60**, pp. 364-378.

Asquith, N.M., M.T.V. Ríos, and J. Smith, 2002: Can Forest-Protection Carbon Projects Improve Rural Livelihoods? Analysis Of The Noel Kempff Mercado Climate Action Project, Bolivia. *Mitigation And Adaptation Strategies For Global Change*, **7**, pp. 323-337.

Atkinson, G., R. Dubourg, K. Hamilton, M. Munasinghe, D. Pearce, and C. Young, 1997: Measuring Sustainable Development. *Macroeconomics and the Environment*

Australian Industry Commission, 1995: *Research and Development* Australian Government Publishing Service.

Ausubel, J.H., and W.D. Nordhaus, 1983: A Review of Estimates of Future Carbon Dioxide Emissions. In: *Changing Climate*. National Research Council, National Academy of Sciences, National Academy Press, pp. 153-185.

Ballet, J., J.-L. Dubois, and F.-R. Mahieu, 2003: Le développement socialement durable: un moyen d׳int´ger capacities et durabilit□3?. In: *Third Conference on the Capability Approach*, 6-9 September 2003, University of Pavia.

Baloff, N., 1966: The learning curve - some controversial issues. *The Journal of Industrial Economics*, **14**(3), pp. 275-282.

Barker, T., 2003: Representing global, climate change, adaptation and mitigation. *Global Environmental Change*, **13**, pp. 1-6.

Barker, T., H. Pan, J. Koehler, R. Warren, and S. Winne, 2006: Avoiding dangerous climate change by inducing technological progress: Scenarios using a large-scale econometric model. In: *The Met Office Conference on 'Avoiding Dangerous Climate Change'*, February 2005.

Barrett, S., 1994: Self-Enforcing International Environmental Agreements. *Oxford Economic Papers*, **46**, pp. 804-878.

Baumert, K.A., O. Blanchard, S. Llosa, and J. Perkaus, 2002: *Building on the Kyoto Protocol: Options for protecting the climate.* World Resources Institute, Washington DC.

Bay, T., and A. Upmann, 2004: On the Double Dividend under Imperfect Competition. *Environmental and Resource Economics*, **28**(2), pp. 169-194.

Beg, N., J.C. Morlot, O. Davidson, Y. Afrane-Okesse, L. Tyani, F. Denton, Y. Sokona, J.P. Thomas, E.L.L. Rovere, J.K. Parikh, K. Parikh, and A. Rahman, 2002: Linkages between Climate Change and Sustainable Development. *Climate Policy*, **2**(5), pp. 129-144.

Bennett, J., 2000: On values and their estimation. *International Journal of Social Economics*, **27**(7/8/9/10), pp. 980-993.

Bewley, T.F., 1986: Knightian decision theory. *Cowles Foundation Discussion Paper*, **807**(Nov)

Bewley, T.F., 2002: Knightian decision theory - part I. *Decisions in Economics and Finance*, **25**(2), pp. 79-110.

BINC, 2004: Part III, Chapter 1. In: *Brazil's Initial National Communication to UNFCCC.*

Botzler, R.G., and S.J. Armstrong, 1998: *Environmental ethics: Divergence and convergence.* Boston.

Bresnahan, T., and M. Trajtenberg, 1992: *General purpose technologies: engines of growth?* National Bureau of Economic Research.

Bromley, D.W., and J. Paavola, 2002: *Economics, ethics, and environmental policy: Contested choices.* Blackwell, Oxford.

Brooks, H., 1995: Review of C. Freeman: The Economics of Hope- Essays on Technical Change, Economic Growth and the Environment. *Minerva*, **33**(2), pp. 199-203.

Brunnermier, S., and M. Cohen, 2003: Determinants of environmental innovation in us manufacturing industries. *Journal of Environmental Economics and Management*, **45**, pp. 278-293.

Burton, I., S. Huq, B. Lim, O. Pilifosova, and E.L. Shipper, 2002: From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy*, **2**((2-3)), pp. 145-159.

Carraro, C., and D. Siniscalco, 1993: Strategies for the International Protection of the Environment. *Journal of Public Economics*, **52**, pp. 309-328.

Carvalho, G., P. Moutinho, D. Nepstad, L. Mattos, and M. Santilli, 2004: An Amazon Perspective on the Forest-Climate Connection: Opportunity for Climate Mitigation, Conservation and Development? *Environment, Development and Sustainability*, **6**((1-2)), pp. 163-174.

CEC, 2000: *Commission of the European Communities* **-** *Communication from the commission on the precautionary principle.* Brussels.

Chander, P., and H. Tulkens, 1995: A Core-Theoretic Solution for the Design of Cooperative Agreements on Transfrontier Pollution. *International Tax and Public Finance*, **2**, pp. 279-293.

Chander, P., and H. Tulkens, 1997: The Core of an Economy with Multilateral Environmental Externalities. *International Journal of Game Theory*, **26**, pp. 379-401.

Chiroleu-Assouline, M., and M. Fodha, 2005: Double Dividend with Involuntary Unemployment: Efficiency and Intergenerational Equity. *Environmental and Resource Economics*, **31**(4), pp. 389-403.

Christiansson, L., 1995: *Diffusion and learning curves of renewable energy technologies.* International Institute for Applied Systems Analysis.

CINC, 2004: *China's Initial National Communication to UNFCCC.*

Clarke, L.E., and J.P. Weyant, 2002: Modeling induced technological change: An overview. In: *In: Technological Change and the Environment*. RFF Press, Washinton D.C, pp. pp. 320-363.

Cohen, W., and D. Levinthal, 1989: Innovation and learning: The two faces of R&D. *The Economic Journal*, **99**, pp. 569-596.

Cox, J., J. Ingersoll, and S. S. Ross, 1985: A theory of the term structure of interest rates. *Econometrica*, **53**, pp. 385-403.

CSD, 2001: *Indicators of Sustainable Development: Guidelines and methodologies. CSD work programme on Indicators of Sustainable Development 1995-2000.* pp. www.un.org/esa/sustdev/publications/indisd-mg2001.pdf - Text version.

CSD, 2005: *Investing in Development: A Practical Plan to Achieve the Millenium Development Goals.* Eartscan London.

Dang, H.H., A. Michaelowa, and D.D. Tuan, 2003: Synergy of adaptation and mitigation strategies in the context of sustainable development: The case of Vietnam. *Climate Policy*, **3**, pp. S81-S96.

Dasgupta, P., 1993: *An Inquiry into Well-Being and Destitution.* Oxford University Press, New York.

Dasgupta, P., K.-G. Mäler, and S. Barrett, 1999: Intergenerational Equity, Social Discount Rates, and Global Warming: in Portney. In: *In: Discounting and Intergenerational Equity*. Resources for the Future, Washington D.C.

Davidson, O., K. Halsnaes, S. Huq, M. Kok, B. Metz, Y. Sokona, and J. Verhagen, 2003: Development and climate: The Case of Sub-Saharan Africa. *Climate Policy*, **3**(no Suppl. 1), pp. 97-113.

Day, G., and D. Montgomery, 1983: Diagnosing the experience curve. *Journal of Marketing*, **47**, pp. 44-58.

Dessai, S., and M. Hulme, 2004: Does climate adaptation policy need probabilities? *Climate Policy*, **4**, pp. 107-128.

Dessues, S., and D. O' Connor, 2003: Climate Policy without Tears: CGE-Based Anciallary Benefits Estimates for Chile. *Environmental and Resource Economics*, **25**, pp. 287-317.

Dimson, E., P. Marsh, and M. M. Staunton, 2000: *The Millenium book: A century of investment returns.* ABN-AMRO, Londres.

Drèze, J.H., 1981: Inferring Risk Tolerance from Deductibles in Insurance Contracts. *The Geneva Papers*, **6**, pp. 48-52.

Dubois, D., and H. Prade, 1998: Possibility theory: Qualitative and quantitative aspects. In: *Handbook of Defeasible Reasoning and Uncertainty Management Systems*. Kluwer Academic, Dordrecht, pp. 169-226.

Dudek, D., A. Golub, and E. Strukova, 2003: Ancillary Benefits of Reducing Greenhouse Gas Emissions in Transitional Economies. *World Development*, **31**(10), pp. 1759-1769.

Duque, J.C., and R. Ramos, 2004: *Design of Homogeneous Territorial Units: A Methodological Proposal. 44th Congress of the European Regional Science Association.* Porto.

Dutton, J., and A. Thomas, 1984: Treating progress functions as a managerial opportunity. *The Academy of Management Review*, **9**(2), pp. 235-247.

Edenhofer, O., K. Lessmann, C. Kemfert, M. Grubb, and J. Koehler, 2005: Technological Change: Exploring its Implication for the Economics of Stabilisation. Insights from the Innovation Modelling Comparison Project. *The Energy Journal*, **Special Issue**

Edmonds, J., M. Wise, and J. Dooley, 1997: Atmospheric Stabilization and the Role of Energy Technology. In: *Climate Change Policy, Risk Prioritization and U. S. Economic Growth*. American Council for Capital Formation, Washington DC, pp. 71-94.

Edmonds, J.A., 2004: Technology Options for a Long-term Mitigation Response to Climate Change. In: *2004 Earth Technologies Forum*, April 13, Pacific Northwest National Laboratory, Richland, WA.

Ellesberg, D., 2001: *Risk, Ambiguity and Decision*. Routledge.

Ellsberg, D., 1961: Risk, ambiguity, and the Savage axioms. *Quarterly Journal of Economics*, **75**, pp. 643-69.

Eyckmans, J., and M. Finus, 2003: *Coalition Formation in Global Warming Game: How the Design of Protocols Affects the Success of Environmental Treaty-Making*. *Pre-publication draft.*

Faninger, G., 2003: Towards Sustainable Development In Austria: Renewable Energy Contributions. *Mitigation And Adaptation Strategies For Global Change*, **8**, pp. 177-188.

Fearnside, P.M., 2001: The Potential Of Brazil⁄s Forest Sector For Mitigating Globalwarming Under The Kyoto Protocol. *Mitigation And Adaptation Strategies For Global Change*, **6**, pp. 355-372.

Finus, M., 2002: New Developments in Coalition Theory: An Application to the Case of Global Pollution. In: *The International Dimension of Environmental Policy*. Kluwer, Dordrecht, Holland

Flannery, B.P., and H.S. Khesghi, 2005: An industry perspective on successful development and global commercialization of innovative technologies for GHG mitigation. In: *Intergovernmental Panel on Climate Change Workshop on Industry Technology Development, Transfer and Diffusion*, September 2004, Tokyo.

Foxon, T.J., 2003: *Inducing innovation for a low-carbon future: Drivers, barriers and policies.* The Carbon Trust, London.

Freeman, C., 1994: The economics of technological change. *Cambridge Journal of Economics*, **18**, pp. 463-514.

GEF, 2004: *Annual Report 2004: Producing Results for the Global Environment.* Global Environment Facility, Washington D.C.

GEF, 2004a: *Programming to Implement the Guidance for the Special Climate Change Fund Adopted by the Conference of the Parties to the United Nations Framework Convention on Climate Change at its Ninth Session.*

GEF, 2004b: *GEF Assistance to Address Adaptation.*

Germain, M., P.L. Toint, and H. Tulkens, 1998: Financial Transfers to Sustain Cooperative International Optimality in Stock Pollutant Abatement. In: *Sustainability and Firms: Technological Change and the Changing Regulatory Environment*. Edward Elgar, Cheltenham, UK, pp. 205-219.

Germain, M., P.L. Toint, H. Tulkens, and A.d. Zeeuw, 2003: Transfers to Sustain Core Theoretic Cooperation in International Stock Pollutant Control. *Journal of Economic Dynamics & Control*, **28**, pp. 79-99.

GETS, 2001: *Addressing Climate Change: An Initial Report of an International Public-Private Collaboration.* Battelle Memorial Institute, Washinton, D.C.

Ghemawat, P., 1985: Building strategy on the experience curve. *Harvard Business Review*, pp. 143-149.

Gielen, D., and C.H. Chen, 2001: The CO2 emission reduction benefits of Chinese energy policies and environmental policies: A case study for Shanghai, period 1995-2020. *Ecological Economics*, **39**(2), pp. 257-270.

Gilboa, I., and D. Schmeidler, 1989: Maximin expected utility with non-unique prior. *Journal of Mathematical Economics*, **18**, pp. 141, 153.

Godard, O., C. Henry, P. Lagadec, and E. Michel-Kerjan, 2002: Trait□3? des nouveaux risques. Précaution, crise, assurance. *Folio Actuel*, **100**

Gollier, C., 2001: Should we beware of the precautionary principle? *Economic Policy*, **16**, pp. 301-328.

Gollier, C., 2002a: Discounting an uncertain future. *Journal of Public Economics*, **85**, pp. 149-166.

Gollier, C., 2002b: Time horizon and the discount rate. *Journal of Economic Theory*, **107**, pp. 463-473.

Gollier, C., 2004: *The consumption-based determinants of the term structure of discount rates, mimeo*. University of Toulouse.

Goulder, L., and S. Schneider, 1999: Induced technological change and the attractiveness of CO_2 abatement policies. *Resource and Energy Economics*, **21**, pp. 211-253.

Goulder, L.H., 2004: Induced Technological Change and Climate Policy. *The Pew Center*

Graham, J.D., and J.B. Wiener (eds.), 1995: *Risk Versus Risk: Tradeoffs in Protecting Health and the Environment. Vol. I 'Fundamentals'*. Harvard University Press.

Griliches, Z., 1958: Research Costs and Social Returns: Hybrid Corn and Related Innovations. *Journal of Political Economy*, **66**, pp. 419-431.

Griliches, Z., 1992: The search for R&D spillovers. *Scandinavian Journal of Economics*, **94**, pp. 29-47. Supplement.

Gritsevskyi, A., and N. Nakicenovic, 2000: Modeling uncertainty of induced technological change. *Energy Policy*, **28**(13), pp. 907-921.

Grubb, M., 2005: Technology Innovation and Climate Change policy: An overview of issues and options. *Keio Journal of Economics*, **In press**

Grubb, M., J. Köhler, and D. Anderson, 2002: Induced Technical Change In Energy And Environmental Modeling: Analytic Approaches and Policy Implications. *Annual Review of Energy and Environment*, **27**, pp. 271-308.

Grubler, A., 1998: *Technology and Global Change*. Cambridge University Press, Cambridge.

Grübler, A., N. Nakicenovic, and W.D. Nordhaus (eds.), 2002: *Technological Change and the Environment*. Washington, DC.

Grübler, A., N. Nakicenovic, and D.G. Victor, 1999: Dynamics of energy technologies and global change. *Energy Policy*, **27**, pp. 247-280.

Ha-Duong, M., 2003: Imprecise probability bridge scenario-forecast gap. In: *Annual Meeting of the International Energy Workshop*, 24-26 June, EMF/IEA/IIASA, Laxenburg, Austria.

Halsnæs, K., 2002: A review of the Literature on Climate Change and Sustainable development. In: *Climate Change and Sustainable Development*. Earthscan. 10, 9 ed.

Halsnæs, K., 2005: *Perspectives on Future Climate Change Cooperation* Draft paper for Nordic Council of Ministers.

Halsnæs, K., and A. Markandya, 2002: Analytical approaches for decision-making, sustainable development and greenhouse gas emission-reduction policies. In: *Climate change and sustainable development. Prospects for developing countries*. Earthscan Publications Ltd., London, pp. 129-162.

Halsnæs, K., and A. Olhoff., 2005: International Markets for Greenhouse Gas Emission Reduction Policies - Possibilities for Integrating Developing Countries. *Energy Policy*, **Forthcoming**

Halsnæs, K., and J. Verhagen, 2005: Development Based Climate Change Adaptation and Mitigation - Conceptual Issues and Lessons Learned in Studies in Developing Countries. *Mitigation and Adaptation Journal*, **Forthcoming**

Harris, J., J. Anderson, and W. Shafron, 2000: Investment in energy efficiency: a survey of Australian firms. *Energy Policy*, **28 (2000)**, pp. 867-876.

Heal, G., 1998: *Valuing the Future: Economic Theory and Sustainability*. Columbia University Press, New York.

Heal, G., 2003: Special Issue. *Resource and Energy Economics*, **25**(1), pp. 1-126.

Heller, T., and P.R. Shukla, 2003: *Development and Climate: Engaging Developing Countries*. Pew Centre on Global Climate Change, Arlington, USA.

Herman, R.J., T. Vollebergha, and C. Kemfert, 2005: Special Issue on Technological Change and the Environment - Technological Change. *Ecological Economics*, **54**(2-3), pp. 133-346.

Hirsch, W., 1952: Manufacturing progress functions. *The Review of Economics and Statistics*, **34**(2), pp. 143-155.

Hirsch, W., 1956: Firm progress ratios. *Econometrica*, **24**(2), pp. 136-143.

Hoel, M., and K. Schneider, 1997: Incentives to Participate in an International Environmental Agreement. *Environmental and Resource Economics*, **9**, pp. 153-170.

Hoffert, M.I., K. Caldeira, G. Benford, D.R. Criswell, C. Green, H. Herzog, A.K. Jain, H.S.

Kheshgi, K.S. Lackner, J.S. Lewis, H.D. Lightfoot, W. Manheimer, J.C. Mankins, M.E. Mauel, L.J. Perkins, M.E. Schlesinger, T. Volk, and T.M.L. Wigley, 2002: Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet. *Science*, **298**, pp. 981-987.

Hunyadi, M., 2004: La logique du raisonnement de pr?ecaution. Revue europ?eenne des sciences sociales. *Cahiers Vilfredo Pareto*, **XLII**(130), pp. 9-33.

Huq, S., 2002: The Bonn-Marrakech agreements on funding. *Climate Policy*, **2**, pp. 243-246.

IEA, 2000: *Experience Curves for Energy Technology Policy.* International Energy agency, Paris.

IEA, 2004: *World Energy Outlook.* International Energy Agency, Paris.

IINC, 2004: *India's Initial National Communication to UNFCCC, Chapter 6.*

IPCC, 1996: *Climate Change 1995: Economic and Social Dimensions of Climate Change.* Cambridge University Press, Cambridge.

IPCC, 2000: *IPCC Special Report on Methodological and Technological Issues on Technology Transfer.* Cambridge University Press, Cambridge.

IPCC, 2001: *Climate Change 2001: Mitigation* **-** *Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge.

IPCC, 2001a: *Climate Change 2001: Impacts, Adaptation and Vulnerability* **-** *Contribution of Working Group II to the Third Assessment Report of Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge.

IPCC, 2002: *Synthesis Report: Contributions of Working Group I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* Cambridge University Press, Cambridge.

IPCC, 2005: *Guidance notes for lead authors of the IPCC Fourth Assessment Report on addressing uncertainties.* Intergovernmental panel on Climate Change - Working Group III, Technical Support Unit.

IPIECA, 1995: *Technology Cooperation and Capacity Building: The Oil Industry Experience.* IPIECA and UNEP, London.

Irwin, D.A., and P.J. Klenow, 1994: Learning-by-doing spillovers in the semiconductor industry. *Journal of Political Economy*, **102(6)**, pp. 1200-1227.

Jaffe, A., and K. Palmer, 1996: *Environmental regulation and innovation: A panel data study.* National Bureau of Economic Research.

Jaffe, A., and R. Stavins, 1994a: The Energy Paradox and the Diffusion of Conservation Technology. *Resource and Energy Economics*, **16**(2), pp. 91-122.

Jaffe, A., and R. Stavins, 1994b: The Energy-Efficiency Gap: What Does it Mean? *Energy Policy*, **22**(10), pp. 804-810.

Jaffe, A.B., R.G. Newell, and R.N. Stavins, 2004: A Tale of Two Market Failures: Technology and Environmental Policy. *Resources for the Future*, **Discussion Paper 04-38**

Jonas, v.H.S., 1979: Das Prinzip Verantwortung. Versuch einer Ethik fur die technologische Zivilisation. Insel. The Imperative of Responsibility: In Search of an Ethics for the Technological Age.

Joskow, P., and N. Rose, 1985: The effects of technological change, experience, and environmental regulation on the construction cost of coal-burning generation units. *RAND Journal of Economics*, **16**(1), pp. 1-27.

Jung, T.Y., E.L.L. Rovere, H. Gaj, P.R. Shukla, and D. Zhou, 2000: Structural Changes in Developing Countries and Their Implication to Energy-related CO2 Emissions. *Technological Forecasting and Social Change*, **63**(2-3), pp. 111-136.

Kagan, J., 2002: *Surprise, Uncertainty, and Mental Structures.* Harvard University Press.

Kaitala, V., K.-G. Mäler, and H. Tulkens, 1995: The Acid Rain Game as a Resource Allocation Process with an Application to the International Cooperation among Finland, Russia and Estonia. *Scandinavian Journal of Economics*, **97**, pp. 325-343.

Kapshe, M., P.R. Shukla, and A. Garg, 2003: Climate change impacts on infrastructure and energy systems. In: *In: Climate Change and India: Vulnerability Assessment and Adaptation*. Universities Press (India) Pvt Ltd, Hyderabad

Kates, R.W., 2000: Cautionary tales: adaptation and the global poor. *Climatic Change*, **45**, pp. 5-17.

Keeney, R.L., and H. Raiffa, 1993: *Decisions with Multiple Objectives, Preferences, and Value Tradeoffs.* Cambridge University Press, Cambridge.

Kelly, P.M., and W.N. Adger, 1999: *Assessing Vulnerability to Climate Change and Facilitating Adaptation.* UK.

Klevorick, A., R. Levin, R. Nelson, and S. Winter, 1995: On the sources and significance of interindustry differences in technological opportunities. *Research Policy*, **24**, pp. 185-205.

Knight, F.H., 1921: *Risk, Uncertainty and Profit.* Houghton Mifflin, Boston.

Kouvaritakis, N., A. Soria, and S. Isoard, 2000: Endogenous learning in world post-Kyoto scenarios: Application of the POLES model under adaptive expectations. *International Journal of Global Energy Issues*, **14**(1-4), pp. 222-248.

Kriegler, E., 2005: *Imprecise probability analysis for integrated assessment of climate change*. University of Potsdam, Germany.

Krupnick, A.J., D. Brutraw, and A. Markandya, 2000: *The Ancillary Benefits and Costs of Climate Change Mitigation: A Conceptual Framework. Paper presented to the Expert Workshop on Assessing the Ancillary benefits and Costs of Greenhouse Gas Mitigation Strategies.* Washington D.C.

Krupnick, A.J., K. Harrison, E. Nickell, and M. Toman, 1996: The Value of Health Health Benefits from Ambient Air Quality Improvements in Central and Eastern Europe. *Environmental and Resource Economics*, **7**(4), pp. 307-332.

Kuntz-Duriseti, K., 2004: Evaluating the economic value of the precautionary principle: using cost benefit analysis to place a value on precaution. *Environmental Science and Policy*, **7**, pp. 291-301.

Langrish, J., M. Gibbons, W. Evans, and F. Jevons, 1972: *Wealth from Knowledge: Studies of Innovation in Industry.* MacMillion.

Lanjouw, J., and A. Mody, 1996: Innovation and the international diffusion of environmentally responsive technology. *Research Policy*, **25**, pp. 549-571.

Larson, E.D., W. Zongxin, P. DeLaquil, C. Wenying, and G. Pengfei, 2003: Future implications of China's energy-technology choices. *Energy Policy*, **31 (2003)**, pp. 1189-1204.

Lehtonen, M., 2004: The environmental-social interface of sustainable development: capabilities, social capital, institutions. *Ecological Economics*, **49**, pp. 199-214.

Leimbach, M., 2003: Equity and carbon emission trading: A model analysis. *Energy Policy*, **31**, pp. 1033-1044.

Lieberman, M., 1984: The learning curve and pricing in the chemical processing industries. *Rand Journal of Economics*, **15**(2), pp. 213-228.

Löschel, A., 2002: Technological change in economic models of environmental policy: A survey. *Ecological Economics*, **43**, pp. 105-126.

Manning, M., and M. Petit, 2004: A concept paper for the AR4 cross cutting theme: Uncertainties and risk. In: *IPCC Workshop on Describing Scientic Uncertainties in Climate Change to Support Analysis of Risk and of Options*. National University of Ireland, Maynooth, Co. Kildare, Ireland, pp. 41-56.

Manning, M., M. Petit, D. Easterling, J. Murphy, A. Patwardhan, H.-H. Rogner, R. Swart, and G. Yohe, 2004: *IPCC Workshop on Describing Scientic Uncertainties in Climate Change to Support Analysis of Risk and of Options.* National University of Ireland, Maynooth, Co. Kildare, Ireland.

Markandya, A., 1998: *The Indirect Costs and Benefits of Greenhouse Gas Limitations.* UNEP Collaborating Centre on Energy and Environment. Risø National Laboratory, Denmark.

Markandya, A., and K. Halsnaes, 2002a: *Climate Change and Sustainable Development.* Earthscan, London.

Markandya, A., and K. Halsnaes, 2002b: Developing Countries and Climate Change. In: *In: The Economics of Climate Change*. Routledge(2004)

Markandya, A., K. Halsnæs, P. Mason, and A. Olhoff, 2002: A conceptual framework for analysing climate change in the context of sustainable development. In: *Climate change and sustainable development* **-** *Prospects for developing countries*. Earthscan Publications Ltd., London, pp. 15-48.

Markandya, A., and D.T.G. Rubbelke, 2004: Ancillary benefits of climate policy. *Jahrbucher fur Nationalokonomie un Statistik*, **224 (4)**, pp. 488-503.

Masera, O.R., A.D. Cerón, and A. Ordóñez, 2001: Forestry mitigation Options Formexico: Finding Synergies Between National Sustainable Development Priorities And Global Concerns. *Mitigation and Adaptation Strategies for Global Change*, **6**, pp. 291-312.

Mashelkar, R.A., D.K. Biswas, N.R. Krishnan, O.P. Mathur, R. Natarajan, K.P. Niyati, P.R. Shukla, D.V. Singh, and S. Singhal, 2002: *Report of the Expert Committee on Auto Fuel Policy*. Ministry of Petroleum and Natural Gas, Government of India, New Delhi.

McDonald, A., and L. Schrattenholzer, 2001: Learning rates for energy technologies. *Energy Policy*, **29**, pp. 255-261.

Messner, S., 1997: Endogenized technological learning in an energy systems model. *Journal of Evolutionary Economics*, **7**(3), pp. 291-313.

Miketa, A., and L. Schrattenholzer, 2004: Experiments with a methodology to model the role of R&D expenditures in energy technology learning processes: First results. *Energy Policy*, **32**, pp. 1679-1692.

Mills, E., 2005: Insurance in a climate of change. *Science*, **309(5737)**(August 12), pp. 1040-1044.

Mirrlees, J.A., 1999: The theory of moral hazard and unobservable behaviour: Part I. *The Review of Economic Studies* **-** *Special Issue: Contracts*, **66**(1, January), pp. 3-21.

Montgomery, D., and G. Day, 1985: Experience curves: Evidence, empirical issues, and applications. In: *Strategic Marketing and Management*. John Wiley & Sons

Montgomery, W.D., and A.E. Smith, 2005: Price Quantity and Technology Strategies for Climate Change Policy. *EPRI*, **In press**

Moss, R.H., and S.H. Schneider, 2000: Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In: *Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC.* World Meteorological Organization, Geneva, pp. 33-51.

MOST, 2004: *Clean Development Mechanism in China: Taking a Proactive and Sustainable Approach* Chinese Ministry Of Science And Technology, The Deutsche Gesellschaft für Technische Zusammenarbeit, German Technical Cooperation unit (GTZ) of the Federal Ministry for Economic Cooperation and Development, Swiss State Secretariat for Economic Affairs (SECO), World Bank, and a. others.

Mowery, C., and N. Rosenberg, 1989: *Technology and the Pursuit of Economic Growth.* Cambridge University Press.

Mowery, D., and N. Rosenberg, 1979: The influence of market demand upon innovation: A critical review of some recent studies. *Research Policy*, **8** (2), pp. 102-153.

Müller, B., 2001: Varieties of Distributive Justice in Climate Change. An Editorial Comment. *Climatic Change*, **48 (2001)**, pp. 273-288.

Müller, B., 2002: Equity in climate change: The great divide. *Clime Asia*(COP8 Special Issue)

Munasinghe, M., 2002: The sustainomics trans-diciplinary meta-framework for making development more sustainable: applications to energy issues. *International Journal of Sustainable Development*, **4**(2), pp. 6-54.

Munasinghe, M., and R. Swart, 2005: *Primer on Climate Change and Sustainable Development.* Cambridge University Press, UK.

Murray, B.C., A. Keeler, and W.N. Thurman, 2005: Tax Interaction Effects, Environmental Regulation and ŧRule of Thumb. Adjustments to Social Costs. *Environmental and Resource Economics*, **30**(1), pp. 73-92.

Myers, S., and D. Marquis, 1969: *Successful Industrial Innovation.* National Science Foundation.

Na, S.l., and H.S. Shin, 1998: International environmental agreements under uncertainty. *Oxford Economic Papers*, **50**, pp. 141-170.

Nadiri, M., 1993: *Innovations and technological spillovers.* National Bureau of Economic Research.

Nakicenovic, N., N. Victor, and T. Morita, 1998: Emissions scenario database and review of scenarios. *Mitigation and Adaptation Strategies for Global Change*, **3**, pp. 95-120.

National Energy Technology Laboratory (NETL), undated: *Vision 21 Technology Roadmap*. US Department of Energy.

Navrud, S., and R.C. Ready (eds.), 2002: *Valuing Cultural Heritage. Applying Environmental Valuation Techniques to Historic Buildings, Monuments and Artefacts*. Edward Elgar Publishing Ltd, UK.

Nemet, G., 2005: Beyond the learning curve: factors influencing cost reductions in photovoltaics. *Energy Policy*, **In Press**, pp. corrected proof available online 1 August 2005 at http://www.sciencedirect.com.

NETL, 2004: *Carbon Sequestration Technology Roadmap and Program Plan.* National Energy Technology Laboratory, Pittsburgh, PN.

Newell, R., A. Jae, and R. Stavins, 1998: *The induced innovation hypothesis and energy-saving technological change.*, National Bureau of Economic Research.

Newell, R., and W. Pizer, 2004: Uncertain discount rates in climate policy analysis. *Energy Policy* (32), pp. 519-529.

Nordhaus, W., 2002: Modeling induced innovation in climate-change policy. In: *In: Technological Change and the Environment. Resources for the Future*.

Nordhaus, W.D., 1998: *Do real-output and real-wage measures capture reality? The history of lighting suggests not.* Cowles Foundation, New Haven CT.

Nozick, R., 1974: *Anarchy State and Utopia.* Basic Books, New York. O'Neill, B., and et al., 2003: Planning for Future Energy Resources. *Science*, **300**, pp. 581-582.

OECD, 1998: *OECD environmental performance reviews: Second cycle work plan* OECD Environment Monograph, OCDE/GD, **35(97)**, pp. Paris 67 p.

OECD, 2003: *OECD Environmental Indicators: Development, measurement and use*. *Reference paper*. Paris.

OECD, 2004: *Sustainable Development in OECD Countries: Getting the Policies Right.* Paris.

Ohshita, S.B., and L. Ortolano, 2003: The Influence of Economic Reforms on Cleaner Technology Diffusion in China. *Development and Change*(Special Issue on China Environment and Development)

Oxera, 2002: *A Social Time Preference Rate for Use in long term Discounting* The Office of the Deputy Prime Minister, Department for Transport, and Department of the Environment, and Food and Rural Affairs. UK.

Pacala, S., and R. Socolow, 2004: Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with current technologies. *Science*, **305**, pp. 968-972.

Palacios-Huerta, I., and T. Santos, 2002: A Theory of Markets, Institutions and Endogenous Preferences. *Journal of Public Economics*, **Accepted 8 July**

Panayotou, T., J.F. Sachs, and A.P. Zwane, 2002: Compensation for 'Meaningful Participation' in Climate Change Control: A Modest Proposal and Empirical Analysis. *Journal of Environmental Economics and Management*, **43(2002)**, pp. 437-454.

PC, 2002: *India Vision 2020.* Planning Commission, Government of India, New Delhi.

PCAST, 1999: *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation* The President's Committee of Advisors on Science and Technology: Panel on International Cooperation in Energy Research, Development, Demonstration, and Deployment.

Peet, R., and E. Hartwick, 1999: *Theories of Development.* The Guilford Press, New York.

Phelps, E.S. (ed.), 1973: *Economic Justice* **-** *Selected readings*. Penguin Education, New York.

Philibert, C., and J. Podkanski, 2005: *International Energy Technology Collaboration and Climate Change Mitigation* **-** *Case Study 4: Clean Coal Technologies.* Paris.

Popp, D., 2002: ENTICE: Endogenous technological change in the DICE model of global warming. *Submitted to Journal of Environmental Economics and Management*

Portney, P.R., and J. Weyant (eds.), 1999: *Discounting and Intergenerational Equity*. John Hopkins University Press, Baltimore, MD.

Pratt, J., 1964: Risk aversion in the small and in the large. *Econometrica*, **32**, pp. 122-136.

Quarantelli, E.L., 2005: Catastrophes are Different from Disasters: Some Implications for Crisis Planning and Managing Drawn from Katrina. *Catastrophes*, **26**

Rao, S., I. Keppo, and K. Riahi, 2005: Importance of Technological Change and Spillovers in Effective Long-Term Climate Policy. *Energy*, **Forthcoming Special Issue**

Rapping, L., 1965: Learning and world war II production functions. *The Review of Economics and Statistics*, **47**(1), pp. 81-86.

Ravindranath, N.H., P. Sudha, and S. Rao, 2001: Forestry For Sustainable Biomass Production And Carbon Sequesteration In India. *Mitigation and Adaptation Strategies for Global Change*, **6**, pp. 233-256.

Rawls, J., 1971: *A Theory of Justice.* Ma. Harvard University Press, Cambridge.

Ray, A., 1984: *Cost Benefit Analysis: Issues and Methodologies.* Johns Hopkins University Press, Baltimore, MD.

Rayner, S., and E. Malone, L., 1998: The challenge of climate change to the social sciences. In: *What Have We Learned? Of Human Choice and Climate Change*. Battelle Press, pp. Chapter 2.

Reilly, J., P.H. Stone, C.E. Forest, M.D. Webster, H.D. Jacoby, and R.G. Prinn, 2001: Uncertainty and climate change assessments. *Science*, **293**(July 20), pp. 430-433.

Riahi, K., and R.A. Roehrl, 2001: Energy Technology Strategies for Carbon Dioxide Mitigation and Sustainable Development. *Environmental Economics and Policy Studies*, **3**(2), pp. 89-123.

RITE, 2003: *New Earth 21 Project. Research Institute of Innovative Technologies for the Earth.* Kyoto, Japan, Available online at <http://www.rite.or.jp/English/lab/syslab/research/new-earth/new-earth.html>pp.

Roehrl, A.R., and K. Riahi, 2000: Technology dynamics and greenhouse gas emissions mitigation - A cost assessment. *Technological Forecasting and Social Change*, **63**(2-3), pp. 231-261.

Rose, A., B. Stevens, J. Edmonds, and M. Wise, 1998: International Equity and Differentiation in Global Warming Policy. An application to Tradeable Emission Permits. *Environment and Resource Economics*, **12 (1998)**, pp. 25-51.

Rosenberg, N., 1982: *Inside the Black Box: Technology and Economics.* Cambridge University Press.

Rosenberg, N., 1998: Chemical engineering as a general purpose technology. In: *General Purpose Technologies and Economic Growth*. MIT Press

Rotmans, J., and H. Dowlatabadi, 1998: *Integrated Assessment Modeling.* Columbus, OH, Battelle, 292-377pp.

Rycroft, R., and D. Kash, 1999: *The Complexity Challenge: Technological Innovation for the 21st Century.* Cassell Academic.

SAINC, 2003: South Africa's Initial National Communication to UNFCCC.

Sathaye, J., R. Norgaard, and W. Makundi, 1993: A Conceptual Framework for the Evaluation of Cost-Effectiveness of Projects to Reduce GHG Emissions and Sequester Carbon. **Lawrence Berkely Laboratory, LBL-33859**

Schilizzi, S., 2003: Should equity concerns impose limits on the use of market-based instruments? In: *In: Proceedings of the Australian Agricultural and Resource Economics Society National Symposium on Market-Based Policy Instruments 2-3 September 2003, Canberra*. RIRDC, ACT, Australia

Schipper, L., and M. Grubb, 2000: On the rebound? Feedback between energy intensities and energy uses in IEA countries. *Energy Policy*, **28**(6), pp. 367-388.

Schlesinger, M.E., and N.G. Andronova, 2004: Climate sensitivity: Uncertainty and learning. In: *IPCC Workshop on Describing Scientic Uncertainties in Climate Change to Support Analysis of Risk and of Options*. National University of Ireland, Maynooth, Co. Kildare, Ireland, pp. 109-112.

Schmookler, J., 1962: Economic sources of inventive activity. *Journal of Economic History*, **22**(1)

Schneider, S.H., 2001: What is 'dangerous' climate change? *Nature*, **411**(May 3), pp. 17-19.

Sen, A., 1992: *Inequality Reexamined.* Clarendon Press, Oxford.

Sen, A., 1999: *Development as Freedom.* Oxford University Press.

Shukla, P.R., 2003: *Development and Climate*. *Workshop on Development and Climate.* http://developmentfirst.org/india/background.pdf, New Delhi, India.

Shukla, P.R., S.K. Sharma, N.H. Ravindranath, A. Garg, and S. Bhattacharya (eds.), 2003: *Climate Change and India: Vulnerability Assessment and Adaptation*. Universities Press (India) Private Limited, Hyderabad, India.

Simms, A., 2001: *Special Edition, IMPACT October 2001*

Smith, J.B., 1997: Setting priorities for adapting to climate change. *Global Environ. Change*, **3**, pp. 251-264.

Smithson, M., 1988: *Ignorance and Uncertainty* **-** *Emerging Paradigms.* Springer-Verlag.

Soderholm, P., and T. Sundqvist, 2003: *Learning curve analysis for energy technologies: Theoretical and econometric issues*. *Paper presented at the Annual Meeting of the International Energy Workshop (IEW).* Laxenburg, Austria.

Squire, L., and H. van der Tak, 1975: *Economic Analysis of Projects.* John Hopkins University Press, Baltimore MD.

SRES, 2000: *Special report on Emission Scenarios.* Intergovernmental Panel on Climate Change.

STAP, 1996: *Scientific and Technical Advisory Panel.* Global Environmental Facility.

Stokes, D., 1997: *Pasteur's Quadrant: Basic Science and Technological Innovation.* Brookings Institution Press.

Taylor, M., E. Rubin, and D. Hounshell, 2003: Environmental Science & Technology. *Effect of government actions on technological innovation for SO2 control*, **37**(20), pp. 4527-4534.

Tol, R.S.J., and R. Verheyen, 2004: State responsibility and compensation for climate change damages - a legal and economic assessment. *Energy Policy*, **32 (2004)**, pp. 1109 -1130.

Toth, F.L., 2004: Coupling climate and economic dynamics: recent achievements and unresolved problems. In: *The Coupling of Climate and Economic Dynamics: Essays on integrated assessment*. Kluwer Academic Publishers, Boston

UNDP, 2003a: *Global indicators (Millennium Development Goals).*

UNDP, 2003b: *Human Development Report.* Oxford University Press, New York.

UNDP, 2005: *Adaptation Policy frameworks for Climate Change: Developing Strategies, Policies and Measures.* Cambridge University Press.

UNDP, and UNDESA, 2000: *World Energy Assessment.* New York.

UNEP/IVM, 1998: *Handbook on methods for climate change impacts assessment and adaptation strategies.* Amsterdam.

UNFCCC, 1992: *United Nations Framework Convention on Climate Change.* Climate Change Secretariat, Bonn.

Utterback, K., 1996: *Mastering the Dynamics of Innovation.* Harvard Business School Press.

Vaillancourt, K., and J.-P. Waaub, 2004: Equity in international greenhouse gas abatement scenarios: A multicriteria approach. *European Journal of Operational Research*, **153 (2004)**, pp. 489-505.

Vasicek, O., 1977: An equilibrium characterization of the term structure. *Journal of Financial Economics*, **5**, pp. 177-188.

Victor, N., and J. Ausubel, 2002: DRAMs as model prganisms for study of technological evolution. *Technological Forecasting and Social Change*, **69**(3), pp. 243-262.

Vine, E., J. Hamerin, N. Eyre, D. Crossley, M. Maloney, and G. Watt, 2003: Public policy analysis of energy efficiency and load management in changing electricity business. *Energy Policy*, **31 (2003)**, pp. 405-430.

Walley, P., 1991: *Statistical Reasoning with Imprecise Probabilities.* Chapman and Hall, London.

Watts, W., 1999: *Discounting and Sustainability.* The European Commission, DGII Brussels (Photocopy).

WB, 2005: *World Development Indiacators Databank* The World Bank.

WBCSD, 2004: *Energy and Climate: Business Case.*

WBCSD, and WRI, 2004: *The Greenhouse Gas Protocol. A corporate Accounting and Reporting Standard.*

WCED, 1987: *Our Common Future.* Oxford University Press, World Commission on Environment and Development, London.

Weitzman, M.L., 2001: Gamma discounting. *American Economic Review*, **91**, pp. 260-271.

Weitzman, M.L., 2004: *Statistical discounting of an uncertain distant future, mimeo.* Harvard University.

Wesley, E., and F. Peterson, 1999: The Ethics of Burden Sharing in the Global Greenhouse. *Journal of Agricultural and Environmental Ethics*, **11 (1999)**, pp. 167-196.

WETO, 2003: *World Energy, Technology and Climate Policy Outlook 2030.* European Comission Directorate-General for Research Energy, Brussels.

Weyant, J.P., 2004: Introduction and overview [to EMF-19]. *Energy Economics*, **26**, pp. 501-515.

Weyant, J.P., 2004: Special Issue. *Energy Economics*, **26**(4), pp. 501-755.

Weyant, J.P., 2006: Special Issue. *Energy Journal*, **Forthcoming**

Wiener, J., 1999: Global environmental regulation: Instrument choice in legal context. *Yale Law Journal*, **108**, pp. 677-800.

Wigley, T.M.L., and S.C.B. Raper, 2001: Interpretation of high projections for global-mean warming. *Science,* **293**, pp. 451-454.

Wolfers, J., and E. Zitzewitz, 2004: Prediction markets. *Journal of Economic Perspectives*, **18**(2), pp. 107-126.

Wright, T., 1936: Factors affecting the cost of airplanes. *Journal of Aeronautical Sciences*, **3**(2), pp. 122-128.

WSSD, 2002: *Water, energy, health, agriculture and biodiversity. Synthesis of the framework paper of the Working Group on WEHAB.* UN WSSD A/conf.199/L.4.

WWF, 2003: *The Gold: Quality Standards for CDM and the JI.*

Yelle, L., 1979: The learning curve: Historical review and comprehensive survey. *Decision Sciences*, **10**, pp. 302-328.

Yohe, G., and etal., 2005: *Perspectives on Climate Change and Sustainability, Chapter 20.*

Yohe, G., and R. Moss, 2000: Economic Sustainability, Indicators and Climate Change. In: *IPCC Expert Meeting on Climate change and its Linkages with Development, Equity and Sustainability (27-29 April, 1999)*. IPCC and WMO Geneva, Columbo, Sri Lanka

Zanetti, A., S. Schwarz, and R. Enz, 2005: *Natural and man-made catastrophes 2004: More than 300 000 fatalities, record insured losses.*

Zimmerman, M., 1982: Learning effects and the commercialization of new energy technologies: the case of nuclear power. *Bell Journal of Economics*, **13**(2), pp. 290-31.

[i] For a survey see Bromley, D.W, and J. Paavola, 2002, ***Economics, ethics, and environmental policy: Contested choices,*** Blackwell, Oxford.

[ii] **10.2.7 Political Science Perspectives** IPCC 2001; **"Die Globalisierungswächter"** Heike Walk and Achim Brunnengräber, Westfälisches Dampfboot, Münster, 2000, 336pp Reviewed in: Climate Policy, 1, 3, 2001, p. 419-421