A broader palette: The role of technology in climate policy

Knut H. Alfsen and Gunnar S. Eskeland

Report to the Expert Group for Environmental Studies 2007:1

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Preface

Climate change is perhaps the most complicated issue facing the international community today. A growing scientific consensus points to the need for a viable political approach to address the threat of global climate change. In this report to the *Expert Group for Environmental Studies,* Knut Alfsen and Gunnar Eskeland assess the Kyoto Protocol and outline an alternative policy architecture designed to address apparent shortcomings of the Protocol.

The members of the Expert Group for Environmental Studies do not necessarily share the opinions expressed in the report: the authors of the report are solely responsible for analysis, proposals and opinions presented in the report.

Hillevi Larsson
Bengt Kriström
Ing-Marie Gren
Lennart J. Lundqvist
Gunilla Öberg
Bengt Lundegårdh

/ Joakim Sonnegård
Björn Carlén

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Acknowledgement

The authors would like to sincerely thank the reference group and the secretariat at the Expert Group for Environmental Studies *(Expertgruppen för miljöstudier)* for stimulating and very constructive feedback during the process of writing this report[1]. Also many thanks to Anne Therese Gullberg at CICERO for research assistance. All views that are expressed in this report are of course the responsibility of the authors.

[1] Members of the reference group in alphabetic order: Bert Bolin, Staffan Jacobsson, Kjell Jansson, Eva Lövbrand, Svante Mandell, Gunnar Sjöstedt, Jakob Svensson; and from the secretariat at the Expert Group for Environmental Studies: Björn Carlén and Joakim Sonnegård.

Executive summary and outline

Objective and synthesis of this report

The title of this report – "A broader palette" – refers to the need to broaden the debate on climate policy, in particular with regard to what type of international treaties are needed. Since the climate change problem appeared on the international scene some decades ago, economists have focused very much on cost-effective control policies, e.g. CO_2 taxes and emission trading schemes (known as cap-and-trade systems). After some years of experiences of these types of control policies, the time has come to sum up: Do they work as intended, or has reality conspired to expose detrimental flaws and practical weaknesses in a nice theoretically construct? We will argue that the latter is the case, and that a good repair strategy is to complement cap-and-trade systems á la Kyoto Protocol (or the EU Emission Trading Scheme) with treaties giving direct public support to research and development (R&D) for the development of the carbon-lean energy technologies that are needed in the longer term.

The urgency of formulating climate policies for the period after 2012 is highlighted by the fact that we probably have now exceeded the level at which we need to stabilize the greenhouse gas concentration in the atmosphere if we want to be reasonably sure that we can keep the increase in global mean temperature under 2°C in the future – the official EU goal. A warm autumn and winter in Europe and the publication of the Stern review (Stern, 2006), urging strong and immediate action against greenhouse gas emissions, have brought further political attention to the urgency of addressing the climatic challenge.

The most important key to a viable and effective climatic regime after 2012 is to obtain a longer time horizon in our commitments to mitigation. This is required to change expectations and hence promote the necessary development of cheaper climate-friendly technologies. The Kyoto Protocol is sometimes criticized as ”too little, too fast”. It reflects the sentiment that some emission reductions, and not much more, can be attained in the short to medium term. The most important weakness of the Kyoto Protocol is its failure to prepare for greater emission reductions in the longer term. An unfortunate effect of this is the impact that it has had on national policies and private sector investments, where a similar short-sightedness prevails.

In this report we will argue that an important part of the solution to this problem is to recognize that public funds will have to carry a substantial part of the research and development costs of new climate-friendly technologies. This is because promises of future rewards to private investors in technology development are not convincing, in particular when the rewards are more or less directly controlled by governments. Thus, government support, in the form of direct subsidies to R&D and other means such as setting standards and goals for the future, are necessary supplements to a cap-and-trade regime.

At the international level, coordination of such support can be attained through a technology (R&D) treaty for a ”coalition of the willing”, incorporating a long time horizon (perhaps 20 years). Financing and other measures included in the treaty should be verifiable, and a system with a central ”research council” might be preferable. Each party to the treaty could be assured of receiving a proportional share of the resources in the form of research contracts, testing facilities, etc., but the teams carrying out the research and development should be international in scope, securing access to knowledge and technology transfer between the parties to the treaty. The technology treaty should thus secure substantial long-term public funding for research, development and testing of key technologies according to the preferences and comparative advantages of each participating country. Taken together, we believe such an R&D based treaty should have a fair chance of being self-enforcing and also be attractive to nations outside the core industrialised countries. This is because R&D cooperation will attract participants interested in a) gains that yield energy security and climate benefits; b) sharing in research contracts and technology cooperation, and c) increased competitiveness and trade access.

Greater emphasis on R&D efforts is in no way a substitute for supporting emission reductions through cap-and-trade or emission taxes. Rather, the two approaches are logically complementary and mutually supportive. A problem for a cap-and-trade system standing alone is to rally broad participation towards emission limits (or high mitigation rewards). This is a problem that is being addressed by an R&D programme through its promise to bring down future mitigation costs. Symmetrically, a problem for a stand-alone R&D programme is to stimulate the implementation of pre-existing climate-friendly technologies, which is exactly what a cap-and-trade program can provide. Since this weakness of a stand-alone R&D programme also jeopardizes its effectiveness in providing future technologies, the complementarity between R&D and cap-and-trade is fundamental.

These conclusions are in broad agreement with the conclusion of the Stern Review. In its final chapter (chapter 27) it concludes that policy frameworks must deliver on three fronts:

- creating a price for carbon, via, taxes, trading or regulation;
- promoting the development and deployment of new technologies; and
- deepening understanding of the problems, thus changing preferences and behaviour and overcoming market barriers that might inhibit action, notably on energy efficiency.

(Stern, 2006, page 573)

We differ from the Stern Commission and many others on the emphasis given to ”global problems need global solutions”. We argue instead that R&D may be stimulated in many ways; by nations alone or in small coalitions, as well as in large international treaties as outlined above. With an optimistic tone, we argue that free-riding problems of global mitigation will be reduced by supplementing the current cap-and-trade approach with technology efforts along many dimensions. Indeed, there are currently not only countries but also companies, states and other constellations that presently want to act on climate change with greater force than required by the present climate regime. A key point for them may be not only to cut their own emissions but rather to act so as to make a contribution. Contribution to emission reductions by others may be as important as own reductions. We argue that contributions to technological change have the potential to contribute to emission reductions by others, both by broadening participation and by deepening the emission reductions others can opt for.

Sweden, a small and responsible member of ”the coalition of the willing” need not be discouraged by the great ”free-riding incentives” of the global climate regime[2]. The present study is supportive of a small nation both as it works internationally to strengthen global institutions and as it makes an effort to set an example by its actions at home. Reasons for unilateral national R&D efforts include a general value to society of building technological competency (climate-related or otherwise) and the national spill-over effects this has in terms of creating future business opportunities by being a first mover. Also, one may place a value on the impacts on other nations by showing the possibilities that exist in being climate-friendly without high costs. The study indicates that the positive impact on mitigation by others will be determined more by *what* Sweden does in demonstrating climate-friendly technologies than by the quantity of Sweden’s unilateral emission reductions. In particular, if an example is to be set for other countries, then it may be made through efforts and success with technologies that make emission reductions cheaper, assist energy security objectives, and can be profitable from the perspectives of universities, corporations and countries.

For Sweden, this has two implications.

First, on the international scene, Sweden like all other climate concerned nations, should strive to build a sensible climate regime (web of treaties and other cooperative ventures) that is

- broader in country participation than the Kyoto protocol,
- deeper in emission reductions than the Kyoto protocol,
- longer in the duration of commitments to emission reductions than the Kyoto protocol, in particular such as to facilitate far-reaching technological change.

This report makes a strong argument that by addressing the third of these weaknesses first a road is being built towards broader participation and deeper emission reductions. Broader and deeper is impossible unless deeper becomes cheaper, so carbon lean technologies must be forthcoming.

[2] It is a privelege of being small, perhaps, that one need not worry that others will become lazy because Sweden solves the problem for them.

Second, in its mitigation policies at home, Sweden needs to ask: Which policies are effective not only in the sense of delivering emission reductions, but also in implications for broader participation, deeper reductions, and longer commitments? To be specific, if Sweden voluntarily ”goes an extra mile” with the hope of influence mitigation in the rest of the world positively, it is probably more important whether emission-lean technologies are created than whether Sweden delivers additional emission reductions now. Thus, it is likely more important if Sweden can show ”giant leaps” in small areas than modest progress on a broader front. An effort to examine directed efforts in selected areas – drawing on special resources and opportunities available to Sweden – is therefore essential. A reasonable suggestion is perhaps that Sweden, instead of aiming for the 96 percent target in its own emissions, uses the money saved to strengthen the energy technology budget to the tune of up to 5 billion SEK per year. A problem with this (and similar) suggestions is that it is not the Government that directly bears the total cost of the current 96 percent target. How to finance necessary investments in new technologies is therefore a problem (Earmarked greenhouse gas taxes? Auctioning of quotas?) Maybe ways to stimulate or expand R&D include subsidies or partnerships with the private sector, and quite likely the private sector can see an opportunity in investing in technology in a forward-looking way.

On the particular questions of how to stimulate R&D and which technologies should be supported (and some other specific policy questions), we are mostly silent in this report. Rather our aim is to point more broadly in *directions* where policy-makers should look for answers. Detailed solutions will require new studies.

Outline of the report

Our arguments and the report are organised around four main points:

1. We do have a serious climatic problem and we need to bring down the global emissions of greenhouse gases, industrialised countries need to do the most. For these countries the target should be to reduce emissions by 50–80 percent from today’s level by the middle of the century. In order to meet this target, while at the same time meeting the growing demand for energy,

we need massive investment and deployment of climate-friendly technologies. This is described in Part I of the report.

2. In Part II, we describe the international effort to date in search of an effective solution.
3. In Part III we argue that the current regime is inadequate, with regard to mitigation efforts today. More importantly, it is inadequate with regard to facilitating mitigation in the future. Thus, we conclude that the international climate change regime in place today (the Kyoto Protocol) needs to be complemented by other instruments securing deeper investments in energy technology development. The elements of such a strategy are outlined, and the way R&D and cap-and-trade are mutually supportive is highlighted.
4. Almost as a corollary it follows that, as discussed in Part IV, at the national level more attention should be given to efforts to secure breakthroughs in technology development, if necessary at the expense of short term emission reductions.

PART I The climate challenge: Its nature and scale

The climate is changing, but that has always has been so. Why then our current concern with climate change? The aim of this chapter is to clarify both the nature and the scale of the challenge posed by climate change in this century. The twin challenges of stabilising the concentration of greenhouse gases in the atmosphere at a "reasonable" level, while at the same time meeting a steadily growing global demand for energy and transport services, are formidable. As a background to understanding these challenges, in this part we describe the driving forces behind climate change and the climate history of the Earth. We argue that a "reasonable" stabilisation level requires a massive development and deployment of climate friendly energy technologies. From this follows a key message: Sensible long-term climate policies should focus on securing development of new technologies (vertical technological development or deepening technologies) as well as spreading best available technologies (horizontal technological development). The first aim (vertical technological development) is best provided by establishing strong, stable and long-term incentives for the development of climate friendly technologies, first and foremost in the industrialised countries. The second aim is best secured by international treaties making it profitable to choose climate-friendly solutions in every country.

1.1 Introduction

A near global observation network detailing weather conditions year in and year out has been in operation for well over 100 years now, and the message it delivers is clear: The global climate is warming. The mean global temperature is now some 0.8 ± 0.2°C higher than it was at the beginning of the industrial revolution some 200 years ago. Furthermore, past emissions of greenhouse gases and the inertia of the climate system will secure a continued warming in coming decades regardless of what we do today. Considerable changes are already unavoidable. New research also highlights the possibility that the climate system is more sensitive to our perturbations (by steadily increasing emission of the ”greenhouse gases”, CO_2 chief among them) than previously thought. This is disturbing, to say the least, because the growth of our emissions show no sign of abating.

What science is telling us is that without strong and determined action, we may irreversibly bring the Earth’s climate into a new state so far unexplored (by humans). This chapter will briefly present some of the evidence we have for past and present climatic changes.

1.2 Driving forces of climate change

The climate of Earth is fundamentally driven by the energy input from the sun. However, interactions and exchanges of energy and material between a large number of what we can consider climatic sub-systems, modify the climatic responses to variations in the direct energy input. The most important of these sub-systems are the atmosphere, the oceans, the cryosphere (ice and snow), the biosphere, and the lithosphere (rock and soil). The interactions and exchanges between these sub-systems operate on a number of time scales, from the very longest geological time scales spanning million of years to more short-term changes due to chemical and biophysical processes, transforming the continuous changes in energy input into discreet and rapid changes in the climate.

Some of the feedback mechanisms of the climate system of relevance to us today are related to changes in the albedo of the Earth’s surface (reflexivity), and changes in the atmospheric constituency. Human impacts on the climate work particularly through this last mechanism: changes in the atmosphere and their impact via the so-called greenhouse effect (see Box 1 and Box 2).

Box 1 Greenhouse gases and the greenhouse effect

As short-wave visible sun light reach the Earth's atmosphere, some is reflected back to space while the rest penetrates the atmosphere. Here some is absorbed, but a little more than half reaches the surface of the Earth. Some of the light is reflected (depending on the "whiteness" or albedo of the surface) while most is absorbed and thereby heats the surface. The surface then re-emits the heat in the form of long-wave heat waves. Some of this is absorbed in the atmosphere, while the rest escapes to space. The amount of heat absorbed by the atmosphere is determined by the concentration of so called greenhouse gases in the atmosphere. The most important greenhouse gas by far is *water vapour* (H_2O). However, the concentration of this gas in the atmosphere is largely determined by the temperature, and not by direct emissions. This is not the case for other greenhouse gases, where man made emissions strongly influence the concentration levels. The emissions of the most important of these gases are regulated under the Kyoto Protocol. The gases are: CO_2, CH_4, N_2O, PFC, HFC and SF_6. A common way of comparing the effect of the various gases is to compare the effect of one unit of one gas with the effect of one unit of CO_2 over a period of 100 years. The resulting Global warming potentials (GWP100) are shown in the table below.

Table A Greenhouse gases regulated under the Kyoto Protocol and their global warming potentials using a time horizon of 100 years

Greenhouse gases	Global warming potential (GWP_{100})	Pre-industrial concentration	Current concentration	Radiative forcing (W/m^2)
Carbon dioxide – CO_2	1	280 ppm	377,3 ppm	1.66
Methane – CH_4	23	730 ppb	1 847 ppb	0.5
Nitrous oxide – N_2O	296	20 ppb	318 ppb	0.17
Hydrofluorocarbons – HFC	2 547	0		0.34 for all halocarbons
Perfluorocarbons – PFC	6 648	0		collectively
Sulphur hexafluorid – SF_6	23 900	0	5.22 ppt	0.002

Source: Based on http://cdiac.ornl.gov/pns/current_ghg.html (7.12.06) and Statistics Norway
ppm = parts per million (10^{-6}), ppb = parts per billion (10^{-9}), ppt = parts per trillion (10^{-12}).

Box 2 What do we mean by ”the climate” and ”the climate system”?

In discussing climate change it is all too easy to think of own local observations of the weather. For instance, the autumn and winter 2006–2007, were unusually warm in our Nordic countries (as well as in the rest of Europe), and in some places very wet. These strong personal experiences are however far from telling us what is happening to the climate where we live, and of course even less about what is happening (or not) to the global climate. The climate in a given region is determined by the probability distribution (the average and the variability) of the weather as measured over a suitable long time period (usually 30 years). Key parameters include average values of temperature, precipitation and wind, as well as extreme values of these and other parameters. The climate system consists of those parts generating the climate, i.e. the atmosphere, the cryosphere (snow and ice), ocean currents, etc.

The greenhouse effect, i.e. the trapping of long-wave heat radiation from the Earth by radiative active gases in the atmosphere, has been operating on Earth since the atmosphere was first formed. The *natural greenhouse effect* – caused by the presence of water vapour, carbon dioxide and other greenhouse gases in the atmosphere – leads to about a 30°C higher average temperature on Earth than otherwise would have been the case. Life on Earth as we know it thus depends on the operation of the greenhouse effect. However, since the industrial revolution, mankind has increased the concentration of greenhouse gases in the atmosphere – carbon dioxide (CO_2) in particular. The increase has been very rapid viewed on a geological time scale and is leading to the *enhanced greenhouse effect* we are observing today.

1.3 Climate history

Throughout Earth’s 4.6 billion years’ history (see Box 3 for a brief chronology), the climate can be roughly characterised as belonging to one of two types. One type, aptly called ”*Hot houses*”, represents a very warm climate, far warmer than today, with little or no snow and ice on the Earth’s surface. The other type, called ”*Ice houses*”, is characterised by a variable climate where the Earth oscillate between ice ages (periods with extended glaciations of the high latitudes), and interglacials, i.e. periods with far less snow and ice, see Figure 1. The first ice house that still is recognizable took place approximately 700 million years ago. Thereafter followed new ice houses 450 and 280 million years ago. The most recent one, which still persists, started between 2 and 3 million years ago.

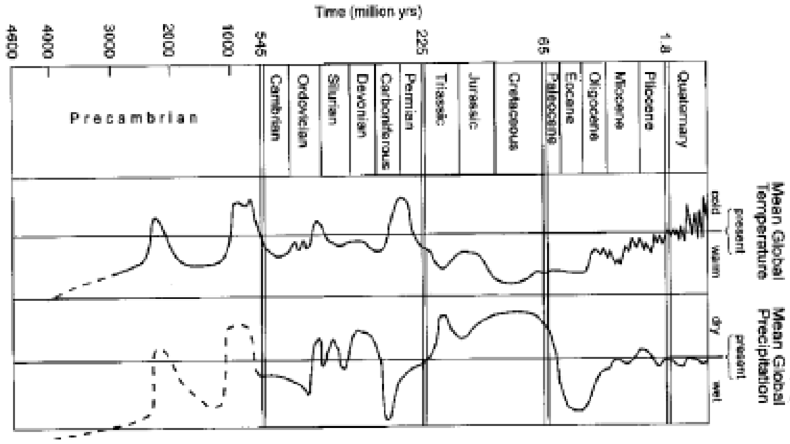
Box 3 Some highlights from the history of the Earth

Time (million years ago)
4 600 The creation
3 300 First life
680 First animal
470 First fish
412 First plant
330 First tropical forest
215 First dinosaur
140 First bird
65 Dinosaurs die out
2.3 First homo
0.1 First homo sapiens sapiens
0.040 Eurasia invaded by homo sapiens
0.015 Cave paintings in France and Spain
0.010 The end of the last ice age
0.008 First civilization
0.004 First cities
0.0005 Uppsala University founded (1477)

– – –

Adapted from C. Boyle (ed.) (1991).

Figure 1 A broad outline of the climate history of the Earth. The upper curve shows temperature, while the lower curve shows precipitation. It is colder and dryer upwards in the figure, and hence, warmer and wetter downwards.



Source: Frakes, L. A. (1979).

Since the start of the most recent ice house period, several tens of ice ages have come and gone, see Figure 2. In the upper panel of the figure a proxy for temperature shows the gradual, if irregular, decline into a new ice house some 3 million years ago.

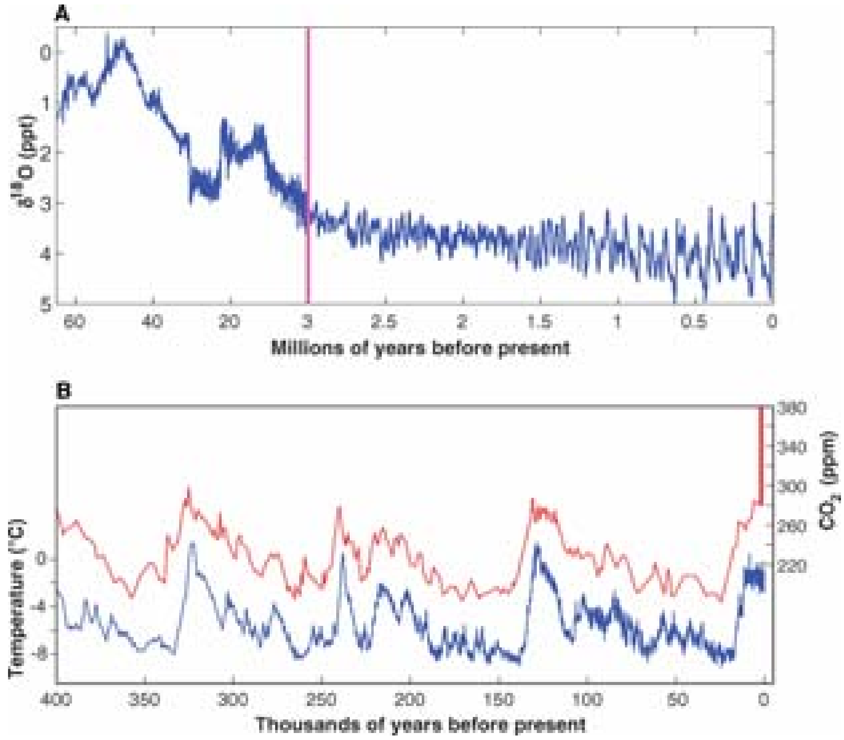
While data on distant history is scant, knowledge improves dramatically when we consider the last ½ to 1 million years. The reason is the existence of ice of this age in the interior of the Antarctic and in Greenland (see e.g. Alley, 2000). Trapped in the ice we find enclosed air, the composition of which give us relatively direct evidence of the constituency of the atmosphere and also the local temperature when the air was originally trapped. In this manner, figures like the lower panel of Figure 2, which show CO_2 concentration (red curve) and temperature (blue curve) at the research Station Vostok in the Antarctic over the last 400 000 years, can be draw. We see a rather regular pattern where the Earth periodically and slowly descend into an ice age that lasts for some 100 000 years, followed by a relatively rapid rise out of the ice age and a shorter period of some 10 000 years in an interglacial period. The figure indicates that the concentration of CO_2 oscillates between a lower level of 180 and an upper level of 280 ppm as the

Earth moves in and out of ice ages. The current surge in CO_2 concentration is indicated by the vertical part at the end of the curve.

We also observe a tight correlation between the development of CO_2 concentration and the temperature. However, the causality, i.e. whether the CO_2 is driving the temperature or vice versa (or both!), is still unresolved when it comes to transitions into and out of ice ages, underlining the complexity of the interactions between the many sub-systems that together determine the climate signal, the temperature in this case.[3]

[3] It is likely that the Milancovic semi-periodicity of received solar radiation is the primary cause of the variations between glacial and interglacial times. This in turn changes the carbon cycle and the atmospheric concentration of CO_2, which in turn represents a positive feed-back mechanism.

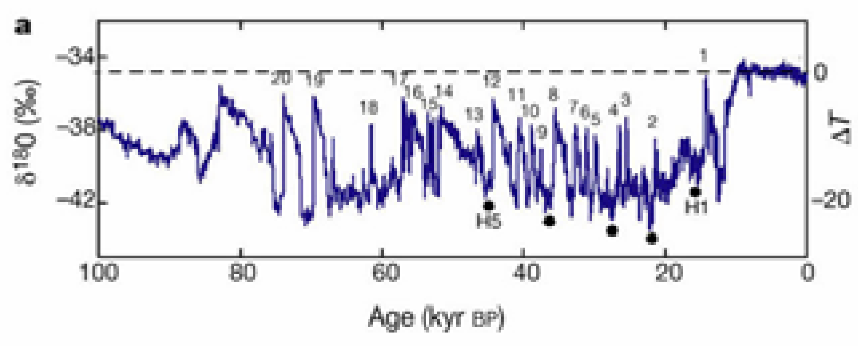
Figure 2 Ice ages since the start of the most recent ice house approximately 3 million years ago.
Upper panel (A): Variations in 18O over the past 60 million years. Higher values of 18O indicate colder climate (greater global ice volume). The gradual cooling over the past 50 million years is evident. Note that the time scale changes at 3 million years.
Lower panel: Fluctuations in temperature and in the atmospheric concentration of carbon dioxide over the past 400 000 years as inferred from Antarctic ice-core records. The vertical red bar is the increase in atmospheric carbon dioxide levels over the past two centuries and before 2006.



Source: Fedorov et al. (2006). Based on Vostok data: Petit et al. (1999), Barnola et al. (1999). Download: http://www.sciencemag.org/cgi/content/full/312/5779/1485/FIG1.

The last ice age, lasting from approximately 100 000 years to 12 000 years ago, has been studied in more detail through analysis of ice cores from Greenland, i.e. a neighbouring site reflecting the climate conditions in Scandinavia better than Antarctic cores. The temperature variations extracted from one of these ice cores are shown in Figure 3.

Figure 3 Greenland temperatures since the beginning of the last ice age



Source: Ganopolski and Rahmstorf (2001).

Although showing temperature conditions in only one location, the figure illustrates well that conditions during the last ice age were far from a long and uniformly ”cold winter night”. Instead we see extreme and violent climate variations taking place on many time scales. In fact, more detailed analysis, not shown in the figure, indicates that dramatic shifts in the climate, representing changes in local mean annual temperature of some 10 to 15°C, took place with time spans of a decade or so. All this happened well before any human interference with the climate was possible, and is thus a reflection of what kind of dramatic variability the natural climate system is able to create at certain locations under the ”right” conditions.

After the end of the last ice age approximately 12 000 years ago, things calmed down as shown in Figure 3. The climate in no way became constant, but the variability has been significantly lower. It is during this period with ”nice weather” that civilizations have been established and flourished: Agriculture emerged independently in at least three locations; permanent settlements, specialisation, accumulation and trade came to be seen for the first time[4]. For thousands of years, tremendous gains in the productivity of nature relative to man’s needs were brought about through agriculture and in other ways, but they resulted more in population

[4] See, for instance Jared Diamond (1998) or Steven Mithen (2003).

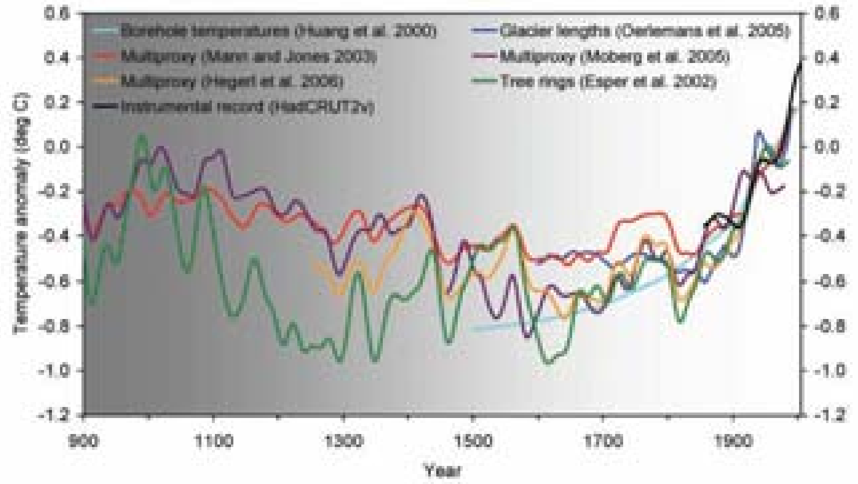
growth than in gains in human condition, as observed by Thomas Malthus and documented by Madisson (2001). Persistent growth in individual human conditions in terms of command of goods and services are demonstrated in historical records first and foremost over the last thousand years, stepping up in the last few hundred years and again in the last century. The break between productivity and population growth that made departures from Malthusian constraints possible and improvements in living conditions feasible has come to a culmination point in the most recent UN population projections, demonstrating that the world's population will stabilize and begin to decline in the current century, probably at about 150 per cent of today's population size. We can only speculate on the role of the relatively stable climate after the last ice age in making this extraordinary historical development possible.

1.4 The last millennium

Analysis of climate-related evidence like tree rings, temperature profiles in deep boreholes, pollen deposition in lakes, and even written statements, etc. has made it possible to construct fairly reliable regional temperature curves for the last thousand years or so, see Figure 4 which shows several reconstructions of the temperature development in the Northern hemisphere over the last thousand years. The figure shows a long-term downward trend in temperatures, abruptly broken by two jumps towards the end of the period; one lasting from approximately 1900 to 1945, the next one commencing in mid 1970s and continuing to this day. The first jump coincides with an absence of volcanic activity (which tends to cool the Earth) and is therefore likely mainly a natural phenomenon[5]. The last jump seems impossible to explain without taking into account the warming effect of anthropogenic emissions of greenhouse gases, and is therefore most likely dominated by human activities (IPCC, 2001b).

[5] Variations of solar radiation also played a role.

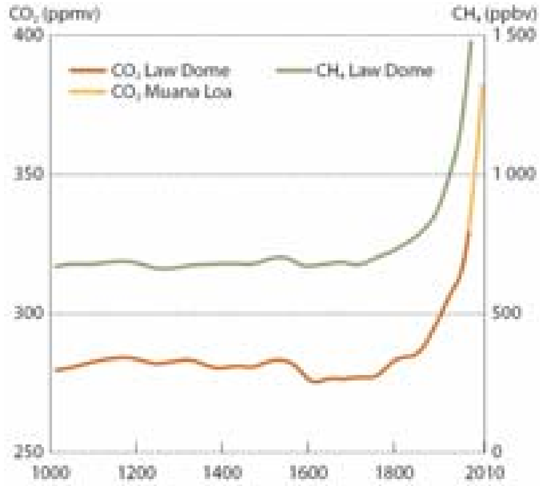
Figure 4 Surface temperatures in the Northern hemisphere as reconstructed by six different research groups



Source: From National Academy of Sciences (2006a) (http://www.nap.edu/catalog/11676.html)

The development of the concentration of the two most important greenhouse gases, CO_2 and CH4, over the last thousands years is illustrated in Figure 5. The first part of the curves is based on data from ice cores, while the last is based on direct measurements. The accelerated growth in concentration levels is noteworthy and alarming.

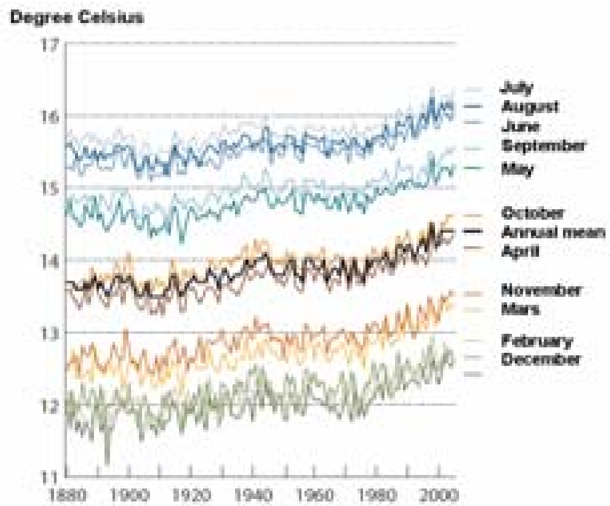
Figure 5 Atmospheric concentration of CO_2 (left axis) and CH4 (right axis) over the last thousand years



Source: Etheridge et al. 2002. http://cdiac.ornl.gov/trends/trends.htm, se under Atmospheric Trace Gas Concentrations., Keeling and Whorf (2005).

The recent rapid increase in the concentration of greenhouse gases has been an important driver for the increase in observed global mean temperatures, see Figure 6 and Box 4.

Figure 6 Observed global monthly mean temperatures



Source: ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/global_meanT_C.all

Box 4 IPCC on climate change

As early as 2001, the UN Intergovernmental Panel on Climate Change (IPCC) concluded in its Third Assessment Report that:

- Most of the observed warming over the last 50 years is likely to stem from increases in the greenhouse gas concentrations resulting from human activity.
- The global average surface temperature during the 21st century is rising at what is likely to be rates unprecendented during the last 10 000 years.
- Nearly all land areas are very likely to become warmer, with more hot days and heat waves and fewer cold days and cold waves note change, Knut.
- The rise in sea level during the 21st century will continue in future centuries.
- The hydrological cycle will become more intense; the increase in global average precipitation and more intense precipitation events are very likely to occur over many areas.

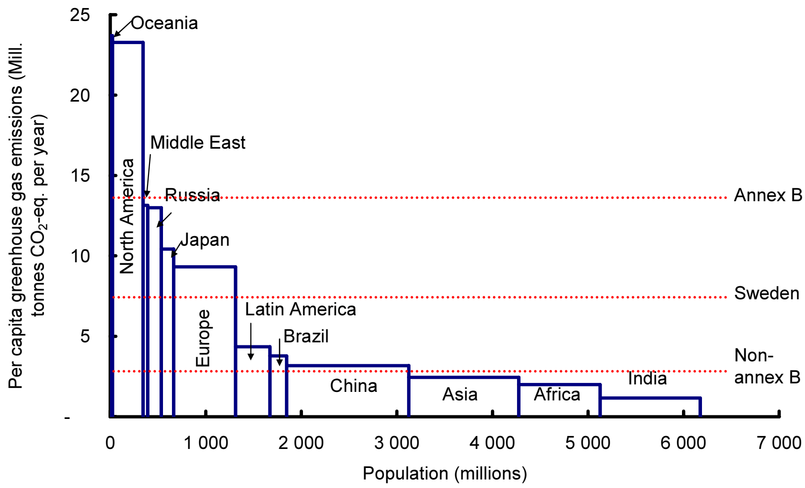
The statement was strengthened in the recent Forth assessment report's Summary for policy makers from Working group I, viz.: "Most of the observed increase in globally averaged temperatures since the mid-20th century is very *likely* due to the observed increase in anthropogenic greenhouse gas concentrations." (IPCC, 2007)

1.5 Future development of emissions

Where do we go from here in terms of greenhouse gas emissions and what may be the consequences for the climate? Future emissions are of course uncertain and depend on fundamental factors like population growth, economic growth, development in technological efficiencies, etc., which are in turn at least partially governed by our own policies and measures to control these factors.

On fundamentals, a starting point for speculating about future emissions is Figure 7, showing per capita emissions of the most important greenhouse gases around the turn of the century. In the figure, per capita emissions are plotted along the vertical axis, while population size is plotted along the horizontal axis. The areas of the rectangles therefore represent total emissions from each of the regions, summing up to almost 30 billion tonnes CO_2-eq. Also shown are average per capita emissions in Annex B countries (countries with emissions obligations under the Kyoto Protocol – including USA and Australia – first listed in Appendix B to the Kyoto Protocol), non-annex B countries (countries without reduction obligations) and Sweden.

Figure 7 Annual greenhouse gas emissions per capita in some world regions and their population. The area of the rectangular boxes reflects total emissions from the various regions.



Source: Data mainly from years around 1999 and downloaded from: http://ghg.unfccc.int/tables/queries.html (30. March 2006).

If we believe in further economic and social development in the poorer regions of the world, the figure strongly suggest that future emission levels will grow substantially. Income- and consumption per capita varies greatly across countries, and the relationship between income and energy use is illustrated by the fact that North America's 300 million people emit more than China's 1.3 billion.

The IPCC has explored future emissions in several so called marker scenarios (IPCC, 2000). Three of these are shown in the upper left part (a) of Figure 8 (marked as A2, A1B and B1, respectively), together with examples of emission pathways that leads to stabilisation of CO_2 levels in the atmosphere in the long run (shown as coloured curves). We note the very wide range in future annual emissions, from a very optimistic declining long-term trend towards the year 2100 in case of the B1 scenario to a rapidly increasing trend in the A2 scenario. It is difficult to assign probabilities to these scenarios, but we note that for the B1 scenario to be realised, we need, as a minimum, a ceiling on the long term total population not much above today's level, continuing and accelerated progress in energy- and emission-efficiency and a generally peaceful and cooperative world throughout the coming century. Many will regard these as very optimistic and perhaps unrealistic assumptions.

The upper right panel of the figure, marked (b), shows the CO_2 concentrations following from the emission paths in the left hand panel (a). There is some, but not much scientific uncertainty associated with the relation between emissions and concentration levels of CO_2. As can be seen, the B1 scenario is on track to stabilising the CO_2 concentration at a level around 550 ppm, up from today's level of 380 ppm[6].

When it comes to the expected temperature impact of the various concentration levels, shown in the lower panel of the figure marked (c), the uncertainty is larger. It is usual to characterize this relation by a "climate sensitivity" parameter defined as the long term equilibrium temperature increase resulting from a doubling of the pre-industrial concentration level of CO_2 (i.e. from 280 ppm to approximately 560 ppm). For many decades this sensitivity has been estimated to be somewhere between 1.4 and 4.5°C. Lately, however, new studies indicate that the upper boundary may in fact have to be raised considerably (Caldeira et al., 2003).

Assuming medium climate sensitivity, it is possible to sketch temperature curves following from the emission curves, as in the lower panel in Figure 8. Here we can note that the B1 scenario gives a 2°C increase above the 2000 level at the end of the century, but at an increasing path.

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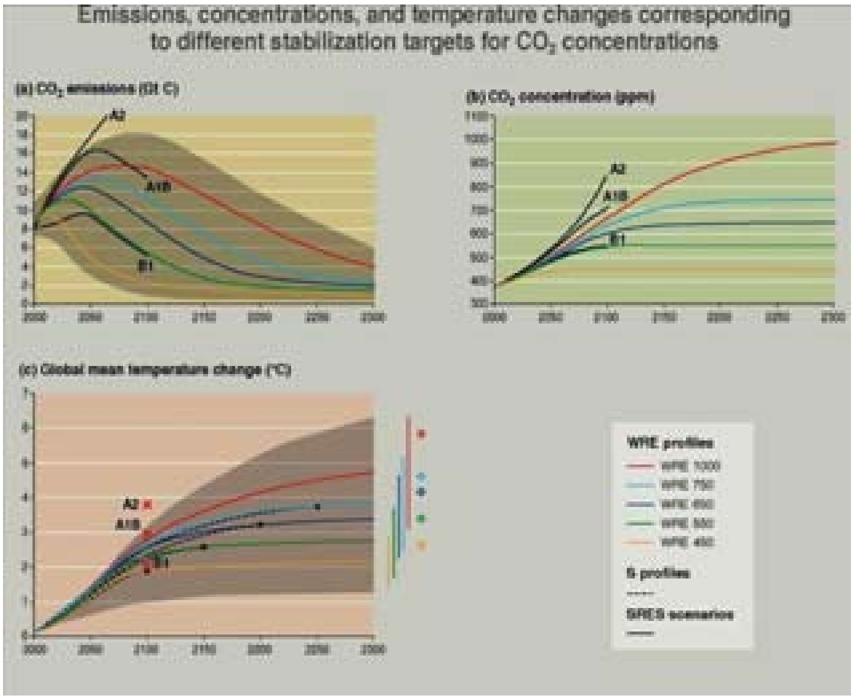
[6] Note that we here refer to CO_2 emissions and concentration levels. In addition other greenhouse gases regulated by the Kyoto Protocol (methane (CH_4), nitrous oxide (N_2O) and several long lived industrialised gases (so called F-gases because they contain fluorine) as well as other gases not regulated under the Kyoto Protocol (e.g. CFCs) contribute significantly to the man-made greenhouse effect. Adding these gases raises the present concentration level from 380 ppm CO_2 alone to a level around 450 ppm CO_2-equivalents. The exact number depends on which gases are included as well as how their different resident times in the atmosphere are taken into account. See table A in Box 1 for a listing of commonly used conversion factors, so-called Global Warming Potentials (GWPs).

Figure 8 Some possible pathways for a) emission of CO_2, b) CO_2 concentration in the atmosphere, and c) global mean temperature change



Source: IPCC, 2001a.

1.6 Impacts of climate change; reasons for concern

We can conclude from the discussion above that the climate is changing, and, as the IPCC already stated in its report in 2001, most of the observed warming over the last 50 years is likely to stem from increases in the greenhouse gas concentrations resulting from human activity. Why should we worry about this?

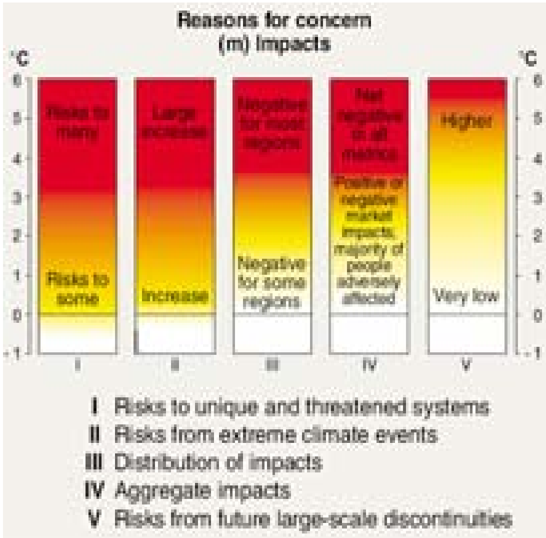
The climate problem has so many dimensions that it can sometimes be difficult to indicate precisely what the core of the climate problem is. Of course the global mean temperature will increase. This will in turn lead to several other changes that are serious enough in themselves, but that will together make the climate problem a truly serious threat. Let us mention a few:

- The extremely rapid changes in climate that human activity has brought upon the natural environment are threatening the adaptive capacity of the eco-systems. Whether we like it or not, even our advanced civilization depends on a large number of well-functioning ecosystems. Rapid climate change thus threatens the basis of our civilization in a fundamental way.

- There is a danger that if our perturbations of the climate are too rapid and strong, for example in the form of large emissions of greenhouse gases, we can provoke the climate to (again) become more unstable, with the complications this will have for basic activities like agriculture.
- Until now, the industrialized countries have been responsible for most of the emissions of greenhouse gases, and the climate change that we will observe over the next few decades is thus mainly caused by the rich countries. At the same time, it is likely that low-lying countries and poor countries will be hardest hit by climate changes. Our Western lifestyle thus constricts the options for social and economic development in the poor part of the world. This makes the climate problem an important element in the conflict between ”North” and ”South.”
- More extreme distribution of precipitation as a result of warming leads to an increased risk of both flooding and slides, on the one hand, and drought and general water shortage on the other. Both create refugees, which may create social unrest, further exacerbating the crisis.
- Increased warming also increases the likelihood of extreme heat waves. This can not only prove deadly for society's weakest, but can also lead to a considerable drop in productivity, as was the case in Europe during the summer of 2003.
- Finally, an important aspect of the climate problem is that it makes little difference where the emissions take place. This is why it will take a coordinated global effort to ”solve” the problem – and why international agreement on binding commitments on emissions reductions is such a challenge.

Figure 9, taken from the Synthesis report of the IPCC's Third Assessment Report, illustrates some of the risks associated with global warming as a function of temperature increases above the year 2000 level. We notice first of all that there is no sharp temperature threshold below which we avoid damages. Rather there is a relatively wide transition zone where risks increase gradually with temperature. Second, things appear to become markedly more serious with temperature increases above 2–3°C.

Figure 9 The risk of damage from climate change increase with the magnitude of climate change, here indicated by the change in global mean temperature above the 2000 level. Five reasons for concern are listed. White indicates neutral or small (positive or negative) impacts. Yellow indicates negative risks for some systems, while red indicates widespread negative impacts.



Source: IPCC (2001b), http://www.ipcc.ch/pub/un/syreng/spm.pdf

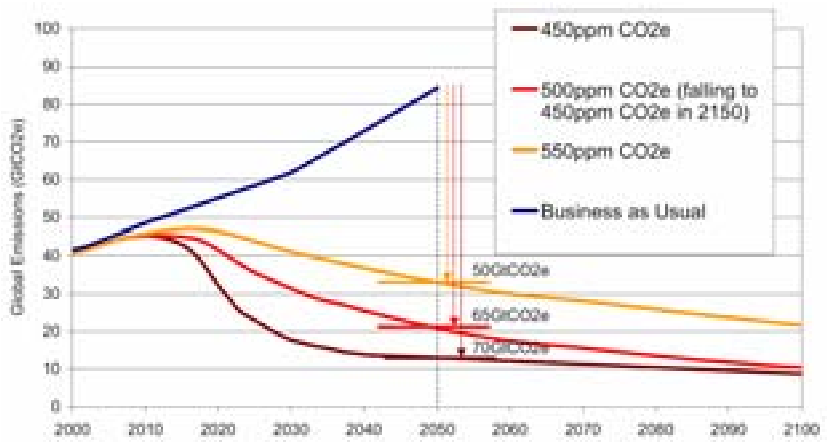
If we somewhat optimistically assume that we can tolerate an increase of the order of 2–3°C above today's level over the next hundred years, we can translate (with some uncertainty) this into a greenhouse gas concentration target. The outcome of this exercise is that we ought to stabilise the CO_2-equivalent concentration at a level between 450 and 550 ppm. Today the concentration level is already above about 450 ppm (see footnote 5) corresponding to a committed greenhouse warming of between 1 and 3°C.[7] *In other words, we have probably already exceeded the level at which we need to stabilise the greenhouse gas concentration if we want to be*

[7] That we have so far only observed a warming of 0,8 degree C above pre-industrial level is due to the great inertia of the climate system (mainly due to the ocean and ice sheets) and some cooling from aerosols in the atmosphere.

reasonably sure that we can keep the temperature increase under 2ºC in the future.

The concentration target can be further transformed into an emission target. Actually, future concentration levels are more related to accumulated emissions than to how these emissions are spread over the years. Still, as Figure 10 illustrates, if we want to reach the goal of stabilizing the concentration of greenhouse gases at the necessary level in the long run (i.e., 400–450 ppm CO_2-eq.), global emissions must essentially be cut by half from today's level until 2050, with continued major reductions after that. Many claim that the goal of cutting global emissions by half by 2050 seems unrealistic, partly because of the necessary economic and social development in the poor parts of the world. In any case, it is probably both fair and realistic to expect somewhat stronger emission reductions from industrialised countries than developing countries. *We therefore conclude that a sensible target for the industrialised countries is to reduce their emissions of greenhouse gases by 50–80 percent from today's level by 2050 (with further reductions thereafter).*[8]

Figure 10 Possible future greenhouse gas emission pathways to stabilise at levels between 450 and 550 ppm CO_2-eq. compared to a business-as-usual scenario (A2)



Source: Stern (2006).

[8] Of course, what matters is total emissions. If a system of emission trading á la the Kyoto Protocol is retained, individual countries may display emissions different from such a target.

This relates to the aggregate of the greenhouse gases in CO_2 equivalents. Fluorinated gases have very long residence times in the atmosphere and are therefore very difficult to reduce. And emissions of methane from wetland and agricultural sources also tend to be difficult to control. Thus, we may end up with far stronger requirements for our CO_2-reductions: The concentration of CO_2 should be stabilised in the region of 350 to 450 ppm (today's level is 380 ppm). Referring to Figure 8, we see that this indicates the need for an emission path well below the B1-scenario.

From all of this it is a fairly robust conclusion that the 2°C target (as proposed by for instance EU) currently is out of reach (Eickhout et al., 2003, Meinshausen, 2004, Hare and Meinshausen, 2004).

With declining reserves of conventional oil and gas throughout this century, prices and technology will likely drive human society increasingly towards coal and/or unconventional reserves of oil and gas increasing the CO_2 concentration further. This is a major challenge, as easily accessible coal reserves are plentiful in e.g. USA, Canada, Russia, China and Australia. If we are to avoid using these reserves, functional and cheap alternative energy technologies must be available and installed when conventional oil and gas ”run out”[9]. This points to technology development as an important part of the solution to the climate problem.

1.7 The role of technology in future emissions

Of course there are other ways to reduce emissions than inventing and implementing climate-friendly technologies on a massive scale. Our life style in the rich part of the world leaves much to be desired when it come to being carbon-efficient. Still, turning down the temperature (in cold countries) and the lights, insulating our houses better (again in cold countries), and increasing our use of public transport solutions will only reduce our emissions by a modest amount; perhaps 10–20 per cent if we are optimistic. Considering that we ought to cut our emissions by more than half from today's level in a few decades, it becomes apparent that we

[9] A previous round of concern and literature on energy shortages would view coal and unconventional petroleum sources as part of potential in ”backstop technologies” – technologies that can take over if and when prices reach a certain level, limiting the economic costs of the end to the supply of oil and gas. In the current setting, of course, the corresponding analytical perspective is whether there are potential ”backstop technologies” in the realm of non-fossil solutions, and how these can be mobilized so as to do without the tremendous reservoir of carbon stored in coal and non-conventional petroleum reserves.

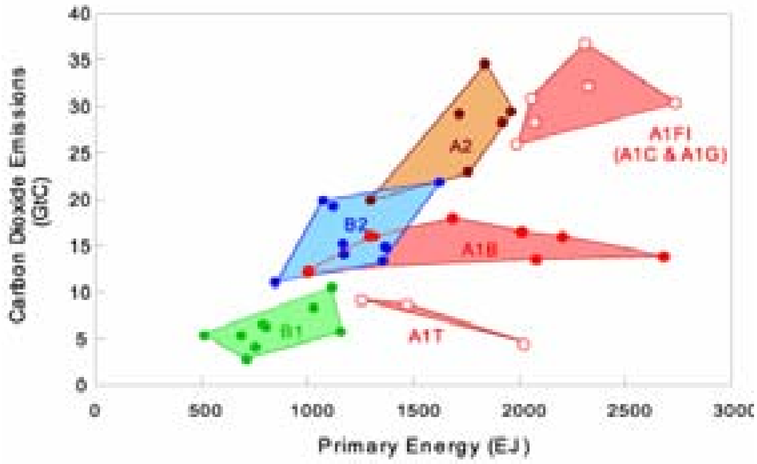
absolutely need new climate friendly technologies with close to zero emissions. While changes in our lifestyle clearly are desirable, they is not enough in themselves to ”save us” from the climate problem.

That technological development and implementation is the ”solution to the problem of climatic change” can also be illustrated with reference to Figure 11. The picture illustrates primary energy use and CO_2 emissions in year 2100 in a large number of long-term scenarios developed by the IPCC (IPCC, 2000). The scenarios are grouped into six so-called scenario *families*. Each family has some common characteristics with respect to key assumptions, such as the extent of globalisation vs fragmentation of the future world, and whether it is environmentally benign or emission intensive. The green and blue scenarios (the B-scenarios) in the figure depict environmentally benign scenarios, while the A-scenarios (orange and red) depict a world where economic growth is given priority. On the other hand, the scenarios marked ”1” (green and red) are scenarios where further globalization of the world is dominating, while the ”2”-scenarios (orange and blue) depicts a more fragmented world, see Box 5 for more detailed descriptions. Note that these scenarios also appeared in Figure 8.

One of the families (the red one – called A1) is further subdivided into three groups, depending on choices of energy technology; a climate-friendly alternative (including nuclear energy) (A1T), a fossil-based alternative (A1FI) and a mix of the two (A1B).

Even though the energy use tends to be largest in the red group (characterised by a globalized and materialistically oriented world) the emissions are seen to depend more on the choice of energy technology than on the type of future envisaged. In fact, the choice of technology seems to matter as much as whether we foresee a materialistic or an environmentfriendly future, or whether we foresee further globalisation or a more fragmented future. This clearly shows how our choice of energy technology is able to a large degree to determine our climate in the long run. Consequences of this finding are discussed in the following.

Figure 11 Energy use and carbon emissions in 40 IPCC scenarios assembled into 6 groups of scenarios in year 2100. See Box 5 for explanatory notes.



Source: IPCC, 2000

Box 5 Long-term emission scenarios

- The A1 storyline and scenario family describ a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity-building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).
- The A2 storyline and scenario family describ a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describ a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and

resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

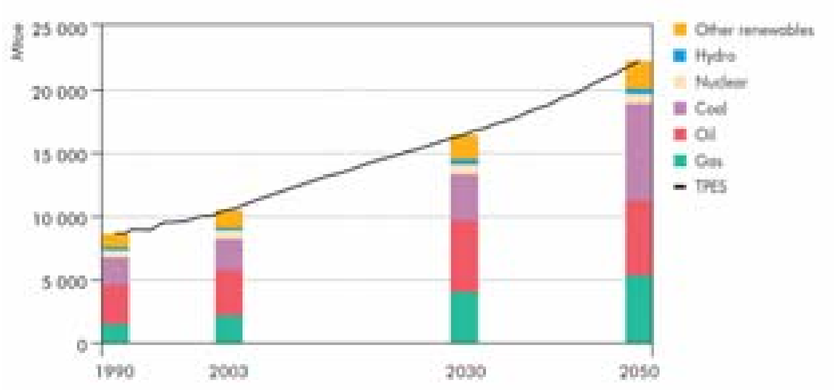
- The B2 storyline and scenario family describ a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

From IPCC (2000a): Summary for policymakers, special report on emission scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.

1.8 The energy challenge

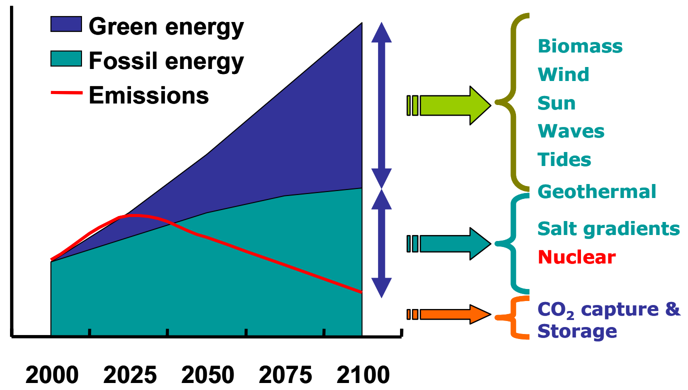
However, the ”technology solution” is in no way easy. Figure 12 and Figure 13 illustrate what can be called the energy challenge ahead of us. The first figure (Figure 12) shows total world primary energy supply towards 2050 in a business-as-usual scenario developed by the IEA (2006). The next figure shows the situation schematically. Demand for energy is expected to grow considerably, mostly driven by economic growth in the poor part of the world. Today almost two billion people do not have electric lights, and we may expect them to aspire to do something about that! By the end of the century, global energy use will thus be several times larger than today (twice as large according to the IEA). At the same time, the emission of greenhouse gases must be cut drastically by the end of the century, as discussed above. The challenge then is to put in place a climate friendly energy system several times the size of today’s energy system, preferably before the middle of the century. If we to be even remotely able to meet this challenge, we need massive investments in almost all forms of climate-friendly technologies. As we will see, since solutions such as nuclear power will quite obviously have to be included in the technology mix, the challenges represent not only technological ones, but also serious challenges of decision-making and governance to our political and institutional machinery.

Figure 12 World total primary energy supply by fuel in the baseline scenario



Source: OECD/IEA (2006).

Figure 13 An illustration of the energy challenge



1.9 Some reflections on the scale of the problem

At the outset it is important to recognise the scale of the challenge of climate change. As we have argued global emissions will have to be reduced substantially below today's level by the middle of the century. This will have to happen simultaneously with continuing population growth, perhaps up to a 50 percent increase by the middle of the century, and social and economic development in the

”third world”. Thus energy consumption is expected to increase, doubling or even trebling world total primary energy use by 2050, as indicated by Figure 12.

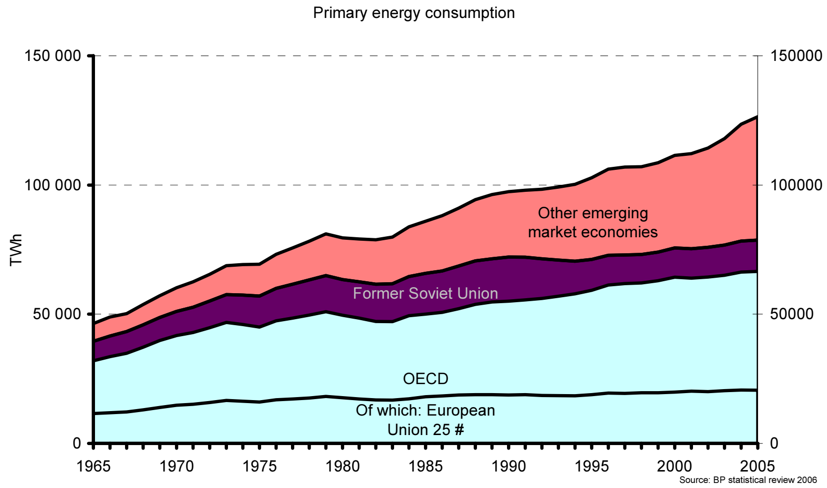
If one distrusts forecasts, a look at Figure 14 and Figure 15, which show the historical development of primary energy consumption and electricity generation respectively, should also help us in grasping the scale of the challenge.

The first figure shows an annual mean growth of global energy consumption of 2.5 per cent per year over the last 40 years, with double that figure for the less developed world. Over the last five years this represents an annual growth of just over 3 000 TWh per year of which 2 400 TWh is coming from ”emerging market economies”, i.e. the developing world.

Focusing on electricity generation (Figure 15), the annual growth over the last 15 years has been 2.9 per cent per year with a 6.3 per cent per year increase in capacity in the developing countries. The growth has been almost 560 TWh per year of the last five years, of which the developing world has been responsible for 380 TWh per year.

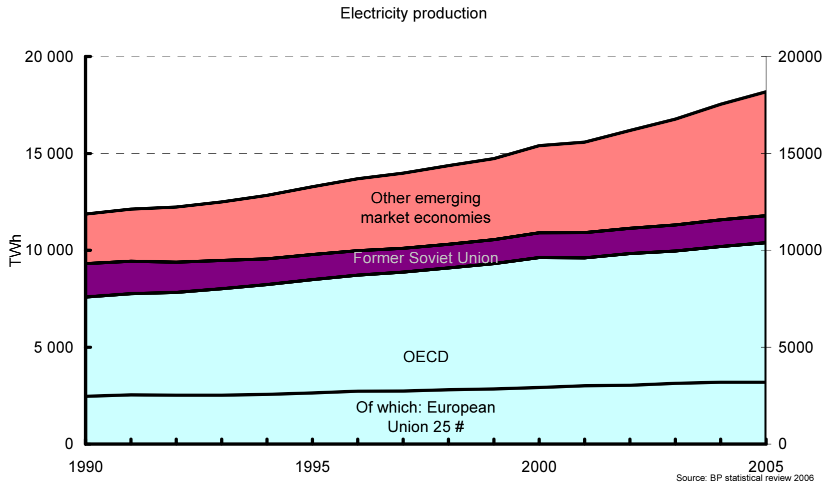
A large power station produces around 500 MW, corresponding to approximately 4 TWh per year if continuously run. Taking into account the need for maintenance etc., we find that the annual growth in electricity production corresponds to roughly 200 new ”power stations” a year, i.e. almost 4 a week! The overwhelming majority of these will be fossil-fuel based if we do not do anything. It is therefore no surprise that without control policies, CO_2 emissions will also more than double over the same time span. To reduce emissions substantially under such conditions is clearly a formidable task. In particular, it is clear that marginal changes in efficiencies, planting of trees, collection of methane from waste deposits, etc., while all desirable actions, do not in themselves have the capacity to meet the challenge.

Figure 14 World primary energy consumption



Source: BP Statistical Review, 2006. Note: "European Union 25#" refer to the 25 Member States of the EU prior to 2007.

Figure 15 Electricity generation



Source: BP statistical review, 2006. Note: "European Union 25#" refer to the 25 Member States of the EU prior to 2007.

1.10 What is a sensible climate policy? A summary of the global challenge

The twin challenge of doubling or more global energy supply while halving or more the emissions of greenhouse gases is formidable in scale and clearly points to the need for massive investments in climate-friendly technologies. The technological development will have to take place both ”horizontally”, i.e. by creating markets for and spreading the best available technologies to all countries and sectors that lags behind in technological maturity, but also ”vertically”, i.e. in depth, by developing genuinely new climate-friendly technologies and substantially lowering the costs for existing technologies. Most probably this development will have to be driven predominantly by the developed world.

In view of this, it is reasonable in our view to conclude that any sensible climate policy will have technological development as a main focus. Thus, any proposal for climate policy action should be measured against this: *Will the policy further the development and implementation of climate-friendly technologies on the required scale before, let us say, 2050?*

Part II The global response so far

This part describes international climate policy so far, i.e. the road leading up to the Kyoto Protocol and the EU-s emission trading scheme. The role of the Intergovernmental Panel on Climate Change (IPCC) is also commented upon.

2.1 A short history of climate policy

The history of our understanding of climate change goes back a little more than 100 years[10], and the history is well told by Weart (2003). fIn this part, we will only briefly mention some highlights of the more recent political history leading up to the Kyoto Protocol. This will then form the basis for our critique of the international response so far, and for suggestions for further developments of the international climate regime.

2.1.1 The creation of IPCC

The Global Atmosphere Research Programme (GARP), which began activities in 1967, already arranged a major 2-week conference on the climate issues in Stockholm in 1974. In 1979 these activities were transformed into the World Climate Research Programme (WCRP). The creation of the WCRP set forth a series of workshops held in Villach, Austria, in the 1980s organised under the auspices of the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU) (Agrawala, 1998a, b). At the 1985 Villach meeting an international group of scientists reached a consensus that, as a result of the increasing concentrations of greenhouse gases in the atmosphere, a rise in the

[10] The Swede Svante Arrhenius played a prominent role in the early phase.

global mean temperature ”greater than any in man’s history” could occur in the first half of the next century. This group of experts also stated that ”…the understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin active collaboration to explore the effectiveness of alternative policies and adjustments” (WMO, 1985). Thus, over twenty years ago science issued a first warning on the potential coming perils of climate change.

In combination with a set of other factors, especially anomalous weather conditions in Europe and America, the 1985 Villach meeting was instrumental in bringing the climate issue onto the international political agenda. In 1986 the Advisory Group on Greenhouse Gases (AGGG) was set up under the joint sponsorship of the WMO, UNEP and the ICSU. Each of these bodies nominated two experts, and the panel consisted of six members: G. Goodman, B. Bolin (again a prominent Swedish scientist!), K. Hare, G. Golitsyn, S. Manabe and M. Kassas (Agrawala, 1998).

During the latter half of the 1980’s the climate issue increasingly gained saliency among the public, scientists and policy-makers, not least through the work of the so-called Brundtland commission (WCED, 1987). More or less at the same time, the Montreal Protocol to the Vienna Convention (signed in 1987), imposing international restrictions on emissions of ozone-depleting substances, was developed. In many ways this Protocol was to become a model for what people thought was necessary in order to tackle the climate problem.

Thus, in 1988, more than 300 scientists and policy-makers from 48 countries, UN organisations, international governmental organisations (IGOs) and non-governmental organisations (NGOs) met in Toronto at the Toronto Conference on the Atmosphere to consider the question. A long heat wave in the US the same summer provided the background for an explicit policy recommendation calling upon national governments to reduce CO_2 emissions by 20 percent from 1988 levels by the year 2005.

Box 6 IPCC assessment reports

1990: First Assessment Report
1992: Update on emission scenarios
1995: Second Assessment Report (SAR)
2001: Third Assessment Report (TAR)
2007: Fourth Assessment Report (4AR)

See http://www.ipcc.ch for more information.

Also in 1988 UNEP and the WMO jointly established the Intergovernmental Panel on Climate Change (IPCC). The IPCC was charged with the task of providing assessments of the scientific literature on climatic change and has done so since 1990 in regular reports.

IPCC is a unique construct and has proven very influential in the political history of climate change. (For more on the IPCC, see e.g. Alfsen and Skodvin, 1998, Agrawala, 1998 a, b).

2.1.2 United Nations Framework Convention on Climate Change (UNFCCC) and the start of international negotiations

Already in 1990, the IPCC published its so-called First Assessment Report (FAR). The timing was not coincidental, as it was published in time to provide important information on our understanding of the climate system to the upcoming United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992.

Here, heads of state from almost all countries in the world established the United Nation Framework Convention on Climate Change (UNFCCC), which stated in its article 2 that the objective of the Convention is the

> 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 time-frame 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: avoid dangerous climatic change.
>
> (UNFCCC, 1997).

The Convention enjoys near universal membership with 189 countries (including the United States) having ratified the Convention to date (2006). Under the Convention, governments:

- gather and share information on greenhouse gas emissions, national policies and best practices,
- launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries,
- cooperate in preparing for adaptation to the impacts of climate change .

However, no strict limits on greenhouse gas emissions were introduced in the Convention, although a principle of early action by the industrialised countries was established. The Convention entered into force on 21 March 1994, and the first Conference of the Parties to the climate convention (COP-1) took place in Berlin in 1995. Here parties decided on a mandate for the negotiations to take place in order to introduce more concrete and stringent emission reduction goals for the industrialised countries, the so-called Berlin Mandate (UNFCCC, 1995). In 1995 the IPCC published its Second Assessment Report, which provided scientific input to the negotiations leading up to the Kyoto Protocol.

2.1.3 The outcome of the negotiations: The Kyoto Protocol

The Kyoto Protocol was signed at the Third Conference of the Parties (COP-3) in Kyoto in late 1997, giving emission restrictions for six (groups of) greenhouse gases[11] for the industrialised countries (designated Annex B in the Kyoto Protocol), for the period 2008–2012, see Table 1. In addition to allocating emission quotas, the Kyoto Protocol also introduced three so-called flexibility mechanisms, allowing countries to trade or transfer some of these quotas, see Box 7.

[11] The targets cover emissions of the six main greenhouse gases, namely: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulphur hexafluoride (SF_6), see Box 1.

The Kyoto Protocol stipulated that a double clause be fulfilled for the treaty to enter into force:

1) At least half of the parties to the UNFCCC must ratify the Protocol (an easy target), and
2) among industrialised countries, countries with at least 55 percent of CO2 emissions in 1990 must ratify (as it turned out – a tough target).

After further negotiations of the details of the Protocol, retraction of Kyoto support from USA and Australia in 2001, and some hesitation from Russia, the Protocol, now amended with the so-called Marrakech accord (UNFCCC, 2001) finally entered into force on 16 February 2005, ten years after the negotiations started in Berlin. This came after the IPCC issued its Third Assessment Report (TAR) in 2001, focusing on the impacts of climate change and ways to adapt to climate change.

Table 1 Countries included in Annex B to the Kyoto Protocol and their emissions quotas

	Quota allocation (1990**–2008/2012)	Base year emissions** ($MtCO_2$-eq.)
EU15*, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland	-8 %	5 110
US***	-7 %	6 103
Canada, Hungary, Japan, Poland	-6 %	2 559
Croatia	-5 %	31
New Zealand, Russian Federation, Ukraine	0	4 027
Norway	+1 %	50
Australia	+8 %	423
Iceland	+10 %	3

*15 member States of the EU (EU15) have redistributed their targets among themselves, taking advantage of a scheme under the Protocol known as a ”bubble”. See Table 2.
** Some countries with economies in transition (EITs) have a baseline other than 1990.
*** The US has indicated its intention not to ratify the Kyoto Protocol.

Note: Although they are listed in the Convention’s Annex I, *Belarus* and *Turkey* are not included in the Protocol’s Annex B as they were not Parties to the Convention when the Protocol was adopted.

Source: UNFCCC.

Table 2 The EU redistribution of emission quotas for the period 2008–2012 relative to 1990

EU15	Emission quotas (1990–2008/2012)	Emissions 1990 (MtCO2-eq.)
Portugal	27,0 %	60
Greece	25,0 %	109
Spain	15,0 %	287
Sweden	4,0 %	72
Finland	0,0 %	71
France	0,0 %	567
Netherlands	-6,0 %	213
Italy	-6,5 %	520
Belgium	-7,5 %	146
United Kingdom	-12,5 %	776
Austria	-13,0 %	79
Ireland	-13,0 %	56
Denmark	-21,0 %	70
Germany	-21,0 %	1226
Luxembourg	-28,0 %	13

Source: UNFCCC.

Box 7 The flexible mechanisms of the Kyoto Protocol

If the number of emission quotas (emission target) allocated to a country is insufficient, there are a number of ways to get more under the Kyoto Protocol. Buying quotas from Annex B countries with a right to trade is one possibility. Another way to obtain quotas is to invest in mitigation projects in developing countries through the Clean Development Mechanism (CDM) or in other Annex B countries through ”joint implementation” (JI). The projects must be approved in accordance with the regulations of the Kyoto Protocol and monitored satisfactorily.

In addition to these flexibility mechanisms, the net carbon removal in forests as a result of increased forest area within national borders can also gives extra quotas. It is also possible to choose to get credit for uptake, or reduced emissions, resulting from changing the way other areas are managed. This choice must be made in 2006 and will also require monitoring and reporting of removals and emissions from these areas in the subsequent commitment periods.

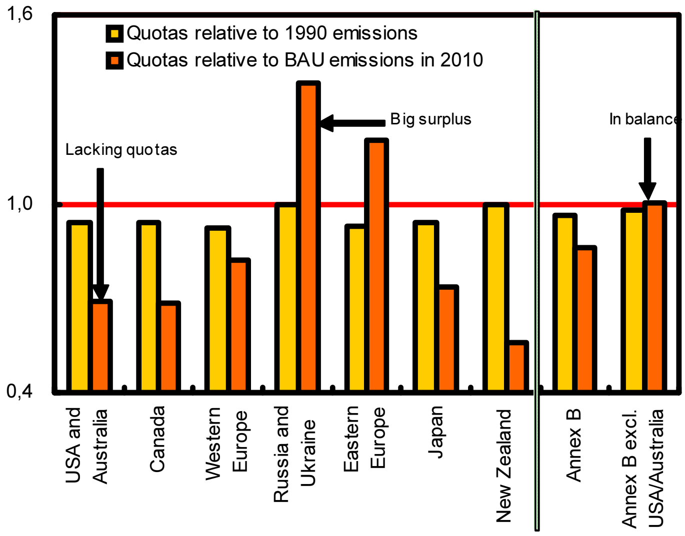
In addition to selling quotas, a country can lose quotas through cancellations. Cancelled quotas disappear from the system and cannot be sold or used to meet commitments. Quotas can be cancelled for several reasons, including net emissions from forests. Quotas can also be cancelled voluntarily. After the commitment period, the quotas are retired as a settlement for what was emitted during the period. Since the emissions will not be known until two years after the first commitment period is over in 2012, there will be a period when countries can trade quotas to help them to meet commitments or to get rid of extra quotas. If a country is left with extra quotas after that, they can be transferred to a subsequent commitment period. However, there are limits to the transfer of quotas acquired from mitigation projects or uptake in forests.

Originally, the Kyoto Protocol was designed to reduce overall annual greenhouse gas emission from the industrialised countries in the first commitment period (2008–2012) by approximately 5 per cent relative to 1990. Compared to what is needed in the long run, Kyoto was thus clearly set up as only a first, very small step. Without participation from USA and Australia, even this slight reduction in emissions is likely to disappear however, and total emissions in the first commitment period are more or less equal to expected business-as-usual emissions. In Figure 16, the yellow columns show the quotas received relative to the 1990 emission level for some groups of countries. Of equal interest, however, is the size of the quotas relative to expected emission levels in the commitment period. This is shown by the orange columns. The far right part of the figure summarises the situation for the totality of Annex B countries, with and without the USA/Australia. It is noteworthy that the allocated quotas seem to match expected emissions in the Annex B countries after the withdrawal of the USA/Australia. In other words, after the USA and Australia withdrew from the Kyoto Protocol, the Protocol is not expected to reduce business-as-usual emissions from the participating countries at all. This illustrates a point we will return to later; namely that voluntary international cap-and-trade treaties have a difficult time embodying strict emission reductions (they may also have difficulties enforcing strong emissions reductions).

At the moment, most countries are in dire straits when it comes to fulfilling the quite weak obligations laid down for the first commitment period. Figure 17 and Figure 18 show how the EU15 countries are faring with regard to achieving the Kyoto targets after the burden redistribution of the over all EU target among EU countries[12]. For countries outside the EU, the situation is not much better.

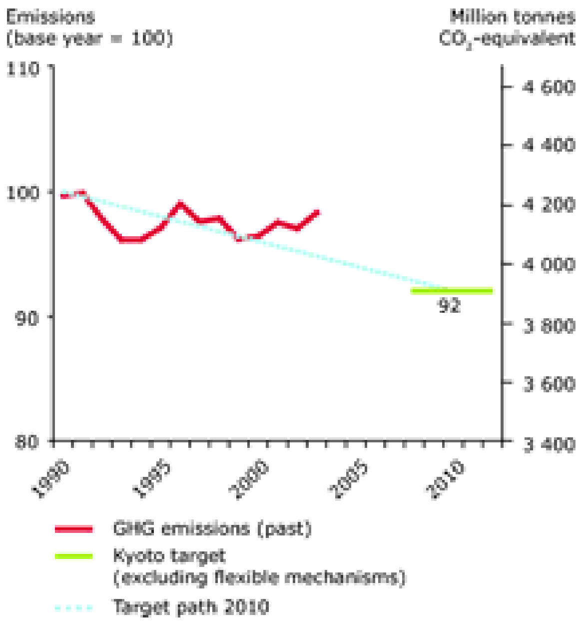
[12] Shown in Table 2.

Figure 16 **Quotas relative to 1990 emissions and expected 2010 emissions in some regions. The figure shows allocated emissions rights relative to 1990 emissions and expected business-as-usual emissions in 2010 for groups of countries. We note that countries with emission obligations (the Annex B countries) have quotas approximately covering expected emissions in 2010 after the USA and Australia withdrew from the Kyoto Protocol in 2001 and 2002.**



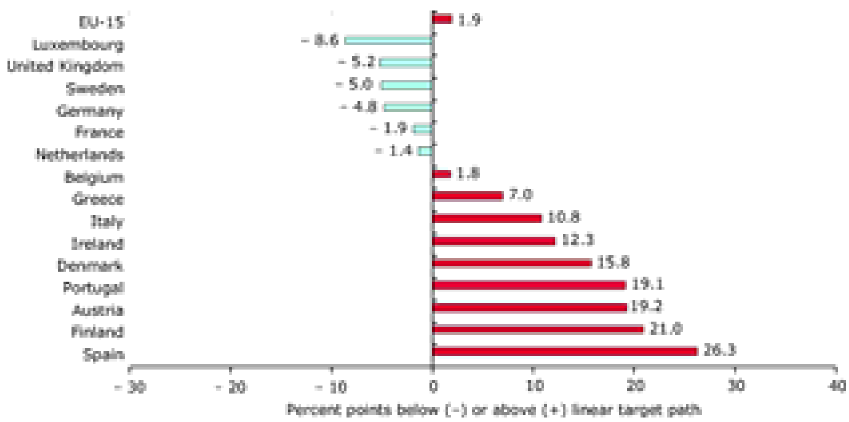
Source: Holtsmark and Alfsen (2004).

Figure 17 Development of EU15 greenhouse gas emissions from base year to 2003 and distance to the (hypothetical) linear EU Kyoto target path (excluding flexible mechanisms).



Source: http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=1456

Figure 18 Distance to target (EU Kyoto Protocol and EU Member State burden-sharing targets) for the EU15 in 2003.



Source: http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=1448. Copyright EEA, Copenhagen, 2005.

In 2005, EU initiated its pre-Kyoto emissions trading scheme (EU ETS). This is to be followed up by all parties to the Kyoto Protocol in the first commitment period (2008–2012). Negotiations for the period after 2012 have started, but are very slow at the moment (beginning 2007), with near total uncertainty as to whether agreement will be reached, and if so, what format the post-Kyoto regime will take. The lack of urgency and political leadership in the international negotiations is unfortunate (to use an understatement) given the challenges we all are up against as described in Part I.

Although the negotiations are slow at the moment, and the results have major weaknesses (more on this in Part III of the report), a major accomplishment over the last 15 years has been the establishment and operation of the Intergovernmental Panel on Climate Change (IPCC). It has structured communication and debate between science and society in a manner that has assured that everybody who wants to know the current knowledge status with regard to climate change has had access to such knowledge. Regarding the nature of this knowledge, it must be fair to state that we currently know the essentials of the risk and opportunities associated with continuing our current behaviour. The main challenge facing us today, after a decade of intensive research in the area of natural sciences, is to get a better understanding of how societies can make the decisions necessary to reduce the risks of climate change to acceptable levels and to develop the necessary technological solutions. Knowledge about social processes should thus be in as much demand as technological expertise in the coming years.

The fact that ten years of negotiations ends up with a treaty that doesn't restrict emissions in the short term and with only very vague and uncertain notions as to how and whether the regulatory regime will be extended past 2012, makes it important to ask the question: How did it become like this and what can be done to rectify the weaknesses? This is the topic of the next parts of the report.

Part III Critique of the Kyoto Protocol and how to rectify some of its weaknesses

"If I were going there, I would not start from here" – Old Scottish farmer standing in the heather of the highlands, when asked by a lost tourist how to get to Edinburgh

In this part we will first describe why the Kyoto Protocol was formulated as a cap-and-trade system and provide a practical critique of this type of agreements. Some pitfalls in implementing such a regime will be described, before we discuss what we believe are serious problems associated with several types of economic instruments (including cap-and-trade systems) when it comes to confronting the climate problem. We will argue that the lack of delivery in terms of near-term emission reductions is no accident, but a logical outcome given how the regimes have been constructed (as Scott Barrett, 2003, and other analysts have demonstrated). Strengths and weaknesses are analysed with a forward-looking perspective. While the current regime is inadequate for vertical technology development, it may serve for horizontal technology development, pointing towards the need for combinations of approaches. An alternative approach to future treaties is described.

3.1 A practical critique of the Kyoto Protocol

How did the Kyoto Protocol aquire its format as a cap-and-trade system? Caps, the first element in "cap-and-trade", have been the focus of climate negotiations from the start, i.e. to establish quantified national emission reductions in a target year or period some time into the future[13]. This first element was inspired in important ways by the success of the Montreal Protocol in controlling ozone depleting substances and by control of the emissions of acidifying substances (mainly SO_2 and NO_x) in

[13] Cf. the so-called Berlin mandate paragraph 2a from 1995 (UNFCCC, 1995).

Europe and North America. This construct invites nations to declare at an early stage their intention with regard to future emissions of greenhouse gases, a cheap thing to do!

However, when the time of reckoning is approaching, it becomes apparent that some countries will have to reduce their emissions more than others (or buy more quotas) either because of strong growth in emissions or because of inherent tight emission targets. It then becomes tempting to opt out of the agreement. It is the nature of international treaties in general, and the Kyoto Protocol in particular, that they emerge in a context of sovereignty, so participation is voluntary. Only very limited means of sanctions exist, and often there are none at all if the retreating party is a powerful one. It should therefore come as no surprise that the USA opted for a withdrawal from the Kyoto Protocol in 2001. As can be seen from Figure 16, the USA was among the countries that had to reduce their emissions most under the Kyoto Protocol when compared to the expected business-as-usual emission level. Around the turn of the century a new administration quickly withdrew from the Kyoto Protocol, noting both that its costs would be considerable and that there were other big emitters – like China and India – that were under no similar obligations.

As Aldy et al. (2003) and Barret (2003) have argued, we find every reason to expect this to be a common pattern that will also be repeated in the future if this kind of regulatory regime is continued. In particular it will be tempting and relatively easy for big emitters with relatively large reduction commitments to withdraw, as these are usually the parties that are less susceptible to pressure and sanctions from the remaining parties to the treaty.

Put another way, if we consider the total cost of compliance (and not the marginal cost which would be equal across countries under a perfecely functioning cap-and-trade system), it seems that parties will tend to withdraw from the treaty if their relative total cost is percieved as substantially larger than those of other parties. When a country with high costs, like the USA, withdraws from the treaty, both the costs and the cost differences among the remaining parties will decrease, in part because the price of quotas will be reduced. Unfortunately, this will also diminish the incentives for necessary and expensive technology developments.

Thus, our arguement that a Kyoto-type Protocol is unlikely to deliver the strong emission reductions that are needed is in part that it will fail to attract participation that is broad enough. It will be too tempting and relatively easy for large nations in particular to opt out of the agreement if the emission targets become expensive. In consequence the expected emissions price and rewards for technology investements will be too low. Hence, such a treaty will not deliver the necessary incentives for the development of new climate friendly technologies. Measured against our ”acid test” of climate policies (i.e. that they encourage technological development and implementation on the required scale), we thus find the Kyoto Protocol wanting.

Trade, the second element in ”cap-and-trade”, is supported by impeccable logic, but has flaws related to its practical implications. On the one hand, the mechanisms of quota trade, joint implementation and the clean development mechanism embedded in the Kyoto Protocol all work to ensure that the emission reductions that occur, however limited, are gained in a fairly cost effective way. Thus, while this type of protocol is likely to fail when it comes to inducing (expensive) technological development in depth, it may be a valuable tool in disseminating already existing, and therefore cheaper, technological solutions throughout the market (technology transfer). In addition, even if expected quota prices alone are insufficient to stimulate development of new technologies, a treaty with direct support to research, development and demonstration (RD&D) of new technologies will be both stronger and better directed if supported in part by expected quota prices or emission taxes.

3.2 Practical pitfalls

Unfortunately, there are also other problems with a cap and trade system like the one instituted under the Kyoto Protocol. These weaknesses have come to the fore in particular under the European emission trading system’s (EU ETS) pre-Kyoto phase. Basically this hinges on the political pressure that has come to bear on the question of how to allocate the emissions quotas. The EU has decided that under it’s pre-Kyoto phase (2005–2007) at most 5 per cent of the quotas can be auctioned or sold, the rest is given away freely. Furthermore, and more damaging, the allocation has been decided by a negotiated process, both between firms and national authorities, and between these authorities and the EU Commission. The outcome of this system is that participants in the

ETS are able to influence their future allocation of quotas. This in turn influences their behaviour and is probably an element in the explanation of the surprisingly high quota prices observed in Europe over the last couple of years. Those selling quotas in today's system send a strong signal that they have a surplus beyond what ”they need”, and may thereby risk a reduced allocation of quotas in the future. Thus, not only are the quotas a subsidy to a polluting activity, but firms may use excess quotas to be deserving recipients in future rounds[14]. As quotas are quite valuable items, the free allocation of them may also induce firms to make more carbon intensive investments than they otherwise would (in order to capture some of the ”quota rent”); a paradoxial effect of a climate control policy! A practical solution to a seemingly minor technical detail like the allocation mechanism, has thus come to undermine a well intended framwork like the cap-and-trade system.

3.3 Can expected rewards alone drive mitigation efforts?

As stated previously, the ”solution” to the climate problem requires the development and adoption of climate friendly technologies on a massive scale, primarily in emission intensive sectors like power production and transport. This in turn requires technological research and development (R&D), partly to lower the cost of existing technologies and partly to develop genuinely new technologies. This of course demands investments up front, and the question arises of whether the investors are likely to be rewarded, so as to recoup their investments. Such rewards should be forthcoming through appropriate pricing of the machinery and/or services rendered by their technology once it exists and is put on the market.

This question is common to all inventors and inventions, and usually patent laws and a (limited) time of monopolistic pricing secure the inventors enough incentives to let the R&D take place. In the applied end of research, a trade-off must be found between the role patent protection plays in motivating investments versus the costs involved in delayed adoption due to monopolistic pricing. We revert to this topic later, but do not treat in detail *how* to

[14] As a potential added benefit from their point of view, other firms are thereby faced with a higher quota price, increasing the operating costs of some of their competitors.

stimulate technological development and adoption (our focus will be that stimulus is worthwhile).

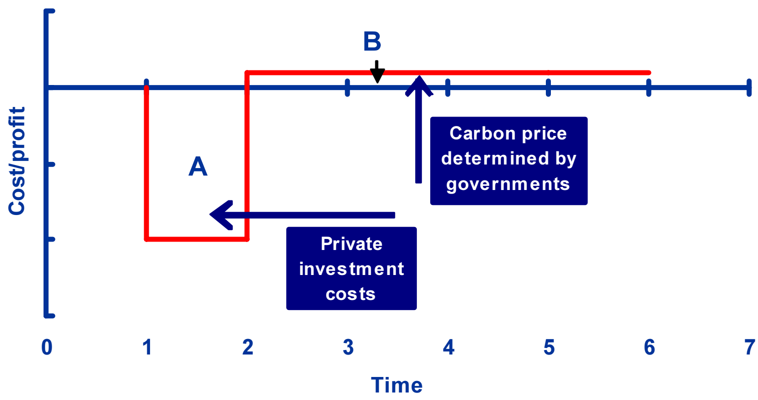
However, in some cases this mechanism breaks down. Most famously perhaps is the case of pharmaceuticals for poor people, like medicine for malaria, where the customers simply cannot afford to pay the price necessary to cover the R&D costs. Just as important, though, is the observation that protection of intellectual property rights (IPR) (and climate policy) involves country decision-making under sovereignty. The USA resisted honoring European IPR until the closure of the 19th century. Presently the drama is being played out between the World's North and South, and the same issue will be critical in the future development of climate mitigation institutions. In principle, investors in climate technology will be rewarded in any country by a combination of its climate policy (ensuring a market paying more for low-carbon products) and its protection of patents. For both, the incentives for a country to make promises may be greater than its incentives to make good on these promises.

The case of climate friendly technologies has some parallels to the case of pharmaceuticals for the poor. The reason is that while the private sector is expected to invest in necessary R&D, basically governments determine the price of emissions through their climate policy (see Figure 19), which is essential when it comes to get the payback on R&D. It can be argued that in the long run governments are unlikely to put the price on emissions much above the marginal cost of employing climate-friendly technologies (once they exist). Pressures in this direction will come from lobbying by pressure groups dependent on using the technology, and will also exist for reasons of international competitiveness[15]. It is thus likely that a plan to let private firms pay for necessary investments in new technologies while governments determine how or whether the firms get any reward for the investments, is dynamically inconsistent (i.e. it is not rational for governments to fulfil their promises to investors once the investments have been made) (Kydland and Prescott, 1977). The subsequent literature on incomplete contracts describes it as a "holdup problem" when a partner to a contract effectively can expropriate the assets of

[15] For the sake of the argument we are simplifying here. In reality there will be a portfolio of more or less climate friendly technologies available. The point is that implementing existing technologies is generally much cheaper than developing new solutions more or less from scratch.

another once the investment has been made. The conclusion is often that investments will be suboptimal, but that a remedy is to let the "expropriator" own much of the investment, supporting the idea that government funds part of R&D. This situation of incomplete contracts deserves further attention and studies from researchers.

Figure 19 Investments costs and pay backs. If area A is larger than area B, investments costs will never be paid back

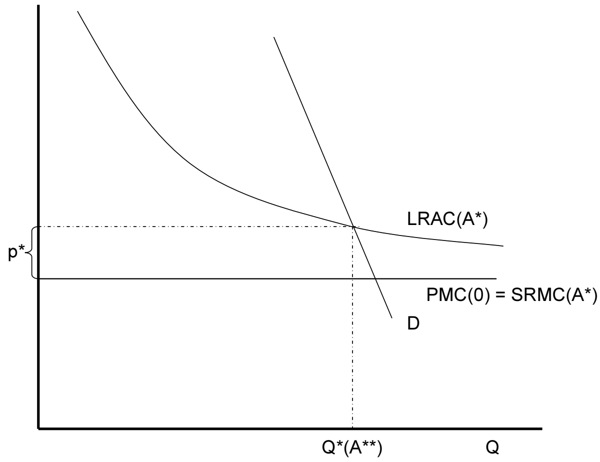


In brief, ideally a carbon friendly technology is developed in the private sector under expectation of rewards that depend on government policy, for instance a carbon tax that "harms" other technologies more than the carbon-lean technology. But once that technology has been developed, welfare can be improved by implementing a lower tax lower than promised, i.e. sufficient for implementation but not sufficient to reward investors. So if government cannot commit to implementing the rewards, the required rewards cannot be expected, and private technology development will fall short of optimal levels[16].

In Figure 20, below, we use a different graphical window to demonstrate that these problems carry over to the case when a quota instrument is employed, and also emphasize the role of scale economy and sunk costs.

[16] An important exposition of this key idea is found in Montgomery and Smith, 2005.

Figure 20 The use of a quota system and the need for investments



The assumption is that a "polluting good" (cars, power plants, or electric power) is produced by a technology with the horizontal line (PMC) as marginal costs, applicable in both the long and the short run. But an alternative technology could be developed, at a fixed costs, and let us assume that the technology would remove emissions, and leave marginal costs *afterwards* at the same level as for the traditional technology. Thus, if the technology had already been developed, no inducement (taxes or quotas) would be needed for it to be competitive in the market place. But investors need to be enticed to invest in developing the new technology, and they could be if the price in the market place at later stages were high enough to let them recoup their investment and give them a reasonable return. The slightly declining curve (LRAC) demonstrates combinations of price (p) and quantity (Q) that would give investors a sufficient profit to be happy to invest. If the curve D represents the demand function for the output in question, a high enough price would establish itself in the market place if producers with the traditional technology had to buy quotas (or pay taxes) in the amount of p*,Q* in the figure.

Thus, for an emission-free producer (or product), it is the quotas that others have to buy that gives her a role in the market place. Regrettably, however, once the technology has been adopted, even if society is very interested in emission-free products, society will have them even if the implemented quota system results in a quota price lower than p*. At a quota price lower than p*, consumers will be happier, so the political economy may very well implement systems with larger quotas or less stringent quota reductions – meaning lower quota prices – or with lower taxes. Of course, if inventors predict this outcome, they will not invest, much in the same way as they will not invest if the patent protection is imperfect, if they think some countries will opt out of the climate regime, if some emitting sources are exempted, given quotas for free, etc.

When such problems relate to the expectations about the future climate regime and its carbon price, then the basic assumption behind "one instrument only" (e.g "cap-and-trade only") in international climate policy fails in the sense that expected rewards cannot be relied on alone to drive far-sighted investments in climate friendly R&D. The palette has to be broadened. This will be an important argument in the following.

Another issue with similar consequences (i.e. the non-investment in R&D), is the possibility that the emission ceiling established in quota trading systems through negotiations (whether at the international or the national level) will be influenced by the current best available technology. Thus, there may be a tendency to set the ceiling at a level achievable by current technologies, and this will preclude incentives for development of radical new and significantly better technologies.

When it comes to the implementation – or adoption – of climate-friendly technologies, however, we will argue that the role of governments is to provide a framework making the preferred technologies competitive vis á vis more polluting alternatives. This can be done by taxing GHG emissions or by introducing cap-and-trade systems á la Kyoto. This means that not only are cap-and-trade approaches (or tax approaches) important in the short term to stimulate adoption of existing technologies. Present adoption approaches are also important to lend credibility and strength to present R&D programmes, to the extent that they indicate future adoption rewards, important to present R&D investments. Thus, as a cap-and-trade programme strengthens an R&D programme and vice versa; the two types of efforts (and treaties) will be complementary.

It is worthwhile emphasizing that amongst analysts, important perspectives that are critical to cap-and-trade type agreements apply in similar ways to R&D type agreements. In particular, under certain conditions, the problems of achieving broad participation for cap-and-trade will apply in an equivalent fashion for R&D cooperation. The exceptions to this, the conditions under which R&D cooperation can support broader participation than cap-and-trade alone, are conditions under which radical technological change (much lower emission factors) is feasible, and where such change is likely to display increasing returns to scale (Barrett, 2006). These are conditions assumed to apply in the two preceding figures (both emphasizing sunk costs and returns to scale). Barrett provides some reasons to speculate that these conditions are likely for transport, but less so for electricity generation. While such judgments will be important, it is of course the case that a belief in the role of technological change is a belief in elements of scale economies, and it is fairly evident from the earlier exposition that technological change has to be radical for mitigation to be feasible[17]. Box 8, below, summarizes both the rationale for and possible instruments in a technology oriented programme.

Box 8 Stimulus to climate-friendly energy technology R&D: Why and how

Why:

As a policy principle, public support for research and development in general is justified by *knowledge spillovers:* Since investors are rewarded less than optimally in the market place (others learn from their gains without compensating them), investments in R&D will be lower than optimal, justifying policy support.

How: General

Patent protection rewards investors in the applied end of knowledge gains through a period of monopoly profit.

Research and development subsidies are used to finance or stimulate more basic research, as through universities, institutes, and in cooperation with private individuals and organizations.

[17] We may serve the reader with an idea of what we mean by radical technological change. One often finds that present but advanced technologies can reduce emission factors by a third, or perhaps two thirds (energy efficiency, hybrid cars, better bulbs, etc.). Pacala and Sokolow (2004) demonstrate that such options can give us the emission reductions that we need until 2050. But if the world economy grows at all, and emissions eventually are not only to be held constant, but reduced, emission factors of important sectors will have to fall by 90 or 100 percent. Radical technological change, required in 30 to 50 years, should be considered as reduction in emission factors in excess of two thirds.

Why: Climate friendly technologies

If expected quota prices (or taxes) for the distant future were sufficiently high, support additional to that above would barely be required. But with *incomplete participation* in treaties and *incomplete commitment*, technological development will be lower than desirable without additional support.

Also, programmes for energy technology could join some nations more concerned about *energy security* with others motivated by *climate change mitigation* (and perhaps other objectives, like *air quality*). Future employment and *competitiveness* will be amongst objectives in practice.

How: climate friendly technologies

Research and development *subsidies*, including financing or co-financing of research in universities and private foundations/corporations. Also, it could be through generous funding of excellent institutes, or through *competitive contract*s for specific goals (as with Kremer's proposal for guaranteed purchases from the first producer who has a given product).

Also, stimulus could be given by agreements on goals, or *future standards*, for instance a carbon efficiency standard for buses by 2015, 2025, promising a market for those making the advances.

Energy technology programmes could be attractive – and work well – for a nation or a few, and *build coalitions* over time. If Europe and the USA cooperate, nations like China and India might opt in.

Government effectiveness will be an important challenge, worthy of careful consideration of mechanisms as with standards and competitive contracts (above). Trust, too, is an issue. Car drivers concerned about future driveability, and car makers, might easily support earmarked fuel taxes in support of future alternative engines or fuels.

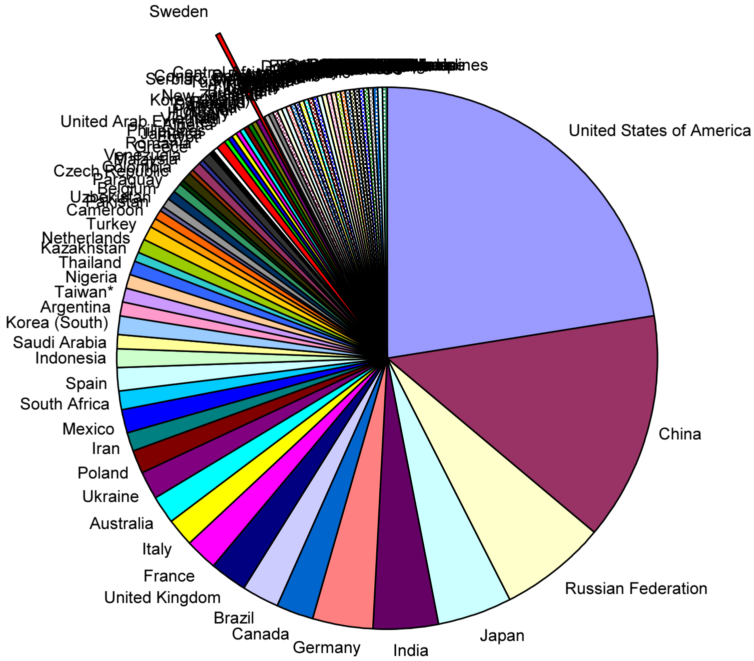
Having described the international response to the climate challenge and found it wanting in several respects, it is time to take a look at what is required. This is done in the following.

3.4 Requirements of an effective international climate regime

With the description of the challenges and problems as a backdrop, we can list some essential requirements of a meaningful climate regime.

- *Breadth:* We need broader participation than the current Kyoto Protocol, i.e. more countries. It is, of course, essential that *all big emitters participate* in a treaty to reduce global emissions. In particular the USA, the EU, Japan and the ”BRIC-countries” (Brazil, Russia, India and China) must participate in a treaty for the treaty to make any sense at a global level. This said, it is also important to get significant contributions from the smaller nations as these stands for up to half of the total global emissions, see Figure 21. In addition, breadth is needed in the sense that more sectors (*e.g.* ocean transport, international air traffic) more measures (e.g. additional sequestration measures, clarification of carbon capture and storage – CCS) need to be included in the ongoing work on climate change.

Figure 21 Greenhouse gas emissions by countries



Source: Data is for years around 1999 and is mainly taken from: http://ghg.unfccc.int/tables/queries.html (30.03.2006). For gaps, data has been supplemented with CO2 data from CDIAC: http://cdiac.ornl.gov/trends/emis/em_cont.htm (Mars 2006).

- *Depth:* We need deeper cuts than what we have up till now. Sweden's national target of 4 percent reduction, Kyoto's overall aim of a 5 percent reduction and Europe's (EU-15) obligation under the Kyoto Protocol of an 8 percent reduction below 1990 levels are clearly not sufficient in the longer term.
- *Length:* Most importantly, we urgently need a longer time perspective in our work and negotiations.

We argue that this three-dimensional weakness in today's regime is best repaired by concentrating first on the third dimension: *length.* The counterargument that a global problem needs (near) global participation (highlighted recently by the Stern Review, Stern, 2006), i.e. that it is essential to broaden participation is correct, but our argument about starting with length is that only such a strategy can broaden participation and deepen emission reductions. Let us, nevertheless, discuss briefly the three weaknesses in the order they appear above.

3.4.1 Broader participation

While "the world" has signed the climate convention (UNFCCC), the Kyoto Protocol puts emission restrictions on a much narrower set of countries. Among "rich" countries that would have been participants with binding commitments to emission reductions (Annex B countries), important countries such as the USA and Australia have opted out. Other countries like China, India and Brazil that are very important in terms of emissions today, and more so in the future, are participating, but without commitments to emission reductions. Thus, it is natural to think of broader participation in at least two ways.

Since some rich countries (notably the USA and Australia) opted out of ratifying the Kyoto Protocol, one obvious meaning of a broader participation is to have these countries signing on to a climate agreement (a cap and trade type, or – as we will argue below – an augmented type of treaty).

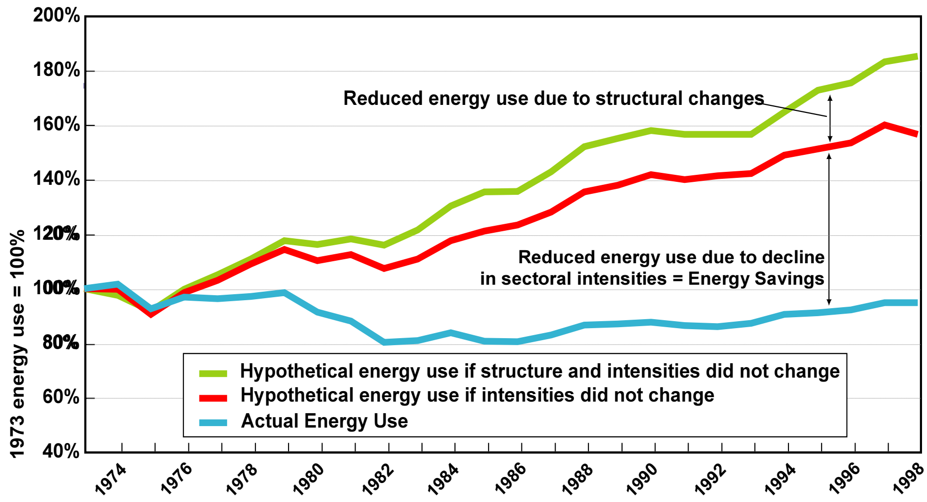
Similarly, an important meaning of broader participation is the entry of individual developing countries into classes with increasingly forceful mitigation implications. A body of literature dealing with this menu of questions is about "post 2012 policy frameworks", in which an important theme is "multistage agreements"[18]. A way of describing this literature is that it provides a bridge between what is general and not very specific in the climate convention (avoiding dangerous human interference with the climate system) and what is specificin the Kyoto Protocol but not of long duration and not broad in particpation. The "post 2012" climate regime literature deals with how to develop future goals for emission limits (what is dangerous interference, is it a temperature limit, a ppm limit, etc), and also how countries can be assumed to carry more of the burden in accordance with their development. It is expected, for instance, that a country like China, now welcome to sign and even benefit directly from participation (through flexibility mechanisms), will participate in the future with binding commitments on emissions, and more rapidly so the more rapidly Chinese incomes rise.

3.4.2 Deeper emission cuts

In striving for "deeper cuts" it is useful to distinguish three sources of emission reductions. First, there is structural change, by which an economy shifts from energy-intensive (or emission-intensive) sectors like manufacturing and transport, to carbon-leaner sectors like non-transportation service sectors. In addition, there is change within sectors, or within activities, by which that activity becomes carbon leaner, as when cars become more fuel efficient or electricity is produced with renewables. Moreover the process by which each activity becomes less emission/energy-intensive can be distinguished in increased use of presently available energy technologies (energy-efficient technology, renewable energy technology, etc), and the development of new technologies. Figure 22 from IEA (IEA, 2004), demonstrates that reduced energy intensities *within* each sector have delivered most of the reduction in overall energy intensity in OECD countries for the last 30 years.

[18] Reviews are provided by Torvanger et al, 2004, 2005.

Figure 22 Reduction in energy use from changes in structure and intensities in 11 IEA countries



Source: IEA (2004).

The balance between sectors of an economy is of course important, and can respond adequately to the challenge of climate change only if broad-based incentives (prices, taxes, quota markets) are suitable, but this would again depend on broad participation. Europe could reduce its emissions at moderate costs if it were ready to scale down its energy intensive manufacturing industries and could handle structural change sensibly. But to the extent that this would merely move greenhouse gas emitting activities to countries with no climate policy and high emissions, it would represent a cost without a climate benefit[19]. For this and for one other reason, we are in favour of the mitigation options that lie in making each activity less energy- or emission-intensive, as is often the case with technological change. The other reason for such a bias is that technological change with reduced emissions in a given activity, can have positive external effects to the extent that the costs of

[19] Such "carbon leakage" is a special case of the "pollution haven" effect. Since greenhouse gas mitigation is a global public good and activities may move to areas with no (or less strict) climate policy, carbon leakage runs counter to the objective of climate policy. Mostly, the literature on pollution effects has concluded it is of no or very slight significance empirically (See, for instance, Eskeland and Harrison, 2003). For greenhouse gas mitigation, a potential of the Clean Development Mechanism (CDM) is to limit carbon leakage by reducing emissions in the South (Kallbekken, forthcoming).

reducing emissions are lowered elsewhere (technological spillovers, priced or not).

It can be argued, thus, that non-global participation in itself provides a rationale for emphasizing

a) technological and other options that make each activity carbon-leaner (as opposed to scaling down carbon-intensive activities); and
b) mitigation at higher cost levels in sectors not exposed to foreign competition.

Both these arguments are in their nature second best, and it is obviously not necessary to "shield" sectors exposed to competition from mitigation policies if one can apply compensatory instruments, as with border taxes for carbon intensive fuels or products into Europe.

3.4.3 Longer time horizon in the commitments to mitigation

The most important key to a viable and effective climatic regime after 2012 is still, in our view, to obtain a longer time horizon in our commitments to mitigation. The Kyoto Protocol is sometimes criticized as "too little, too fast". The "too little" part was discussed above. The "too fast" issue has a simple explanation in the fact that the Kyoto Protocol is about emissions in 2008–2012 and is mostly silent about emission reductions later. More importantly, though; it reflects the sentiment that some, and not much more, can be done in the short to medium term, and that the most important weakness of the Kyoto Protocol is its failure to prepare for greater emission reductions in the longer term. An unfortunate effect of this is the impact it has had on national policies, where a similar short-sightedness prevails.

In view of the fact that development and implementation of new large scale technologies take from 10 to 20 years of concentrated effort, the lack of a longer time horizon is clearly a main barrier to the solution of the climate problem.

A lack of long-term commitments also makes it easier for countries and sectors to postpone action. Since, for a given target either in the form of a cap on temperature increase, or a target for stabilisation of the concentration of greenhouse gases in the atmosphere, it will evidently be cheaper the sooner we start, the lack of a long time horizon is also making the eventual solution more expensive. This lack of commitment also has the unfortunate consequence of costly strategic games. In a situation where government's commitment to future climate policy is in doubt, firms will engage in costly activities to prevent future climate policies from being carried through. These activities are wasteful in themselves, and an effective strategy of this kind by firms will be to make sure future mitigation costs are high (by refraining from investing in long-term mitigation activities).[20] To provide an illustrative example, a possible reading of the fact that European power producers presently invest not only in coal-fired plants but also in domestic coal mining is that the coal mines raise the future costs for governments of hitting hard on coal-fired plants since (or if) the political costs are higher when coal is produced locally than if it were imported. The fact that coal mining in Europe has proven highly uncompetitive relative to imports over a thirty-year period may of course have changed for other reasons, but the possibility that coal mines are being posted as hostages by power plants for protection against future government climate policy serves as an illustration of the costs that can be associated with lacking long term commitment in climate policy.

How will a longer time horizon help broaden and deepen the current climate regime? At present, non-participating developing countries need to know that emission reduction commitments will be cheap (at least considerably cheaper than today) and that they can be combined with economic and social development. Apart from the short term mitigation options that are cheaply available in developing countries (envisaged through the CDM, for instance), international cooperation (at least incorporating the US, Japan and Europe) on the development of climate-friendly energy technologies must play a role in ensuring this. Then, India and China might participate actively, i.e. cut own emissions, engage their own scientists, etc. Over time, as climate friendly technologies are proven and are shown to be cheap, not only broader participation, but also deeper cuts become feasible. To some extent, the tech-led (complementary) regime will be lead by activities that firms and nations think will pay off in terms of profits and competitiveness, and to some extent it will consist of institutional mechanisms trying to ensure that those taking action and investing will profit

[20] Eskeland and Harstad (2006) presents a model in which firms act strategically in the quota market in order to manipulate government behaviour.

over time if successful (these mechanisms are, for example, like matching grants, patents protection, future standards, etc). A world to some extent divided into those taking action and those not taking action will also quite likely see differentiation in trade policy.

3.5 International policies for the future

With Kyoto being silent about post 2012, it is likely investors have lower expectations about mitigation rewards after 2012. As discussed above and elsewhere (Montgomery and Smith, 2005, Kremer, 2000) it is probably hard for countries to signal future emission taxes (or quota regimes) with much credibility. In addition, an international cap-and-trade regime is likely to break down, the more severe the constraints on emissions get, due to the basically voluntary nature of such agreements. What is needed is an agreement (or a set of interlinked treaties) where the participants find it to be to their self-interest to participate.

One part of the solution to this problem is to recognize that public funds will have to carry a substantial part of the research and development costs of new climate-friendly technologies. This cost will have not only to cover the direct research and testing of new technologies, but also the more basic task of establishing the necessary competence through more education and research. As part of this, technological initiatives will also have positive spin-offs to society over and above those related to climate change (in ways similar to those claimed for the Apollo program, defence-related research, and more basic research).

Another part of the solution is measures to obtain the necessary R&D from private investors through the introduction of standards, for instance on emissions from automobiles or power plants. In smaller countries, like the Nordic ones, this is usually not an option. As illustration, recent car-tax reforms in Norway seek to turn demand towards the more climate-friendly models (smaller, diesel, hybrids). The effect that such instruments have when shifting demand between ”models on the shelf” is of course modest compared with the effect they can have a) if a market is large enough to have auto manufacturers change their product; b) if it can be done with a credible plan also for the future, so as to entice long term investments in R&D, and c) if international cooperation on the policy side promised both larger markets and longer-term credibility. California's experience of pushing car manufacturers towards lower air pollutant emissions indicate that market size, commitment and political economy all are important factors (Car makers had no hostages in California in the form of manufacturing plants in state).

Since technologies today have a worldwide market, it is important to coordinate the R&D phase among different nations, with each nation pursuing research in directions where it has comparative advantages.

Thus, the main constituency of the development phase is recognition that basic technology development will have to be funded by governments. Below we will suggest some topics that may be suitable in the case of Sweden.

To achieve the necessary turnaround in our emissions trend will require a near worldwide effort in the form of enormous investments in the development and the implementation of climate-friendly technologies, in particular in the energy and the transport sectors. Adaptive changes to our lifestyles, etc., while useful, will most likely not by themselves be able to deliver the huge reductions that are required. Similarly, energy or carbon efficiency gains in presently inefficient countries are also in all likelihood too small to meet the climate change challenge. Over time, only by replacing basic technologies in both the developing and the developed world will we be able to deliver the reductions that are needed. We are thus faced with the task of replacing our (steadily growing) fossil-based energy and transport systems with climate friendly alternatives within a timeframe of a few decades. To achieve this, strong policies will have to be put in place at both international and national level. As we have argued above, today's policies, whether in the international or the national arena do not suffice. Today's research and development efforts are clearly far below what is needed, see Box 10.

In our view, a way forward could be to develop a technology-based agreement between an "alliance of the willing" as a supplement to a cap-and-trade regime incorporating a long time horizon (perhaps 20 years). Interestingly, examples exist that can offer some guidance in constructing such a framework, see e.g. Box 9 in the case of agricultural R&D. As shown in Box 10, investments in relevant R&D in industrialised countries are at a very low level. The technology treaty should thus secure substantial long term public funding for research, development and testing of key technologies according to the preferences and comparative advantages of each participating country (see Box 12 for some examples from Norway). The financing should be verifiable, and a system with a central "research council" would be preferable in order to facilitate this and necessary international coordination. Each party to the treaty could be assured of receiving a proportional share of the resources in the form of research grants or testing facilities, but the teams carrying out the research and development could also be international in scope. An important objective would be to ensure technology transfer between the parties to the treaty. While protection of intellectual property rights – or rewards – would be important, arrangements should also be built in to have knowledge shared among parties to the treaty. All things considered, we believe such a technological based treaty should have a fair chance of being self enforcing and also be attractive to nations outside the core industrialised countries.

Box 9 Lessons on R&D co-operation from CGIAR

A strong precedent exists from international collaboration on research and development in agriculture.

In the 1950s and 1960s a major concern was how to increase food supply given that the scope for increasing agricultural land area was becoming limited and the world's population was set to double by the end of the century. A major and successful effort was made to improve yields of agriculture research and extension, by bolstering national research stations facilitated by a network of international research centres, later brought together under the aegis of the CGIAR under the chairmanship of the World Bank.

The CGIAR was created in 1971; it now has more than 8,500 CGIAR scientists and staff working in over 100 countries. It draws together the work of national, international and regional organisations, the private sector and 15 international agricultural centres to mobilise agricultural science, promote agricultural growth, reduce poverty and protect the environment. It has an impressive record and can be expected to play a strong role in enabling the agricultural sector to adapt to the impacts of climate change through research on new crop varieties and farming methods. There is a good case for expanding this role to support mitigation and adaptation beyond the agricultural sector. Several lessons from the experience of agriculture are relevant for an international programme in the development and use of low carbon technologies and practices. In the case of agriculture:

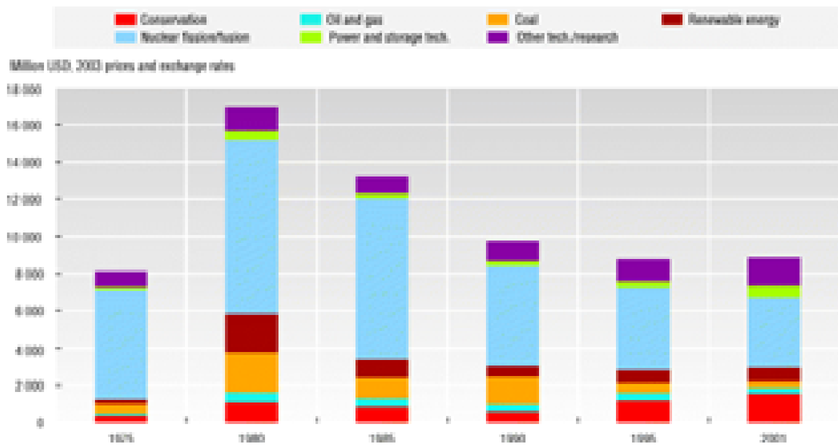
- There was a shared commitment among the sponsors.
- The programme evolved from an already extensive network of national research centres and supplemented and enhanced national efforts.
- It was based on real demonstration and R&D projects, and was not simply a "talking shop".
- The efforts were not centred on one institution in one country, but divided across a set of institutions in several countries specializing on particular crops and livestock farming.
- There were good working links between the international and national centres of R&D.
- There were also good working links between the programme and the users (extension services and farmers), so that technology and knowledge could be rapidly diffused to those who would use it.

Source: Stern (2006).

Box 10 Energy-related R&D in OECD countris

The figure below shows IEA government budgets for energy R&D. The curve of IEA R&D budgets follows the general trend of crude oil prices, with a peak in the early 1980s.

In 1980, because of the search for alternatives to oil as a source of energy, R&D budgets reached USD 16 billion (2003 prices and exchange rates). By 1985, budgets had decreased 20 % and by 1990 another 25 % to today's level of under USD 10 billion.



Source: IEA World Energy Outlook, OECD Factbook 2005, Economic, Environmental and Social Statistics

It is not easy to judge whether world governments – or rich countries – spend enough on energy related R&D, but a "feel" might be found as follows. First, the world's oil bill is USD 14 hundred billion per year. Thus, OECD's USD 9 billion in energy R&D represents 0.6 % of the world's oil expenditures, and of course a lower percent of the world's total energy bill.

If a massive investment in R&D over a decade aimed to reduce the world's oil bill by 20 percent, how much could it cost and still be worth it? The table below calculates that a quadrupling of today's 9bn investment for a ten year period, with a net present value of USD 280 billion, would not amount to more than 2.6 per cent of the targeted savings. Thus, the investment would still be justifiable if it were to cost 40 times as much.

World oil consumption per day (barrels)	100 000 000
World oil consumption per year (barrels)	35 000 000 000
World oil consumption per year at $40 per barrel (USD)	1 400
What if we could save 20% of this, value per year (USD)	280
If savings start in 10 years, lasting for ever, 2 % discount rate, net present value (USD)	12 680
If we quadruple present R&D spending for 10 years, net present value (USD)	326
So, this would be, as percent of what we hope to gain	3 %
Alternative calculation, using 4 percent discount rate	5 %

In reality, government energy R&D aims at more than saving oil (saving heat or coal, improving fuel cells, addressing global warming, and energy security), and savings will also cost something (new cars). But the calculations might illustrate that – in relation to what is at stake – USD 9 billion per year appears to be a small number. In the US and European pharmaceutical industry, firms spent USD 67 billion on R&D in 2004 (average, 10 percent of revenue, Golec and Vernon, 2006). For investments in energy R&D, one might argue (see below) a lot of the benefits are not easily channelled directly back to investors (perhaps not even to the investing country), calling for instruments such as Government funds and treaties.

In addition to direct support to the development of new technologies, we need a framework for securing *implementation* of the technologies once they are proven. Here, a cap-and-trade system like the Kyoto Protocol can serve in important ways. Also, provided it is given a sufficiently long time horizon, it directly strengthen industrial R&D. Furthermore, synergies can be obtained if we manage to combine the subsidy (R&D) and the implementation (cap-and-trade) frameworks, see Table 3.

Table 3 Pros and cons of various treaties

Technology, R&D cooperation regime	Cap-and-trade, or emission tax regime: No	Cap-and-trade, or emission tax regime: Yes
No	– No climate policy	Pro: – Cost effective Con: – Likely to have low participation. – Weak on long term mitigation.
Yes	Pro: – Seeks long term carbon-lean solutions. – Some R&D can be done by country or samll coalition. – Some climate-friendly tech. R&D justified by other objectives: energy security, environment, etc. Con: – R&D program alone likely weak on direction, implementation and adoption, since incentives fail.	Pro: – R&D strengthens long term dimension of tax- or cap-and-trade system. Technological advances will reduce political resistance to mitigation. Cap-and-trade improves direction and efficiency of R&D. Thereby also broadening participation and deepening emission reductions. Con: – Multiple treaties make for complex negotiations.

Having suggested a combined technology treaty and a cap-and-trade system as an international climate regime, we now briefly turn to Sweden to discuss what kind of national policy is most appropriate under such a combined international regime.

Part IV A Swedish response

"If you don't know where you're going, any road will take you there" – George Harrison

In this fourth and final part we will summarise and conclude our analyses with regard to long term (i.e. post-2012) climate policy at the national scale. Climate research is clear about the major changes that will have to happen in this century with respect to emission reductions, and the implications are strong about the need for technological development in the coming decades. This has important implications for the world and thus for international cooperation, as well as for Sweden. What could and should a relatively small country such as Sweden have as a vision for its climate policy abroad and at home in the long term? Before answering that question, we give some background information on Swedish greenhouse gas emissions and climate policy.

4.1 Greenhouse gas emissions in Sweden from 1990

The total Swedish greenhouse gas emissions in 2004 were 69,9 million tonnes CO_2-equivalents ($MtCO_2$-eq.), having fallen by 3.4 per cent from 1990. The emissions intensity of greenhouse gases per capita has also been reduced from 1990 to 2004 from 8.4 to 7.8 tCO_2-eq. per capita[21]. The reductions of emissions are found in particular in the residential and service sector, in agriculture and from waste deposits. The total emissions of CO_2 were 56 million tonnes in 2003; 79 per cent of the total greenhouse gas emissions. Emissions of methane (CH_4), 5.5 $MtCO_2$-eq., made up 8 per cent of the emissions, and emissions of nitrous oxide (N_2O), 8.2 $MtCO_2$-eq., made up 12 per cent of the total emissions. Table 4 together with Figure 23–Figure 25 illustrates historical and present national emissions of greenhouse gases in Sweden.

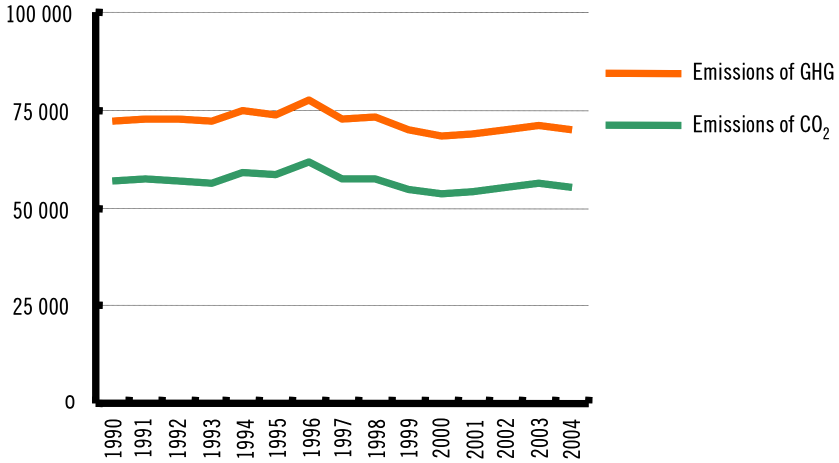
[21] This level is approximately half the per capita level in industrialised countries taken as a group, but at least twice the per capita level in the developing countries.

Table 4 Swedish greenhouse gas emissions in 1990 and 2003

Sector	Emissions 1990 (Mt CO2-eq.)	Share of total emissions 1990	Emissions 2003 (Mt CO2-eq.)	Share of total emissions 2003
Energy (excl. transport)	34.8	48.3 %	32.5	46 %
Transport	19.2	26.6 %	21.2	30 %
Agriculture	9.6	13.3 %	8.5	12 %
Industry processes	5.8	8 %	5.6	8 %
Waste	2.7	3.7 %	2.1	3 %
Dissolvent	-	-	0.7	1 %
Total emissions	72.1	99,9 %	70.6	100 %

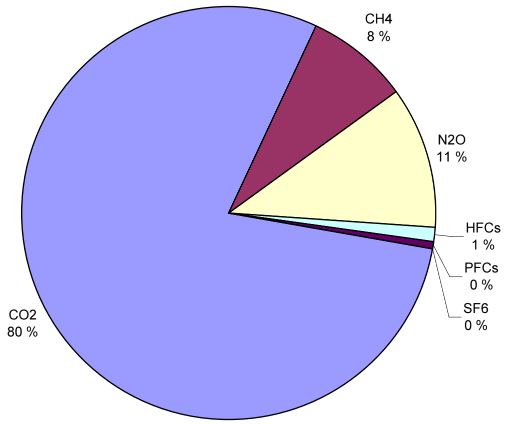
Source: Ministry Memorandum Ds 2005:55 and Govt Bill 2005/06:172.

Figure 23 Emissions of greenhouse gases in Sweden, 1990–2004



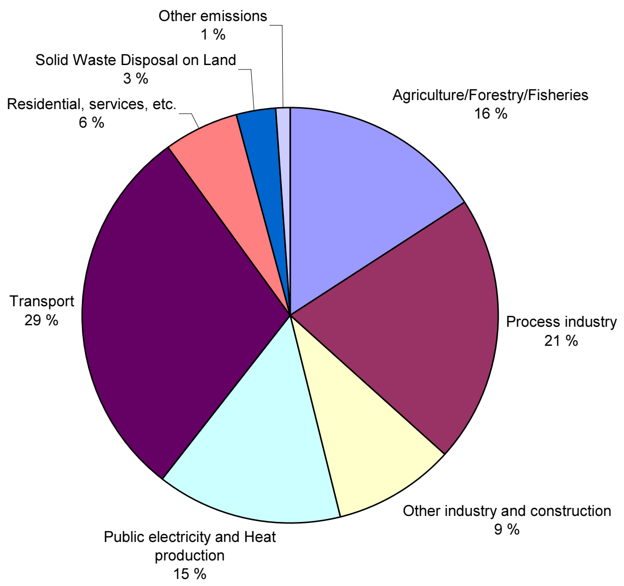
Source: NIR 2006 (utslipp.xls).

Figure 24 Main greenhouse gases in 2004



Source: NIR 2006 (utslipp.xls).

Figure 25 Emissions by sector 2004



Source: Slight reclassification of data from NIR 2006 (National Inventory Report 2006).

4.2 Swedish climate policy since 1990

Swedish climate policy relies on a number of policy instruments:

- Taxes and the EU Emissions Trading Scheme are important measures in Swedish climate policy. The CO2 and energy taxes are cross sector instruments. The energy tax makes up 5.9 per cent, and the CO_2 tax 2.9 per cent of the total tax revenue in Sweden (Carlén 2004:7). The CO_2 tax was introduced in 1991 and is the most effective policy instrument – contributing to more reductions in the emissions than any other policy instrument (Swedish Energy Agency and Swedish Environmental Protection agency 2004:9).
- The European Union Emissions Trading Scheme (EU ETS) covers 30 per cent of the total Swedish emissions in 2000 (Ds 2005:9). Swedish firms are allowed to participate in ETS, but the Swedish Government has decided to reduce emissions by four percentage points below the 1990 level *without* making use of purchased quotas, resulting in greater pressure on other instruments and on the Swedish sectors not in ETS.
- Sweden introduced a trading system of green certificates for renewable energy in 2003. The electricity certificate system aims to increase the supply of electricity from renewable energy sources.
- Other measures include government subsidies for local investment programmes on environmental and climate issues. The specific climate programme KLIMP replaced the more general environmental program LIMP in 2003. According to Gov Bill 2005/06:172, the Swedish government intends to negotiate a voluntary agreement with the energy-intensive industry.

4.2.1 Swedish ambitions – the 96 per cent objective

According to the EU Burden Sharing Agreement under the Kyoto Protocol, Sweden is allowed a 4 per cent increase in greenhouse gas emissions from 1990 to the first commitment period 2008–2012. Sweden has, however, an ambitious national policy aim of *cutting* the greenhouse gas emission by 4 per cent – known as the 96 per cent objective.

The Swedish Government's climate policy (the 96 per cent objective and the objective of abstaining from the use of flexible mechanisms) has been criticised by economists (see Bohm 2004; Carlén 2004) as well as by the conservative political parties (see Motion 2005/06:MJ45) for not taking into account the small effect of Sweden's contribution to solving the global climate problem. These analysts consider the costs too high, based on a number of considerations, the main ones being that:

i) Refraining from participating in the flexibility mechanisms departs from the logic of cost effectiveness, so that greater emission reductions could be found for the same economic sacrifice.

ii) Taking on a more ambitious goal that entailed by the Kyoto Protocol and by EU has modest benefits to the world (it will reduce global greenhouse gas emissions by 0.016 per cent), including in terms of encouraging others to follow.

iii) A Swedish interest in greater emission reductions for the world should instead result in work for a stronger international climate regime (i.e. treaties) or even in work through the flexibility mechanisms rather than unilaterally seeking deeper cuts domestically.

Carlén estimates the costs to the Swedish economy (in GDP terms) based on the assumptions that emission reductions are attained cost-effectively (i.e. through auctioned tradable quotas, or a uniform carbon tax applying to all sectors/sources), see Table 5.

Table 5 Costs to the Swedish economy in GDP terms and per tonne reduced of various climate policy ambition levels.

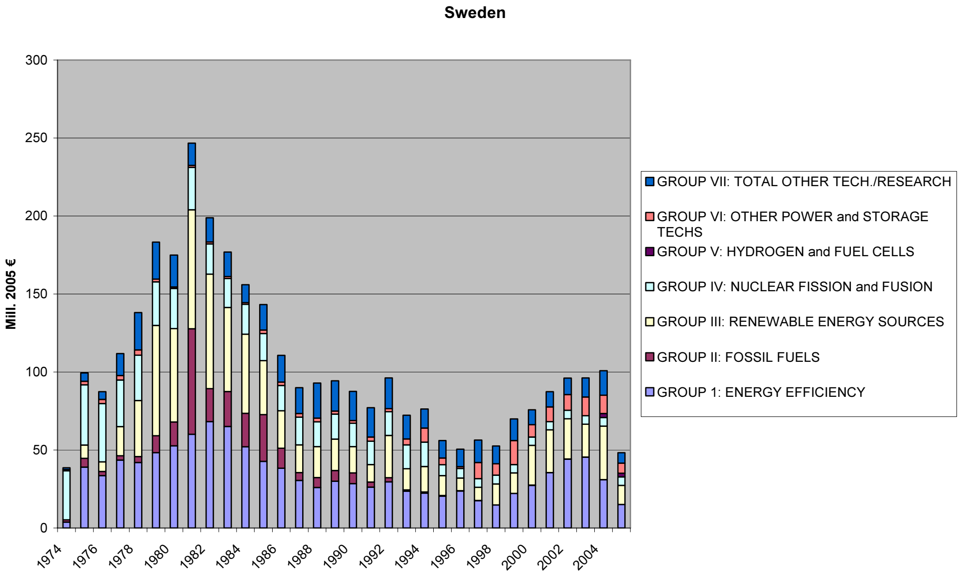
Policy formulation in 2010	- 4 % relative to 1990 emissions, border trade excluded	- 4 % relative to 1990 emissions, but border trade allowed	+ 4 % relative to 1990 emissions, border trade allowed
Total cost to Swedish economy, SEK billion (GDP terms)	33 (25 to 45)	13 (10 to 15)	9 (6 to 11.5)
Costs at margin, SEK per ton	640	100	100

When trade in quotas across the Swedish border is allowed, marginal costs are contained at the price level assumed internationally ($10 per ton, or SEK 100), so when the cost increases, it is because an additional 8 percentage points will be bought in the international market[22]. The total cost to the Swedish economy of attaining the additional 8 percentage points reduction under assumptions of trade increases by 50 percent from 9 to 13 billion SEK (over the 5 year period). If trade is not allowed, so that the Swedish ambition results in additional emission reductions *in Sweden*, the cost at the margin increases to 640 SEK and the total cost almost triples to 33 billion SEK (over the 5 year period). The added cost of the 96 percent target (over and above the Kyoto target) is therefore estimated to be of the order of 5 billion SEK per year.

It is interesting to compare these numbers with the Swedish energy technology R&D budget. Figure 26 illustrates the history of this budget post according to IEA R&D statistics. The figure shows a very similar history to the total IEA picture shown in Box 10. Here, however, we note that the total budget is an order of magnitude less than the estimated cost of the particular Swedish ambitions in national policy. Thus, if Sweden's energy technology R&D budgets were motivated only by reducing future mitigation costs in Sweden (they likely are motivated by more, including other environmental and energy security benefits domestically, and abroad), the assumed effects must be tiny. A reasonable suggestion could then perhaps be that Sweden, instead of aiming for the 96 percent target, uses the money to strengthen the energy technology budget to the tune of up to 5 billion SEK per year.

[22] The assumption that the price is unaffected likely reflects not a belief that the supply of emission reduction possibilities internationally is infinitely elastic, but rather the reality that the 8 percentage points of Swedish emissions that are of some consequence to the Swedish economy represents something unnoticeable to the world.

Figure 26 Swedish energy technology R&D budgets 1974–2005

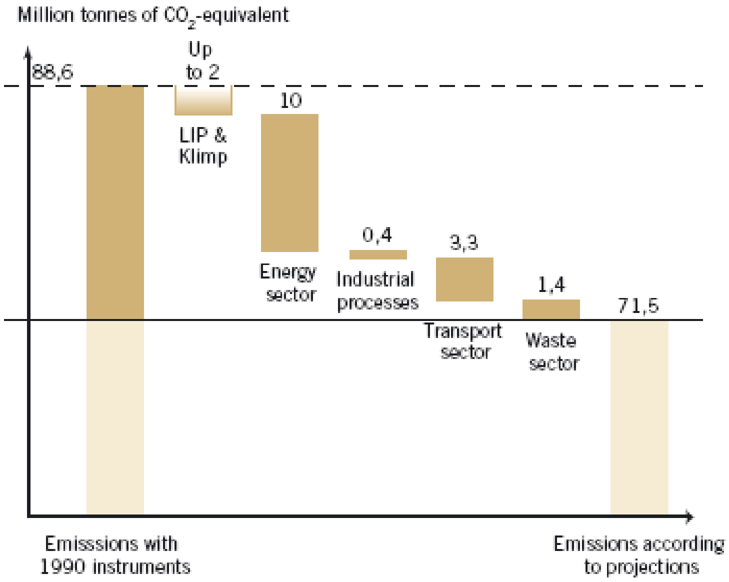


Source: IEA R&D statistics (downloaded 19.12.06).

4.3 Swedish climate policy in the near future

The effect of policies and measures on emissions towards 2010 is illustrated in Figure 27, taken from Sweden's fourth national communication on climate change (Ministry Memorandum, Ds 2005:55). It illustrates that measures targeting the energy sector are expected to provide most of the reductions expected from 1990 to 2010.

Figure 27 The aggregate effect in 2010 of introduced policy instruments in comparison with 1990 instruments by sector



Source: Ministry Report Series, Ds 2005:12:55, Sweden's fourth national communication on climate change.

The total emissions in 2010 in the baseline scenario are 88.6 million tonnes of CO_2-equivalent, up by 22 per cent since 1990. This baseline scenario is based only on the application of the policy instruments of 1990. The emissions can be reduced by 17.1 million tonnes (almost 20 per cent) by pre-existing policy instruments, as summarized in Figure 27. The policy measures in the energy sector; *inter alia* the energy tax, the CO_2 tax, the electricity certificate system and the EU ETS, are expected to reduce emissions by 10 million tonnes. The policy measures in the transport sector, including the motor fuel taxes, tax relief on biomass fuels, the automotive industry's commitment on lower carbon dioxide emissions from new cars, taxation of cars received as a benefit, instruments for increased introduction of green cars, are expected to reduce emissions by 3.3 million tonnes.

Still, while Sweden's economy is growing, there are 2 million tonnes left before Sweden reaches the national target; to reduce the emissions by 4 per cent from 1990-level by 2008–2012 (Govt Bill 2005/06:172, p. 87; Swedish Energy Agency and Swedish Environmental Protection Agency 2004:9). Thus, Sweden has to strengthen (or add new policy instruments) to the already existing climate policy in order to reach the national short-term target of reducing the emissions by four per cent (Swedish Energy Agency and Swedish Environmental Protection Agency 2004). The major challenge is, however, the years after 2010 when emissions are expected to increase.

The main challenges are found in the energy and transport sectorsc which make up 75 per cent of Sweden's total greenhouse gas emissions today. A major question with regards to the energy sector is nuclear power, a reduced share of which will likely increase the costs of any emission reduction target, in particular in the intermediate term.

The second major challenge is the increasing emissions from transport, in particular freight transport (Govt Bill 2005/06:31).

4.3.1 Nuclear and hydro power

Future emissions from the energy sector depend heavily on nuclear phase-out. Without a phase-out, it will be easier to restrict future growth in Swedish CO_2-emissions. Further development of nuclear technologies with the aim of making them even safer and more socially acceptable would also be a substantial contribution towards meeting the global challenge of climate change. Such improvements would – in turn – make it safer and easier for others to choose this avenue, thereby reducing their costs of participating with deeper emission reductions.

Exploitation of the remaining hydro power potential would also alleviate the costs of reducing CO_2 emissions. As with nuclear power, this would confront other environmental issues. Nevertheless, the urgency of the climate problem may require a re-evaluation of the pros and cons related to more extensive use of both nuclear and hydro power.

According to the 1980 referendum, Swedish nuclear power was to be phased out before 2010. A nuclear phase-out law was adopted in 1997, and two nuclear power reactors have already been phased out. Public opinion has, however, changed since the 1980s. Today Sweden (as well as Finland) citizen support for nuclear energy compared to many other EU member states. 32 per cent of the Swedish population supports the development of nuclear energy in order to reduce the dependency on imported energy resources (European Commission 2006:8). The EU average is 12 per cent.

The newly elected coalition government in Sweden will not phase out nuclear power in the period 2006–2010 (Alliace for Sweden 2006a:11). The political platform of the coalition government does, however, make it clear that the new government will not re-open the nuclear reactors already phased out (Alliance for Sweden 2006a:12) – even though e.g. the Swedish Liberal Party would prefer to do so (Motion 2005/06:N436). In other words, Barsebäck 1 and 2 will not be re-opened.

4.3.2 Transport

The emissions from the transport sector are expected to continue to increase, in particular because of an increase in freight transport. The expected 30 per cent increase in 2020 is considered as a major challenge (Govt Bill 2005/06:172, p. 111). The emissions can be reduced by more energy effective vehicles, the development of a transport-effective society and the introduction of renewable fuel (ibid, p. 123). Emissions reductions in the transport sector do, however, require long-term planning, as the effects of the policy instruments might be slow. The transport sector is one of five sectors discussed by the Commission on Oil Independence. The Commission suggests reducing the dependency on oil in the transport sector by 40–50 per cent by 2020. This is an area that benefits from a fairly clear strategic perspective in policy, since it involves choices between near-term strategies that are simple in terms of business profitability when protected by fossil taxes (bioethanol, for instance), but perhaps less meaningful in the long term than technological developments that seem costly today (like wood-based fuels). The transport sectors is, of course, one for which technological advances will have great applicability across countries, though at any point in time a country's climate policy will, in part, determine the domestic market. It is, nevertheless, an area in which R&D treaties would seem promising (Barrett, 2006).

4.3.3 Natural gas

There is a debate on the role of natural gas in Sweden in the years ahead. Here we only note that given the ambitions with regard to mitigation, gas as a fossil fuel (albeit with lower GHG emission factors than other fossil fuels) can play only a limited role in the energy future of a climate-friendly Sweden.

4.4 Swedish climate policy post 2012

In March 2005, the European Council adopted a target of containing global climate change to no more than 2°C by 2100[23]: The European Parliament (EP) endorsed this target in a report adopted by the EP in November 2005. This target is also the starting point of the Swedish Government's Bill on climate policy (Govt Bill 2005/06:172). It is normally assumed that this target implies a 60–80 per cent[24] reduction in emissions in the developed countries.[25] According to Swedish Energy and Environmental Protection Agencies, Sweden should reduce emissions by 50–60 per cent – as emissions per capita are relatively low compared to other developed countries (Swedish Energy Agency and Swedish Environmental Protection Agency 2004:17). Moreover Swedish climate policy is based on a convergence aim; the emission quotas per capita should converge towards a sustainable level globally. As a start the total emission quotas per capita in Sweden should be brought down to 4.5 tonnes CO_2-equivalents (Govt Bill 2005/06:172, p. 72) from today's level of 7.8 tCO_2-eq. This is not, however, sufficient to fulfil a 50–60 per cent reduction in Sweden's total greenhouse gas emissions by 2050, and the emissions per capita have to decrease further after the first target is reached (Govt Bill 2005/06:172, p. 96). According to the same Bill, the emissions should be reduced by 25 per cent by 2020.

The political platform of the coalition government states that the ”Alliance” agrees on the environmental and climate policy aims (Alliance for Sweden 2006b). The four government parties do not,

[23]As noted in section 1.6, we have already probably surpassed the concentration level necessary to secure a temperature increase below 2°C. Considering continued population and economic growth, the target therefore is highly unrealistic.
[24] See for examples the Report to the European Parliament ”Winning the Battle against Global Climate Change”.
[25] Such a decrease will allow the developing countries to increase their emissions compared to 1990 level in the short term.

however, not share the same view on emissions reduction targets. The Liberal Party is advocating the 2°C target, and has advocated specific emissions reductions targets; 30 per cent reduction by 2020, 40 per cent by 2030, 55 per cent by 2050, and 80 percent by 2100 – compared to 1990 level (Motion 2005/2006:MJ46). The Christian Democrats supports the 96-percent target and a 25 per cent reduction by 2020 (Motion 2005/06:MJ47). The Centre Party supports the 96 percent target as well as a 30 per cent decrease by 2030 and a 50 per cent decrease by 2050. The Moderate Party have, however, not submitted any specific proposals, but commented that the 25 per cent reduction target by 2020 ”might sound ambitious and good but there are only 14 years left to this point” (Motion 2005/2006:MJ:45).[26] Recently, however, the new Government stated support for the German position on the EU that greenhouse gas emissions should be reduced by 30 percent in 2020 relative to 1990 levels[27]. There is in other words broad political support both for the 96 per cent target and for the middle and long term targets.

It now seems prudent to suggest that studies are commenced with the aim of detailing scenarios that would show how these targets can be met and what is required in terms of decisions and resources.

4.5 A broader palette: Suggestions for a long term and solution oriented climate policy for Sweden

Sweden's climate policy is impressive and well founded in several ways. But it is also marked by inconsistencies and challenges, particularly when looking to decades ahead, and to the international scene. It is well founded in the sense that there seems to be broad support for ambitious targets of emission reductions in the long term. The consensus is less impressive if one asks how these targets are to be attained, and clarification would be healthy not the least to demonstrate commitment, and thereby to deliver effectively. It makes good sense to emphasize that consensus building and political support are essential, and that Sweden's capital in this area probably represents a long heritage (like an

[26] Authors interpretations. Original Swedish text: ”kan låta amitiöst och bra men det är bara 14 år fram til dess”.
[27] Dagens Nyheter 18. December 2006.

aftermath of discussions about nuclear energy) as well as awareness amongst politicians who have held an open dialogue and dedicated funds to information. For this reason, one should not take lightly a change of course, but emphasize the fact that effectiveness depends on steadiness, and steadiness depends on policy being well grounded in popular understanding and support.

The long-term challenge in Swedish climate policy, given the ambitious reduction targets, is how to reduce the total greenhouse gas emissions from a level of around 70 million to 15–20 million by 2050[28]. Presently pursued policies are quite effective in delivering on the 96 percent target by 2010 (some choices remain), but leave big questions about what will be done to prevent emissions from increasing after that point, let alone to deliver significant additional reductions. Some important questions for Sweden while looking ahead are as follows:

1) Sweden may want to take a lead in influencing the climate regime (the evolving set of treaties), and will then need a position on in which direction to influence it.
2) As a part of the country's strategy to influence the emission behaviour of other countries, through treaties or in other ways, Sweden may want to examine its own strategy for the pursuit of emission reductions.
3) A position that Sweden increases its credibility and positive influence by "voluntarily" and unilaterally pursuing own ambitious targets, and domestically (not through flexibility mechanisms) should probably be revisited: influence may be sought not only in the emission reductions themselves, but also in how they are pursued/attained.
4) In particular, it seems likely that influence may lie in demonstrating technological advances that are appealing to others either directly (as when Swedish renewables technology is attractive to others) or as process/instrument lessons (as when the Swedish process of seeking cost reductions in renewables can be applied by others in other areas).

[28] The Low Emission Commission in Norway has shown that this is technically possible for Norway and not very expensive (NOU 2006:18). The Swedish Commission for Oil Independence has also pointed out how to reduce emissions towards 2020.

The price Sweden pays for pursuing its own ambitious targets, and for not exploiting flexibility mechanisms is a significant one (20–40 billion SEK for the period 2008–2012). These resources could alternatively be used for strengthening the energy technology R&D budget. If a plan for greater technology focus could ensure advances that are i) more promising in the long term for emission reductions, ii) more promising for Swedish business development, and iii) more promising with respect to positive influence on other nations, then such a redirection could be justifiable, even if it delivered lower domestic emission reductions in the short to intermediate term.

The question of influence from Sweden on the rest of the world is, perhaps surprisingly, an important one. Put succinctly, if Sweden is interested in world emissions, its own emissions are important only to the extent they influence the emissions of others. Then, extending that argument, a proper question for Sweden is how Sweden's actions can influence those of others. This opens the menu from being merely influencing others' behaviour through the sum of Sweden's own emissions via influence through 1, 2, 3 and 4 above. Importantly, though, there are good reasons to be sceptical about the ability of small countries to influence policies internationally. In general, economists' approaches to such a question have been more supportive of strategies in which positive contributions (own emission reductions) are made *conditional* on others also contributing. In practical life, this resembles the way in which the US Senate precluded through the Byrd-Hagel resolution ratifying a treaty unless other big emitters were also bound by emission limits. Box 11, below, lists alternative assumptions leading to the possibility that unilateral contributions to emission reductions may influence others positively. While this list allows for the possibility of a positive influence from first movers, one should notice that the assumptions are not overly generous (in the sense of always being applicable), and also that they do not point to the emission reductions themselves, in total, as the most compelling channel of influence. Rather, the case for positive influence seems to be through technological advances that are either directly useful or of demonstrative value to others.

Box 11 Can unilateral mitigation measures influence participation by others positively?

Economists have generally been critical of unilateral voluntary contributions for global public goods such as greenhouse gas emission reductions, arguing that free-riding is likely, and that one should rather leverage one's actions through treaties. While that logic is generally rock solid, there are conditions in which unilateral mitigation can make sense. A tentative list is as follows:

The Porter Hypothesis (Michael Porter). Porter argues, in the case of national environmental goods (e.g. not global) that a country that moves early with environmental regulations will benefit not only through the environmental improvements, but also in terms of competitiveness and business profits, since firms will develop technologies for the markets that will eventually develop in other countries.

Economists have been divided but quite critical of the Porter hypothesis, if only because countries should pursue environmental protection when they find it worth it, and firms should not need the aid of government in spotting growth markets (see, for example, Palmer et al, 1995).

Others might follow: Technology as a public good

A firm case in which unilateral action leads others to follow would be if one nation creates technological breakthroughs that reduce the costs for others in mitigation (like Toyota's hybrid technology). Barrett, 2006, argues that technological cooperation would be particularly promising for climate change if technological development is characterized by breakthroughs and scale economy. To the extent that technology has been developed and is protected by intellectual property rights and emission taxes (ensuring a market), these followers would reward the early movers in monetary terms, as in the Porter hypothesis.

Others might follow: Your demonstration lowers my cost estimate

It is conceivable that a forceful example inspires followers even if in no way changing costs, for instance if it convinces other of the importance of fighting climate change, or that the mitigation costs are lower than otherwise expected.

Others might follow: Effects through norms, subtle incentives or more direct ones

Finally, a "shaming" effect might be in play, by which unilateral contributions signal to others norms and informal (or emerging explicit) incentive structures.

The present analysis views favourably the arguments that technological advances will have the nature of public goods and thus display spillovers. This means that unilateral efforts in that direction can generate benefits in terms of followers. It also means that attention to intellectual property rights is worthwhile, that international cooperation on technology may be worth while, and that focus on cost effectiveness may lead to flawed conclusions.

Recently, an official “Low Emission Commission” delivered a report to the Government of Norway, highlighting how Norway can reduce its greenhouse gas emissions by two-thirds below today’s level before the year 2050 (Norwegian Government Official Reports 2006:18). The Commission noted that many different criteria can be taken into account in choosing mitigation measures. The Commission emphasized that the selected measures should to the greatest degree possible be:

Few in number and large in scope. The Commission chose a few wide-ranging measures instead of many small ones so that decision-making efforts could be focused.

Based on relatively familiar technology. The Commission chose measures that largely build on familiar or recognizable technology.
Politically feasible. The Commission focused on measures on which it was considered easier to achieve political acceptance. A number of measures that would have required major changes in behaviour were thus excluded.

Able to contribute to international technology development. The Commission wanted the measures to contribute to a desirable development in technology at the international level, and at the same time as providing a basis for new industrial development in Norway.

Robust. The Commission wanted the proposed measures, to the greatest possible extent, to be reasonable under various assumptions about the future development of the economy, trade, energy prices, climate agreements, and so on.

Cost-effective. The Commission emphasized that the measures should not be unreasonably expensive in relation to the emissions reductions they can achieve, as well as the other positive or negative social they may have.

On the basis of these principles, a number of measures were proposed, among them a significant increase in technological R&D. It was recommended that the research and development focus on the themes listed in Box 12 based on specific conditions and competencies in Norway. A similar list should be developed for Sweden.

Box 12 Some climate-friendly technologies recommended in Norway

- technologies for carbon capture and storage (CCS),
- wind power (especially on the high sea),
- pellet and clean-burning woodstoves and fireplaces,
- biofuels (in particular production based on forest products),
- solar cells,
- hydrogen technologies,
- heat pumps, and
- low-emission ships.

Source: NOU 2006:18: Et klimavennlig Norge (A climate-friendly Norway).

The line of reasoning in the current study departs a little from the mandate of the Norwegian Commission, in particular in how we emphasize influence on the behaviour of others. A difference in emphasis is therefore not to highlight *"relatively familiar technology"*, since influencing others would ask for narrow and deep technological breakthroughs, rather than broader and less surprising ones. Of course, in both contexts one would want to be both realistic and to deliver quickly, if possible.

Information and political commitment around policies for the long term:

At the outset we would like to emphasise the continuous need for information at all levels of society as risks and challenges but also solutions and opportunities associated with climate change develop. This should help mobilise the necessary decision power and technological capacity in a way that enables our civilisation to prepare itself for coming changes with minimal sacrifices.

Internationally:

On the international scene Sweden should seek to broaden the current policy palette by supporting the development of:

- *A technologicaly oriented treaty* among a "coalition of the willing" to secure long-term and internationally coordinated funding for the development and testing of key climate technologies. Sweden may want to give emphasis to the production and utilisation of biofuels in transport activities, and the development of socially acceptable nuclear and hydro power, based on its comparative advantages. Other areas of emphasis for Sweden should be sought, built on competence and resources, including the reward potential in strategic business development.
- *A strengthened cap-and-trade regime coupled with the technology efforts,* with a long time horizon and strengthened restrictions on future emissions, in order to secure the competitiveness of newly developed climate-friendly technologies.

In between the international scene and the domestic one, Sweden should seek and encourage cooperation in the field of technological development, in particular in those areas important to Sweden technologically. An example could be that Sweden could take an interest in influencing a long-term focus, first within Europe, on standards for the transportation sector, and programmes to develop and meet such standards. Similarly, for areas in which Sweden already has made important progress (heating, bio-energy), how one can advance greater adoption abroad is a perfectly valid question when the agenda is to influence others.

On the domestic scene, we suggest that it is more important that Sweden supports technology developments for eventual deep emission cuts, than strives for the lowest possible Swedish emissions in the short term.

4.6 Final words

Sweden has been an environmentally progressive nation for many decades, including at international level. It is thus with eager anticipation we put forward our proposals for a broader palette when it comes to long-term climate policy. Looking ahead over the next few years, it seems possible that the next administration in the USA will consider new directions for its climate policy in 2009, a decision that will, to a great extent, run in parallel with decisions the USA will have to take to reduce its reliance on imported petroleum. Thus, new openings and opportunities will most likely appear in the international climate negotiations at a time when Sweden will have the Presidency of the European Union (autumn of 2009). We hope our report will contribute to a needed debate on alternatives and solutions before this moment of opportunities.

On the basis of the above, we suggest the following course for Swedish climate policy post 2012:

At the outset we would like to emphasise the continuous need for information at all levels of society as risks and challenges but also solutions and opportunities associated with climate change develop. This should help mobilise the necessary decision power and technological capacity in a way that enables our civilisation to prepare itself for coming changes with minimal sacrifices.

On the international scene Sweden should seek to broaden the current policy palette by supporting the development of:

- A technologically oriented treaty among a "coalition of the willing" to secure long term and internationally coordinated funding for the development and testing of key climate technologies. Sweden may want to give emphasis to the production and utilisation of biofuels in transport activities, and the development of socially acceptable nuclear and hydro power, based on its comparative advantages.
- A strengthened cap-and-trade regime coupled to the technology treaty, with a long time horizon and strengthened restrictions on future emissions, in order to secure the competitiveness of newly developed climate friendly technologies.

In between the international scene and the domestic one, Sweden should seek and encourage cooperation in the field of technological developments, in particular in those areas important to Sweden technologically. An example could be that Sweden could take an interest in influencing a long-term focus, first within Europe, on standards for the transportation sector, and programmes to develop and meet such standards. Similarly, for areas in which Sweden already has made important progress (heating, bio-energy), how one can advance greater adoption abroad is a perfectly valid question when the agenda is to influence others.

On the domestic scene, we suggest that it is more important that Sweden support technology developments for eventual deep emission cuts, than striving for the lowest possible Swedish emissions in the short term.

References

Agrawala, S. (1998a): “Context and Early Origins of the Intergovernmental Panel on Climate Change”, *Climatic Change,* Vol. 39, Number 4/August, 1998, pp. 605–620, DOI 10.1023/A:1005315532386.

Agrawala, S. (1998b): “Structural and Process History of the Intergovernmental Panel on Climate Change”, *Climatic Change,* Vol. 39, Number 4/August, 1998. pp. 621–642, DOI 10.1023/A:1005312331477.

Aldy, J. E., Barrett, S. og Stavins, R.N. (2003): ”Thirteen plus one: a comparison of global climate policy architectures”, *Climate Policy* 3 4, pp. 372–397.

Alfsen, Knut H. and Tora Skodvin (1998): The Intergovernmental Panel on Climate Change (IPCC) and scientific consensus: How scientists come to say what they say about climate change, CICERO Policy Note 1998:3.

Alley, R. B. (2000): *The two-mile time machine,* Princeton University Press, Princeton, 229 pp.

Alliance for Sweden (2006a): Energipolitik för jobb, välfärd och miljö. Juni 2006.
http://www.moderat.se/(S(zvzcdd55z5mgukbmhb1nruay))/material/pdffiler/moderat_13214.pdf

Alliance for Sweden (2006b): Flera i arbete – mer att dela på. Valmanifest 2006.
http://www.maktskifte06.se/fileadmin/Upload/pdf/Valmanifest_2006.pdf

Barnola, J.M., D. Raynaud, C. Lorius and N.I. Barkov (1999): Historical CO2 record from the Vostok ice core, In *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Barrett, S. (2003): *Environment & statecraft. The strategy of environmental treaty-making,* Oxford University Press, Oxford, 427 pp.

Barrett, S. (2006): Climate Treaties and "Breakthrough" Technologies, *American Economic Review,* Vol. 96, Issue: 2, pp. 22–25.

Bohm, Peter (2004): Den svenska klimatpolitikens kostnader och betydelse. A2004:003. Institutet för tillväxtpolitiska studier.

Boyle, C. (ed.)(1991): *The Human Dawn,* Time-Life Books B.V., Amsterdam.

BP, (2006): BP statistical review of world energy, http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390

Caldeira, Ken, Atul K. Jain, Martin I. Hoffert (2003): Climate Sensitivity Uncertainty and the Need for Energy Without CO_2 Emission, *Science* Vol. 299. no. 5615, pp. 2052–2054, DOI: 10.1126/science.1078938

Carlén, Björn (2004): BNP-effekter av svensk klimatpolitik – en kommentar. A2004:008. Institutet för tillväxtpolitiska studier.

Diamond, Jared (1998): *Guns, germs and steel.* Vintage, Random House, London. 480 pp.

Departementsskrivelse (Ministry Memorándum) (Ds) (2005): Sweden's fourth national communication on climate change. Departementsskrivelse (Ministry Memorándum) 2005:55.

Eickhout, B., Den Elzen, M.G.J. and Vuuren, D.P. van (2003): Multi-gas emission profiles for stabilising greenhouse gas concentrations: Emission implications of limiting global temperature increase to 2°C. RIVM Report 728001026. The Netherlands.

Eskeland, G. S. and A. Harrisson (2003): Moving to Greener Pastures? Multinationals and the Pollution-haven Hypothesis. *Journal of Development Economics,* vol 70, pp. 1–23.

Eskeland, G. S. and B. Harstad. (2006): "Trading for the future: Signaling in permit markets?" CMS-EMS discussion paper 1429, December, 2006. Northwestern University.

Etheridge, D.M., L.P. Steele, R.J. Francey, and R.L. Langenfelds (2002): Historical CH4 Records Since About 1000 A.D. From Ice Core Data, In *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

EU (2002): Directive 2002/91/EC of The European Parliament and of the Council of 16 December 2002 on the energy performance of buildings,
http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_001/l_00120030104en00650071.pdf .

European Commission (2006): Special Eurobarometer: Attitudes towards Energy.
http://ec.europa.eu/energy/green-paper-energy/doc/2006_01_24/2006_01_24_ebs_247_en.pdf

European Parliament (2005): "Winning the Battle Against Global Climate Change" (2005/2049/(INI)). Resolution.

Fedorov, A. V., P. S. Dekens, M. McCarthy, A. C. Ravelo, P. B. deMenocal, M. Barreiro, R. C. Pacanowski, S. G. Philander (2006): The Pliocene Paradox (Mechanisms for a Permanent El Niño), *Science* Vol. 312, no. 5779, pp. 1485–1489 DOI: 10.1126/science.1122666.

Frakes, L. A. (1979): *Climates through geologic times.* Amsterdam: Elsevier.

Ganopolski, A. and S. Rahmstorf (2001): Rapid changes of glacial climate simulated in a coupled climate model. *Nature* 409: 153–158 (11 January 2001).

Golec, J. and J. A. Vernon (2006): European Pharmaceutical Price Regulation, Firm Profitability, and R&D Spending, NBER working paper, w12676, National Bureau of Economic Research, November, Cambridge, Mass.

Hansen, James, Larissa Nazarenko, Reto Ruedy, Makiko Sato, Josh Willis, Anthony Del Genio, Dorothy Koch, Andrew Lacis, Ken Lo, Surabi Menon, Tica Novakov, Judith Perlwitz, Gary Russell, Gavin A. Schmidt, and Nicholas Tausnev (2005): Earth's Energy Imbalance: Confirmation and Implications, *Science,* Vol 308, Issue 5727, 1431–1435, 3 June 2005.

Hare, B. and M. Meinshausen (2004): How Much Warming are we Committed, PIK report No. 93.

Hoffert, Martin I.; Caldeira, Ken; Jain, Atul K.; Haites, Erik F.; Harvey, L. D. Danny; Potter, Seth D.; Schlesinger, Michael E.; Schneider, Stephen H.; Watts, Robert G.; Wigley, Tom M. L.; Wuebbles, Donald J. (1998): Energy implications of future stabilization of atmospheric CO2 content, *Nature* 395, Issue 6705, p. 881, DOI: 10.1038/27638.

Hoffert, Martin I., Ken Caldeira, Gregory Benford, David R. Criswell, Christopher Green, Howard Herzog, Atul K. Jain, Haroon S. Kheshgi, Klaus S. Lackner, John S. Lewis, H. Douglas Lightfoot, Wallace Manheimer, John C. Mankins, Michael E. Mauel, L. John Perkins, Michael E. Schlesinger, Tyler Volk, Tom M. L. Wigley (2002): Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet, *Science* Vol. 298, no. 5595, pp. 981–987, DOI: 10.1126/science.1072357

Holtsmark, Bjart J. and Knut H. Alfsen (2004): Kyoto-protokollen – et mislykket prosjekt? *Internasjonal Politik*k 62 (3:2004), pp. 413–433

IEA (2004): *Thirty years of energy use in IEA countries: Oil crisis and climate challenges.* IEA/OECD: Paris, France.

IEA (2006) *Energy Technology Perspectives: Scenarios and strategies to 2050.* IEA/OECD, Paris, France.

IPCC (2000): *Emissions Scenarios.* 2000. Special Report of the Intergovernmental Panel on Climate Change, Nebojsa Nakicenovic and Rob Swart (Eds.), Cambridge University Press, UK. pp. 570.

IPCC (2000a): *Summary for policymakers, special report on emission scenarios.* A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.

IPCC (2001a): *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

IPCC (2001b): *Climate Change 2001: Synthesis Report.* A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Integovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

IPCC (2001c): *Climate Change 2001: Impacts, Adaptation & Vulnerability.* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), James J. McCarthy, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken and Kasey S. White (Eds.), Cambridge University Press, UK. pp. 1000.

IPCC (2001d): *Climate Change 2001: Mitigation.* Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Bert Metz, Ogunlade Davidson, Rob Swart and Jiahua Pan (Eds.), Cambridge University Press, UK. pp. 700.

IPCC (2007): *Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* http://www.ipcc.ch

Kallbeken, S. "Why the CDM will reduce carbon leakage", *Climate Policy.*

Keeling, C.D. and T.P. Whorf (2005): Atmospheric CO2 records from sites in the SIO air sampling network, In *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Kremer, Michael (2000): "Creating Markets for New Vaccines Parts I and II," NBER Working Paper 7716 and 7717, May 2000.

Kydland, Finn E., Edward C. and Prescott (1977): Rules Rather than Discretion: The inconsistency of Optimal Plans, *Journal of Political Economy,* Vol. 85, No. 3 (Jun., 1977), pp. 473–492.

Madisson, Angus (2001). *The World Economy: A millennial perspective.* OECD, Paris.

Meinshausen, M. (2004): On the risk of overshooting 2°C, Presentasjon gitt på: Side-Event "Climate Risks and 2°C" at COP-10, Buenos Aires, 15 December 2004.

Mithen, Steven (2003): *After the ice,* Weidenfeld and Nicolson, London, 622 pp.

Montgomery, W. David, Anne E. Smith (2005): Price, Quantity, and Technology Strategies for Climate Change Policy. Forthcoming in: Michael Schlesinger, Haroon Kheshgi, Joel Smith, Francisco de la Chesnaye, John M. Reilly, Tom Wilson and Charles Kolstad (Eds., 2007): *Human-Induced Climate Change. An Interdisciplinary Assessment,* Cambridge University Press, Cambridge. ISBN-13: 9780521866033.
See www.crai.com/.%5Cpubs%5Cpub_4141.pdf

Motion 2005/06:MJ45 med anledning av prop. 2005/06:172 Nationell klimatpolitik i global samverkan. Catharina Elmsäter-Svärd m.fl. (m). http://www.riksdagen.se/webbnav/index.aspx?nid=410&typ=mot&rm=2005/06&bet=MJ45.

Motion 2005/06:MJ46 med anledning av prop. 2005/06:172 Nationell klimatpolitik i global samverkan. Lennart Fremling m.fl. (fp). http://www.riksdagen.se/webbnav/index.aspx?nid=410&typ=mot&rm=2005/06&bet=MJ46

Motion 2005/06:N436. Energipolitik för tillväxt och välfärd. Eva Flybort m.fl. (fp). http://www.riksdagen.se/Webbnav/index.aspx?nid=410&dok_id=GT02N436&rm=2005/06&bet=N436#_Toc118353459

Motion 2005/06:MJ47 med anledning av prop. 2005/06:172 Nationell klimatpolitik i global samverkan. Sven Gunnar Persson m.fl. (kd). http://www.riksdagen.se/webbnav/index.aspx?nid=410&typ=mot&rm=2005/06&bet=MJ47

Motion 2005/06:MJ49 med anledning av prop. 2005/06:172 Nationell klimatpolitik i global samverkan. Claes Västerteg m.fl. (c). http://www.riksdagen.se/webbnav/index.aspx?nid=410&typ=mot&rm=2005/06&bet=MJ49.

National Academy of Sciences (2006a): *Surface Temperature Reconstructions for the Last 2,000 Years,* Report in brief, June 2006.

National Inventory Report (NIR) (2006): Sweden's National Inventory Report 2006. Submitted under the United Nations Framework Convention on Climate Change, Swedish environmental protection agency.

OECD/IEA (2006): *Energy Technology Perspectives: In support of the G8 plan of action.* OECD, Paris.

Pacala, S. and R. Socolow (2004): Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies, *Science,* vol. 305, pp. 968-972, DOI: 10.1126 /science.1100103

Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.-M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davis, G. Delayque, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pépin, C. Ritz, E. Saltzman, and M. Stievenard

(1999): Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, *Nature* 399: 429-436. Data hos:
http://cdiac.ornl.gov/trends/temp/vostok/jouz_tem.htm .

Palmer, K., W. Oates and P. Portney (1995): Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm? *The Journal of Economic Perspectives,* Vol. 9, No. 4. (Autumn, 1995), pp. 119–132.

Prop. (Govt Bill) 2005/06:172. Nationell klimatpolitik i global samverkan. Regjeringens proposisjon 2005/06:172.

Statens energimyndighet (Swedish Energy Agency) and Naturvårdsverket (Swedish Environmental Protection Agency) 2004. Kontrollstation 2004.

Stern, Nicholas (2006): The Economics of Climate Change, The Stern Review, Cabinet Office – HM Treasury, Cambridge University Press, Cambridge, See also
http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

Torvanger, A., M. Twena, J. Vevatne (2004): Climate policy beyond 2012: a survey of long-term targets and future frameworks, CICERO Report, 2004.

Torvanger, A., G. Bang, H. Kolshus, J. Vevatne (2005): Broadening the climate regime: Design and feasibility of multi-stage climate agreements, CICERO Report, 2005

UNFCCC (1992): The United Nations Framework Convention on Climate.
http://unfccc.int/resource/docs/convkp/conveng.pdf

UNFCCC (1995): The Berlin Mandate. Decisions adopted by the Conference of the Parties no. 1.
http://unfccc.int/resource/docs/cop1/07a01.pdf

UNFCCC (1997): The Kyoto Protocol to the United Nations Framework Convention on Climate Change.
http://unfccc.int/resource/docs/convkp/kpeng.pdf

UNFCCC (2001): The Marrakech Accords.
http://unfccc.int/resource/docs/cop7/13a01.pdf

Weart, S. R. (2003): *The discovery of global warming,* Harvard University Press, Cambridge, Massachusetts, 228 pp.

WMO (1985): “Report of the International Conference on the Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated

Impacts", in Villach, Austria, 9–15 October 1985 (Geneva: WMO – No. 661).
World Commission on Environment and Development (WCED) (1987): *Our Common Future,* Oxford: Oxford University Press.