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Exploring Distribution of Commitments - A Follow-up to the Berlin Mandate

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This study explores burden sharing among OECD countries related to the negotiations by the Ad Hoc Group on the Berlin Mandate (AGBM) to strengthen commitments by these countries to abate emissions of greenhouse gases. A protocol to the Climate Convention (or another legal instrument) will be proposed at the third Conference of the Parties in 1997. Burden sharing among industrialized countries is a new, relatively unexplored research area. This study has been financed jointly by the Norwegian Ministry of Finance and the Ministry of the Environment. The authors wish to thank Elisabeth Meze for valuable project assistance, Grete Torrissen for important contributions to the report, Geir Asheim and Tora Skodvin for valuable discussions, and Mariann Murvoll for efficient work on our literature references.

EXECUTIVE SUMMARY

The first Conference of the Parties (COP) to the UN Framework Convention on Climate Change (FCCC) was held in Berlin in spring 1995. The Conference established an open-ended Ad Hoc Group on the Berlin Mandate (AGBM) to develop a climate policy process that will enable governments to take appropriate action for the period after the year 2000. The goal of the AGBM is to negotiate a policy that strengthens the present commitments by Annex I countries to reduce their net emissions of greenhouse gases. A protocol to the FCCC (or another legal instrument) will be adopted by the third COP in 1997. Since these commitments may imply a substantial cost for the participating countries, the policy process must attempt to define the ways in which the burden can be shared.

Burden sharing among industrialized countries is a new, relatively unexplored research area. This study reviews and analyzes the major issues that must be considered when defining the principles for the distribution of commitments. The study also explores the consequences of different types of agreements.

Burden sharing is achieved when countries manage to negotiate a distribution of commitments that all parties perceive to be in conformity with their concept(s) of fairness. Thus, burden sharing relates both to the process of distributing commitments given the participants' concepts of fairness, and to the final result in terms of a specific distribution of the total cost among participating countries. With respect to the FCCC this means that the final burden sharing is a specific distribution of the total abatement cost among participating countries that meet the negotiated emission-reduction target.

Countries belonging to the Organization for Economic Cooperation and Development (OECD) must take the lead in accepting new and more ambitious commitments to reduced emissions. This study focuses on the role and responsibilities of members of the OECD, rather than all countries included in the group defined as Annex I by the FCCC. In addition, as used in the study, OECD includes countries that were members in 1992 but not those that have become members since; Mexico, the Czech Republic and Hungary. The other Annex I countries are in the process of making the transition to a market economy in Central and East Europe, and Russia. The European Union, formerly the European Economic Community, is a separate party to the FCCC and included in the Annex I group of countries.

Although a number of studies exist regarding burden sharing issues related to developing countries and foreign aid, the challenge with regard to the AGBM negotiations is to identify issues that are important for a comparison of *similar* countries. In short we need to improve our understanding of questions pertaining to burden sharing among them. Studies of this type are an important source of background information for negotiations and are required if governments are to engage in effective negotiations. Such groundwork is vital for the success of the AGBM negotiations in terms of an ambitious common abatement target and the commitments accepted by each country.

This study explores three main issues pertaining to burden sharing in the context of climate change policies:

- the handling of a mix of climate gases,
- the concept and measurement of costs, and
- the climate protocol negotiations.

We analyze the complex area of burden sharing related to the AGBM process from different perspectives using different methods and models.

In addition to national circumstances, the perspective of an OECD country in the negotiations among other factors depends on the common OECD target, the type of agreement, and the burden sharing arrangement. For OECD countries to accept an agreement that has potentially costly national consequences, four conditions are essential:
- the common target must be at an acceptable ambition level (in terms of emissions abatement and total cost);
- the cost distribution and welfare implications for each OECD country depends on national circumstances and must be considered fair by each country;
- the cost-effectiveness must be considered high enough; and
- the level of uncertainty with respect to the cost share of each country must not be too high.

Primary findings
The main findings of the study are summarized below:
- At present the Global Warming Potential (GWP) method is the only realistic tool for a comparison of different greenhouse gases.
- The available methodologies for comparing the effects of climate gases, together with uncertainties in the understanding of the mechanisms of the gases, put restrictions on which gases should be included in negotiations.
- Calculations in this study suggest that an a moderate climate policy is beneficial. If emissions can be reduced for a relatively low cost or uncertainty about the effects of climate change is introduced, this may provide a good reason for advancing climate policy measures.
- An agreement with emphasis on commitments to implement certain climate policies, such as the removal of subsidies on fossil fuels or minimum fossil fuel taxes, might have some advantages in terms of cost-effectiveness and fairness compared to agreements which rely mainly on quantified national reduction commitments.
- The burden sharing rules that could be defined based on available data may have quite different burden sharing and welfare implications for different OECD countries.
- The achievable outcome of the negotiations in terms of a common OECD target is likely to be determined by countries with relatively low concern for climate change and either low or high abatement costs.
- The achievable common target for OECD depends on the ability to introduce elements into the agreements that reduce the cost share of high abatement cost countries, thus moving in the direction from ‘emissions reduction sharing’ to ‘cost sharing’.

Many other issues pertaining to burden sharing and the AGBM negotiations are important and should be explored and further developed. These include the general framework and models for analyzing burden sharing; the optimal choice of time horizon(s) in policy analyses; and the formulation of burden sharing rules based on national circumstances, in particular welfare impacts and comparability across countries.

In the following summary the main findings of the study are presented.

The concept and measurement of costs
A comparison of the costs of a given agreement among countries may have a variety of aims. Costs should be measured according to the aim. Until now, the most common way to measure the costs of climate policies has been to estimate the national cost of reducing the emissions of CO_2 in terms of the reduction of GDP. The studies provide clear evidence for the claim that agreements which set equal quantified reductions for all the participants will result in

unequal and unjust distribution of costs. To require all countries to reduce emissions by a given percentage, for instance, in general punishes countries with a high energy efficiency, while it is favorable to countries with low energy efficiency. This is not consistent with the polluter-pays principle, which has been formally adopted by the OECD. The distribution of commitments should instead reflect the opportunities of achieving emission reductions at low costs in order to meet generally accepted principles of fairness.

An extreme alternative to equal quantified reductions is to impose a uniform charge on emissions for all participating countries. If the countries first agree on a common emission target, a uniform charge will assure cost-effectiveness. But, apart from the practical difficulties of implementing such a charge, a uniform charge may also be regarded as unfair because countries differ in their opinions about the need for a climate policy. A given charge on emissions may lead to a higher loss of GDP in Switzerland for example, than in the Netherlands, but this does not mean that the charge leaves the Netherlands better off than Switzerland. If the charge corresponds exactly to what the Swiss government thinks is appropriate, but not to what the Dutch government would prefer, Switzerland is the winner of this game. Therefore, a uniform charge will have to be assessed from a unanimous concept of welfare across countries in order to be efficient.

There are no institutions given the authority or the ability to assess a uniform charge on behalf of the world, or of groups of independent countries. How far to go in common efforts to control climate change is the major subject to be negotiated. As a consequence, the measurement of national costs of climate agreements ought to reflect each country's evaluation of the need for such an agreement. This suggests that the benefits of reducing the speed of climate change are taken into account, and that the burden of an agreement is related to the discrepancy between the result of the agreement and the most preferred policy as viewed by one country. To make such estimates, one may regard negotiations as a two-step procedure. In the first step, each country assesses its preferred choice of a global climate policy. In the second step, the countries enter the negotiations by trying to achieve an agreement as close as possible to their preferred choice. The cost of a negotiated agreement can be defined as the loss of welfare that occurs because the agreement diverges from the optimal choice. Thus, if the agreement corresponds to a country's preferred choice, the cost is zero. If it is more or less ambitious, the cost is positive.

This definition of national cost requires valuation of the benefits of a climate policy or, alternatively, the effects of climate change. Valuation of the effects of climate change have been carried out in a few studies. The estimates are very uncertain, and in some cases utterly controversial. The estimates also vary across studies. However, when it comes to recommendations for a climate policy, most studies seem to conclude by warning against aggressive actions to mitigate climate change at an early stage. This is because other investments usually yield benefits much earlier than the benefits yielded from abatement measures. Thus, the present value of the benefits of abatement measures tends to be small.

On the other hand, the present value of these benefits is also dependent on the choice of a discount rate. Therefore, the rate used in an analysis of climate policy is crucial. Unfortunately, however, there is no concensus among experts about the proper rate. IPCC regards any rate between 1.5 to 6% as reasonable. This means that the present value of avoiding a damage at USD 1 million a hundred years ahead ranges between USD 2 290 and USD 226 000. Thus, when evaluating a strategy for a climate policy, the weight of a major part of the benefits differs by a scale from 1 to 100, even if the effects of climate change are fully understood and the exact value of these effects can be assessed.

This indicates that a closer study of discounting should play a central role in studies of burden sharing. One way to determine the discount rate is to estimate the rate of change in the value of capital over time. For capital invested in economic activities, this rate of change materializes in the rate of return on capital. The rate of return tends to be equal in all sectors of the economy because the capital aims at yielding economic return. The value of abatement capital, on the other hand, is subject to environmental constraints. For example, higher concentrations of greenhouse gases will lead to an increase in damages that result from climate change, and thereby increase the value of abatement capital. Because of the relationship between concentrations, abatement capital and economic output (damages), the value of abatement capital may follow a different path from the value of other capital.

By studying a simplified optimization model where abatement capital is separated from other capital, it is possible to show how the values of these capital categories differ. In the study, it is assumed that investments in abatement require considerable costs of installation and learning, search and adjustment, compared to other investments, and that the damages of climate change are relatively high. The rate of return of productive capital is assumed to be 5.5%. Due to the damages of climate change, the social rate of discount is a little less than 5%. For abatement capital, the discount rate is negative in the first 20 to 25 years, and slightly positive afterwards. Thus, if public investors in an economy, similar to the one described in the model, apply the same rate of discount for abatement capital as they do for other investments, the benefits of climate measures will be seriously underestimated.

Despite this result, the optimal path for investments in abatement follows the pattern recommended in studies that apply a "standard" discount rate; namely to keep investments low in the beginning. There are three main reasons why a precautious climate policy at an early stage is optimal. First, the adjustment costs for investing in abatement are high, especially in the beginning. After some years, the adjustment costs are expected to be reduced due to learning. Second, the damage of climate change is relatively small in the beginning. Under full certainty there is hardly any reason for initiating precautionary actions. Uncertainty, especially about the effects of climate change, may advance the initiation of a climate policy considerably. Similarly uncertainty about the costs of climate measures will also tend to advance the initiation of a climate policy, although to a limited extent. The third reason for a cautious climate policy is that higher concentrations of greenhouse gases lead to a higher natural decay of concentrations. This effect, which is significant over the first 20 years, works opposite to the damage caused by higher concentrations.

Thus, this study does not differ from other studies in the recommendation of a policy path. The main difference is the explanation of why a cautious climate policy at an early stage is optimal. Most studies argue that the social return on alternative investments is too high to allow for the initiation of climate measures, thereby indicating a relaxed attitude to climate policy. In this study, the cautious policy is explained explicitly by the high costs of abatement measures, and partly by the assumption of certainty. Thus, the need to find less costly ways to reduce the emissions of greenhouse gases is emphasized.

According to the calculations, the optimal policy, or zero-cost policy, in the base case implies that emissions of CO_2 are reduced by about 50% around 2045 compared to the emissions when no investments in abatement are carried out. Increasing this target to 60% leads to a 0.5% loss of total welfare over the whole period, and a reduction in emission at 70% implies a welfare loss of 1.5%. These estimates are somewhat lower than most of the cost-estimates of emission control measured in terms of reductions in GDP.

Coordinated climate-policy options
The AGBM is intended to negotiate a protocol (or another legal instrument) to the Climate Convention which commits the Annex I countries to take action to reduce emissions of CO_2 and other climate gases not controlled by the Montreal Protocol. In accordance with the Berlin Mandate the focus in the AGBM process has so far been mainly on an agreement which specifies 'quantified emission limitation and reduction objectives' (QELROs). However, a climate protocol could also take other forms. The main alternative is a protocol which, instead of QELROs, commits the relevant parties to implement specified policies, for example carbon related fossil fuel taxes above a minimum level. We use a simulation model developed at CICERO to compare burden sharing consequences of these two types of agreements. As with all applied, numerical models the results of our simulations are closely linked to the model framework and the set of assumptions. Therefore, all results must be interpreted with care. Rather than giving any final answers, the results must be seen as a step in the process leading towards an increased understanding of this issue.

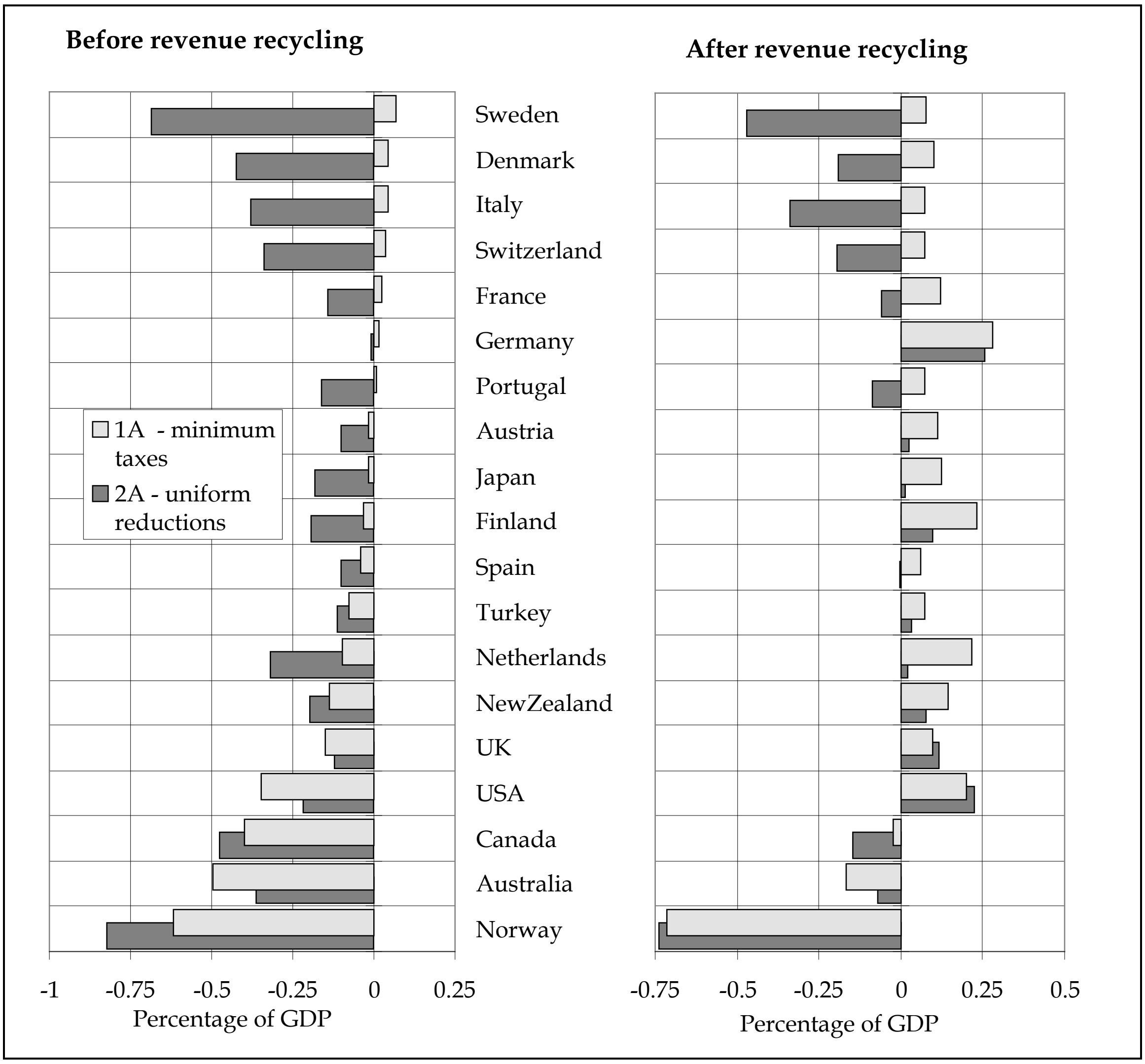
An agreement among the OECD countries to reduce their total combustion of fossil fuels will directly affect the fossil fuel markets with terms-of-trade changes as one of the results. Together with the implemented policies, this will also affect the collection of public revenue in the different countries. These two effects of a climate agreement are analyzed by the use of the simulation model. Furthermore the numerical estimates of the total abatement costs in the different countries also take into account:

- The transfer of resource rent from net exporters of fossil fuels to net importers.
- The fact that the level of fossil fuel taxes in the reference situation is essential to the magnitude of the costs of the implementation of a country's commitments. (The reason is that the marginal increase in dead-weight loss of increased taxation is higher, the higher the tax is in the first place.)

In scenario 1A we analyze an agreement which implies a cost-effective approach in the sense that a 20% emission reduction target for the OECD area as a whole is reached through coordinated, efficient taxation of fossil fuel consumption. Specifically, instead of complete harmonization of the taxes, we assume that the agreement analyzed, specifies minimum taxes. That means that the participating parties are assumed to be committed to implementing these minimum taxes if the current fossil fuel taxes are lower than the minimum taxes. We compare this to an agreement (2A) which commits all participating parties to 20% emission reductions. It should be stressed that we simulate the model as if we are still in 1993. The simulation results should nevertheless be interpreted in a long-term perspective. If such emission reductions were carried out on a short-term basis, the costs would be much larger than the presented estimates.

Figure 1 shows the changes in the welfare indicators measured as a percentage of the GDP brought about by the implementation of the climate agreements analyzed in scenarios 1A and 2A. The term *welfare reductions* is defined as the sum of the income loss and the reduction in consumers surplus. The left diagram gives the welfare changes before the net public revenue increase is recycled into the economy. Norway experiences large losses irrespective of the type of agreement reached due to Norway's special role as a small country highly dependent on fossil fuel exports and estimated reductions in the price of oil and gas. The other three participating parties with welfare losses above 0.25% (before revenue recycling) in scenario 1A are the USA, Canada and Australia. This is due mainly to low fossil fuel taxes in the reference situation. In the cases of Canada and Australia, it is also related to their considerable fossil fuel exports. When several of the other countries experience limited welfare losses and even net gains in scenario 1A, the reason is partly that the terms-of-trade effects from lower fossil fuel prices are considerable due to high import shares.

Figure 1 Welfare changes in two types of agreements.



Countries like Sweden, Denmark and Italy, that have already implemented substantial fossil fuel taxes, will have an advantage in this type of agreement. However, such taxes could also mean that on a unilateral basis these countries have implemented abatement measures. It seems reasonable to credit such initiatives in a climate agreement.

The chart in Figure 1 representing welfare losses after revenue recycling shows the changes in the welfare indicators taking into account when revenue generated replaces or reduces other taxes. Scenario 1A indicates that an emission reduction of the size we are considering here is a 'no regret' option for several OECD countries if the commitments are cost-effectively distributed. The underlying terms-of-trade gains play a crucial role here. The terms-of-trade changes partly explain the negative welfare effects for Norway, Australia and Canada even when revenue recycling is taken into account.

The relatively large welfare losses in scenario 2A in countries such as Sweden, Denmark, Italy and Switzerland to some extent reflect the high fossil fuel taxes in the reference situation. Other factors, such as the carbon intensity in the reference situation, also play a role here.

If it is possible to reach and implement a climate agreement which implies commitments towards the implementation of certain policies, such agreements would have several advantages. As far as burden sharing is concerned such agreements imply that credits are given to countries that have already implemented a national climate policy. One of the disadvantages of quantitative emission restrictions is that it is difficult to reach a consensus on how to adjust the different national quotas in order to give proper weight to this type of consideration. Differentiation of national quotas based on national circumstances must ultimately be based on numerical calculations. However, such calculations could always be improved or be made the object of discussion.

The climate protocol negotiations: burden sharing rules and achievable agreements

A fair sharing of the burden of reducing greenhouse gas emissions is quickly becoming an essential issue in the on-going climate protocol negotiations among the OECD countries. Suggestions that all Annex I countries should cut greenhouse gas emissions by the same percentage, or that they should stabilize their emission levels in some future year relative to their emissions in a specific base year, could distribute abatement costs very unevenly across OECD countries. Instead, differentiation among countries and a possible differentiation arrangement might be more attractive to some countries.

We first conclude that there exist some rather strong relationships between the ambition of greenhouse policies and the likely group-formation processes in the protocol negotiations. Thus, is seems most likely that a large group of countries within the OECD would be built by politically and economically powerful countries pursuing a rather ambitious emission reduction goal which results in more than negligible abatement cost. It is less likely that a large group of OECD countries will be established when few OECD countries pursue a modest emission reduction goal. Neither is it likely that a large group of OECD countries will be built when few OECD countries pursue an overly ambitious emission reduction goal, given existing constraints and opportunities. However, so far there has been no indication that any of the politically and economically powerful countries are acting as a leader in the climate protocol negotiations. Moreover, most countries seem to be concerned mostly about national goals. In such a situation, issues of fairness and equity become even more prominent.

The FCCC underlines the significance of equity between developing and developed countries and, in addition, equity among countries belonging to the OECD. The most significant principles of fairness - namely the egalitarian, sovereignty, horizontal, vertical, and polluter pays principle - are discussed, and three burden sharing rules or formulae are explored. A burden sharing formula would define national emissions entitlements, or changes from the status quo, and would take into account national characteristics such as population, GDP, and current emissions. It could also reflect national responsibility, sensitivity, or need for various emitting activities.

We have explored three types of burden sharing rules, namely Formulae I, II and III. The intention is not to advocate any of the three burden sharing rules in particular but to explore different types of formulae and examine how they distribute abatement costs across the OECD. It is assumed that the overall level of abatement remains 20% of total 1993 OECD emissions but the required targets in individual countries change. The study describes how each formula will distribute the burden across the OECD countries and how much individual countries will have to reduce in order to contribute their share of the total amount of emissions reduced by the OECD. All OECD countries (except Iceland, the Czech Republic and Mexico) are examined. Furthermore, the above-mentioned simulation model is used to estimate how Formulae I, II and III distribute abatement costs across OECD countries and the level of cost-effectiveness within the OECD achieved by the formulae. Finally, to compare the formulae and the resultant cost distributions, the welfare changes following a 20%

reduction in each OECD country are included as a reference case. This case resembles the policy proposal made by the German delegation at the AGBM-3 meeting in March 1996 in Geneva.

Formula I is based on the premise that a country which is identical to the average OECD country, so to speak, should reduce its emissions with exactly 20%. A country which exceeds the OECD average with respect to one or more of four variables should reduce its emissions with more than 20%. Similarly, if a country is below the OECD average with respect to one or more of the variables its target will be below 20%. Formula I's four variables are CO_2 emissions per capita, GDP, CO_2 emissions per unit of GDP and GDP per capita. The variables can be understood as proxies for emission entitlements, size of countries, energy efficiency, and wealth. Each variable is given a weight, and the sum of the weights is 100.

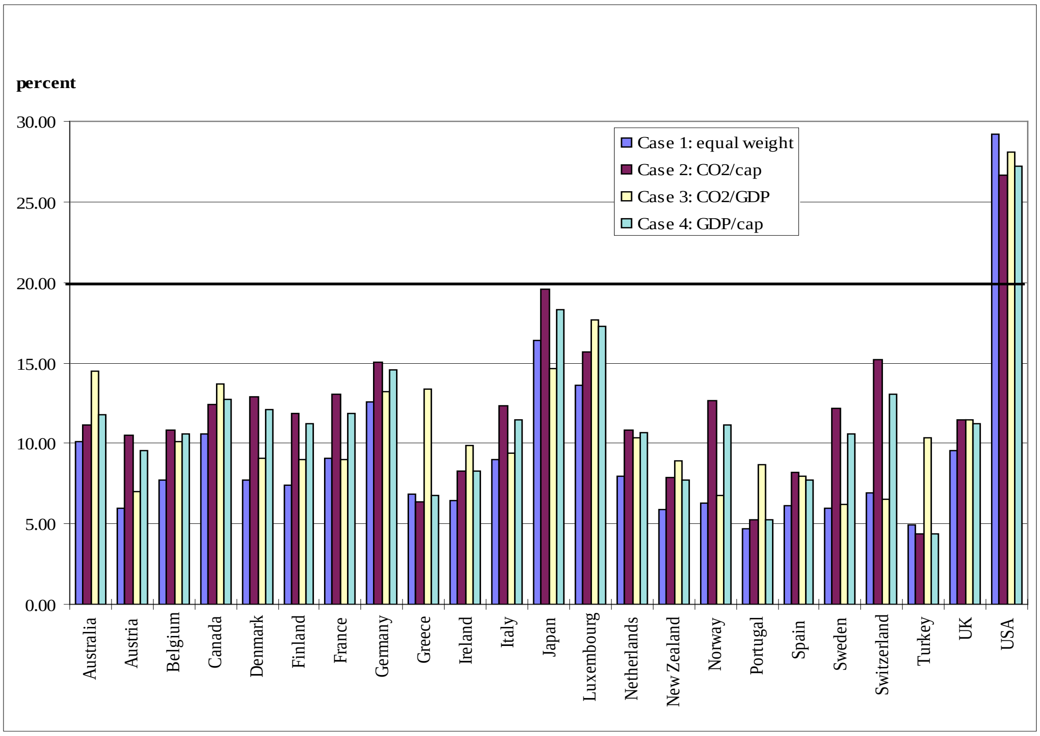
Four variants of Formula I - cases 1, 2, 3, and 4 - are also explored (see Figure 2). When achievement of horizontal equity is considered most fair, it could be argued that case 3 is unfair to relatively poor countries, whereas cases 1 and 4 are favorable to most European countries, but unfair to the United States. Of these four cases of Formula I, therefore, case 2 represents the most equitable distribution of emission reductions across OECD countries. Consequently, the cost implications of case 2, which implies that the United States reduces slightly less while almost all other relatively wealthy OECD countries reduce more, are estimated.

We show then that in Formula I, Norway, the United States, Sweden, Canada, Switzerland and Australia experience the biggest welfare loss in percentage of GDP. The welfare loss of the United States is explained by its large emission reduction. The large welfare loss of Sweden, and to some extent Norway, is related to the high taxes on fossil fuels in the reference situation which result in high marginal abatement costs. Canada's welfare loss is almost as large as the welfare loss of the United States despite the fact that the Canadian emission reduction is considerably smaller than that of the United States. This result must be seen in relation to the role these countries play in the fossil fuel markets, especially the gas market in North America.

Significantly, the model simulation shows that a number of countries will experience net welfare gains from the implementation of this type of burden sharing formula. Germany in particular receives large net gains. The total welfare loss amounts to 0.19% of the total GDP of the OECD area. Hence, Formula I is more cost-effective than the reference case's uniform reductions resulting in a total welfare loss of 0.21%. This is due to large reductions in the USA which, according to the model, has relatively low marginal abatement costs.

It is concluded that the percentage distribution of commitments across countries to reduce emissions may show substantial deviation from the abatement cost distribution. It is apparent, however, that Formulae I, II and III do not produce a burden sharing arrangement that equalizes the economic costs across the OECD, and they do not satisfy the principle of horizontal equity in the FCCC. To produce more equitable results it is possible that these formulae could be adjusted or that other formulae could be introduced.

Figure 2 Formula I - emission reduction as a percentage of national CO_2 emissions (OECD reduction 20% of 1993 level).



Achievable agreements

To analyze the negotiations on the Berlin Mandate among the OECD countries it is important to consider differences in national circumstances. Parties are heterogeneous with respect to economic structure, energy structure, resource base, geography and climate, and there is uncertainty of different characteristics attached to possible climate impacts in these countries. The idea is to survey these circumstances and analyze their influence on the position of the parties in the negotiations, and how these positions might influence the negotiations and their outcome.

Against this background we present a classification of a selected group of OECD countries according to predicted interest for cost-sharing solutions or systems, such as ‘equal cost per capita’, as compared to emission reduction sharing solutions, such as ‘equal percentage reduction’. The hypothesis is that countries with relatively high marginal emissions abatement costs prefer ‘equal cost per capita’ since they will then have better control of cost implications of the commitments accepted and are likely to face lower costs than under the alternative ‘equal percentage reduction’ type agreement. On the other hand countries that have a relatively low marginal emissions abatement costs prefer ‘equal percentage reduction’ since such agreements probably mean moderate costs for these countries. Under an ‘equal cost per capita’ agreement they would probably face commitments involving higher costs.

In the survey we examine percentage shares of different energy sources, CO_2 emissions per capita and per unit of GDP, in addition to percentage contribution of energy-related CO_2 emissions by economic sector. We also survey estimates of CO_2 emissions abatement costs.

When it comes to abatement cost studies, the available number of bottom-up studies is much smaller than top-down studies. There is quite some variation in the emission estimates and, in particular, for some of the countries. For some of our selected OECD countries no abatement cost studies are available. The difficulties involved in comparing estimates based on different models and assumptions should be emphasized.

Based on the survey of energy structure, emissions structure, abatement cost estimates, and model estimates in this study, we proceed to make a classification of the selected OECD countries according to marginal emissions abatement costs in three groups: one group of high cost countries, one group of low cost countries, and one group of average cost countries. The classification is shown in Table 1.

Table 1 Classification of OECD countries according to marginal emissions abatement cost.

Low cost	Average cost	High cost
GER, UK, USA	AUST, CAN, DK, FIN, FRA, NL, SPA	JAP, NOR, SWE

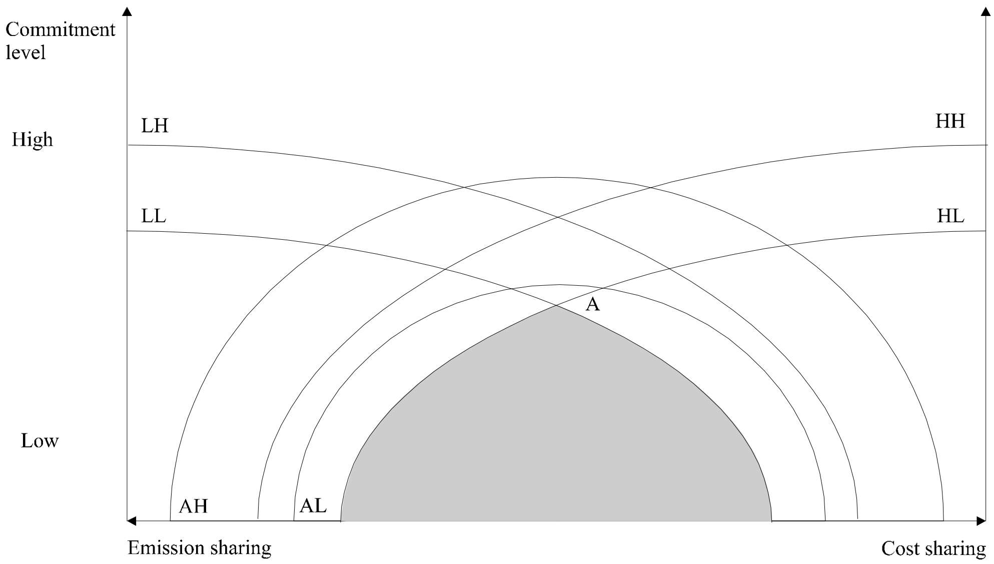
When explaining the position of countries prior to climate negotiations, the costs of emission control in each country will be important. However, if the benefits of climate measures are also taken into account, one might come up with a quite different grouping of countries based on their interests and conflicts. Moreover, the way in which the targets of common actions are expressed may also be of importance for the possibility of achieving consensus among countries. For example, calculations indicate that countries that face different abatement costs and have different opinions about the benefits of a climate policy may agree about the optimal emission reductions if the targets are expressed in terms of percentage reductions in each country's contribution to concentrations. If instead the agreement is expressed in terms of the absolute contribution, such as the European Union has suggested, conflicts of interests are likely to occur between countries which high abatement costs and countries with low abatement costs. On the other hand, different opinions about the benefits of climate control do not seem to lead to serious conflicts of interest, according to these calculations.

To accept the outcome of the negotiations and commit to emissions abatement, all OECD parties must find that this option is better than the best alternative actions, such as leaving the negotiations or trying to reduce the ambition level for the OECD to the extent possible, thus reducing the common emission reduction target.

In addition to marginal abatement costs, we also focus attention on a second dimension in the negotiations, namely the national concern for future climate change. By national concern we think of both the government's and general public's interest in the protection of the global climate system. Such interest may be motivated by anticipated climate change impacts and related costs (or benefits), but may also be motivated by a genuine concern for the global climate system as a collective good for present and future generations. For the sake of simplicity, we assume that the OECD countries can be divided into two groups, those that show more than average concern for future climate change and those that seem to have a less than average concern.

Let us introduce the concept of the *achievable set*, which can be defined as the set of possible agreements that makes all countries better off by participating rather than sitting on the sidelines and having no agreement (or an agreement of no real influence on total OECD emissions and national policies). Based on the classification of countries according to concern for climate change we introduce a new notation for these groups of countries. The dimension of relative abatement cost and system preference is thus combined with the level of concern for climate change and commitment level for reducing emissions within the OECD, as shown in Figure 3, where the country group notation is explained in the caption.

Figure 3 The achievable set of negotiations.



HH - High abatement cost and above average level of concern for climate change
HL - High abatement cost but a below average level of concern for climate change
LH - Low abatement cost and an above average level of concern for climate change
LL - Low abatement cost and a below average level of concern for climate change
AH - Average abatement cost and an above average level of concern for climate change
AL - Average abatement cost and a below average level of concern for climate change

We assume that one of the objectives of the negotiations is to reach as high a commitment level as possible for the involved countries. In the figure this translates into finding the highest point contained in the achievable set, which is shaded. We also note that the HH, LH, AH and AL curves do not determine what is achievable in the negotiations. The achievable solutions and the highest possible commitment level, represented by A, is determined by the LL and HL groups. Thus the countries of below average concern for climate change, and low or high abatement cost determine the achievable level of commitment in terms of a common emissions abatement target for the OECD group. From the figure we also see that the achievable target can be increased if the level of concern in the LL and/or HL groups is increased.

The point A also determines the ‘optimal mix’ of ‘cost sharing’ and ‘emissions reduction sharing’ in terms of an agreement or proposed burden sharing system. An important challenge during the negotiations will be to introduce flexibility with respect to this dimension in the process, such that a menu for choosing different levels and combinations of ‘cost sharing’ and ‘emission reduction sharing’ in one burden sharing system is developed. It would be most promising for the negotiations to move in the direction of an agreement type where concessions are given both to ‘cost sharing’ and ‘emissions reduction sharing’.

A general option to introduce flexibility is to favor differentiation among the OECD countries where different economic situations and national circumstances is accounted for. One way of doing this is to define burden sharing rules based on national circumstances.

However, there is a tradeoff in terms of adding complicating factors to the negotiations. One more option outside of the AGBM negotiations that could increase flexibility and the level of cost-effectiveness is Joint Implementation (JI) under the FCCC. There is, however, some uncertainty associated with JI since the mechanism is not yet operational.

Handling a mix of climate gases

A comprehensive approach
Stabilisation of the concentration of CO_2 at present levels requires large and immediate reductions in current anthropogenic emissions, in fact 50 to 70% (see the new IPCC second assessment report). However, there are several other gases that also lead to an enhancement of the greenhouse effect. These gases affect climate both directly and indirectly. Thus, a wider focus on greenhouse gases may increase the ability to reduce both the cost and the impact of man-made interference on the climate system. How this can be carried out in a burden sharing regime under the FCCC needs some consideration.

Article 3.3 of the FCCC states that in order to achieve a precautionary, cost-effective approach to climate change, policies and measures should "*….be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors.*" Thus, while comprehensiveness is established as a guiding principle for action under the Climate Convention there is no explanation of how the principle is to be understood and interpreted in practical terms.

There are at least two ways of interpreting the principle of a comprehensive approach. First, comprehensiveness may be interpreted as a way to regulate emissions of all greenhouse gases in separate agreements. This interpretation implies that emissions of specified GHGs could be regulated in separate protocols, negotiated sequentially. When all relevant gases were covered, the regime as a whole could be regarded as comprehensive. Secondly, the principle could be understood as an appeal to regulate emissions of *any* of the GHGs according to a common measure, *without specifying which gas.* This would give each party some freedom in the choice of which gases or set of gases to regulate in order to achieve a joint target. The latter interpretation is substantially more scientifically complex since it requires a method that allows for a comparison of changes in the emissions of different gases. This interpretation also permits the development of *individual paths to implement a common target.* Such a target may be formulated as a common percentage reduction. In the following, the second interpretation of the concept of a comprehensive approach is chosen.

Application of a comprehensive approach defined this way would allow the parties to the FCCC to minimise their costs by substituting one gas for another when reducing emissions. It also increases the possibilities for the countries to reduce their total contribution to the greenhouse effect and facilitate individual solutions that may enhance cost-effective strategies and solutions. Since the problem of man-made perturbations of the climate system is not only a CO_2 problem, the comprehensive approach introduces a potentially important flexibility in the process of developing solutions for the negotiations and implementation of an agreement.

Within the framework of such a regime, the joint target must be specified in some common measure. CO_2 equivalents using GWPs, radiative forcing or temperature change are variables that could be used in this context. Currently, calculation of 'CO_2 equivalents' based on GWPs is the most commonly applied method used by policy makers to compare emissions of different climate gases.

Climate change indices
Similar changes in concentrations of different GHGs have very different effects on the radiative balance of the atmosphere. This is mainly due to large variations in the efficiency of the absorption of long-wave radiation. In addition, equal emission reductions have very different effects on future climate change if different lifetimes are used. To implement an agreement which includes reductions of other GHGs than CO_2, a measure of the contribution to climate change from different gases is needed. The commonly adopted measure is the *global warming potential* (GWP) of a gas. This gives a crude measure of the greenhouse strength of a gas compared with that of CO_2.

GWP is a relative measure that expresses the globally averaged radiative forcing due to a given emission (in kilograms) of a species integrated over a chosen *time horizon* compared with a similar emission of a reference species (usually CO_2). Based on the GWPs, total emissions of GHGs can be interpreted as emissions in *CO_2 equivalents.* The CO_2 equivalent of a gas is equal to the product of the emissions of the gas (in kg) and its GWP value. GWPs are usually given for the instantaneous emission (pulse) of 1 kg of a gas over a time horizon of 20, 100 and 500 years. However, increased amounts of climate gases may lead not only to global warming but also to changes in other, and potentially more important, parts of the climate system. These may include changes in precipitation, soil moisture, frequency of hurricanes, ocean currents, etc., any one of which may have a strong regional influence. More sophisticated indices of climate change that incorporate regional differences and impacts on human welfare, have recently been proposed. As there are many uncertainties in the regional predictions of climate change from climate models and in the concepts of how to evaluate changes in human welfare, these indices are in the early stages of development. Research in this area is very important due to the well known shortcomings of the GWPs. Nevertheless, GWPs will probably be the primary tool for several years to come for incorporation of non-CO_2 gases in agreements.

Agreements including non-CO_2 gases
Adverse effects of climate change occur on a wide range of time scales. Plant growth reacts directly to the changes in temperature and precipitation, while there is a considerable time-lag in effects like melting ice-caps and heating of the ocean leading to a rise in sea level. For some of the damage effects, like extinction of species, a high *rate of change* could be more damaging than the maximum change at some time in the future. Therefore, an optimal agreement should focus on both the rate of change and the eventual magnitude of the changes. Climate gases have a wide range of lifetimes in the atmosphere, from about 10 years for methane to, for example, several thousand years for the stable perfluorocarbons. Reductions in emissions of short-lived gases will have greater influence on the rate of change, while reductions in the long-lived gases will primarily affect the maximum change. The choice of a time horizon in the evaluation of the GWP for each gas will determine the priority given to mitigation of a rapid climate change versus maximum climate change. We identify three possible approaches to this problem:

1. Emissions of *all* GHGs are weighted with GWPs calculated with the same time horizon.
2. Emissions of *each* GHG are weighted with GWPs calculated with a time horizon similar to their atmospheric lifetime. The time horizon for each gas is equal for all countries, and for baseline and future emissions.
3. Emissions of *each* GHG are weighted with GWPs calculated with a time horizon chosen by each country. The time horizon for each gas could be different for the countries, but must be equal for baseline and future emissions.

An agreement based on alternative 2 or 3 could increase the cost-effectiveness of a policy to reduce climate change, and would encourage reductions of gases with both short and long lifetimes by allowing the usage of GWP values for each gas with time horizons approximately equal to their atmospheric lifetime. However, it would make the negotiation process more complicated by adding the issue of choosing time horizons for each gas (alternative 2). For countries with significant potential for reductions of emissions of climate gases other than CO_2, alternative 2 or 3 could be significantly more cost-effective.

Three factors determine weather a GHG is a candidate to be included in such an agreement:

- The gas, for example CFCs and NO_x, must not be regulated by other international agreements.
- Scientifically sound estimates of the GWP values must exist.
- There must exist a reasonable database of the emissions, and a methodology to monitor the evolution of future emissions from each country.

The following gases could be included in an initial phase of the process towards a comprehensive approach. (It should be noted that this list includes gases that are greenhouse gases *by definition*, without consideration of variations in their potency as greenhouse gases or varying levels in current emissions):

- carbon dioxide (CO_2)
- methane (CH_4) (including indirect effects)
- nitrous oxide (N_2O)
- perfluorocarbons (CF_4, C_2F_6, C_3F_8, etc.)
- sulphur hexafluoride (SF_6)
- hydrofluorocarbons (HFC)
- other halocarbons not controlled by the Montreal agreement ($CHCl_3$, CH_2Cl_2, CF_3I)

Climate gases that are already regulated by international agreements (for example CFCs and NO_x) or lead to negative radiative forcing (for example SO_2) are also left out. However, NO_x emitted from *aircraft* may be included, in contrast to NO_x emitted from *surface* sources. NO_x emissions from surface sources have a dual role in the climate system as they lead to increased ozone concentrations (positive radiative forcing) and decreased methane concentrations (negative radiative forcing). Due to non-linear chemical effects, the influence is also dependent on the location of the sources. For NO_x emissions from aircraft the negative effect is probably very small compared to the warming effect and the forcing shows less variation along the east-west direction.

INTRODUCTION

Aim and scope of the study

Burden sharing among industrialized countries is a new, relatively unexplored research area. The objective of this study is to provide information to facilitate negotiations to strengthen commitments for countries belonging to the Organization for Economic Cooperation and Development (OECD) to reduce greenhouse gas emissions. The study reviews and analyzes the major issues that must be considered when defining the principles for the distribution of commitments. The study also explores the consequences of different types of agreements.

If we interpret a stable climate system as a collective good, then, in general terms burden sharing can be defined as the way in which a group of countries, benefiting from a collective good, agrees to share the costs of providing the collective good.[1,2]

The first Conference of the Parties to the UN Framework Convention on Climate Change (FCCC) was held in Berlin in March and April 1995. The Conference established an open-ended Ad Hoc Group on the Berlin Mandate (AGBM). The purpose of the AGBM is to develop a climate policy process that enables governments to take appropriate action for the period after year 2000. The goal of the AGBM negotiations is to end up with strengthened commitments for Annex I countries, specifically the OECD countries, to reduce their net emissions of greenhouse gases (GHGs) through the adoption of a protocol (or another legal instrument) by the third Conference of the Parties (COP) in 1997.[3] The text of the Berlin Mandate reads:

“The process will, *inter alia*: Aim, as the priority in the process of strengthening the commitments in Article 4.2(a) and (b) of the Convention, for developed country/other Parties included in Annex I, both to elaborate policies and measures, as well as to set quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010, and 2020, for their anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, taking into account the differences in starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as *the need for equitable and appropriate contributions* by each of these Parties to the global effort, and also the process of analysis and assessment referred to in section III, paragraph 4, below; Not introduce any new commitments for Parties not included in Annex I, but reaffirm existing commitments in Article 4.1 and continue to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4.3, 4.5 and 4.7; …”. (Our italics.)

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[1] There are natural variations in the climate system. The idea here is that to avoid significant costs related to climate change impacts on economic activities and ecosystems the anthropogenic component of future climate change should not exceed some level.

[2] A collective good is characterized by non-excludability, which means that it is impossible or uneconomic to exclude people (or countries) from enjoying the good in question.

[3] Annex I Parties to the FCCC are industrialized countries: the OECD (with the exception of Mexico, which was not member of the OECD when the FCCC was signed in Rio in 1992); and the European Union, formerly the European Economic Community, as a separate part; and Russia and countries in Central and Eastern Europe undergoing the process of transition to a market economy (including the Czech Republic and Hungary, which became members of the OECD after 1992).

According to the Climate Convention, Annex I countries are likely to be the first countries to accept legally binding commitments to curb greenhouse gas emissions.[4] It is likely that OECD countries must play a leading role in accepting new and more ambitious commitments to reduce GHG emissions. These commitments may imply substantial costs for OECD countries, although the costs are likely to vary significantly across countries.

Burden sharing is achieved when countries manage to negotiate a distribution of commitments and costs that all parties perceive as conforming to their concept(s) of fairness. Thus, burden sharing relates both to the process of distributing commitments, given the participants' concepts of fairness, and to the final result in terms of a specific distribution of the total cost between participating countries. This means that the final burden sharing is a specific distribution of the total abatement cost between participating countries which meet the negotiated emission reduction target. In this study we limit our attention to OECD countries. When the common emission reduction target for the OECD is adopted, a reduction of future, national climate change impacts will also be implicitly determined and, thereby, a distribution of benefits in terms of reduced climate change between countries.[5] Our main focus in this study is on the distribution of emissions reduction costs.

At the outset of this study we found that analyzing burden sharing among OECD countries is a rather new and under-explored research area. There are number of studies of burden sharing issues related to developing countries and aid from industrialized countries. However, our challenge is to analyze burden sharing among countries that are relatively similar with respect to development level and income per capita. Thus we have found it necessary to identify the issues that seem important in order to compare these countries and improve our understanding of questions pertaining to burden sharing among them. Studies and information of this type provide necessary background information for negotiations and are required by negotiators in actual negotiations. Such groundwork is also deemed crucial for the success of the AGBM negotiations for definition of an ambitious, common emissions reduction target as well as the actual commitments accepted by each country.

Three main issues pertaining to burden sharing are explored in this study. The first issue relates to the handling of a mix of climate gases. We discuss the issue of including climate gases other than carbon dioxide in the negotiations, and how this could be done. The set of gases included may have different implications for cost-effectiveness and burden sharing due to different national economic structures and energy systems.

The second issue explored in the study relates to how national burdens or costs could be measured and compared. We also discuss the relationship between cost definitions and national implications of different agreement types.

The third major issue explored here relates to relevant fairness principles, the merit of burden sharing rules based on national circumstances, and the understanding of the negotiation process and its possibilities. Obviously, many more issues pertaining to burden sharing should be explored to provide even more background information for the AGBM negotiations.

Burden sharing is a very complex concept that can be analyzed from many perspectives, using a number of methods. For the purpose of the AGBM negotiations our choice of methods is motivated by the list of crucial issues presented above. The AGBM process is analyzed from different perspectives using different methods and models. We assume that all OECD countries must eventually sign an agreement, but that the ambition level of the reduction target for these countries could be so low as to have no real effect on national

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[4] The FCCC also contains a list of Annex II Parties, which are OECD countries with the exception of Mexico, the Czech republic and Hungary, which became members of the OECD after 1992. Both Annex I and Annex II countries have obligations to reduce their emissions of climate gases. In addition Annex II countries have obligations to finance the additional cost of choosing a more environment-friendly development path in non-Annex I countries; that is, developing countries.

[5] Man-made emissions of climate gases determine the anthropogenic component of future climate change, so the emissions of other regions and countries also are relevant.

policies and emissions. If the welfare implications for one or more countries are considered unfair by a country, they would have the opportunity to refuse to sign the agreement. For these countries the objective would then be to forward an alternative agreement which lowers the common target and, thus, implies lower costs.
An agreement resulting from the AGBM negotiations could imply costly national commitments to reduce emissions of greenhouse gases.[6] For OECD countries to accept such an agreement we found it necessary to analyze how these four major concerns can be satisfied for all OECD countries:

- the common target must be at an acceptable ambition level (in terms of emissions abatement and total cost);
- the cost distribution and welfare implications for each OECD country depends on national circumstances and must be deemed fair by each country;
- the level of cost-effectiveness must be considered high enough; and
- the level of uncertainty with respect to the cost share of each country must not be too high.

To what extent a burden sharing alternative is considered fair and acceptable to countries will be influenced by the common target, the number and identity of countries participating, the choice of the coordinated policy option and implementation, welfare impacts (i.e. national costs), and the cost-effectiveness of the climate measures. Furthermore, acceptance depends on preferences for various ethical principles and burden sharing rules, willingness to pay for emissions reduction in various countries (which, among other things depends on expected climate change consequences for each country), and the level of development. The national cost-share and abatement cost curve depend on many factors including the national economic structure, the energy structure (the shares of different fuels), and the level of energy efficiency. In the AGBM negotiations, differences in national circumstances within Annex I countries have opened a discussion on differentiation and 'quantified emission limitation and reduction objectives' (QELROs), cf. FCCC and AGBM (1995). Countries are likely to be less willing to participate if they anticipate uncertainty and a relatively high probability of substantially higher costs to meet the future target.
There are many potential burden sharing alternatives which might be more or less acceptable to the participating countries. The realized burden sharing will influence the participation of countries and ambitions in terms of the agreed upon, common climate target. The climate target and institutional arrangements must be negotiated among the Parties to the Climate Convention. FCCC and AGBM (1995) lists some possible burden sharing or collective targets, including percentage reduction per year, percentage reduction by a certain year, cap on global emissions through action by Annex I Parties, and emission budgets for a certain period of time.
The conceivable types of agreements resulting from the AGBM negotiations can be divided into four main groups:

- uniform percentage emission reduction,
- emission reduction shares based on burden sharing rules,
- cost-shares based on equity rules, and
- coordination of policy measures.

This study analyzes agreement examples of all four types. Equal percentage reduction across countries for a target year compared to a base year belongs to the first type listed and serves as a base case. Agreements of this type are likely to distribute costs quite unevenly among countries.

[6] In the study we will also refer to *climate gases* instead of *greenhouse gases* since when we want to apply a wider focus including indirect effects and gases that affect solar radiation in addition to long-wave (terrestrial) radiation.

Referring to the second type listed, a realized burden sharing can be based on a specific burden sharing rule. It can be defined as a method that describes relevant parameters (such as Gross Domestic Product (GDP), population size, and national emission level of carbon dioxide) and the weighting method or formula that generates a specific share for each country to reduce their emissions by, for example, x tons of carbon dioxide.[7] As an example, a burden sharing rule could generate the share X_i for country i as a function of the common abatement target X, GDP, population, and emission level in country i. In addition, the base year for these data must be specified, together with a target year for achieving the emissions abatement.

For the third type listed, one possible equity rule is to make the abatement cost per capita or as a percentage of GDP equal across countries. However, this rule will be hampered by data problems since cost calculations are difficult within countries. This becomes even more demanding when more than one country is examined because it is difficult to make the calculations comparable across countries. The models employed in different countries may show considerable variation and, in addition, the calculations may be based on different assumptions.

Referring to the fourth and last agreement type listed, a reference situation for comparing different types of commitments and policy measures could be a uniform carbon tax within the participating group of countries. It may be argued that a fair distribution of commitments and costs of meeting these commitments should be based on the contribution to global warming and, accordingly, the emissions of greenhouse gases in each country. A uniform tax can be a domestic tax collected by the national governments or an international tax paid to an international agency. One potential problem with a uniform tax regime is the implicit assumption of equal willingness to pay for reduced emissions among the participants. The willingness to pay may vary considerably among countries according to the level of welfare and the expected impact of future climate change. Another example of such an agreements is to adopt minimum energy or carbon taxes, or agree on the removal of subsidies, for example subsidies on coal production.

The burden sharing implications of a tax regime can be compared to other climate policy alternatives, such as national emission constraints met by policy measures of each country's choice, Joint Implementation as defined by the FCCC, and tradable quotas. Combinations of these policy options are also possible. For example a national emissions constraint implemented through a national tax, or an emissions constraint for a group of countries implemented through tradable quotas. Thus, the level of coordination among OECD countries within the context of new commitments can vary from a common emissions target met through national commitments and national policy measures chosen by each country to a more cost-effective agreement on a uniform carbon tax across the participating Parties. In the 'Common Action' initiative by the OECD and the International Energy Agency (IEA) the intention is to assess policies and measures to reduce GHG emissions and explore different levels of coordinated climate policy within the OECD (OECD and IEA, 1995).

A substantial amount of literature exists on ethical principles and rules for the allocation of tradable emission quotas between companies or between countries.[8] There are many similarities between the issue of allocating tradable emission quotas and the issue of emission reduction commitments, the main issue of the AGBM negotiations. If the negotiations should result with an agreement containing elements of emission allowances or entitlements, these may be interpreted as non-tradable emission quotas. For both non-tradable and tradable quotas the initial allocation of quotas will influence the final allocation of net costs among companies or welfare impacts among countries, unless the quotas are allocated through an

[7] Greenhouse gases other than carbon dioxide could be included in national emissions. With the help of Global Warming Potentials (GWPs) for a chosen time-horizon these gases could be expressed in units of carbon dioxide equivalents.

[8] See, for example, Barrett (1992) and Bohm and Larsen (1994).

auction. An auction transfers income to the regulating authority, whereas the initial allocation of quotas directly transfers resources to companies or countries.
In principle, cost-effectiveness and a specific burden sharing alternative can be met independently of each other. Cost-effectiveness means that the common target is met in the least expensive way. If feasible, for political and other reasons the optimal solution would be to distribute abatement activities between countries so as to undertake the cheapest options and minimize the cost, and then distribute the cost-shares among countries according to a fairness principle. However, such a procedure is not feasible for political and other reasons, and we are left with agreements that, by necessity, are considered fair for all participating countries, but that are not likely to be cost-effective at the international level.[9]

Report structure

The study is divided into three main parts, where the first part is based on natural science, the second part based on economics, and the third part based on political science and a synthesis of all previous chapters.
Chapters 2 and 3 discuss the introduction in the negotiations of climate gases in addition to carbon dioxide, and how the effect of different gases on the climate can be compared. The choice of method for comparing the climate effect of different long-lived and well-mixed climate gases will influence the cost-effective choice of policy measures. It will also have implications for the distribution of costs and benefits between generations. Consequently, the use of Global Warming Potentials (GWPs) or other tools, and the choice of a time horizon become important issues in the discussion. In chapter 3 some gases with indirect climate effects are considered for inclusion in climate policy negotiations. Some of these gases have a potential regional climate effect. If they are included in the calculations, this may influence the choice of cost-effective policy measures. On the other hand however, they may introduce a complicating element into the negotiations.
In chapter 4 we discuss the definition and measurement of emission reduction costs, and compare these costs across countries. A brief survey of cost studies is given. In chapter 5 we analyze policy measures intended to reduce greenhouse gas emissions within OECD countries, and we discuss the importance of the degree of coordination and the way measures are implemented. An economic model is presented for the purpose of comparing implications of different agreements within the OECD with respect to welfare changes, with emphasis on fossil fuel markets and terms of trade effects. An agreement which specifies minimum fossil fuel taxes is used as the starting point for the analysis. The long-term perspective of climate policy makes burden sharing over generations and intergenerational equity relevant. This is the topic of chapter 6.
The third and final part of the study analyzes the AGBM negotiations from the perspective of international policy. Chapter 7 discusses the anatomy of the negotiations and proceeds to a survey of relevant ethical principles. Three specific burden sharing rules are given as illustrations and used to analyze the effects for different countries with respect to national commitments generated as share of the OECD total emission abatement target. Furthermore, they are used to analyze the effects as emission abatement as percentage of national emissions, and as change in welfare from the model presented in chapter 5. The sensitivity of these results, following the weighting of components in the rules, is analyzed in several cases.
Finally, in chapter 8, a synthesis of previous chapters is developed by comparing national circumstances in different countries, identifying groups of countries that have similar interests in the negotiations, analyzing characteristics of the achievable set of the negotiations, and how this set could be identified and possibly expanded.

[9] Which means that the marginal abatement cost differs from country to country. The emissions abatement at the national level can still be cost-effective if costs are minimized at the national level.

Well-mixed climate gases

Summary

The Climate Convention recommends a comprehensive approach to minimize the effects of climate change. A first step in this process, which could increase cost-effectiveness and reduce the costs for some countries, is to include not only carbon dioxide but also other well-mixed gases in a protocol. Greenhouse gases with lifetimes longer than about two years are well mixed globally. Thus, the effect of gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), the chlorofluorocarbons (CFCs), the hydrofluorocarbons (HFCs), SF_6, CF_4 and C_2F_6, is independent of the location of the sources. As a measure of their relative strenght Global Warming Potentials (GWPs) have been developed to compare emissions of well-mixed greenhouse gases. Although the concept of GWPs has several well known shortcomings, it will most probably continue to be the basic tool for policy makers for several years. An important parameter in the calculation of GWPs is the choice of a time horizon. The choice of time horizon will probably be a central part of the negotiations of a protocol to the Climate Convention which includes non-CO_2 gases. Since each country has different possibilities to reduce emissions of GHGs with different lifetimes, the choice of time horizon will also affect the burden sharing and the cost effectiveness of reduction policies. Climate changes, and their impact on our natural environment, occur on different timescales. The choice of a short time horizon (for example 20 years) will favor reductions of shorte-lived gases such as methane, and will in general cause a slower rate of change of climate. As the expected impacts of climate changes will influence each country differently, the choice of time horizon could also affect their willingness to reduce emissions. Three possible approaches to an agreement which includes CO_2 and other well mixed greenhouse gases than are discussed, including possible agreements which allow different time horizons for different gases depending on their atmospheric lifetime.

Introduction

Stabilisation of the concentration of CO_2 at present levels requires very large (50-70%) and immediate reductions in current anthropogenic emissions (IPCC, 1995b). There are however, several other gases that also lead to an enhancement of the greenhouse effect. These gases affect climate both directly and indirectly. Thus, a wider focus on greenhouse gases may increase the possibility of reducing the man-made interference with the climate system. It may also make the reduction process more cost-effective. How this can be carried out in a burden sharing regime under the FCCC needs some consideration.

Article 3.3 of the FCCC states that in order to achieve a precautionary, cost-effective approach to climate change, policies and measures should "*….be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors.*" Thus, while comprehensiveness is established as a guiding principle for action under the Climate Convention, there is no explanation of how the principle is to be understood and interpreted in practical terms.

As pointed out by Fuglestvedt and Skodvin (1996), there are at least two ways of interpreting the principle of the comprehensive approach. First, comprehensiveness may be interpreted that spparate agreements can be used to regulate emissions of each greenhouse gas. This interpretation would imply that emissions of specified greenhouse gases could be regulated in separate protocols, negotiated sequentially. When all relevant gases were covered, the regime as a whole could be regarded as comprehensive. The principle could, however, also be understood as an appeal to regulate emissions of *any* of the GHGs according to a common measure, *without specifying each gas individually.* This would give each country some freedom with respect to which gas or set of gases they choose to regulate in order to achieve a joint target. The latter interpretation is substantially more scientifically complex since it requires a method that allows for a comparison of changes in the emissions of different gases. This interpretation also permits the development of *individual paths to implement a common target* that may be formulated as a common percentage reduction. This interpretation is used in this discussion.

Application of a comprehensive approach defined this way would allow the Parties to the FCCC to minimize their costs by substituting one gas for another when reducing emissions. It also increases the ways in which countries can reduce their total contribution to the enhanced greenhouse effect and facilitate individual solutions that may enhance cost-effective strategies and solutions. Since the problem of man-made perturbations of the climate system is not only a CO_2 problem (cf. Table 2.1 and section 3.1), the comprehensive approach introduces a potentially important flexibility in the process of developing solutions to the negotiations and implementation of an agreement.

Within the framework of such a regime, the joint target must be specified in some common measure. CO_2 equivalents by the use of GWPs, radiative forcing, or temperature change are variables that could be used in this context. Currently, calculation of "CO_2 equivalents" based on GWPs (cf. section 2.4) is the most common method for policymakers to make a comparison of emissions, as more sophisticated methods are not yet available (cf. section 2.5).

The environmental problem areas of acidification, local pollution causing health effects, ozone depletion and climate change - that is, environmental problems associated with anthropogenic emissions into the atmosphere - are closely linked in the sense that the same substances may contribute to several problems. SO_2 and NOx, for example, are primarily associated with the acidification, but they also have potentially significant effects on the climate system (cf. Chapter 3). CFCs and HCFCs, identified as major ozone-depleting substances, also play a significant role as greenhouse gases. HFCs, the major substitute to ozone depleting substances, are also identified as greenhouse gases. Taking the complex web of interrelationships into account, some have suggested that the most appropriate way to handle these problems is to handle them simultaneously in a "Law of the Atmosphere"-treaty that would be analogous to the 1982 Law of the Sea Convention (i.e. the 1988 Toronto Conference). It is argued that only by regulating these gases simultaneously can adverse effects resulting from the regulations themselves be avoided. In 1992, with the adoption of the FCCC, a “Law of the Atmosphere” approach was abandoned in favor of a sequential framework convention and protocol approach, where comprehensiveness is an important principle.

In this report the term *greenhouse gases* (GHGs) refers to gases that affect climate by absorption and re-emissions of terrestrial longwave radiation. The term *climate gases* includes gases that affect solar shortwave radiation (e.g. ozone) in addition to the longwave active gases. In this chapter the concept of *global warming potential* as a measure of the individual gases’ contribution to climate change is discussed. The choice of *time horizon* in the evaluation of the GWP values, and its implications for burden sharing, is discussed.

The greenhouse effect

The Earth receives energy in the form of shortwave electromagnetic radiation (mainly visible light) from the Sun. About 30% of the energy is reflected back to space from the surface and from air molecules in the atmosphere without affecting atmospheric temperatures. The remaining 70% is absorbed by the atmosphere (25%) and by the Earth’s surface (45%), thus heating the Earth/atmosphere system. The much lower temperatures found at the Earth’s surface and the atmosphere (compared with the Sun), implies that the Earth/atmosphere system emits radiation at longer wavelengths than it receives. Averaged over the whole globe and over a year there must be a close balance between the energy of the outgoing longwave radiation and the incoming solar radiation.

Greenhouse gases and clouds have the important property that they efficiently absorb longwave radiation. This means that a significant fraction of the energy emitted from the ground as longwave radiation is absorbed by the atmosphere and subsequently re-emitted in equal amounts in all directions. The surface of the Earth thus receives large amounts of energy in the form of of longwave radiation from the atmosphere. This recycling is called *the greenhouse effect*, and is so efficient that of the total amount of radiative energy reaching the Earth’s surface about two thirds is longwave radiation from its own atmosphere and only one

Table 2.1. Contributions to radiative forcing since pre-industrial times (IPCC, 1994a, 1995b).

Gas	**Radiative forcing from changes since pre-industrial times** (W/m^2)
CO_2	1.56
CH_4	0.47
N_2O	0.14
CFC-11 (CCl_3F)	0.06
CFC-12 (CCl_2F_2)	0.14
Other gases (mainly CCl_4, HCFC-22 and CFC-113)	0.08
Total	**2.45**

third is shortwave solar radiation. The naturally occuring greenhouse effect causes the averaged global surface temperature (at present about +15°C) to be about 33°C higher than it otherwise would have been.

The major natural greenhouse gases are water vapor and carbon dioxide (CO_2), with smaller contributions from methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Clouds also absorb longwave radiation efficiently and, thus, contribute to the natural greenhouse effect. Increased emissions from anthropogenic activity have lead to enhanced concentrations of many climate gases. Table 2.1 shows the contribution of the various climate gases to the enhanced greenhouse effect since pre-industrial times.

The heating of the surface is further enhanced through geophysical and biogeochemical feedback effects. A positive feedback effect enhances the initial temperature increase, while a negative feedback effect reduces the initial warming. The positive feedback effects are dominating (mainly through: increased temperature $\Rightarrow$ increased concentrations of water vapor $\Rightarrow$ increased greenhouse effect $\Rightarrow$ increased temperatures), and lead to more than a doubling of the estimated warming following an increase in the concentrations of greenhouse gases. Another positive feedback mechanism is through reductions in the snow and ice cover which increase the absorbtion of solar radiation at the surface, thus increasing the heating. There will most likely be significant feedbacks through changes in clouds. However, since clouds both contribute to surface cooling by reflecting shortwave radiation and to heating through their greenhouse effect, and since not all the microphysical processes that goveren the formation of clouds are fully understood, the magnitude and even the direction (positive/negative) of this feedback is uncertain.

Climate gases

Atmospheric lifetime and mixing

Components emitted into the atmosphere are eventually removed by chemical or physical processes in the atmosphere or by deposition at the ground or to the oceans. The impact of increased emissions of climate gases is very dependent on the removal time, or lifetime, of the component. The lifetime is defined as the time it takes to remove 63% of the gas (that is, reduce the concentration to 1/e of the initial concentration), given that there are no further emissions. The lifetime of a gas determines the extent of mixing in the atmosphere. As zonal winds are strong in the atmosphere, gases with lifetimes longer than about a week will be well-mixed zonally. Gases with lifetimes of a few months will be well mixed within the hemisphere where the source is located, while interhemispheric mixing requires lifetimes of two years or more. The lifetimes of the most important climate gases are given in Table 2.2. The lifetime of CO_2 is defined somewhat differently, as there are large natural sources and sinks which balance each other. The lifetime refers to the *removal time* of excess CO_2 from sources that are not part of the more rapid, but balanced, natural cycle (for example from fossile fuels). The estimated lifetime for CO_2 assumes that the natural sources are constant.

The lifetime also determines how fast the atmospheric concentration of a gas responds to changes in emission rates (cf. Section 2.6).

Direct versus indirect climate gases

Gases that are *emitted* to the atmosphere (hereafter called source gases) may influence the radiative balance directly due to their radiative properties. Source gases may also cause radiative forcing indirectly by changing the concentrations of other gases. The climatically relevant source gases may therefore be divided into three categories. First, there are the gases that have a *direct* impact on climate due to their own radiative properties. Second, there are emissions of gases which have little or no direct effect on climate, but do have an indirect effect through impacts on chemical processes in the atmosphere. The concentrations of compounds interacting with shortwave and/or longwave radiation may thus be changed. The third category includes the source gases that have the ability to affect climate both directly and indirectly. Table 2.2 shows examples of important source gases with direct and/or indirect impacts on climate.

Table 2.2 Overview of source gases with direct and/or indirect effects on climate, and their atmospheric lifetime (IPCC,1995b)

Emission of	Lifetime	Direct effects **	Indirect effects
Carbon dioxide (CO_2)	50-200 yr *	X	
Hydrofluorocarbons (HCF)	2-250 yr	X	
Perfluoromethane (CF_4)	50000 yr	X	
Nitrous oxide (N_2O)	120 yr	X	X
Methane (CH_4)	12 yr	X	X
Chlorofluorocarbons (CFC)	50-1700 yr	X	X
Hydrochlorofluorocarbons (HCFC)	1.5-20 yr	X	X
Nitrogen oxides (NOx = NO + NO_2)	12 h - 2 days		X
Non-methane hydrocarbons (NMHC)	1 h - 3 months		X
Carbon monoxide (CO)	3 months		X

*) No single lifetime for CO_2 can be defined, because of the different rates of uptake by the different sub-processes.

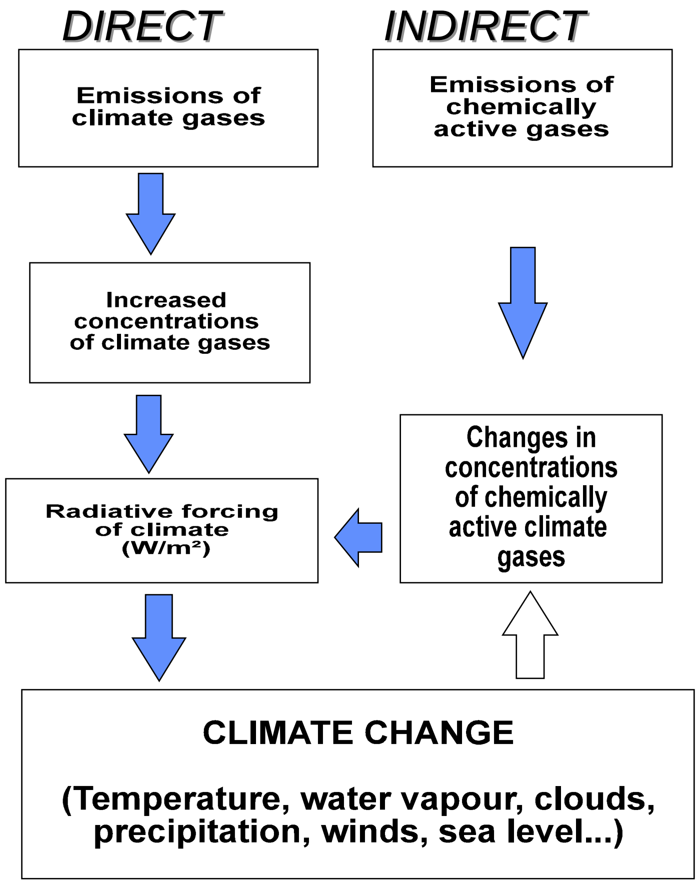
**) CO_2 and other gases marked only under "direct effects" do not affect the levels of other climate gases through chemical reactions in the atmosphere. They may, however, affect climate gases and aerosols through effects on atmospheric temperatures and humidity.

Figure 2.1 shows the principles for direct and indirect effects of emissions on climate, as well as climate feedbacks through atmospheric chemistry. In this report we will focus on the indirect chemical effects marked by the filled-arrow pathway in Figure 2.1. In chapter 3 we discuss the indirect effects of emissions of nitrogen oxides (NOx) through influence on concentrations of tropospheric ozone (O_3) and methane (CH_4).

In addition to the effects of atmospheric chemistry on climate, the chemical processes in the atmosphere will be affected by changes in climate (open arrow in Figure 2.1). Climate change may affect chemistry through several mechanisms. For instance, changes in temperatures, water vapor levels, or clouds may have significant effects on atmospheric chemistry.

Climate change will also influence atmospheric composition through impacts on source strengths of several gases. For instance, important sources of CH_4 are sensitive to temperature, soil moisture and the level of the water table. These mechanisms work through changes in factors external to the atmospheric chemistry system and are not addressed here. These secondary effects through impacts of climate changes on the biosphere are quite uncertain as they depend on local climate change through non-linear relations in the atmospheric chemistry and in sources of climate gases. The uncertainty arises due to uncertainty in local climate predictions and due to an incomplete understanding of the processes governing atmospheric

Figure 2.1 The principles for direct effects, indirect effects and climate feedbacks through atmospheric chemistry. The filled arrows show processes that are taken into consideration in this report.



chemistry and the source strength of climate gases. Therefore, in this report we will restrict the discussion to indirect chemical effects (Chapter 3).

Indirect effects on climate are called *positive* if they result in a positive radiative forcing (warming) of climate. Correspondingly, they are termed *negative* if they lead to a negative forcing (cooling).

Emissions and trends of climatically relevant gases

Carbon dioxide (CO_2)

The pre-industrial level of CO_2 in the atmosphere was about 280 ppmv, while the present level is approximately 360 ppmv; an increase of 30%. The present rate of increase is 0.4%

Table 2.3 Global carbon budget for the period 1980-1989 (IPCC, 1995b).

CO_2 sources		GtC/yr *
(a)	Emissions from fossil fuel and cement production	5.5 ± 0.5
(b)	Net emissions from changes in tropical land use	1.6 ± 1.0
(c)	Total anthropogenic emissions (a + b)	7.1 ± 1.1
Partitioning among reservoirs:		
(d)	Storage in the atmosphere	3.3 ± 0.2
(e)	Ocean uptake	2.0 ± 0.8
(f)	Uptake by Northern Hemisphere re-growth	0.5 ± 0.5
(g)	Added terrestrial sinks (CO_2 fertilisation, nitrogen fertilisation, climate effects) {a + b - (d + e + f)}	1.3 ± 1.5

*) The numbers are given in gigatonnes of carbon per year (1 GtC = 1 PgC/yr = 3.7 Gt CO_2).

per year (IPCC, 1995b). This increase can be attributed to man-made emissions, mainly caused by the use of fossil fuels and deforestation. Table 2.3 shows the emissions of CO_2 from anthropogenic sources in the 1980s and the fate of these emissions.

The total annual anthropogenic CO_2 emissions are small compared to the natural emissions of CO_2 from the ocean and the biosphere (3-4%). However, these emissions are approximately balanced by a uptake of the same magnitude. This is not the case for the man-made CO_2 emissions which constitute a one-way flux of carbon. Over time, this leads to an accumulation of CO_2 in the atmosphere, as is observed since pre-industrial times.

Methane (CH_4)

Typical pre-industrial levels of methane in the atmosphere were approximately 700 ppbv, while the present levels are 145% higher, i.e. 1720 ppbv. Currently methane concentrations increase by about 0.7% per year. The increase since pre-industrial times is due primarily to emission from man-made sources. Studies indicate that the lifetime of methane in the atmosphere has increased slightly since pre-industrial times, making a small, but significant, contribution to the enhanced levels.

About two thirds of the total global emissions of methane are of anthropogenic origin. The emissions related to production and use of fossil fuels are approximately 20% of the total. Among the fossil sources, natural gas and coal mines are responsible for the largest fractions. As shown in Table 2.4., important non-fossil sources related to anthropogenic activities are enteric fermentation, rice paddies, biomass burning, and waste.

Table 2.4 Estimated sources of methane, Tg*(CH_4)/yr (IPCC, 1994a).

Identified sources	Individual estimate	Total
Natural		
Wetlands	115 (55-150)	
Termites	20 (10-50)	
Oceans	10 (5-50)	
Other	15 (10-40)	
Total identified natural sources		160 (110-210)
Anthropogenic		
Total fossil-fuel related		100 (70-120)
Natural gas	40 (25-50)	
Coal mines	30 (15-45)	
Petroleum industry	15 (5-30)	
Coal combustion	? (1-30)	
Biospheric sources		
Enteric fermentation	85 (65-100)	
Rice paddies	60 (20-100)	
Biomass burning	40 (20-80)	
Landfills	40 (20-70)	
Animal waste	25 (20-30)	
Domestic sewage	25 (15-80)	
Total biospheric		275 (200-350)
Total identified anthropogenic sources		375 (300-450)
TOTAL IDENTIFIED SOURCES		535 (410-660)

* Tg/yr = 10^{12} g per year

Nitrous oxide N_2O

The levels of N_2O have increased by about 15% since pre-industrial times, most likely due to human activities. Presently, concentrations increase by about 0.25% per year and the level is now about 310 ppbv. The global emissions of N_2O are distributed among a relatively large number of small sources where no single sources dominate. The global anthropogenic emission is 3-8 Tg(N)/yr and the natural sources are probably twice as large. The most important man-made source is cultivated soils.

Global warming potentials

Similar changes in concentrations of different GHGs (for example an increase in CO_2 and methane by 1 ppmv each), have very different effects on the radiative balance of the atmosphere. This is mainly due to large variations in the efficiency of absorption of longwave radiation. Perturbations of gases that absorb radiation at wavelenghts which are not absorbed by other gases and which are not already present in significant amounts themselves, generally make the strongest contributions.

To implement an agreement which includes reductions of other GHGs as well as CO_2, a measure of the contribution to climate change from different gases is needed. The most commonly applied measure is the *global warming potential* (GWP) of a gas, which gives a crude measure of the greenhouse strength of a gas compared with that of CO_2.

Table 2.5 Estimated sources of N_2O, Tg (N) per year. (WMO, 1995).

A. Natural	Oceans	1.4-5.2
	Tropical Soils	
	Wet forests	2.2-3.7
	Dry savannas	0.5-2.0
	Temperate Soils	
	Forests	0.05-2.0
	Grasslands	?
B. Anthropogenic	Cultivated Soils	1-3
	Animal Waste	0.2-0.5
	Biomass Burning	0.2-1.0
	Stationary Combustion	0.1-0.3
	Mobile Sources	0.1-0.6
	Adipic Acid Production	0.4-0.6
	Nitric Acid Production	0.1-0.3

The strength of the contribution to the greenhouse effect of a given perturbation of the atmospheric composition is commonly expressed in terms of *radiative forcing*. In IPCC (1992) radiative forcing due to a perturbation of a species is defined as "*the net radiative flux changes at the tropopause, keeping the concentrations of all other species constant*". The tropopause is the altitude region between the troposphere (region of decreasing temperature with height) and stratosphere (region of increasing temperature with height), usually found between 10 and 15 km altitude. The natural greenhouse effect gives a radiative forcing of about 150 W/m^2, while the commonly used "benchmark" test -doubling of CO_2 concentrations ($2xCO_2$)- gives a radiative forcing of about 4 W/m^2. The $2xCO_2$ test has been used extensively in climate models and generally leads to a calculated increase in the global annual mean surface temperature of 1.5-4.5°C at equlibrium.

The GWP is a useful tool for policy makers because it enables them to easily compare the relative effects of different climate gases. GWP is a relative measure that express the globally-averaged radiative forcing due to a given emission (in kilograms) of a species integrated over a *time horizon* compared with a similar emission of a reference species (usually CO_2). Based on the GWPs, total emissions of GHGs can be interpreted as emissions *CO_2 equivalents.* The CO_2 equivalent of a gas is equal to the product of the emissions of the gas (in kg) and its GWP value. GWPs are usually given for an instantanous emission (pulse) of 1 kg of a gas over a time horizon of 20, 100 and 500 years. However, for some species with short to intermediate lifetimes, and/or with indirect non-linear chemical responses (such as methane and $NO_{x,}$ see chapter 3), it might be more appropriate to use sustained emissions with a given rate of emissions for both the gas and the reference species (Fuglestvedt et al., 1996a). Since a policy to reduce GHG emissions will aim at sustained reductions of the emissions from various sources, the concept of sustained GWPs (SGWPs) is more logical than pulsed GWPs. However, as the introduction of SGWPs raise scientific questions which need to be thoroughly investigated by the scientific community through the IPCC. As a result, pulsed GWPs will still be the basis for the current negotiations.

Pulsed GWPs (hereafter just GWPs) are calculated by equation 1:

$$GWP(x) = \frac{\int_0^{TH} a_x \cdot [x(t)]dt}{\int_0^{TH} a_r \cdot [r(t)]dt} \tag{1}$$

where TH is the time horizon over which the calculation is considered, a_x is the radiative forcing for a unit increase in the atmospheric concentration of gas x, *x(t)* is the time-decaying abundance of a pulse of injected gas, and the denominator is the corresponding quantities for the reference gas (CO_2). GWP values for the most important greenhouse gases are given in Table 2.6. The time development of CO_2 (*r(t)*) is based on a carbon-cycle model (IPCC, 1995b) which gives a decline in excess CO_2 concentrations corresponding to a lifetime of CO_2 of the order of 150 years. The GWP value of gases with shorter lifetimes than this decreases with increasing time horizon (for example methane), while for extremely long-lived gases (like SF_6, CF_4 and C_2F_6) the GWP value increases with increasing time horizon.

GWPs are suited for comparing the climate effect of emissions of well-mixed gases (i.e. with a lifetime of more than about two years), with absorption spectra that do not significantly overlap with absorption due to other species. Calculation of GWPs requires knowledge of radiative forcing, per unit mass or concentration, atmospheric lifetime of both the specific species and the reference gas, chemical degradation processes, present and future chemical composition of the atmosphere, and present and future physical states (tempertures, water vapor, cloud properties, etc.).

For gases with lifetimes shorter than about 2 years, the GWP concept is not well suited. They can often exhibit strong regional and seasonal variations in the concentrations and, thus, also in radiative forcing. The motions in the atmosphere are driven by pressure gradients due to differences in air temperatures, and modulated by the rotation of the Earth. For shorter lived gases, the regional differences in forcing can change the temperature pattern, and thus influence the weather patterns (for example the way low pressure systems move at mid-latitudes or how monsoon circulations in the tropics behave). The impact on climate and, in particular, on regional changes can be pronounced, even if the globally and annually averaged forcing (and thus the GWP value) is small.

Regional changes and climate-change indecies

To fully assess the burden imposed on society by changes in climate gases, more detailed knowledge than just how the globally averaged temperatures might change is needed. Information on how averages of climate variables like temperatures, precipitation, wind speed, sea levels, etc., change locally, is needed. In addition, knowledge about how frequencies of extreme events like hurricanes, droughts, flooding, etc., is also important. If all these factors were known it would be possible to feed them into models which simulate the biological activity and to estimate how factors like net primary production and thus the potential for agriculture, would change on a regional basis.

Unfortunately, state-of-the-art climate models are not able to provide these kind of data with sufficient reliability. The differences between the models with respect to predictions of regional changes are still significant and, at present, they do not incorporate biospheric modules which are necessary to be able to simulate possible feedback effects through changes in biological activity. For example, if climate change led to a significant increase of moisture in arid regions, increased growth would store significant amounts of carbon, thus slowing the increase in the greenhouse effect. However, even if the exact pattern is not known, there is sufficient knowledge about the climate system to say that there will be significant regional differences in climate change, both from the well-mixed GHGs and, in particular, from regional differences in the altered concentrations of short lived substances affecting climate (such as ozone and sulphate aerosols). Due to this, and to differences in vulnerability to climate change, there will be large differences between regions and nations in costs caused by damages of climate change. Nevertheless, there have been some attempts

Table 2.6 Updated GWP-values from IPCC (1995b)

Species	Global Warming Potential (GWP) (Time Horizon)		
	20 years	100 years	500 years
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)*	56	21	6.5
Nitrous oxide (N_2O)	280	310	170
HFC-134a	3400	1300	420
HFC-152a	460	140	42
Sulphur hexafluoride (SF_6)	16300	23900	34900
Perfluoromethane (CF_4)	4400	6500	10000
Perfluoroethane (C_2F_6)	6200	9200	14000

* Include indirect effects through formation of ozone and stratospheric water vapor.

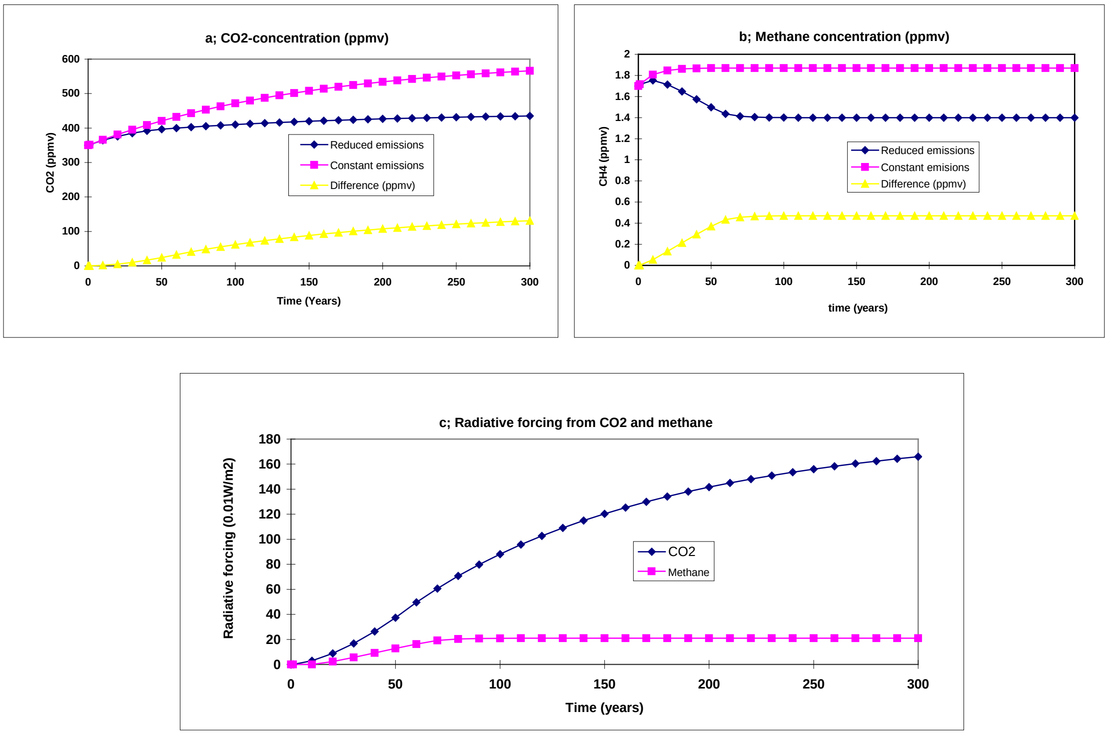
recently to develop new welfare-based indexes which incorporate a damage function and discount rates (e.g Hammit et al., 1996).

The imperfection of the model predictions with respect to regional changes is likely to be significant for at least another decade and this has several implications. First, GWPs will probably still be the most applied measure of the relative impact of each greenhouse gas. Secondly, it is not yet possible to reliably identify regions or nations which will benefit from climate change and which regions will be most adversivly affected. However, knowledge of potential 'winners' and 'loosers' would probably make it even harder to obtain international agreements on GHG abatements, as nations which would most likely benefit from climate change would be less interested in costly reductions of GHG emissions.

Policy measures on climate gases with different lifetimes

Climate gases have a wide range of atmospheric lifetimes (cf. Table 2.6). This has two major implications for the choice of a strategy aimed at reducing climate change. First, the lifetime is the primary factor in determining how extensive reductions of the emissions of a particular gas must be in order to stabilize atmospheric concentrations. Gases, such as methane, with shorter lifetimes (about 10 years) generally need smaller emission reductions than gases with longer lifetimes. For methane IPCC (1995b) estimates that an 8% reduction in the anthropogenic emissions will stabilize the concentrations at present levels. However, for excess carbon dioxide, which has a lifetime on the order of 150 years, an immediate reduction of 50-70% in the anthropogenic emissions is needed to stabilize concentrations.

Figure 2.2 Time development of CO_2 (a) and methane (b) concentrations in a simplified model for two scenarios: Constant "present day" emissions and a 25% emission reduction over 60 years. Radiative forcing due to the changes in the two gases for the two scenarios is shown in 2.2c.



Secondly, the differences in lifetimes have a large impact on when the effect of the emission reductions will have a significant impact on concentrations and thereby on climate. This is illustrated in Figure 2.2 for CO_2 and methane. Future concentrations are calculated based on two simplified scenarios to demonstrate the effect of different lifetimes: a 'constant emission' scenario with constant emissions rates, and a 'reduced emission' scenario, in which the emissions are assumed to be reduced by 0.5% per year for 60 years (total reduction 25%), and then kept constant. The lifetime of each gas is assumed to be constant throughout the period; 150 years for CO_2 and 10 years for methane. The initial concentrations are set to 350 ppmv of CO_2 and 1.7 ppmv of methane as in the present atmosphere. This simplified approach means that the calculated changes in concentrations are just for illustrative purposes.

Figure 2.2c shows the radiative forcing due to the difference between the concentrations in the two scenarios for CO_2 and methane. During the first decades the radiative forcing is of similar magnitude for both gases, while after about 70 years the forcing from methane levels off, and the forcing from the CO_2 increase becomes dominant. Strategies or agreements that primarily lead to reductions of emissions of climate gases with short lifetimes will thus give slower increase in the forcing during the intial years. Strategies that focus on reductions of emissions of long-lived climate gases will reduce the maximum change on a century timescale.

When considering the impact of climate change both aspects are important. The Earth's climate has changed significantly since prehistoric times. The predicted *rate* of change during the next centuries, however, is much higher than what has been observed since the end of the last glacial period about 10.000 years ago. The ability of natural environments to adapt to the changes is very dependent on how rapidly the changes take place. If the changes, and thus the transition of climate zones, take place more rapidly than plants are able to grow and re-establish, destruction of particular natural environments might occur and, as a result, extinction of species. Therefore, the cost of the impact of climate change might depend not just on the actual level, but also on the rate of change (Peck and Teisberg, 1994).

However, it is also important to limit the maximum change. With respect to changes in sea level, for example, the delay due to slow penetration of heat to the deeper waters makes the total change more important than the rate of change during the initial stages. In addition, species that are trapped (for instance on islands or in mountainous areas) and not able to migrate poleward or to higher latitudes as the climate becomes warmer, will be threatened by extinction if the total change becomes too large.

Implications for burden sharing and cost-effectiveness

Based on these considerations it can be concluded that an agreement that leads to reductions in emissions of both short-lived and long-lived climate gases can contribute more to the final goal of avoiding harmful effects of climate change, than an agreement for CO_2 only . The broader agreement would then put a limit on total emissions of GHGs weighted by their GWP values (i.e. using CO_2 equivalents). The question of giving weight to short-term or long-term changes will be determined by the choice of time horizon for the GWP values. Different countries will probably have different opinions on which time horizon is the most appropriate. Differences in opinion reflect differences in vulnerability to and concern for different aspects of climate change (short-term vs. long-term) and to differences in the potential for emission reductions of the different GHGs (cf. section 8.3). The choice of a time horizon will also significantly affect the distribution of costs among the countries, as the potential for reductions of gases with short or long lifetimes is very different from country to country (cf. section 4.1).

One of the basic questions is then: How should the CO_2 equivalents be calculated?

From the analysis above three different approaches can be identified:

1. Emissions of *all* GHGs are weighted with GWPs calculated with the same time horizon.

2. Emissions of *each* GHG are weighted with GWPs calculated with a time horizon similar to their atmospheric lifetime. The time horizon for each gas is equal for all countries and for baseline and future emissions.

3. Emissions of *each* GHG are weighted with GWPs calculated with a time horizon choosen by each country. The time horizon for each gas could be different for each country, but must be equal for baseline and future emissions.

The first alternative is probably the simplest both scientifically and for the negotiations. Scentifically because CO_2 is the most important GHG, and if a single time horizon is to be chosen, it should be similar to the atmospheric lifetime of this gas. In the negotiations there would simply be a factor less to negotiate. The disadvantages are that mitigation of climate change impacts that occur on different timescales is neglected, and that the total cost of achieving a given emissions reduction of GHGs, in terms of CO_2 equivalents, could be higher than for the other alternatives. In countries where the abatement cost is high, but with significant potential for reductions of other GHGs, the costs would be lower than in a CO_2 only agreement, but higher than for alternative 2.

Alternative 2 is a simple way to encourage reductions of gases with both short and long lifetimes by allowing the use of GWP values for each gas with a time horizon approximately equal to their atmospheric lifetime. Determination of appropriate time horizons for each gas should be left to the scientific community (for example the IPCC), otherwise it would easily become a matter of political controversy. Presently, GWPs are calculated with time horizons of 20, 100 and 500 years (cf. Table 2.6). Using a time horizon of 20 years for methane, instead of 100 years which is the most likely time horizon if one had to choose only one, would increase the weight of methane emissions by 160%. Countries with high emissions of methane will therefore be encouraged to reduce emissions of this greenhouse gas. Likewise, countries (like Norway) with high emissions of gases with long lifetimes (such as SF_6, CF_4 and C_2F_6), for which a time horizon of 500 years will be chosen, would get an incentive to reduce the emissions of these gases first. In the implementation of an agreement based on alternative 2, the countries will seek to reduce their emissions according to what is most cost-effective in the respective countries.

Alternative 3, in which the time horizon for each gas is chosen by each country within some limits (for example between 10 and 500 years), could improve the cost-effectiveness even further. However, as this alternative leaves a large part of the scientific understanding to be interpreted by each country (sources and sinks for GHGs, lifetimes, indirect effects, etc.), which is necessary to calculate GWPs, this alternative would probably be difficult to negotiate.

The principle of including several different GHGs with GWPs with different time horizons is also relatively simple to apply in climate policy agreements which, for example, specify a taxation of GHG emissions. In this case, the tax rates for emission of each gas should simply be weighted by the GWPs. This kind of agreement could reduce the burdens of reductions of GHG emissions compared with CO_2-only agreements, especially for countries with low emissions of CO_2.

Three factors determine whether a GHG is a candidate to be included in such an agreement.

- The gas must not be regulated by other international agreements (e.g. CFCs and NO_x).
- Scientifically sound estimates of the GWP-values must exist.
- A reasonable database of the emissions, and a methodology to monitor the evolution of future emissions from each country must exist.

At present the basis is probably good enough to include the following gases in addition to CO_2.

- Methane
- HFCs
- SF_6
- CF_4
- C_2F_6 and higher perflourocarbons.
- N_2O

For nitrous oxide (N_2O) several of the sources are still not well known, therefore, it might be somewhat premature to include this gas in a climate agreement at present.

Intergenerational aspects

The emphasis on reductions of short-lived or long-lived GHGs (i.e. the choice of time horizon) can also have implications for intergenerational aspects of climate change (cf. chapter 6). Obviously, future generations would care about the absolute magnitude of the changes at some given time into the future, and this should favor long time horizons. However, as discussed above, rapid changes could trigger more severe non-linear responses and lead to serious impacts on natural environments and then extinction of species. Inclusion of intergenerational considerations does not change the conclusions above. An agreement which includes other GHGs in addition to CO_2 should aim at limiting the total emissions of GHGs, with emphasis on reductions of the emissions of both short-lived and long-lived GHGs.

THE ROLE OF GASES WITH INDIRECT EFFECTS ON CLIMATE

SUMMARY

The man-made interference with the climate system is due not only to emissions of CO_2. Several other gases cause radiative forcing of climate directly, and some gases affect climate indirectly by affecting chemical and physical processes in the atmosphere. While CO_2, N_2O, CH_4 and several halocarbons have long enough lifetimes to give homogeneous mixing throughout the troposphere, there are also climatically relevant gases that have so short lifetimes that their concentration show large spatial variations. The radiative forcing caused by short-lived gases is also strongly regional, which emphasizes the regional dimension of the climate-change problem. The climate sensitivity to short-lived gases may also depend on the location of the emissions. New possibilities and more flexibility that may help to formulate effective measures are introduced by taking non-CO_2 gases and indirect effects into account. Therefore, a comprehensive approach including some important short-lived and chemically active gases may be desirable. On the other hand, an approach including several effects and gases may also be more demanding in the process of negotiations. In this chapter a short overview of some significant indirect effects is given and the nature and magnitude of their contributions are briefly discussed. The potential importance of linkages between the gases through common emission sources is also pointed out. A wider perspective including several non-CO_2 gases is recommended as a component of a burden sharing regime. However, the methodologies available at present for comparing the effects of climate gases, together with the significant uncertainties in the understanding of the mechanisms and the sources and sinks of the gases, put restrictions on which gases should be included. A list of gases that can be included in negotiations is suggested.

Radiative forcing of climate due to indirect effects

In chapter 2 the importance of CO_2 and the other well-mixed gases was discussed. Here we consider short-lived gases with indirect effects (see Table 2.2 and Figure 2.1) and their contribution to the total anthropogenic radiative forcing of climate.

In addition to the gases that have a *direct* impact on climate due to their own radiative properties, there are emissions of gases which have no or only a negligible direct effect on climate, but which are *indirectly* affecting climate through impacts on chemical processes in the atmosphere. The concentrations of compounds interacting with shortwave and/or longwave radiation may thus be changed. As indicated in Table 2.2, there are also source gases that can affect climate both directly and indirectly.

The most important radiatively active compounds that are influenced by indirect effects through atmospheric chemistry are:

- Tropospheric ozone (O_3)
- Stratospheric ozone (O_3)
- Methane (CH_4)
- Stratospheric water vapor (H_2O)
- Aerosols
- Hydrofluorocarbons (HFCs)
- Hydrochlorofluorocarbons (HCFCs)

In addition, aerosols formed from sulphur dioxide, SO_2, (and other source gases) affect the radiative balance and climate by affecting the properties of clouds.

In this chapter we will consider only the *indirect effects of emissions* through chemical processes in the atmosphere that occur prior to climate change. Indirect effects are called

Table 3.1 Indirect effects of some source gases on climate.

Emissions of:	**Indirect effect through:**	**Sign of indirect effect ***
CH_4	Increases in tropospheric ozone	+
	Decreases in OH and thereby increased lifetimes of gases removed by OH (CH_4, HCFC, HFC)	+
	Increases in stratospheric H_2O	+
	Increased occurrence of polar stratospheric clouds (PSCs)	-
	Changes in stratospheric ozone	+/-
	Production of CO_2 (from CH_4 of fossil origin)	+
CFC, HCFC, Halons, and other ozone-depleting substances	Depletion of stratospheric ozone	-
	Increases in tropospheric UV and thereby OH leading to reduced lifetimes of gases removed by OH (CH_4, HCFC, HFC)	-
	Changes in tropospheric O_3 due to increases in UV	- /+
CO	Increases in tropospheric ozone	+
	Decreases in OH and thereby increased lifetimes of gases removed by OH (CH_4, HCFC, HFC)	+
	Production of CO_2 (from CO of fossil origin)	+
NMHC (non-methane hydrocarbons)	Increases in tropospheric ozone	+
	Decreases in OH and thereby increased lifetimes of gases removed by OH (CH_4, HCFC, HFC)	+
	Production of CO_2 (from NMHC of fossil origin)	+
NOx	Increases in tropospheric ozone	+
	Increases in OH and thereby decreased lifetimes of gases removed by OH (CH_4, HCFC, HFC)	-

* (+ indicates warming, - means cooling)

positive if they result in a positive radiative forcing of climate. Correspondingly, they are termed *negative* if they lead to a negative forcing. Negative forcing leads to a cooling effect, while a positive forcing causes warming. Table 3.1 gives an overview of important indirect effects of some source gases. (In the table, + indicates warming, while - means cooling.)

In general, quantification of indirect effects is uncertain, but the indirect effects of methane emissions are considered reasonably well-quantified. In IPCC (1994a) and IPCC (1995b) these effects were included in the GWPs for methane. Figure 3.1 shows the contribution from the various effects to the total climate effect from methane emissions (Fuglestvedt et al., 1996a).

Through their effects on the concentrations of stratospheric ozone, the halocarbons have significant indirect effects that counteract their direct warming effect. Estimates of the indirect negative components of the GWPs are available, but in the latest IPCC report (IPCC 1995b) only tentative GWPs are given for ozone-depleting substances such as CFCs and HCFCs. However, since these gases are controlled by the Montreal Protocol, they will not be included in an agreement under the FCCC to reduce the emissions of greenhouse gases.

Figure 3.2 (IPCC, 1995b) shows estimates of the anthropogenically induced global, annual radiative forcing since pre-industrial times due to various emissions, together with an

Figure 3.1 The contribution from the various effects to the total climate effect of methane emissions. LW and SW indicates longwave and shortwave forcing, respectively. (Based on Fuglestvedt et al., 1996a.)

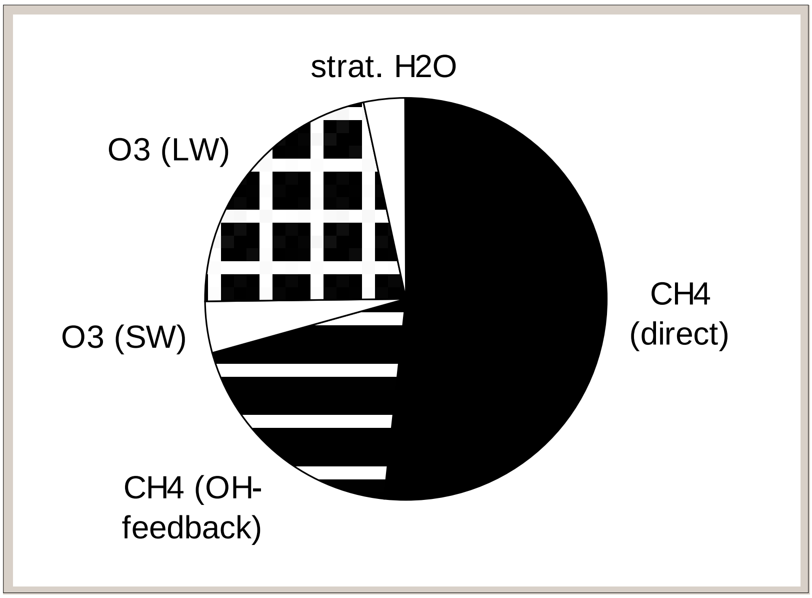
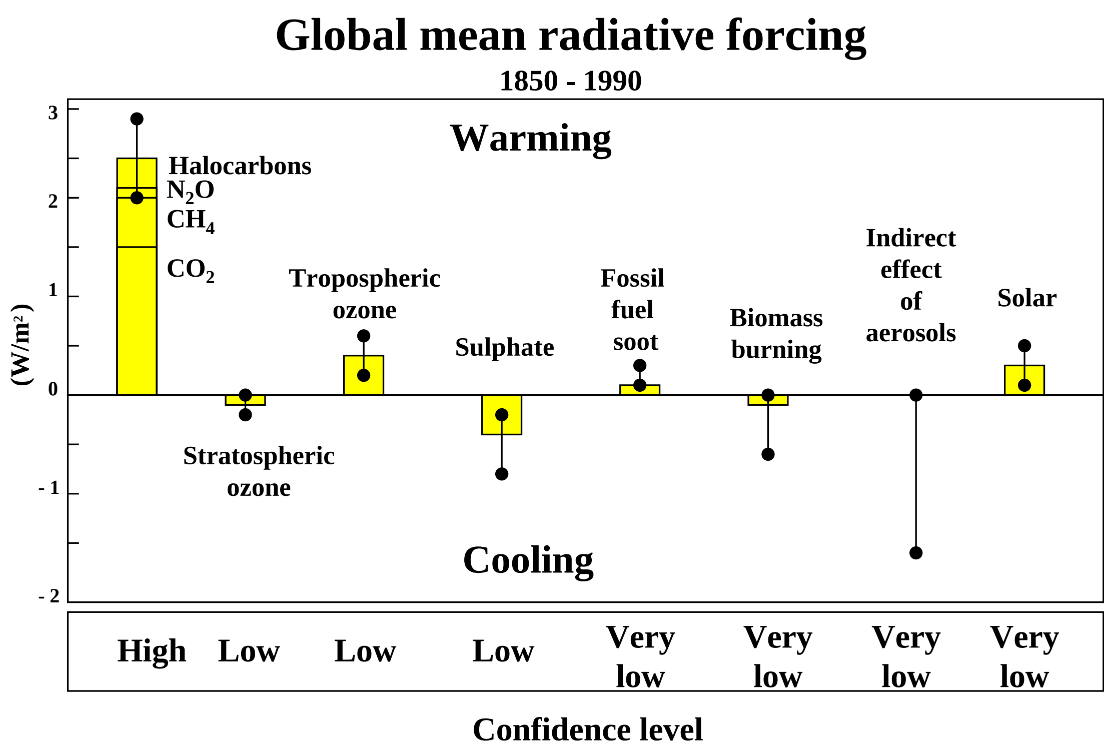


Figure 3.2 Global, annual radiative forcing due to changes in the concentrations of climate gases and aerosols since pre-industrial times. The indirect effect of aerosols through changes in clouds is also indicated as is the forcing from solar variations (IPCC, 1995b).



estimate of the forcing due to solar variations. The level of uncertainty is also given. The largest single contribution is from CO_2 which gives a radiative forcing of 1.56 W/m$^{2.}$. The total forcing from the well-mixed gases (CO_2, CH_4, N_2O, CFC-11, CFC-12, CFC-113, CCl_4, HCFC-22) is 2.45 W/m^2 (see Table 2.1). The estimated radiative forcing for these well-mixed gases is based on observed changes in concentrations, and the confidence in these numbers is relatively high (±15% for the total forcing from these gases).

Estimates of radiative forcing from changes in *tropospheric* ozone since pre-industrial times give a positive radiative forcing of 0.4 (0.2-0.6) W/m^2. The radiative forcing from the observed changes in stratospheric ozone during the period 1980-90 is estimated to be approximately -0.1 W/m^2 (with an uncertainty factor of 2). The increase in sulphate aerosol concentration since pre-industrial times has been estimated to result in a forcing in the range -0.2 to -0.8 W/m^2, with a central estimate of -0.4 W/m^2. The forcing due to aerosols from biomass burning is estimated to -0.2 W/m^2 with a factor of 3 uncertainty. Increased levels of soot are estimated to give a forcing of 0.1 W/m^2 (with an uncertainty factor of 3). By affecting the properties of clouds, aerosols may also indirectly affect climate, and this effect is estimated to 0 to -1.5 W/m^2. No central value is given due to the large uncertainties related to the understanding of this mechanism. Radiative forcing from changes in the solar output since 1850 is estimated to 0.3 W/m^2 (0.1-0.5 W/m^2). This forcing may seem significant compared to the forcing from the various gases since pre-industrial times. However, as pointed out in IPCC (1994a, 1995b), changes in the solar irradiance are cyclical in nature, and it is believed that, due to the thermal inertia in the climate system, only a small fraction of the possible temperature change resulting from such transient changes in irradiance is realized. In contrast, the changes in GHGs represent a sustained and cumulative effect over many decades (IPCC, 1994a).

For some components, the climatic impacts in terms of *radiative forcing* show significant regional variation. While gases with lifetimes greater than two years are well mixed throughout the troposphere, the concentrations of compounds with shorter lifetimes show large spatial variations. The forcing from CO_2, CH_4, N_2O and halocarbons are globally homogeneous, while the forcing from changes in stratospheric and tropospheric ozone, sulphate, soot, biomass burning particles and clouds show significant regional variations.

Changes in climate gases that give a regionally heterogeneous radiative forcing will generally have larger impacts on climate than homogenous changes with similar globally averaged radiative forcing. This is due to the physical processes that determines the circulation patterns in the atmosphere. The winds are driven by pressure gradients which are caused by heterogeneous heating of the surface and the atmosphere. Heterogeneous radiative forcing will have stronger influence on the pattern of heating than homogeneous changes. Thus, if the radiative forcing is heterogeneous, the circulation pattern is more likely to change in a way that causes larger climate changes in some regions and possibly less in others.

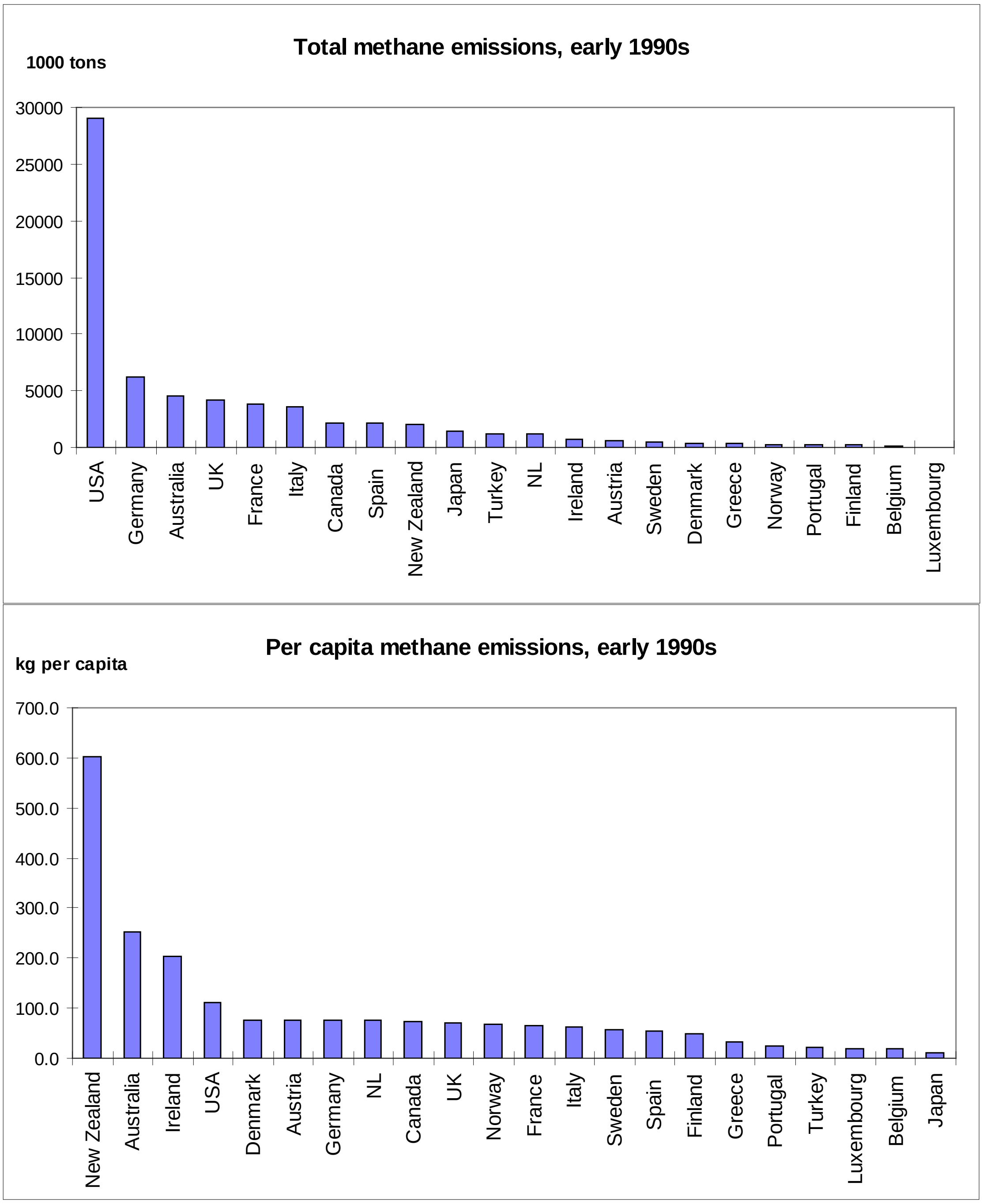
As discussed, the problem of anthropogenic interference with the climate system is not solely a

Table 3.2 Estimated sources of NOx (TgN/yr) (WMO, 1995).

Range	Range	Likely
Natural Soils*	5-12	7
Lightning	3-20	7
Biomass Burning	3-13	8
Subsonic Aircraft	0.2-1	0.4
Fossil Fuel	21-25	24
Agricultural Soils*	?	?

IPCC (1995b) gives 12 TgN/yr for total emissions from soils.

Figure 3.3 Emissions of CH_4 as absolute emissions and per capita (OECD, 1995a).

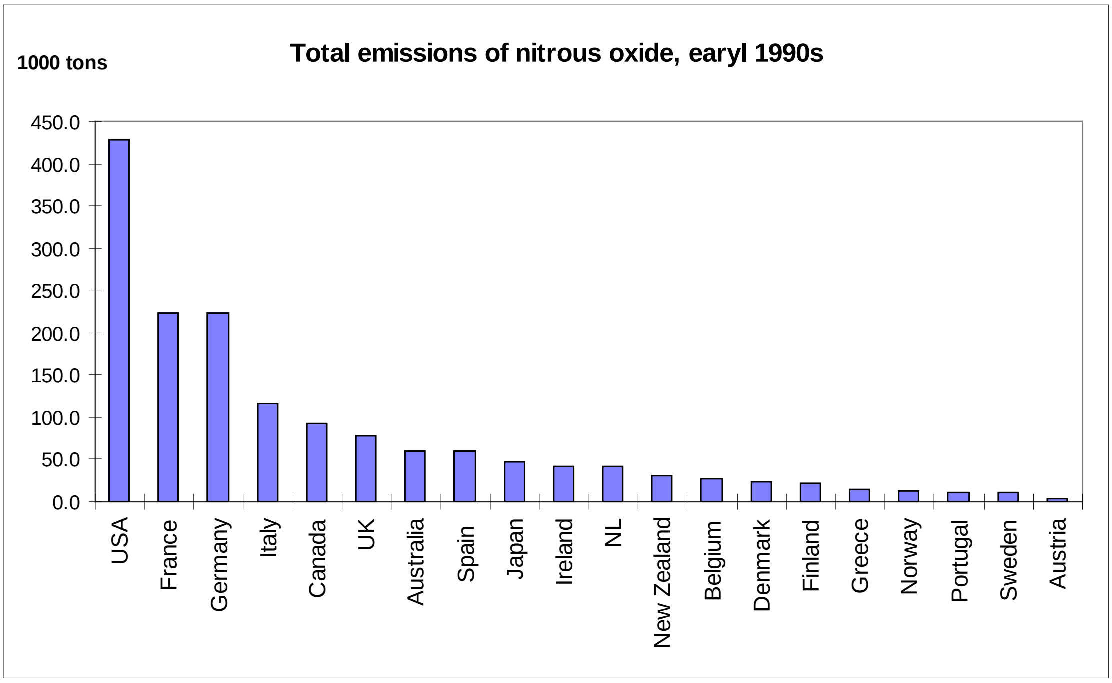


CO_2 problem. Several other gases contribute significantly and on a country level the contribution from the non-CO_2 gases may be larger. Methane, nitrous oxide, halocarbons and ozone are the most important non-CO_2 gases that contribute to global warming. The levels of methane and nitrous oxide have increased by 145% and 15%, respectively, since pre-industrial times, while halocarbons like CFCs and HCFCs were not present in the natural and unperturbed atmosphere.

Observations and model studies together indicate that the amount of tropospheric ozone in the Northern Hemisphere may have doubled since pre-industrial times (IPCC, 1994a). The enhancement is a result of increased emissions of nitrogen oxides ($NO+NO_2=NOx$), carbon monoxide (CO), methane, and non-methane hydrocarbons (NMHC). As shown in chapter 2, the global methane emissions are dominated by anthropogenic sources. This is also the case for the other ozone precursors. The global emission of NOx is strongly affected by anthropogenic sources (see Table 3.2). The dominating source is combustion of fossil fuels, while biomass burning also contributes significantly. The emissions of NOx have increased by more than a factor of three since pre-industrial times due to human activities.

The atmospheric levels of CO are also strongly affected by human emissions; both directly due to CO emissions, but also due to the degradation of CH_4 and NMHC in the atmosphere that produces CO (see Table 3.3). The direct emissions of CO may have increased by almost a factor of 5 since pre-industrial times. There are large variations among countries in the emissions of the non-CO_2 gases. This is illustrated in Figure 3.3 and Figure 3.4 which show

Figure 3.4 Emissions of N_2O given as absolute emissions and per capita (OECD, 1995a).



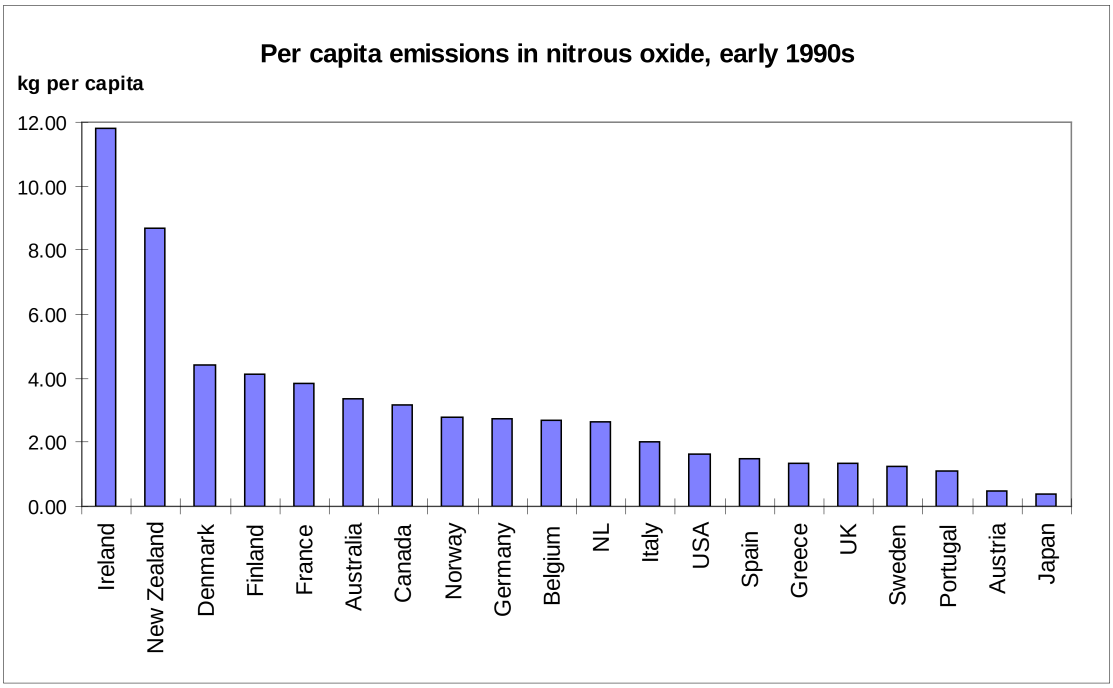


Table 3.3 Estimated sources and sinks of CO (Tg(CO)/yr) (IPCC, 1994a).

Tg(CO)/yr	**Range**
Technological	300 - 550
Biomass burning	300 - 700
Biogenic	60 - 160
Oceans	20 - 200
Methane oxidation in the atmosphere	400 - 1000
NMHC oxidation in the atmosphere	200 - 600

the emissions (in absolute numbers and on a per capita basis) of methane and nitrous oxide, respectively.

Source relations

A given source may emit a wide spectrum of pollutants and the emitted substances have many different effects. Emissions may cause *local* effects (human health, plant damage, corrosion of materials), *regional* effects (ozone episodes, acid deposition) and *global* effects (stratospheric ozone depletion or climate change). The emitted gases that affect climate also show large variations with respect to the mechanisms by which they affect climate. The gases have different *lifetimes* which is important for the geographical extension of the effect as well as for the accumulation rate of the gas and the time it takes for the concentration and effects to adjust to changes in emissions. The climatic effects of the gases may also have a different *sign* (i.e. causing warming or cooling).

One typical example of links between gases through common emission sources is emissions of SO_2 and CO_2 from fossil fuel combustion - a dominating source of both gases. As discussed earlier, SO_2 has negative effects on climate and a lifetime of the order of a few days. This means that the negative radiative forcing of this gas is limited to the regions where the emissions occur. Another important consequence of the short lifetime is that reductions in emissions will have an immediate effect on the atmospheric levels and radiative forcing. This is not the case for the simultaneously emitted CO_2. Due to its long lifetime, CO_2 is well mixed throughout the atmosphere and the concentration adjusts very slowly to changes in the emission. For instance, if the anthropogenic *emissions* of this gas were stabilized at present levels the atmospheric *concentrations* would continue to increase for two centuries (IPCC, 1995b). To stabilize the concentrations, the man-made emissions would have to be reduced by 50-70% immediately.

Figure 3.5 from Charlson et al. (1991) illustrates one consequence of these factors for the atmospheric loading of CO_2 and sulphate aerosols (formed from SO_2). As the use of fossil fuels grows, the atmospheric levels of CO_2 and sulphate increase. If this is followed by a stabilization of the combustion of fossil fuels and thereby also the emissions, the sulphate levels will adjust within weeks and stabilize. The CO_2 concentrations, however, will continue to increase for a long time. When the combustion of fossil fuels is reduced, the CO_2 levels start to level off while the sulphate levels are reduced. This means that measures to reduce the burning of fossil fuels will have two opposing effects acting on different time scales: one *immediate* effect that *reduces the cooling* (due to sulphate) and one *slow effect* that *reduces the (increase in) warming*. The removal of the cooling effect will make the warming effect from CO_2 more pronounced.

The sulphur content and thereby the SO_2 emissions, varies considerably among the various types of fuels as shown in Table 3.4. This means that the relative importance in the future of these strong anthropogenic effects on climate will depend critically on the changes in the mix of fossil fuels and the implementation of desulphurization measures.

Figure 3.5 Schematic illustration of the effects of a scenario of fossil fuels combustion (a) on the atmospheric levels of CO_2 and sulphate aerosols (b). (From Charlson et al., 1990).

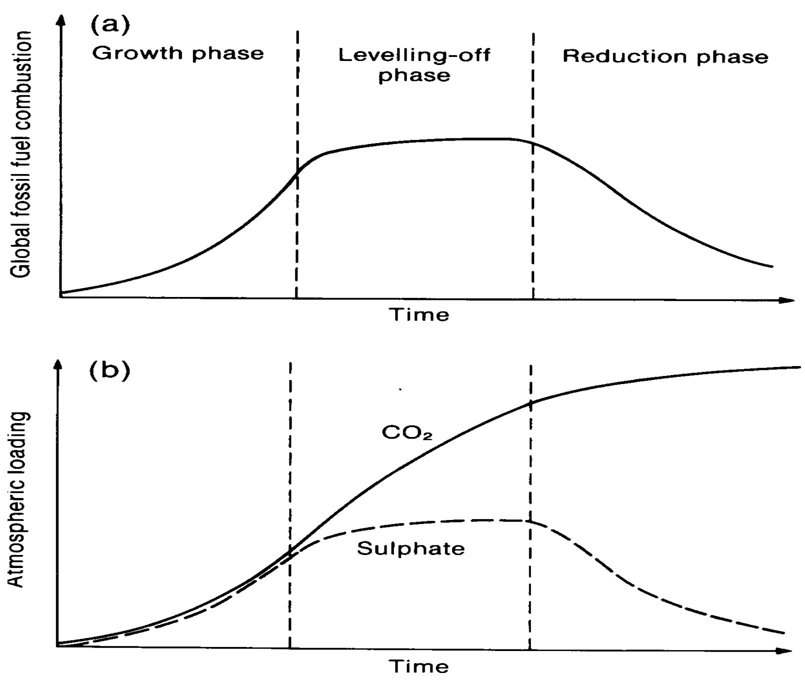


Table 3.4 Typical emission factors for CO_2 and SO_2 from various fuels.

	CO_2 (kg/GJ)*	SO_2 (g/GJ)**
Coal	95	550-700
Heavy oil	77	400-1000
Diesel oil	74	60
Gasoline	69	15
Natural Gas	56	0
Biomass	-	22

* CO_2: Numbers from IPCC (1994b). ** SO_2: Numbers from Statistics Norway

Table 3.4 shows that coal has the highest CO_2 emissions per energy content among the fossil fuels. Coal also has a relatively high content of sulphur, but there are large variations among the different types of coal. Among the liquid fuels, heavy oil gives the highest emissions of SO_2[1] and CO_2, although the latter gas shows only a small variation between the liquid fuels. Natural gas has the lowest CO_2 emissions per energy content and no emissions of SO_2. If the stock of biomass is sustained there is no net emission of CO_2 from the burning of biomass. On the other hand, some SO_2 is emitted from biomass burning.

Effects of changes in the emissions of NO_x, CO and hydrocarbons

As discussed in section 3.2, increased levels of tropospheric ozone and methane give important contributions to the man-made radiative forcing of climate. Ozone is not emitted in significant amounts, but is formed chemically in the atmosphere during the oxidation of CH_4, NMHC and CO in the presence of NOx and solar radiation. Methane is also a chemically active gas, and its removal is affected by the levels of several man-made pollutants such as NOx and CO. Several of the gases that affect the levels of tropospheric ozone and methane have the same emissions sources as CO_2, implying that measures to reduce CO_2 emissions may also affect the emissions of these gases. Thus, through such source relations measures directed towards CO_2 may also affect climate indirectly.

Fuglestvedt et al. (1996b) used a three-dimensional global chemical-tracer model to study the indirect radiative forcing from reduced emissions of NOx, CO and NMHC. The role of NOx from surface sources with respect to climate change was the main focus. Through production of tropospheric ozone, NOx contributes to warming. But NOx also increases OH levels, thereby reducing the levels of methane and giving a cooling effect. The lifetime of NOx varies from hours to days, giving large spatial variations in the levels of NOx. Due to non-linearities in the O_3 chemistry depending on background levels of NOx, CO and NMHC and on solar insolation, there are also large geographical differences in the effect of NOx on O_3. Geographical regions representing different chemical and physical conditions were selected, and the emissions of NOx in these regions were reduced by 20%. Tests where the emissions of CO and NMHC were reduced in addition to the emissions of NOx, were also performed. For three of the regions, the climate impacts of NOx emissions through changes in the levels of O_3 and CH_4 are quantified in terms of radiative forcing. The following model experiments were carried out:

Test 1: The emissions of NOx were *reduced by 20%.*

Test 2: The emissions of NOx were *reduced by 20%* while the emissions of NMHC and CO were *reduced by 30% each*

For the Scandinavian region, the model studies showed that the ozone responses to NOx reductions are very dependent on changes in other ozone precursors. Close to the ground, the changes in ozone were similar in tests 1 and 2. In the upper troposphere, however, there are pronounced differences between test 1 and 2. In test 2, ozone concentrations in the upper troposphere increase north of approximately 30°N during summer, while ozone reductions are calculated in test 1. This is the altitude region of the troposphere where ozone changes have the greatest impacts on climate. The responses in this altitude region in test 2 reduce the climate impact of the reductions in emissions of ozone precursors. For ozone, the global annual radiative forcing for test 2 is almost 60% lower than the forcing in test 1.

Changes in the emissions of NOx from surface sources lead to changes in methane that are of opposite sign compared to the ozone response. As for ozone, there are regional variations in the response in methane to changes in NOx. Since the ozone and methane responses counteract each other it is of interest to compare the radiative forcing from these changes. Such comparisons are hampered, however, by the very different natures of these two responses. The radiative forcing from methane changes shows a quite homogeneous global pattern while the ozone effect is much more regional, despite the longer lifetime at higher altitudes. In addition, due to the relatively long lifetime of methane, the response is delayed accordingly, while the ozone response occurs within a few weeks. This fundamental difference in the nature of climate forcing mechanism put limitations on the meaning of adding the numbers for global mean radiative forcing to calculate a *net effect.*

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[1] In many cases (generally for larger appliances) the SO_2 emissions will also be determined by desulphurization measures.

Figure 3.6 Global annual forcing from changes in ozone and methane in response to a 20% reduction in NOx emissions from surface sources in Southeast Asia (SEA), USA and Scandinavia (SCA) (from Fuglestvedt et al., 1996b).

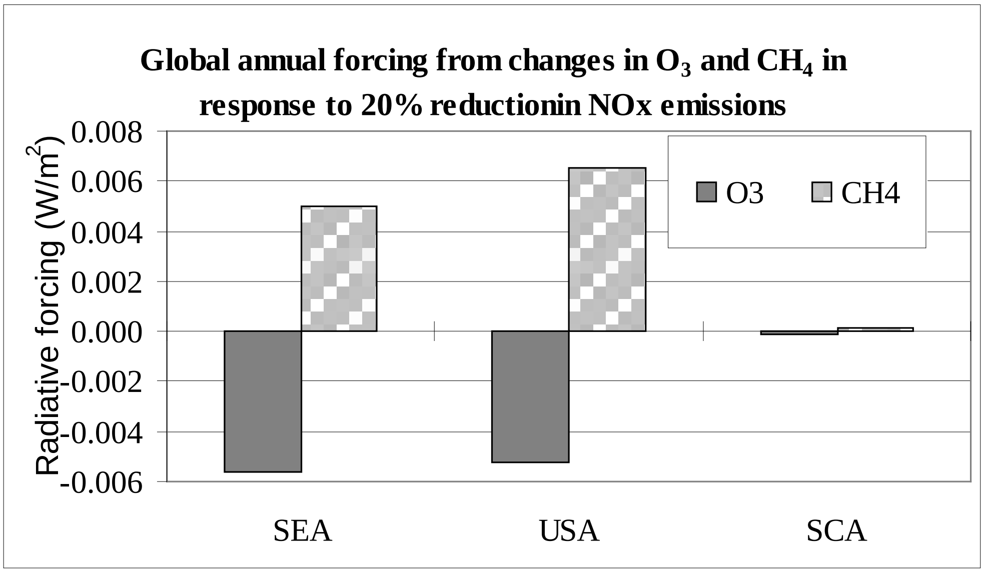


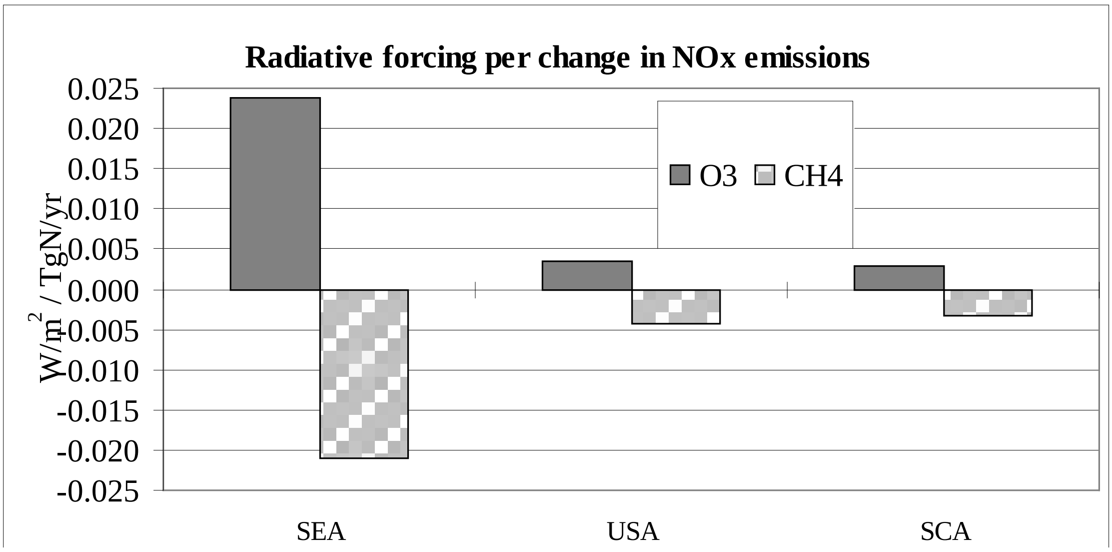
Figure 3.6 shows the global annual radiative forcing from changes in O_3 and CH_4 in response to 20% reductions in NOx from surface sources in the three regions, the USA, Southeast Asia and Scandinavia. The ozone and methane effects in Southeast Asia and the USA are of similar magnitudes, while the effects for Scandinavia are very small compared to the two other groups. For all groups, the ozone forcing and the methane forcing are of similar magnitude but of opposite sign.

The magnitudes of the NOx emissions in the regions considered by Fuglestvedt et al. (1996b) are very different. This is a consequence of the very different sizes of the regions, as well as technological and economical factors. Since the same *percentage* reduction in all regions are applied, the reductions in *absolute* numbers are also very different. The forcing due to the changes in O_3 and CH_4 were therefore normalized to the magnitude of the emission reductions to investigate the sensitivity to NOx reductions in each region (see Figure 3.7). Significantly higher sensitivity in terms of radiative forcing to reductions in NOx emissions are found for Southeast Asia compared to the other regions. Differences in seasonal variations are also evident. On a per mass basis, the radiative forcing sensitivity to NOx changes is similar for the USA and Scandinavia. The responses in O_3 are lower when the emissions of NMHC and CO also decrease, pointing to the need to take several gases into account in the formulation of strategies. For the ozone forcing the sensitivity for Southeast Asia is larger than for Scandinavia (test 1) by a factor of approximately 8, while the sensitivity for the USA is approximately 20% larger than for Scandinavia. For radiative forcing from methane, the ratio between the sensitivity in Southeast Asia and Scandinavia is about 6.5. These difference are due to the lower existing NOx levels in Southeast Asia compared to the other two regions, as well as differences in solar insolation, cloud cover and temperatures.

The study by Fuglestvedt et al. (1996b) shows that emissions of NOx from ground sources have potentially important impacts on climate. These impacts, however, are very different in nature: a global methane effect with a delay of approximately a decade, and an ozone effect of a regional character with an almost instantaneous adjustment. In terms of global average values, the ozone forcing is very small. On a regional scale, however, the effects are significant and large enough to affect the circulation pattern. Both mechanisms may affect climate on a hemispheric to global scale through changes in local heating rates and dynamics.

The study by Fuglestvedt et al. (1996b) also shows that the effects of NOx emissions on ozone in the free troposphere depend on changes in the levels of other precursors for ozone production. This is well known for surface ozone (for example Isaksen et al., 1978). Therefore, the effects of NOx reductions depend on how the measures to reduce emissions affect the emissions of other gases. Several source gases have common emission sources (NOx, CO, CO_2, SO_2, NMHC) and measures implemented to reduce the emissions of one gas may also, depending on the nature of the measure, affect the emission of other gases.

Figure 3.7 Global annual forcing from changes in ozone and methane normalized to the reduction in NOx emissions in Southeast Asia (SEA), USA and Scandinavia (SCA) (from Fuglestvedt et al., 1996b).



Berntsen et al. (1996) modelled the responses in ozone from increased emissions of NOx, NMHC and CO in Asia. Using the 1980 emissions as reference, the anthropogenic emissions were doubled, which is expected to occur by the year 2000. From the changes in ozone Berntsen et al. calculated a radiative forcing of about 0.5 W/m^2 over large areas in Asia and a Northern Hemispheric average of 0.13 W/m^2. The regional forcing was almost as large as the negative forcing from sulphate in this region. (The forcing from sulphate is for the period since pre-industrial times, while the ozone forcing calculated by Berntsen et al. is for a much shorter time period; only two decades). Measures to reduce the emissions of sulphur dioxide in this region will make the relative contribution from the ozone forcing larger. Since measures to reduce emissions of SO_2 often are directed at cleansing and scrubbing, these measures will not affect the emissions of NOx. On the other hand, fuel switching or measures to increase the energy efficiency may affect the emissions of NOx.

In Fuglestvedt et al. (1996a) chemical changes, radiative forcing and preliminary Global Warming Potentials (GWPs) taking indirect effects into account, were calculated (based on the sustained emissions approach, see section 2.4) for emissions of CH_4, CO and NOx. For the latter gas, tentative SGWPs were given only for NOx from *aircraft* and not for surface sources due to large uncertainties and inadequate models. The SGWPs for CO were estimated to 10, 3 and 1 and for the time horizons 20, 100 and 500 years, respectively. For NOx emitted from aircraft the positive radiative forcing from changes in O_3 is significantly larger than the negative radiative forcing from the changes in CH_4 and it was therefore concluded that the *net* effect of NOx emitted from aircraft is positive. For NOx from aircraft, the SGWPs were approximately 1600, 450 and 150 for time horizons of 20, 100 and 500 years. Although the estimates must be considered preliminary and should be regarded only as an estimate of the order of magnitude of the SGWPs, they underline the role of gases with indirect effects on climate.

Policy implications of atmospheric chemistry interactions

As shown in this chapter there are many gases and indirect effects that can be taken into account in negotiations and formulations of strategies to reduce anthropogenic radiative forcing of climate. Application of a comprehensive approach that includes several gases increases the possibilities for the parties under the FCCC to reduce their total contribution to climatic change. It also facilitates individual solutions that may help create cost-effective strategies and solutions. Thus, a comprehensive approach introduces more flexibility in the process of developing solutions to the negotiations and implementation of the agreements. A comprehensive approach may, therefore, be one component in a burden sharing regime. It also introduces possibilities to implement measures that will have a rather immediate effect on the man-made changes. In addition, an approach including the short-lived gases gives emphasis to the regional aspect of the human interference with the climate system.

However, a comprehensive approach is also much more demanding with respect to scientific knowledge and to the communication of knowledge between scientists and policy makers. There are still large uncertainties related to the understanding of indirect effects and this field is the subject of much research. Furthermore, the sources (and sinks) are in many cases also poorly known. However, better knowledge can be expected in the future as the parties under the FCCC meet their obligations to report their emission inventories. The limitations in knowledge put restrictions on the gases which can be easily handled in negotiations and policy formulation. Furthermore, the need for good methods to transform complex scientific knowledge into understandable information that can be used by policy makers is especially necessary when indirect effects are considered.

In a study by Fuglestvedt and Skodvin (1996) on how to define the comprehensive approach, it was concluded that the following gases could be included in an initial phase of the process[2]:

- carbon dioxide (CO_2)
- methane (CH_4) (including indirect effects)
- nitrous oxide (N_2O)
- perfluoromethane (CF_4)
- perfluoroethane (C_2F_6)
- perfluoropropane (C_3F_8) and higher perfluorocarbons
- sulphur hexafluoride (SF_6)
- hydrofluorocarbons (HFC)
- chloroform ($CHCl_3$)
- methylene chloride (CH_2Cl_2)
- trifluoroiodo-methane (CF_3I)

Since it is clearly stated in article 4 of the FCCC that gases controlled by the Montreal Protocol shall not be covered by the climate convention, gases such as CFCs, HCFCs and Halons are not included in the list of gases given above. Climate gases that already are regulated by international agreements (for example NOx) or lead to negative radiative forcing (for example SO_2), were also left out. However, NOx emitted from *aircraft* may be included, in contrast to NOx emitted from *surface* sources. For NOx emissions from aircraft the

[2] It should be noted that this list includes gases that are greenhouse gases *by definition*, without consideration of variations neither in their potency as greenhouse gases nor varying levels in current emissions. Moreover, the relative importance of some of these gases may increase despite their current insignificance, due to their capability of serving as substitutes for ozone depleting substances or more potent GHGs.

negative effect is probably very small compared to the warming effect and the forcing shows less variation along the East-West direction. Several studies have quantified the radiative forcing of NOx from aircraft and Global Warming Potentials are becoming available. Thus, if not at present, then in the near future these emissions may be included. Carbon monoxide (CO) has indirect effects on climate by enhancing tropospheric ozone and methane, and could therefore also be included in the list above. This gas has a relatively short lifetime (2 to 3 months) giving regional variations in concentrations. The effects of this gas also show some dependence on the location of emission (Northern vs. Southern Hemisphere). At present, more research is needed for CO, but when more knowledge and better methodologies are available, CO may be included. Regarding comparison of the effects of various climate gases, there are many difficulties connected with alternative methods such as climate model-based methods (cf. section 2.5) and, at present, application of Global Warming Potentials is the only adequate method available (see chapter 2). Later, if appropriate methods are available, gases with regional effects may be included in a comprehensive approach.

As shown in this chapter, emissions of NOx from *surface sources* have significant effects on climate. One may therefore wish to include this gas in strategies to reduce man-made disturbances of climate. However, including NOx emitted from surface sources in a comprehensive approach under the FCCC will be difficult due to several reasons:

1) So far there is no adequate, simple method by which the climate effects of NOx from surface sources can be compared to those of other climate gases. NOx emissions lead to reduced levels of methane (negative radiative forcing) and enhanced levels of tropospheric ozone (positive radiative forcing). Both effects show significant dependence on the location of the NOx emissions (see section 3.3). These characteristics are difficult to handle in a simple manner (i.e. by applying GWPs). Taking the large uncertainties into account, it is not yet possible to conclude whether emissions of NOx from surface sources have a positive or a negative *net* effect on climate. For NOx from aircraft, on the other hand, studies show that the negative effect is small compared to the warming effect. More research is needed to understand in a satisfactory manner the effects of NOx from surface sources. In addition, the dependence on the location of emissions due to non-linear chemical effects, introduces a need for region-specific considerations.

2) Emissions of NOx (except from international boat traffic and aircraft emissions taking place above 1000 m) are already controlled under the UN ECE Convention on Long-Range Transboundary Air Pollution (LRTAP). Several OECD countries have already implemented

measures to reduce their emissions of NOx and it may be difficult to find mechanisms to take this into account. Defining the baseline emissions will also be a problem.

3) Reductions in NOx may occur as a consequence of measures implemented to reduce CO_2 emissions. In this way, reductions in the human disturbances of the climate system through NOx may be reduced. (However, in some cases, more efficient use of fossil fuels may increase the emissions of NOx.)

4) There are several other reasons to reduce NOx emitted from surface sources since these emissions are causing many other environmental problems including acid precipitation, local health effects directly and through formation of surface ozone and euthrophication.

In addition, at present, the NOx emissions from surface sources probably constitute a relatively small effect compared to forcing from CO_2, CH_4 and N_2O.

THE MEASUREMENT OF COSTS

Summary

The measurement of climate policy costs depends on the question posed. For example, to evaluate the control of CO_2 emissions from a single country's point of view, it is crucial to know the cost in terms of loss of GDP compared to no control. When comparing the burden of different countries imposed by an international agreement, it seems more appropriate to measure the loss of welfare compared with what the country would have regarded as the optimal international agreement. This chapter discusses different measurements of costs, by showing how they relate to the implementation of policy, and to principles of burden sharing. Moreover, we show how the choice of a relevant measurement of climate costs may directly affect the explanation of a given strategy, and indirectly affect the choice of climate policy instruments.

In economic analysis it is common to distinguish the question of how to make a cake as big as possible from the question of how to share the cake between parties. In the context of climate change, it is difficult to draw this distinction. The extent to which measures to reduce global warming will be implemented depends on the costs incurred by each country as a result of the agreement, and on the benefits, which are the results of a total, coordinated action. Therefore, from a single country's point of view, the benefits of the policy that follows an agreement are directly related to the distribution of commitments. This highlights issues such as fairness and justice, and explains why equity has been discussed so frequently in relation to climate change.

Aaheim (1995) points out how easy it is to find weaknesses in nearly any operational definition of the national cost of a climate policy. In this chapter, we consider alternative interpretations of the cost, and show how different measurements may be relevant in different contexts when analyzing the economics of climate change. When analyzing costs in the context of burden sharing, it seems to be reasonable to relate the concept to the principle for sharing the responsibilities of actions that affect climate change. The "polluter-pays principle" is often taken as the point of departure for assessments of the national costs of environmental policies. We start with a discussion of how this principle relates to the problem of allocating commitments within a climate agreement. Other principles for the allocation of commitments are discussed in chapter 7. Because there is no cross-national government that can implement any common welfare target, it is not straightforward to implement the polluter-pays principle in a multinational context. Thus, the goal of this chapter is to arrive at measurements for the cost of national climate policy which are suitable for comparing the country-by-country costs of climate policies.

The distribution of costs between parties

The polluter-pays principle

The OECD has formally adopted the polluter-pays principle as a general guide for the allocation of the costs of environmental policy (OECD, 1974). At a first glance, the principle is clearly acceptable within the economic systems of the OECD, as it defines pollution as limitation of a good on which there is shortage, just like any other good. In other words, you pay what is required for the goods you need. The implementation of the polluter-pays principle has, however, been subject to some debate, which basically relates to the interpretation of the principle. To consider the cost of environmental policy, it becomes necessary to clarify the interpretation and the implementation of this principle. How costs are defined may have important impacts for the relevance of comparing the costs among countries. Therefore, a short review of the discussion from this point of view is worthwhile.

Pigou (1920) suggested that the polluter-pays principle could be implemented effectively by the introduction of a tax on polluting activities, or activities with so-called “externalities”. The tax should correspond to the social damage caused by the polluting activity in order to compensate for the restrictions that it imposes on other’s activities. In Pigou’s view, this would restore socially correct prices and lead to an optimal allocation of resources, provided that the income effect of the tax was neutralized. This view was generally held until Coase (1960) argued that a charge on a polluting activity also implied restrictions on the polluter. To make the polluter fully responsible for the whole damage could not be optimal, because he might then have to pay a lot more than those affected by the pollution would be willing to accept in compensation for the damage. Instead of charges introduced by central governments, Coase suggested negotiations between the polluters and the affected parties, and thought of this as the only way to achieve social efficiency.

Baumol (1972) noticed that if social damage is defined as the sum over the marginal disutilities of the externality, Pigouvian taxes would be optimal also in Coase’s context. Of interest here, which may also have been Coase’s main concern, is the choice of policy instruments, their implications on the costs and their allocation. Although it may be possible in principle to assess the sum over marginal disutilities of an externality, it is not a realistic task in practice. Therefore, a charge set by the authorities will usually be incorrect, and may be further biased by other concerns held by the authorities, such as that of collecting tax revenues, a position in which central authorities have monopoly power.

If possible, therefore, negotiations between equal parties are to be preferred to environmental charges. The main problem with negotiations occurs when the parties are not equal, or when a large number of non-organized polluters affect a large number of non-organized people, such that the transaction costs of an agreement become large. Both cases are typical for environmental problems. The first case requires a neutral mediator. The second case requires that the parties organize. In an ideal world, central authorities may play the roles of both mediator and organizer by introducing charges. Based on such an assumption, one may often assess the national cost of an environmental policy in accordance with the polluter-pays principle as the social loss of reallocation resulting from a Pigouvian tax.

Interpretation and implementation of the polluter-pays principle in global climate policy

Implementation of the polluter-pays principle in climate policy is a somewhat more complex affair than in national environmental policy. To make the polluters pay means that the "polluters" are made responsible for their contribution to climate change, for instance by paying a charge corresponding to the aggregate marginal disutility of greenhouse gas emissions. Consequently, a uniform charge must be imposed worldwide. However, to base an analysis of climate negotiations on a unanimous concept of aggregated disutility of greenhouse gas emissions is not very convincing. One may rather regard negotiations about climate change as a two-step affair: First, the value of controlling the emissions of climate gases is assessed for each country, for instance by determining the Pigouvian tax or Coase's negotiated compensation. Second, each nation negotiates a global agreement, trying to minimize the "distance" between this agreement and their own interests, which are defined in the first step. When the second step is carried through, one cannot easily identify the aggregated marginal disutility of emissions. Such a measure remains country specific.

What the cost of a concerted policy is to be defined as is, therefore, a question of what purpose the cost estimate is to serve. There has been a great interest in estimates of the national cost of restricting the emissions of CO_2 in the future. These estimates provide important information about the correspondence between the targets for emission control and the necessary economic efforts required to achieve these targets. This information is crucial for the assessment of the first step of decisions presented above. Moreover, the studies show that different countries face widely different costs of emission control. As a result, to require the same reduction in emissions per capita, or the same percentage reduction, may be highly inappropriate when considering the distribution of commitments. An achievement of these studies is the presentation of evidence in favour of flexible implementation of climate measures, such as activities implemented jointly or tradable permits.

A comparison of costs between countries often aims at an examination of how successfully each party emerges from a climate agreement. "Pure" cost estimates, such as the cost of emission control, are of less interest in such a context because the success will also have to be considered in relation to the benefits of a policy. If the national cost of a charge of a unified emission target is higher in the Netherlands than in Switzerland, for example, it does not mean that the agreement makes Switzerland better off than the Netherlands. The opposite could be the case, for instance, if the emission target corresponds exactly to what the Dutch people are willing to pay for a climate policy, but not to what the people from Switzerland are willing to pay. For comparisons between nations, it is necessary to go to the second step of decisions presented above, and consider the benefits of the policy as well.

As mentioned above, one may justify comparisons of costs among countries because the marginal disutilities of greenhouse gas emissions, in the terms of Pigou, differ from country to country. It might be tempting to think that there would exist an international agreement where the optimal charges in principle should deviate accordingly. This is a too hasty conclusion. The optimality of the Pigouvian tax (or Coase's efficient agreement) is conditioned upon the assumption that it makes sense to take a uniform welfare function for the world as a whole as a basis for the assessment of the charge. But it is not possible to go the other way around and establish a welfare function which is based purely on each country's own welfare function, unless a weight is explicitly attached to each country.

From a theoretical point of view, we are faced with Arrow's impossibility theorem in a global context, which tells us that we cannot find the "best" agreement without defining some kind of "dictator". The polluter-pays principle might be implemented within each country, but unless we construct a global welfare function, it cannot be implemented on a global scale. On the other hand, economic literature on climate change has primarily been occupied with cost-effective implementation of emission targets. Since the benefits of emissions reductions are not of any significance in these studies, there is no need for a welfare function. Uniform charges then provide a cost-effective solution for the group of countries subject to the target. In that case, the implementation of a uniform charge will be of interest. The way in which alternative coordinated policies affect the costs of emission control for different OECD countries is analyzed in chapter 5.

In what terms should targets be expressed?

Cost estimates and the distribution of costs among parties is critically dependent on the terms in which the commitments of a negotiated agreement are expressed; for instance targets for reduction in emission, required taxes or other terms. This is clearly not only a question of resource allocation but also, perhaps primarily, one of ethics and fairness. For example, when discussing the polluter pays-principle above, the question of who the polluters are was not touched upon. This is not straightforward, as climate change is determined by aggregated emissions over several generations. Such aspects are discussed in chapter 6. In this section, we will limit the discussion about the choice of targets to the aspect of cost effectiveness and social efficiency.

In any case, it is possible to implement a negotiated agreement by a Pigouvian tax, either country-wise or as a uniform tax. To express agreements in terms of taxes is regarded by most observers as unrealistic, but any physical target will have a dual tax that may be considered.[1] For instance, a twenty or thirty per cent reduction in CO_2 emissions, or a quota for the emissions, may effectively be achieved by a charge. Thus, there are good reasons for comparing the costs of climate policies between countries by means of the economic effects of a required carbon tax. This is also the most frequent choice in studies of the climate costs. There are, however, a number of problems with this approach that require a few comments.

An international carbon tax

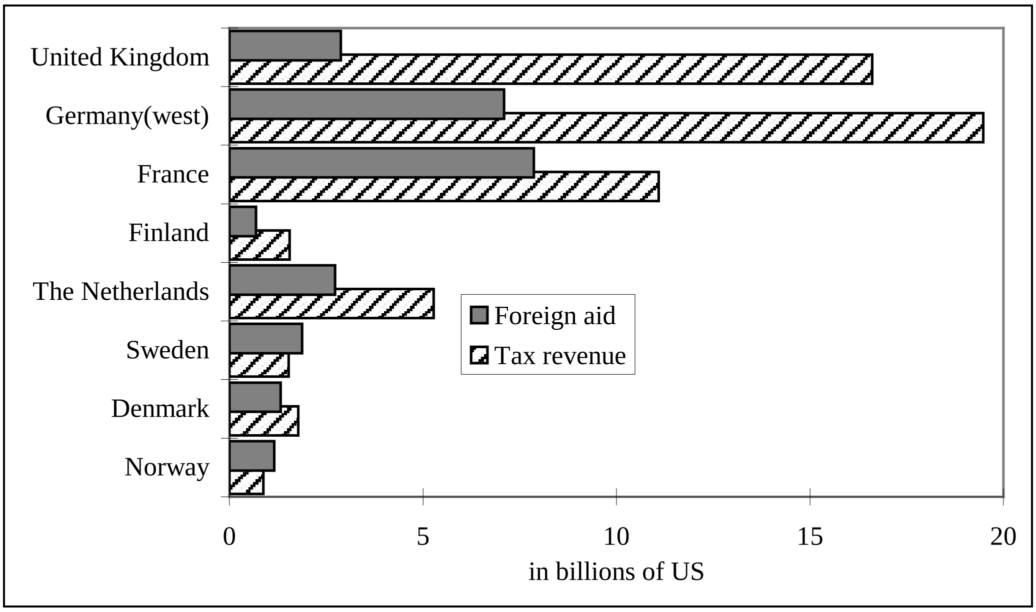
In a static context, and under full certainty, there are no major differences between an agreement which is expressed in terms of charges or in terms of emission quotas. If a charge, or a distribution of charges, is agreed upon, there is a dual emission allowance for each country. The agreement thereby embeds an implicit allocation of emission rights. However, a fixed allocation of emission rights is valid only for a limited period of time. As countries develop, the allocation of emission rights would have to be re-negotiated unless the initial allocation takes future growth into account. This implies, for instance, that a future rate for economic growth has to be attached to each country. To avoid these difficulties, an allocation of charges is clearly preferable. Then, re-negotiations could concentrate on the general level of the charge. Chapter 5 provides a more detailed discussion of the advantages of expressing a coordinated policy in terms of charges instead of emission quotas.

In general, however, climate agreements expressed in terms of charges have been regarded as unrealistic. The reason is partly skepticism, especially in developing countries, towards worldwide use of economic instruments in environmental policy. Developing countries clearly fear the negative effects on income distribution from a charge on carbon emissions. Others may fear that the environmental effects of a given tax are uncertain and turn out much lower than predicted.

The level of skepticism may be somewhat lower within the OECD. Still, the management of a cross-national tax on carbon emissions may be problematic; see for example Hoel (1992). There are many practical difficulties with such a charge. To overcome these difficulties requires a rather open-minded attitude toward finding solutions. It may also require each country to renounce their interests in other areas of international policy. If, for instance, the OECD countries agreed to implement a coordinated policy by an agreement in terms of charges on CO_2 emissions, it would be difficult, if not impossible, to control whether or not the charge is actually implemented. Each country could easily replace some of the other taxes on fossil fuels implemented already by the negotiated charge on CO_2 emissions. The policy would then come down to a question of what to call the taxes on fossil fuels. To be effective, therefore, each country would have to pay the revenues from the carbon tax to an

[1] Weitzman (1974) has shown that under uncertainty, within some institutional settings, it may be efficient to prefer quotas to

Figure 4.1 Revenues of a unified carbon tax of 100 USD and transfers from some OECD countries



[2]*Source: NORAD*

international board, which then reimburses the revenues to the governments according to some specified rule. The problem with this reimbursement is that if the value received by each country is closely related to the amount paid in taxes in the country, the tax will have no effect.

The question is then whether it is possible to create such a board, and whether any acceptable rule for the reimbursement of tax revenues may exist. An example of such a rule might be to substitute some of the present transfers from OECD countries to international organizations such as the UN, and to developing countries as foreign aid by the carbon charge revenues. Strictly speaking, the revenues from the carbon tax should be lower than or equal to these transfers, such that the carbon tax affects relative prices without affecting the income distribution. For practical purposes, it may be sufficient that the transfers are big enough to provide a substantial difference between the sum paid to the board and the sum repaid.

Figure 4.1 shows the revenues in some countries of a carbon tax at 100 USD per ton carbon in some future year, provided that this level of the tax is sufficient to stabilize CO_2 emissions at

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taxes if the concern for excessive environmental damage is higher than the concern for excessive abatement costs.
2

their 1992 level.[3] These revenues are compared to the net aid to developing countries. There are only a few countries for which the amount of foreign aid exceeds the revenue from a CO_2 charge at this level. On the other hand, several such "sinks" for tax revenues are necessary, some of which might be transfers back to the country where the tax was paid, in order to avoid linkage between carbon taxes and foreign aid. There are also other problems related to the establishment of an appropriate board with the mandate to allocate the transfers. Single OECD countries are probably not indifferent as to how transfers are allocated.

The mix of climate gases

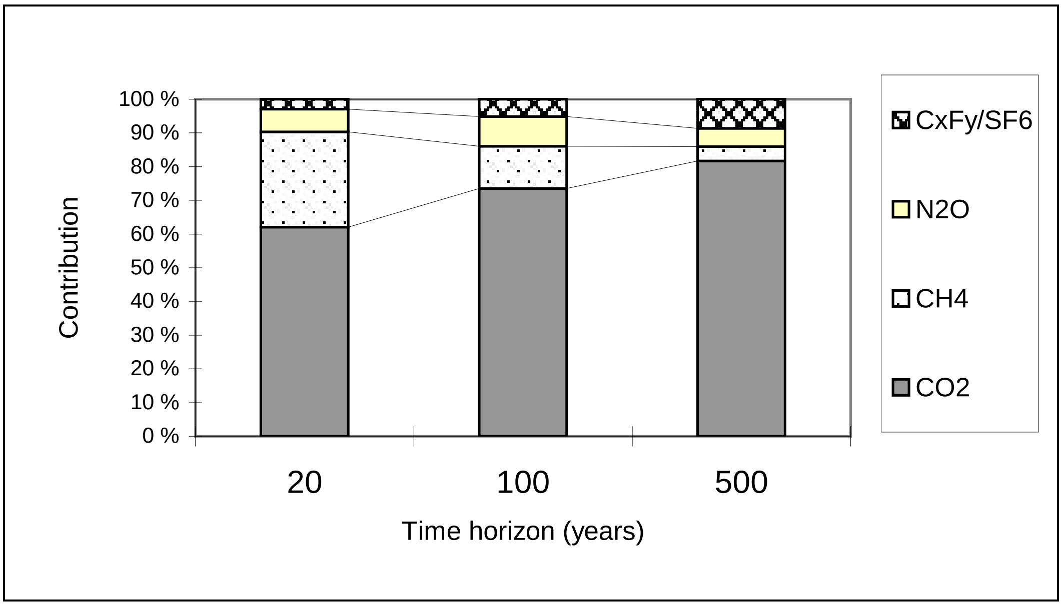
As pointed out in chapters 2 and 3, emissions of CO_2 are not proportional to the effects of climate change. The reason for focusing on emissions of CO_2 in economic analyses can be partly explained by the fact that these emissions are very easy to estimate from computable macro-economic energy models. Other greenhouse gases are not equally easy to deal with because they are not directly related to economic activities. For instance, although emissions of methane are anthropogenic, they are also closely related to natural processes. Measures to reduce emissions of methane will often require investments which cannot be initiated efficiently by charging an economic transaction, at least not unless new markets are created. This is not an equally straightforward task in macro-economic modeling. It also implies problems with respect to the interpretation of the polluter-pays principle. To our knowledge, no comprehensive economic analyses of cost-effective combinations of climate measures have been carried out. The cost of CO_2 emissions-control may, therefore, represent an upper limit for climate costs, especially in countries with significant possibilities of reducing the emissions of other greenhouse gases.

A comprehensive approach to the analysis of climate policy means that the mix of different greenhouse gases is taken into account when estimating the contribution from emissions to climate change. This may be done by modeling the economic system and the atmospheric processes simultaneously. When negotiating a reduction of emissions among countries, such an approach may be unrealistic because too many assumptions about future development have to be made. Alternatively, an aggregator for the emissions of different gases may be constructed. The usual tool for making such aggregates is the global warming potential (GWP).[4] Since different greenhouse gases have different life times, the GWP will be affected by the choice of a time horizon. Methane, for instance, has a high GWP if the time horizon is short, because the life time of methane is relatively short compared to the life time of the reference gas CO_2.

[3] The GREEN model estimates the required carbon tax for a reduction in emissions by 2% per year compared with a reference scenario to be approximately 100 USD provided the emission-quotas can be traded. Other studies requires higher taxes for the same reduction in emissions.

[4] See chapter 2 for a presentation of the GWP concept.

Figure 4.2 Contributions from different gases to the total GHG emissions (in CO_2 equivalents) for Norway for three different time horizons (from Fuglestvedt and Skodvin, 1996)



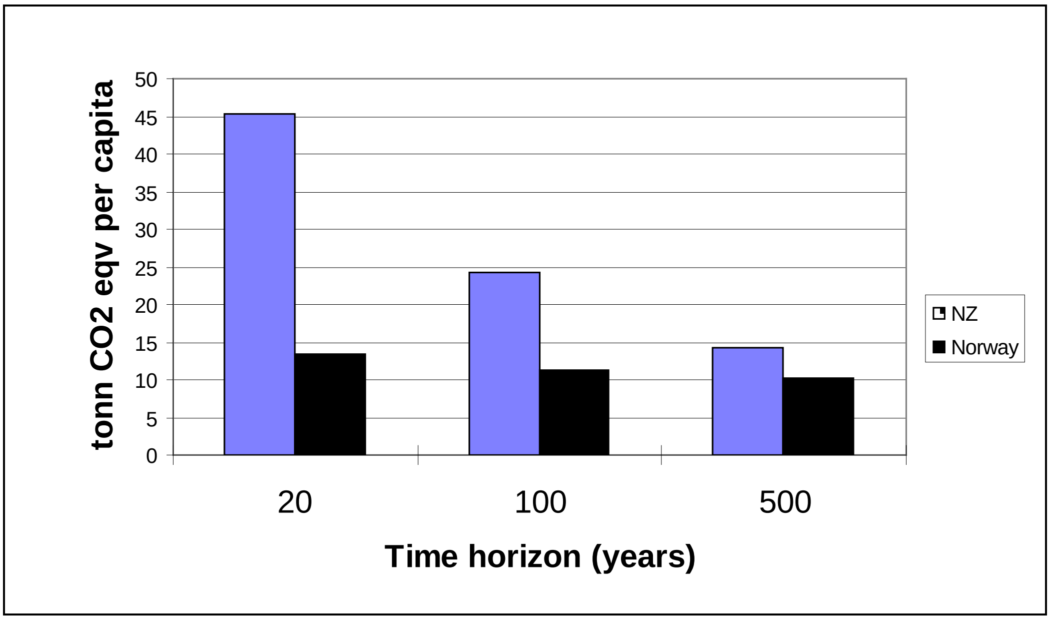
To illustrate the importance of the choice of a time horizon, Figure 4.2 shows the GWP of different gases measured with alternative time horizons for Norwegian emissions. Methane, which contributes to 20% of the emissions when the time horizon is 20 years, contributes to less than 5% when the horizon is 500 years. For N_2O, the contribution is highest when the time horizon is 100 years, while the contribution from other, long-lived gases increases significantly when the time horizon is expanded.

The other side of this discussion is how reductions of emissions of each gas are to be measured in terms of GWP. Clearly, countries which are able to reduce emissions of short-lived greenhouse gases, such as methane, at a low cost, will prefer short time-horizons when emissions are to be converted by GWP to CO_2 equivalents. Countries that have to limit their climate policy mainly to reductions in the emissions of CO_2 will prefer long time-horizons. A comparison between Norway and New Zealand illustrates the different points of departure.

Figure 4.3 shows total GHG emissions per capita in terms of GWP measured with alternative time horizons. When measuring GWP relative to CO_2 emissions, Norway's emissions are hardly affected by the choice of horizon because most of the emissions consist of CO_2 and even longer living gases. For New Zealand, however, the emissions are reduced by more than 50% if GWP is related to a 500 year time horizon compared with that of 20 years. Thus, the figure shows that the cost of reducing emissions in New Zealand may be more than doubled if the time horizon for the calculation of GWP is increased from 20 to 500 years. It should be noted, however, that the differences exhibited in Figure 4.3 are not typical for the OECD countries. The composition of emissions of greenhouse gases in most OECD countries is similar to that of Norway, while New Zealand's emissions of methane are extra-ordinarily high.[5] In general, the problem is not as great as indicated by the comparison of these two countries.

The different life times of gases may also have a direct impact on the choice of measures. As discussed at length in section 4.2, the choice of a discount rate is vital for what climate actions to take. In traditional discounting the discount rate is chosen in accordance with the social return on capital or

Figure 4.3 Total GHG emissions (as CO_2 equivalents) for New Zealand and Norway given as total numbers on a per capita basis for various time horizons (from Fuglestvedt and Skodvin, 1996)



by the cost of postponing consumption. It will be shown that such an approach may not favor implementation of climate policy measures because the increase in the value of a stable concentration of greenhouse gases, which is likely to take place over time, is not taken into account. In this case, a biased rate of discount will be more serious for measures directed against long-lived gases than for short-lived gases. The reason is simply that the effect of the bias increases over time. As a consequence, a traditional discounting is likely to overemphasize the value of measures directed against for example methane compared to those directed against CO_2.

[5] See Table 3.3.

The national cost of a climate policy

In economic terms there is no difference between the concepts of burden and costs, but costs may be defined differently according to the context in which the concept is used. In the preceding section, we have shown that several measures of the national cost may be of interest when exploring burden sharing. Assessing the cost of emission control is vital in order to consider how far to go in climate policy. Estimates of these costs also provide the most tangible information about the economics of climate policy. When focusing on the interests of different countries, on their attitude in negotiations, and how they end up in a final agreement their optimal choice of a coordinated policy must be taken as the point of departure.

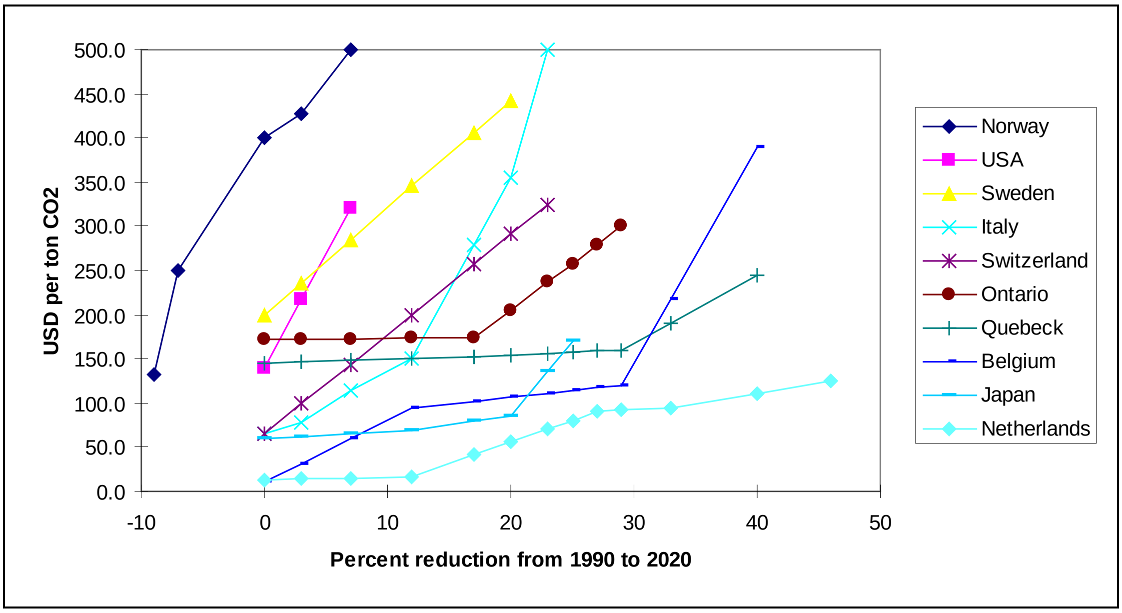
There are a number of cost estimates for emission control by country. Only a few studies are made of optimal policies, and none of them are applicable to an analysis of the dependency between optimal policy and country-specific features. In this chapter, we make a brief survey of some studies of emission control. Several other studies are discussed in chapter 8. Moreover, we refer to some estimates of damage of climate change. The last part of this section is devoted to an optimal control-study of climate policy based on a model that easily catches country-specific features. Some sensitivity analyses based on the same model are carried out in chapter 8.

The cost of emission control

The first studies of the economic effects of climate policies were made by extending energy models to include emissions of CO_2 from the use of fossil fuels. There are several ways in which this cost could be measured appropriately. One approach is to examine the introduction of new technologies which would reduce emissions and estimate the cost of installing these technologies. This approach is usually referred to as "bottom-up" study. The other approach, so-called "top-down" studies, use computable macro-economic models to estimate the cost. The costs are usually measured in terms of the reductions in GDP resulting from the introduction of a carbon tax.

The two methods differ substantially. While bottom-up studies emphasize the potential of new technologies, the top-down studies emphasize the potential of more efficient markets. Therefore, it is difficult to compare the results. For instance, so called "no-regret" options, which represent ways to reduce emissions of greenhouse gases and yield a profit as well, are represented by new technologies in the bottom-up studies. In top-down studies such options are typically represented by the abandonment of energy subsidies. A closer discussion of the approaches and a survey of the main studies are given by Aaheim (1996a). Here, we will briefly summarize the conclusions.

Figure 4.4 Costs per ton reduction of CO2-emissions in 2020 compared with emissions in 1990. Per cent. USD



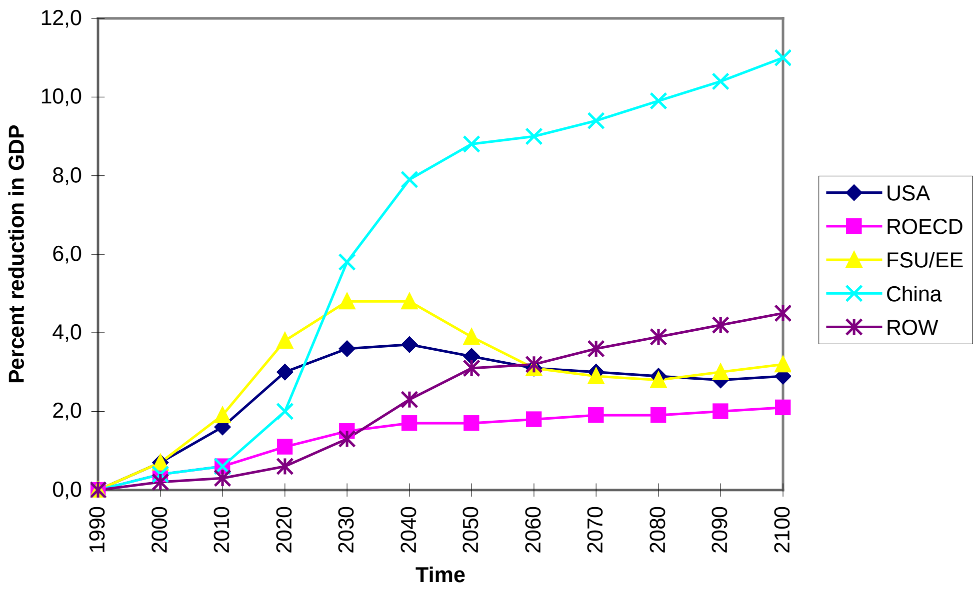
Many bottom-up studies show that there may be a significant no-regret potential in many countries. The UNEP (1994) estimates the potential in some developing countries to be 50%. The potential is also likely to be present in the OECD countries. However, the results vary significantly between studies and between countries. Figure 4.4 shows the cost-curves for a number of OECD countries (and province within Canada) estimated from models in the ETSAP network.[6] The costs are referred to as a percentage reduction in CO_2-emissions in 2020 compared with the emissions in 1990.

Variations in the costs among countries relate mainly to present technical opportunities. The Netherlands is assumed to have possibilities of reducing their consumption of fossil fuels and also to inject CO_2 into empty gas-reservoirs at a low cost. In general, those countries with high emissions of CO_2 per capita seem to exhibit relatively low costs of emission reductions, and vice versa. The exceptions are the USA, which has high costs of abatement in this study, and Japan, which seems to have many opportunities to achieve emission reductions at low costs. The results for both countries, however, are not in concurrence with other studies, which exhibit low costs for the USA and high costs for Japan. It may be the study, and not reality, that makes USA and Japan exceptions here.

A number of top-down studies have been carried out for each of the OECD countries. The results vary according to the country and model in use. In general, the studies estimate the reduction in GDP within an interval of 0.5 and 1.5% per year for each 10% reduction in emissions around year 2010 for

[6] See Kram and Hill (1996).

Figure 4.5 Estimated reductions in GDP for five world regions (Manne and Richels, 1991)



most of the countries. In a longer time perspective, 50 to 100 years, the costs in terms of reductions of GDP are estimated to be within the interval 0.3 and 0.7%. Variation among countries relates mainly to the possibilities of substituting coal for some less carbon-intensive fuels, and to expected future economic growth. Manne and Richels (1991) estimated the costs of emissions reductions for five world regions: the USA, the rest of OECD (ROECD), the former Soviet Union and the east-bloc countries (FSU/EE), China, and rest of the world (ROW). The reduction scenario allows for an increase of 15% in global emissions till 2030, but stabilization thereafter. This corresponds to a moderate reduction in emissions in the first period, a reduction by 50% around 2050 and by nearly 75% in 2100. The results are displayed in Figure 4.5.

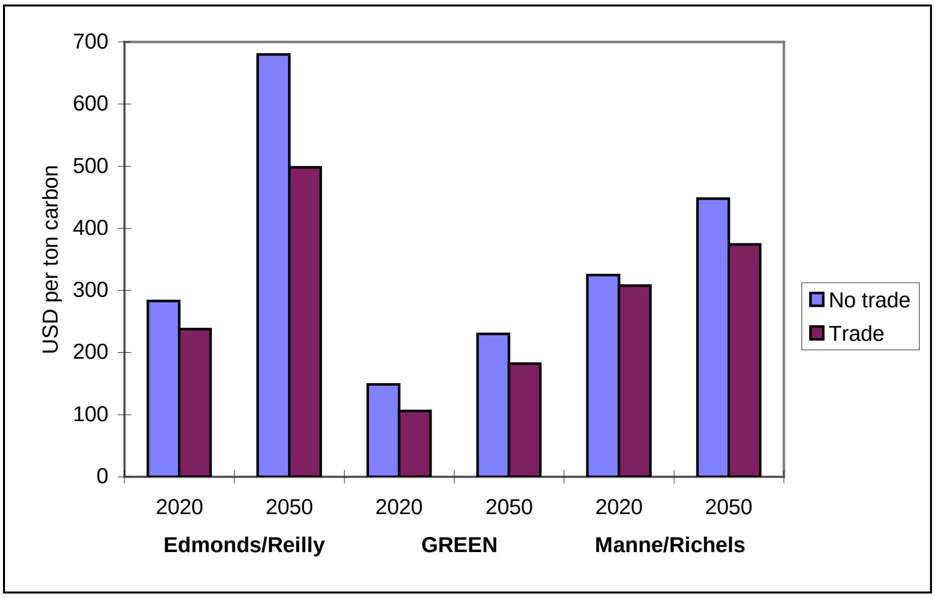
The results illustrate the importance of future expected growth and the ability to substitute coal for less CO_2-intensive energy carriers. For China, both factors contribute to an increase in the costs. The cost of limiting the growth of emissions in the former east bloc countries is high in the first 30 to 40 years, but the costs are reduced later, partly due to the availability of huge gas reserves. The USA has higher costs that other OECD countries, which Manne and Richels explain by the fact carbon intensity of the US economy is higher from the outset. Availability of oil and gas reserves also explains the low costs in the rest of the world, which includes all the members of OPEC. These results may indicate that the model overemphasizes the impact on costs of the availability of domestic energy resources, as the result is somewhat counter intuitive. Being a typical traded good, the availability of domestic oil reserves should not have a major impact on the ability to substitute other energy sources for oil.

As has noted, the bottom-up studies and the top-down studies apply different measures for the cost of emission control. Support of the GDP measure used in the top-down studies is given by Weitzman (1976). By means of a very simple macro-economic model, he shows that in intertemporal equilibrium, GDP equals the amount of consumption that, if held constant, would yield the same total welfare as the optimal, feasible consumption path. The result applies, however, only under very strong assumptions. Weitzman assumes, for instance, that the macro production-function includes all input factors of relevance, such as natural resources, for the national output. Since changes in the wealth of natural resources are not reflected in the GDP figures, the GDP measure may be seriously biased compared to an acceptable measure of welfare for countries, such as Norway, with vast amounts of natural resources.

In principle, GDP should be adjusted for the utilization of all natural resources, and thereby reflect the changes in all components of the national wealth. However, the impact from extraction of fossil fuels is of particular interest when analyzing climate change since a global climate policy may significantly affect the world market for fossil fuels. To what extent is difficult to predict, but from a theoretical point of view, an announcement of increasing carbon taxes should encourage small producers to advance extraction (enhance the supply), and thereby counteract the effect on emissions. However, a coordinated action among producers may give different results.

Berg *et al.* (1996) study the impact on the petroleum wealth of a number of countries if a carbon tax of 10 USD per barrel of oil is introduced worldwide. They show that the effect is very dependent on OPEC’s market power. A strong OPEC cartel will react against the charge by reducing production. This is a great advantage for non-members of the OPEC, compared to a situation with a competitive oil market. The study estimates the reduction in petroleum wealth to be 8% in the cartel case compared to 39% in the competitive case. For OPEC the difference is small, 23 versus 25%. Moreover, the total wealth is higher in OPEC in the cartel case, which means that the total loss is higher when OPEC acts as a cartel. The wealth of gas reserves is also affected by the carbon charge, but it is relatively insensitive to OPEC’s market power. For Norway for example, the loss in the wealth of gas is 26%, the same as for the total wealth of gas in OECD countries in Europe. The rest of OECD loses 18% of their wealth of gas while non-OECD countries lose 31%.

Figure 4.6 Required carbon tax to achieve a 2% reduction in emissions by OECD countries



As mentioned earlier, an evaluation of global policy issues needs to take into account the possibilities of reallocations. The aim of a given policy can be regarded as restoring "socially correct" prices. Thus, this effect should not be disregarded when evaluating the cost. When it comes to climate policy, this has two important aspects. First, climate change is expected to impose a social cost not reflected in market prices. To tax the causes of climate change would, therefore, contribute to making the economy more efficient, contrary to many other taxes which work in the opposite direction. By introducing for instance carbon charges at the expense of other taxes, a country may thereby yield a social benefit. Second, the over-all cost of global efforts to control climate change may be affected by the possibilities of trading “emission quotas” across countries. The possibility of getting a so-called "double dividend" from the introduction of carbon charges has received a great deal of attention among economists, and turns out to be of significant importance when it comes to comparisons of costs between countries. A closer study of the effect of carbon charges in OECD countries is given in chapter 5.

The effect of trading emission quotas has been analyzed in several studies. Dean (1993) compares the results from three different models: The Edmonds-Reilly model, the GREEN model and the Manne and Richels’ GLOBAL 2100 model. In all three models the charges required to achieve a 2% annual reduction in emissions within the OECD compared to a reference scenario are estimated according to the alternative assumptions that the quotas are tradable and non-tradable. Figure 4.6 shows the results generated by each of the three models for the years 2020 and 2050.

The figures show that the advantage of trading quotas increases over time, but there are differences between the models with respect to the size of the gains from trading. The Edmonds-Reilly model estimates a 30% reduction of the tax when quotas are made tradable, while the other models give a more moderate reduction. However, the effects on the GDP are more significant in the GREEN model and less significant in the Edmonds-Reilly model, thus making the effects on the national cost of introducing tradable quotas more equal.

The cost of a negotiated agreement on climate policy.

There is no doubt that the main contribution from economics to the political process of climate change relates to effective means of emission control. There are different views as to how an effective climate policy should be designed worldwide and, in particular, there are diverging opinions about joint implementation under the FCCC. Such disagreements are generally concerned about whether the recommended policies will work out as intended. The concern for effective means of emission control is usually expressed by developed countries. However, the different views on how these means works are insufficient for explaining country interests. These interests cannot be studied properly without taking each country's anticipated need for a global climate policy into account. In economic terms, this means that we have to consider the benefits of a climate policy.

Countries may have different motivations for a reluctant or an ardent attitude in climate negotiations. These may partly be explained by the anticipated benefits of a climate policy. Benefits in this context should be defined broadly. The benefits of less change of future climate may constitute only a part of the total benefits of an international agreement on climate change. Political benefits may be equally important. The European Union (EU), for instance, may try to use climate negotiations to demonstrate their ability to act as one unit in international affairs. This might encourage the EU, as a separate entity, to take a leading role in the negotiations. In this case, it is important to take a distinct position relative to that of the USA, such that EU's interest becomes dependent on the position of the USA. Governments of single countries may use the negotiations as an alibi towards green movements at home, etc. In the remainder of this chapter, however, we will limit the discussion to the economic effects of damages from a slower rate of change in the climate.

In recent years, there has been an increasing interest in calculating estimates of the costs of climate change. The estimates are, of course, uncertain and partly speculative. Consequently, the figures vary considerably among the studies, especially when comparing single effects of climate change. Also, the valuation of many of the effects is highly controversial, such as the value of increased morbidity. As a result, studies based on such estimates are not applicable for giving recommendations about specific targets in climate policy. On the other hand, considerations about the benefits are useful for studies of

Table 4-1 Estimates of economic damage at 2×CO2 in the USA. 1000 billions of USD.

Effect	Cline (1992) $2\times CO_2$: 2.5°C	Titus (1992) $2\times CO_2$: 4°C	Tol (1993)* $2\times CO_2$: 3°C	Nordhaus (1991)** $2\times CO_2$: 3°C	Fankhauser (1995)*** $2\times CO_2$: 2.5°C
Sea level rise	6.1	5.0	8.5	10.7	7.9
Agriculture	15.2	1.0	10.0	1.0	7.4
Forests	2.9	38.0	..	0.0	0.6
Energy	9.0	7.1	..	1.0	6.9
Water supply	6.1	9.9	..	|	13.7
Other sectors	1.5	..	..	|	..
Eco-system	3.5	..	5.0	|	7.4
Welfare loss	..	..	12.0	|	..
Mortality	5.0	8.2	37.4	35.9	10.0
Migration	0.4	..	1.0	|	0.5
Air pollution	3.0	23.7	..	|	6.4
Water pollution	..	28.4	..	|	|
Accidents	0.7	..	0.3	|	0.2
Total	53.4	121.3	74.2	48.6	61.0
% of GDP (1988)	1.1	2.5	1.5	1.0	1.3

* Applies for the USA and Canada.

**Nordhaus(1991) do not specify these 9 items but suggests a total of 0.75% of GDP

*** Water supply and water pollution are taken together.

policy design, for instance in relation to timing of policy, and how abatement costs and anticipation of effects of climate change may affect the policy. As argued above, it is necessary to include such aspects when exploring the national cost of climate policy.

Fankhauser (1995) compares different estimates of the damage of climate change in the USA from a number of studies. Damage is defined as annual loss for the present-day economy exposed to the estimated effects at $2\times CO_2$. The estimates are given in Table 4-1 The assumptions about the temperature sensitivity range from 2.5 to 4°C. The sensitivity range may explain some of the differences in the estimates of the total damage. However, the divergence between estimates of different effects is considerable. This is partly due to different estimates of physical effects and partly to different valuation of the effects. For instance, Titus (1992) assumes much more serious damage to forests than the others, while Tol (1993) assigns the double of the value of a human life compared with Fankhauser (1995).

Although there are substantial variations, these studies indicate that the costs of climate change are not overwhelming. Recall the studies of the costs of emission control, which estimate the long term cost to be between 0.3 and 0.7% of GDP per 10% reduction in emissions. Noting that a full halt in the increase of atmospheric concentrations of greenhouse gases requires an immediate reduction in emissions of 50-70%, it is not surprising that most economic studies recommend a relaxed attitude towards the initiation of climate policy. However, Cline (1992) demonstrates that this conclusion is highly dependent on the choice of a discount rate. Applying a discount rate less than 2%, he concludes that aggressive actions against climate change might actually be beneficial.

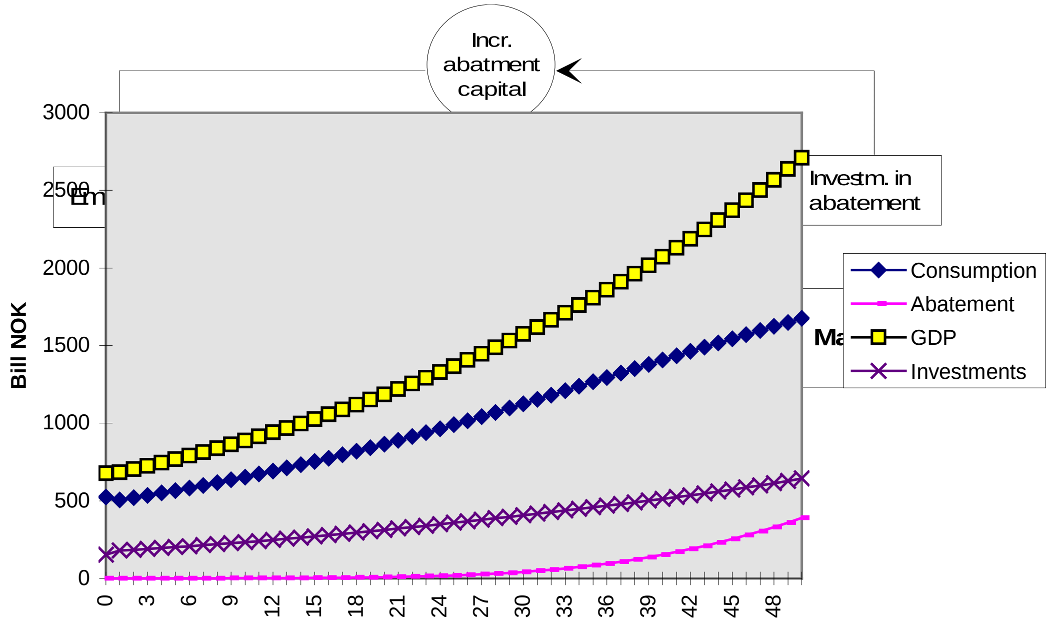
Because of the long-term nature of the problem, the choice of a discount rate has turned out to be perhaps the most sensitive assumption in economic analysis of climate policy. To explore the interests of a country prior to climate negotiations, it is essential to pay particular attention to the problem of discounting. Within a theoretical framework, Weitzman (1994) shows that there may be good reasons to apply a lower discount rate for the benefits of environmental policy than for traditional economic benefits. This is because the value of the environment is likely to increase over time. In the case of climate change, this means that the optimal policy will be subject to changes in the atmospheric concentrations of greenhouse gases over time. To establish the connection between policy and atmospheric concentrations, we need to model the linkages between economic activities and the concentrations of greenhouse gases. Moreover, the dynamics of this system must be explicitly modeled in order to achieve a consistent equilibrium over time. The first task, to establish the environmental effects of economic activities and the repercussions back on the economy is what the studies referred to in Figure 4.6 aims at. However, none of the studies include the dynamic aspect.

On one hand, the links between economic activities and concentrations of greenhouse gases are represented by emissions from economic activities which affect concentrations. On the other hand, changes in the concentrations affect economic activities through damages. Figure 4.7 illustrates the main features of a highly simplified model which enables an assessment of the economic value of a changing climate.[7] The dynamics of the model are taken care of by explicitly distinguishing between stocks (real capital, abatement capital and concentrations of greenhouse gases) and flows (consumption, emissions and investments).

The model maximizes welfare of consumption over a given time interval. Welfare is modeled in a fairly standardized way by means of an additive utility function.[8] The national product is produced with real capital (or productive capital) as input. Production causes emissions which contribute to an increase in the concentrations of greenhouse gases. Increased concentrations lead to physical damage in terms of reductions in the national product. Emissions can be controlled by investing in abatement, which creates "abatement capital". These investments are supposed to affect only emissions, and can

[7] A documentation of the model is given in Aaheim (1996b)
[8] See section 6.4 for a more detailed discussion.

Figure 4.8 Main characteristics of a model for the optimal climate policy of one country



be identified as the incremental cost of abatement measures. For instance, the extra costs of more energy efficient equipment contribute to the abatement costs. One way to make the agents of an economy impose such costs is to introduce a charge on carbon emissions. Abated emissions are represented by the reduction of emissions compared with the pre-tax emissions. The cost is the total cost increase in the production from pre-tax to post-tax levels, measured in terms of the use of physical resources. All prices, including the discount rates, are endogenous. It is also assumed that investments in abatement capital are subject to adjustment costs, such as transaction costs, training, costs of installation, etc.

Since our goal is to assess the optimal climate policy of one country, we need to make some assumptions about what other countries do when the country under consideration imposes its own policy. For instance, if one country is free to choose the policy of all other countries, it would of course be optimal to act as a free rider. For the calculations presented in this chapter and in chapter 8, a very restricted set of policies in "all other countries" is assumed; namely, a proportional reduction in emissions in all countries. In other words, the country in focus develops its optimal policy under the assumption that all other countries do the same as themselves.

The analytical solution of this model confirms the well-known Ramsey rule for economic growth:[9] The social return on investments in productive capital equals the sum of the impatience rate in consumption and the rate of consumption growth (adjusted for the elasticity of intertemporal

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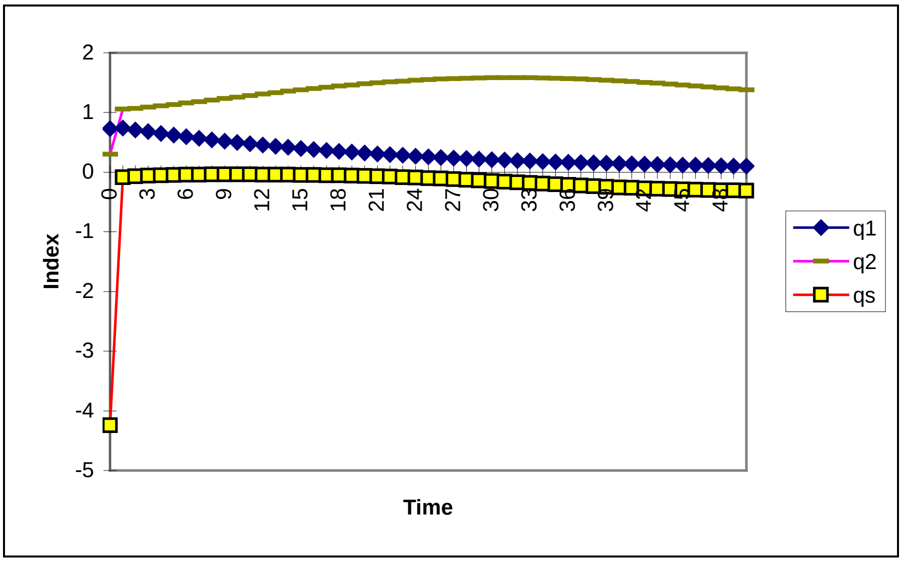
[9] See Ramsey (1928)

Figure 4.9 Evolution of the shadow prices for the state variables.



substitution). That is, consumers save money till their marginal utility of postponing consumption equals the social return on investments. Since production is affected by changes in climate, the social return on productive capital is equal to the marginal productivity of capital ("private return") minus the marginal value of emissions. The social return on abatement capital can be defined as the marginal reduction in abatement costs per unit of abatement capital plus the value of marginal emission reductions. This is usually termed the marginal benefits of abatement. In equilibrium the social return on abatement capital equals the social return on productive capital plus the growth rate for emissions, adjusted for the intertemporal elasticity of a substitution for abatement. This may be interpreted as the marginal value of postponing abatement.

These conditions state that it is appropriate to discount the benefits of investing in abatement at the same rate as for other investments only when it is optimal to keep investments in abatement constant. To assess an appropriate discount rate it is necessary to complete the whole model. The parameters are calibrated with Norwegian data as far as possible. However, the parameters for the adjustment costs of abatement are chosen more freely. Damage and total costs are chosen in order to compare them with average estimates from reported studies. However, since many of the parameters are not estimated elsewhere, the costs are not fully "controlled" *ex ante*. It has turned out, however, that the parameters in the base case represent comparably high costs of investing in abatement, but abatement capital has a strong effect on emissions, when in place. These two effects counteract each other, but is of great importance for the optimal abatement policy path. Moreover, the damage costs in the model are assumed to be relatively high. The period under consideration is 50 years, from 1995 to 2045.

The paths for the main macro-economic indicators following the optimal policy in the base case are shown in Figure 4.8. Full certainty is assumed in this case. The base case typically follows an economic growth pattern, with approximately the same proportion between real investments and consumption throughout the period. The average annual growth rate in consumption is 2.3%. Investment in abatement is small until 2020, but grows fast beyond. In the terminal year, these investments amount to about two third of real investments. In other words, the optimal policy is clearly in favor of moderate action now, a result which confirms the results by Nordhaus (1993) and Manne *et al.* (1994), but indicates a more active policy later. Similar results have been published recently by Wigley, Edmonds and Richels (1996). The explanation for this result occurring here is partly that the damage from climate change is negligible at present and starts to get significant around 2025. Another reason is that it is very costly to invest in climate measures, especially in the beginning, when there is no "learning effect". In the model, this learning is related only to the stock of abatement capital.

The discount rates are assessed endogenously by the rate of change in the shadow prices of state variables. The only exogenous choice that has to be made relates to the marginal productivity of productive capital, which can interpreted as the real rate of return on private investments (approximately 5.5%). Figure 4.9 shows the evolution of shadow prices for the three state variables. The negative slope of these curves are the discount rates. The social discount rate is usually related to the social return on productive capital, that is q_1 in Figure 4.9. This price is falling over the entire period at a rate between 4.4% in the beginning and 3.3% in the end. In other words, the social return is between 1 to 2% lower than the initial return on productive capital. This is because the social return is to be adjusted for the emissions caused by production, and because the return on 'private' investments decreases slightly over time.

Of greatest interest for climate policy, of course, is the evolution of the price of abatement capital (q_2 in the figure). According to the figure, this path deviates considerably from that of productive capital. It starts at a higher level and increases over the first 30 years. This implies that the discount rate for abatement capital is negative during this period, which means that abatement capital actually increases its value during these years. The reason why the investment rate is kept at a low level, in fact close to zero, is that the adjustment costs impose a threshold for these investments. In addition, the price is sensitive to investments during these first years. After the speeding up of abatement investments after 2025, the price of abatement capital starts declining, and in 2045 the corresponding discount rate is 1.3%.

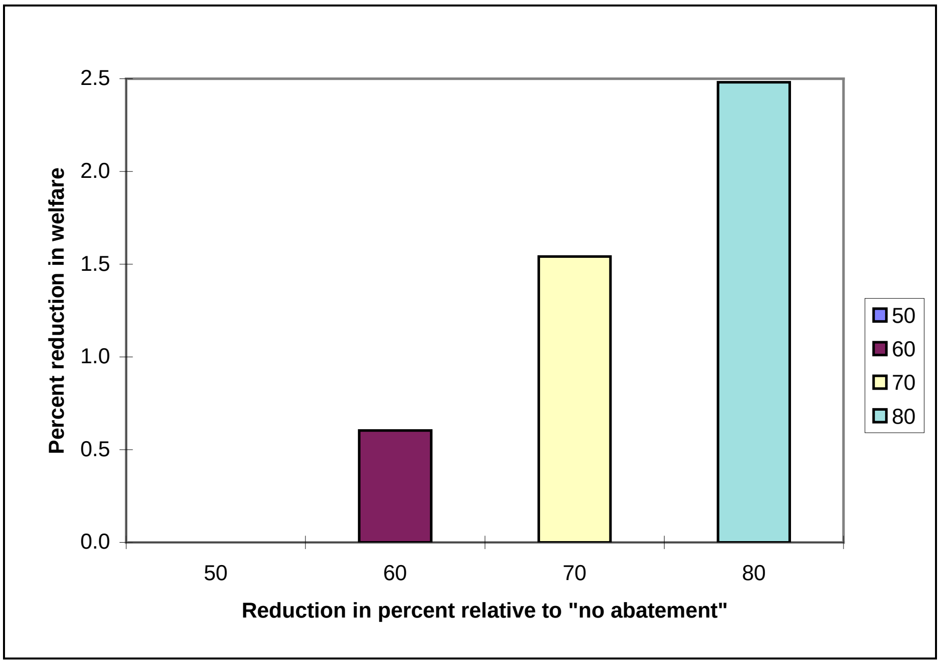
A second explanation for the reluctant abatement policy relates to the third state variable, concentrations of greenhouse gases which are controlled indirectly. The level of the shadow price of concentrations (q_S in the figure) gives important information about the optimal policy path. Intuitively one might expect the value of higher concentrations to be negative because they are the source of damage imposed on production. On the other hand, the absolute decay of concentrations increases with higher level of concentrations. This contributes positively to the system. Therefore, the price starts close to zero, is slightly positive until 2010 and declines after that. Since higher concentrations are not negative during the first years under consideration, it is understandable that abatement is low.

The optimal emissions contribute to an increase in concentrations at 53 ppmv in 2045 (for a period of 10 years), which is nearly a doubling from 1995, when emissions contributed to 27.5. Compared with the case of no abatement, this corresponds to about a 50% reduction of emissions in 2045. As shown in Figure 4.8, most of these reductions are carried out during the last ten years of the period. Note also that "no-abatement" in this case means that the emission coefficient remains constant over the whole period. This may be quite different from a "business-as-usual" scenario, which may include sch factors as enhancement of energy effectiveness over time. The concentration of greenhouse gases in 2045 is 534 ppmv under optimal policy, which is close to $2\times CO_2$ at 560 - much higher than most other predictions indicate. Thus, the optimal 50% reduction in emissions by 2050 does not represent a precautionary strategy with respect to climate change.

The importance of these results when considering the costs of climate policies is that any other policy will be sub-optimal for this specific economy. Less abatement than 50% in the year 2045 achieved by the path given by the optimal solution will imply a social cost in terms of a loss in welfare. Within the simplified framework given in the model, the standard way of measuring the costs of emission targets is to calculate the loss in GDP as a result of abatement investments replacing productive investments. Then, the cost of any emission target would be positive, since the model does not allow for possibilities of achieving a double dividend. This means that the different interests of countries prior to climate negotiations can be defined with reference to this optimal, or zero, net-loss policy, since any other abatement policy imposes a loss to the country.

The climate cost-curve for a country may now be calculated. Such a cost curve may be established by calculating the welfare loss if the country were forced to impose emission paths different from the optimal one; for instance emission paths which require early investments. The percentage loss of welfare from such targets valid for 2045 is given in Figure 4.10. The loss is calculated as a percentage reduction in total welfare over the period under an assumption that the total value of productive and abatement capital in 2045 is to be the same as it is in the optimal case. Thus, a higher level of abatement means that the stock of abatement capital is higher, and the stock of real capital is lower in the terminal year. The figures show that the cost of emission targets constitutes between 0.7 and 0.8%

Figure 4.10 Percentage loss of welfare with alternative emission targets in 2045



loss in welfare for each 10% reduction of emissions. This, in fact, is not very different from other studies. The difference relates to the point of reference.

It is of interest to see whether the approach followed above actually yields significantly different answers to what the cost of climate policy is, compared with the more standard approaches. We have seen that the reluctant attitude towards climate actions now is confirmed, however, for very different reasons and that the percentage loss of emission control is about the same as in other studies, even when measured by a different indicator. To compare this with a more traditional approach, we have calculated the benefit-cost ratio for the optimal policy under alternative discount rates. To show how such a comparison may depend on country specific features, such as damage cost and uncertainty, we have calculated the ratio for three cases. The base case is the case discussed in this chapter. The alternative is a low damage cost case, where the expected damage cost is about 40% lower than in the base case. When uncertainty about climate change is introduced, the optimal policy is based on a moderate uncertainty about effects, namely that about two thirds of the observed effects of climate change deviate less than +/- 2.5% from the expected value.

Costs are measured as the reduction in GDP by following the optimal policy compared with GDP as if abatement investments were allocated to productive investments. The present values of these costs were 101 bill. NOK in the base case, NOK 72 billion in the case with low damage, and NOK 131 billion in the uncertainty case. In other words, the zero welfare loss implies considerably different costs of abatement for different countries. Table 4-2 shows the benefit-cost ratio by optimal

Table 4-2 Cost-benefit ratio for optimal policies with alternative country specifics

Discount rate (%)	Base case	Low damage cost	Uncertain effects of climate change
2	0.798	0.978	0.644
5.5	0.788	0.980	0.635

abatement policy. The benefits are measured as abated damage. As usual in similar cost-benefit analysis, the cost-benefit ratio is calculated for alternative discount rates.

It is perhaps surprising that the choice of a discount rate is of minimal importance for the cost-benefit ratio. This suggests that the profile of the optimal abatement policy confirms the result of other cost-benefit studies saying that it is worthwhile to start abatement with caution. The low damage cost case is approximately the same as a policy recommended by a traditional cost-benefit analysis. The profitability in this case increases slightly by enhancing the discount rate. Thus, the optimal policy in the model is even more cautious that a benefit-cost analysis would suggest.

The different measurements of costs presented in this chapter illustrates the importance of making the concept of climate costs precise, and to making clear the context in which the measurement is to be used. To compare the estimated cost of emission control measures in terms of a reduction in GDP may be quite misleading if the aim is to examine what interests different countries may have when entering climate negotiations. We have also shown that a study of optimal climate policies may suggest quite different strategies than those suggested by traditional cost-benefit approaches. Most of the cost-benefit studies that have been carried out have emphasized the value of postponing abatement policies now. The main explanation is that the resources should be invested instead in alternative, productive, activities that will make us better able to meet climate change in the future, and will provide new technologies that will make abatement less expensive in the future. The cautious policy suggested by the study of optimal policy is explained somewhat differently. One explanation is the abatement cost, which is very high in the beginning. Thus, finding cheaper ways to reduce emissions may have direct and immediate impacts on climate policy. The second is that the damages due to climate change are regarded low at present. A third explanation indicated in Table 4-2 is that we have not yet regarded uncertainty. To take uncertainty into account seems to speed up climate policy significantly. This will be discussed more closely in section 8.3.

The cost of climate policy in studies of burden sharing

Ideally, the amount to spend on actions to slow down the speed of climate change should not exceed the expected benefits of these actions. In order to decide on a national climate policy, it is important to assess the costs of controlling the emissions of greenhouse gases. However, the benefits of reducing emissions are results of the actions of all the countries in the world. In order to evaluate the benefits of one country's climate policy, it is necessary to make some assumption about what other countries will do. The study of burden sharing may then be regarded as a two-step procedure. In the first step, the national policy is developed according to some rule for the distribution of abatement activities. In the second step, the countries negotiate a global target for climate policy in order to minimize the 'distance' from their own most preferred policy and the global agreement.

This puts strong requirements on the information required to study the sharing of burden of climate policy. In particular, it is vital to know how national characteristics, such as economic structure, abatement costs and anticipated effects of climate change, may affect the optimal climate policy of each country. National studies of emission control show that the main, explanatory factors for variations in the cost of emission control between countries are energy efficiency and energy structure in the countries. It is difficult to tell whether the few exceptions from this pattern are real or due to the choice of methods and assumptions in the studies.

Much less is known about the effects of the potential benefits of a climate policy. This is partly because little is known about the effects of climate change, and estimates of such effects are very uncertain. Another reason is the weakness of the methods usually applied to evaluate the benefits. For instance, most of the studies that have been carried out assume full certainty, and the implicit value of the climate is assumed to be constant and thereby independent of the change in the climate. Considering uncertainty and dependency between a changing climate and its implicit value, we show that the optimal policy may be quite different from the policy advocated by the traditional cost-benefit studies. Most economic studies warn against an aggressive climate policy now. They emphasize the advantages of investing in alternative activities, which may make countries better prepared for climate change in the future. By taking the changing value of the climate into account, it is shown in this stuydy that an aggressive policy may be beneficial if a way is found to reduce emissions at a low cost. Moreover, uncertainty about the effects of climate change may be a good reason for advancing actions.

5. COORDINATED CLIMATE-POLICY OPTIONS

Summary

The main purpose of this chapter is to analyze how different types of climate agreements, with the common characteristic that they commit OECD countries to reduce their CO_2 emissions, will distribute the abatement costs across these countries. This issue is analyzed both theoretically and within the framework of a numerical model. The model simulations presented assume that the OECD countries redesign their fossil fuel taxation to meet their commitments. These tax changes will cause changes in terms-of-trade and affect public revenue. One of the conclusions is that these changes will be in favor of countries with large net-import of fossil fuels and low fossil fuel taxes. A second conclusion is that an agreement with emphasis on commitments to the implementation of certain policies, exemplified by minimum fossil fuel taxes, might have some advantages not only in relation to cost-effectiveness but also in connection to fairness compared to agreements which rely mainly on quantified, national emission-reduction commitments.

5.1 Introduction

This chapter analyzes how different types of climate agreements, with the intention to reduce global CO_2 emissions through actions taken in the OECD area, will distribute costs among the member countries. The most important factors taken into consideration are terms-of-trade changes and the importance of the degree of coordination and implementation of measures.[1] An evaluation of the advantages and disadvantages of different policy measures is also provided.

The AGBM is intended to negotiate a protocol (or another legal instrument) to the Climate Convention which commits the Annex I countries to take action to reduce emissions of CO_2 and other climate gases not controlled by the Montreal Protocol. In accordance with the Berlin Mandate the focus in the AGBM process has so far been mainly on an agreement which specifies “quantified emission limitation and reduction objectives” (QELROs).[2] However, a climate protocol could also take other forms. The main alternative is a protocol which, instead of QELROs, commits the relevant parties to implement specified policies, for example carbon related fossil fuel taxes above a minimum level. The choice at this point will have consequences both for the degree of cost-effectiveness and the distribution of costs and benefits.

[1] ‘Terms-of-trade’ is the relationship between the prices of exports and prices of imports. A country is said to improve its ‘terms-of-trade’ if the prices of its exports are increased relative to the prices of its imports.

[2] The Berlin Mandate, paragraph II.

Just as an agreement which specifies QELROs could take several forms, an agreement which specifies policy commitments could be based on various principles. There is no doubt that taxation is a cost-effective policy instrument to reduce emissions of climate gases, especially emissions of CO_2, because of the linear relationship between the carbon content in the different fossil fuels and the emissions from combustion.[3] A certain, quantified CO_2 emission reduction in the OECD area as a whole could be reached in a cost-effective way, for example by a coordinated design of domestic fossil fuel taxes across the OECD countries.[4] Although such coordinated actions would bring about a cost-effective solution, it is by no means certain that the distribution of the costs and benefits would be considered fair. On the other hand, it is not more likely that an agreement which specifies QELROs will bring about a more acceptable distribution of the costs, but such an agreement would certainly not be cost-effective.[5] In addition to analyzing different types of protocols specifying QELROs, we will therefore discuss a type of agreement which commits the participating countries to implement fossil fuel taxation policies that satisfies certain specified requirements. The main purpose of this chapter is to compare different types of climate agreements and the distribution of costs and benefits across the OECD countries that follows from them. In addition, we will also be able to say something about cost-effectiveness.

In the following analysis of different types of agreements, we use a simulation model developed at Center for International Climate and Environmental Research - Oslo (CICERO) to explore how some essential differences in starting points between the OECD countries might cause considerable differences in the costs of achieving different types of commitments. The model and the economic theory behind it is described in detail in Holtsmark (1996). The characteristics of the starting points in focus are basically the fossil fuel taxes and the fossil fuel resource base. One of the purposes of this chapter is to make this analysis within a model framework that incorporates the links between these characteristics and a strategic behavior of the different national governments.

[3] Because of this linear relationship, a tax on fossil fuel consumption has the same effect as a tax on CO_2 emission. In the case of several other climate gases, for example methane, it is not that simple to design taxation policies with the same degree of accuracy and, thereby, cost-effectiveness.

[4] We are talking here about harmonization of domestic fossil fuel taxes collected by the national governments from the private sector in the different countries. An alternative type of agreement is one that implies the introduction of an international tax on greenhouse gas emissions paid by the national governments to an international agency. The international agency would also have the task of reimbursing the revenue to the participating countries according to some specified rules. Because it seems unrealistic to expect that such and agreement could be reached this case is not analyzed in the present report. Some further comments on this are found in chapter 4, however.

[5] From a theoretical point of view the quotas could be sized such that the emission reductions will be cost-effectively distributed. The problem is that there is a lack of unquestionable empirical information about variations in national abatement costs which, thus, leaves this as a *theoretical* possibility only.

An agreement among the OECD countries to reduce their total combustion of fossil fuels will directly affect the fossil fuel markets with terms-of-trade changes as one of the results. Together with the implemented policies, this will also affect the collection of public revenue in the different countries. These two effects of a climate agreement are analyzed by the use of the Holtsmark simulation model.[6] The quantitative estimates made by the model take into account that the large OECD countries, in particular, have significant market power in the fossil fuel markets. Therefore, by efficient use of their tax instruments, these countries will to some extent be able to reduce their own abatement costs.

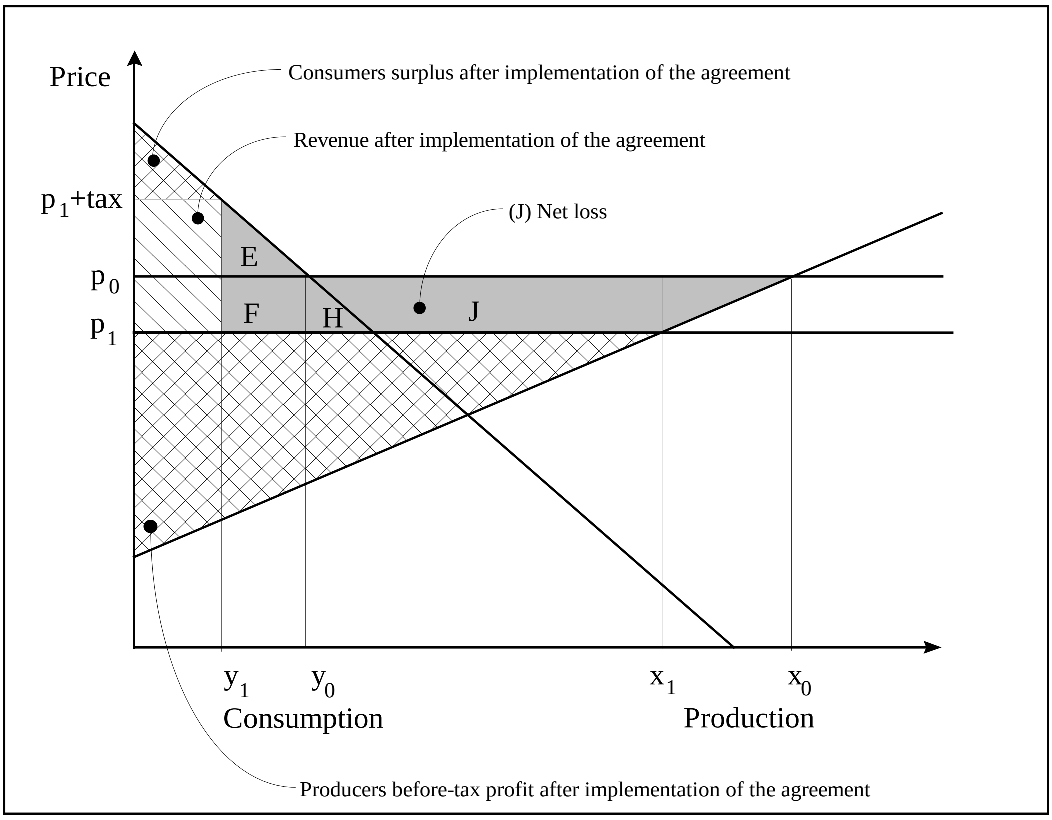
The numerical estimates of the total abatement costs in the different countries also take into account the transfer of resource rent from net exporters of fossil fuels to net importers. These estimates are adjusted for the losses and benefits from changing public revenue caused not only by changing tax rates, but also by terms-of-trade changes in the fossil fuel markets. Moreover it is discussed how different emphasis on the benefits from revenue generation might alter the taxation policy in this situation.[7]

This chapter is organized into ten sections. The following section provides an introduction to the model simulations, and may be essential for some readers if they want to understand the model simulations presented later in the chapter. In section 5.3 we briefly present some characteristics of the OECD countries which are essential in the model simulations. In section 5.4 we present some essential characteristics of the types of agreements analyzed in the model. In section 5.5 we present a model simulation that takes as its starting point an agreement committing the OECD countries to keep their fossil fuel taxes above a certain level. In section 5.6, equal-percentage emission reductions are analyzed. The size of the emissions reductions could theoretically be differentiated across the countries to secure a fair distribution of the costs. An agreement of this type is analyzed in section 5.7. In section 5.8

[6] The approach in this chapter has some similarities to the approach in Golombek, Hagem and Hoel (1995) and Golombek and Bråten (1994), which analyse how taxes on fossil fuels should be designed in a group of countries which have committed themselves to reducing *global* emissions of CO_2. Their analysis is, however, focused at cost-*effectiveness*, not as this report, on the *distribution* of costs.

[7] Although there is a vast amount of literature on the costs of combating greenhouse gas emissions, a large part of the literature is focused only on the measurement of the direct abatement costs. Surprisingly, most of the studies take into account neither the gains from revenue recycling nor the benefits or losses from changes in terms-of-trade (cf. Ekins (1995) and Hoeller and Wallin (1991)). Some examples of model studies taking terms-of-trade effects into account are Burniaux et al. (1992), DFAT and ABARE (1995), and Rosendahl (1994). Unfortunately none of these studies analyzes the benefits of revenue recycling. Several other studies, for example Jorgensen and Wilcoxen (1993), emphasize on the other hand the importance of taking revenue recycling into account, but ignore the terms-of-trade effects of several countries implementing climate policies at the same time. The contribution of our analysis is to give some indications on how the costs of a likely climate agreement will vary among the OECD countries when dead-weight-loss from taxation, gains from revenue recycling and terms-of-trade effects are taken into account. This is done while taking into account the effect of all the OECD countries implementing efficient abatement measures at the same time.

Figure 5.1 An illustration of the costs and benefits from a climate agreement in the case of a net exporter of fossil fuels.



and 5.9 we offer some brief comments regarding the burden sharing aspects of Activities Implemented Jointly and tradable quotas. Finally, conclusions are presented in section 5.10.

5.2 The distribution of costs and benefits

As an introduction to the model analysis in the following sections, we will here give a theoretical summary of some costs and benefits which will follow from a climate agreement. For the sake of discussion, let us assume that there is only one type of fossil fuel with a world market price p_0 in an equilibrium situation before a climate agreement is implemented. We also assume that the climate agreement commits a number of countries to reduce their *demand* for the fossil fuel, while suppliers of the fossil fuel are not committed to take any specific actions to reduce the supply. If the supply of the fossil fuel to the world market could be characterized by a rising supply curve, the reduced demand brought about by the climate agreement will cause a fall in the price of fossil fuels on the world market.[8]

[8] If the suppliers are behaving strategically and are forward looking, it is not quite obvious that such a climate agreement will cause an immediate price fall. For a further discussion, see Rosendahl (1994) and Berg, et al. (1996).

Assume that we look at a country with a net export of fossil fuels, but which is so small that we can ignore its power in the fossil fuel market. Such a country's situation could be described by Figure 5.1. The horizontal line at the price level p_0 should be interpreted as an approximation of the non-domestic supply of fossil fuel before the implementation of the climate agreement. For simplicity let us assume that there are no taxes on production or consumption of fossil fuel in this country in this equilibrium. The upward sloping line represents the country's supply at different price levels, while the downward sloping line represents the corresponding demand. Consequently, the domestic consumption of the fossil fuel is y_0, while the domestic production is x_0.

The net export is then (x_0 - y_0). If the supply curve represents the domestic marginal cost curve, the area below this curve is an indicator of the extraction costs. Because the producers' total income is p_0x_0, the triangle limited by the vertical axis, the price line and the supply curve represents the producers' before-tax profit. Correspondingly, the area limited by the price level (p_0), the vertical axis and the demand curve represents the consumers' surplus. Ultimately, the sum of these two triangles (which includes both the shaded, the hatched and the cross-hatched areas) could be used as an indicator of this country's net benefit from consumption and production of fossil fuels before the implementation of the climate agreement.

The dotted horizontal line labeled p_1 represents the price level in the new equilibrium which will be established after the implementation of the climate agreement. The domestic production is then reduced to x_1. We assume that the country we are analyzing is committed to reducing its consumption of fossil fuels from y_0 to y_1, and that this is brought about by the introduction of a tax on the consumption of fossil fuels. The tax will constitute a wedge between the world market price (i.e. p_1) and the domestic consumer price.

Analyzing the consequences of the climate agreement, we should first of all remark that the consumers' surplus is reduced to the upper cross-hatched triangle and the producers' profit is reduced to the lower cross-hatched area. The hatched quadrangle represents the public revenue from the fossil fuel taxation. Thus, the country's total net benefit from the production of fossil fuels after the implementation of the climate agreement is reduced to the sum of the hatched and cross-hatched areas. Hence, the climate agreement has caused an income loss to this country, with the loss corresponding to the size of the shaded areas (E+F+H+J). The sum of the areas E, F, and H represents the dead-weight-loss from taxation of fossil fuels in this country and the area J represents this country's net income loss from a lower fossil fuel price in the world market.[9]

Figure 5.2 An illustration of the costs and benefits from a climate agreement in the case of a fossil fuel net importer without significant market power.

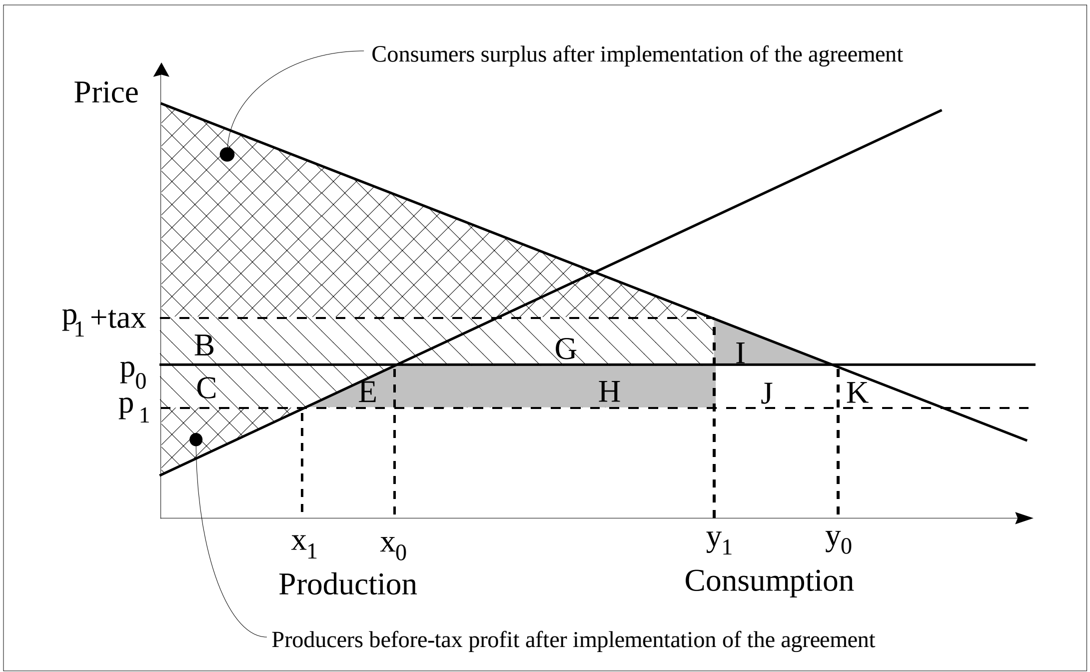


Figure 5.2 describes the corresponding case of a net importing country; one which is also without significant market power.[10] The net benefit from the production and consumption of fossil fuels in this country is the sum of the hatched and cross-hatched areas plus the triangle I, where the triangle *below* the price line p_0 represents the producers' profit and the triangle above represents the consumers' surplus.

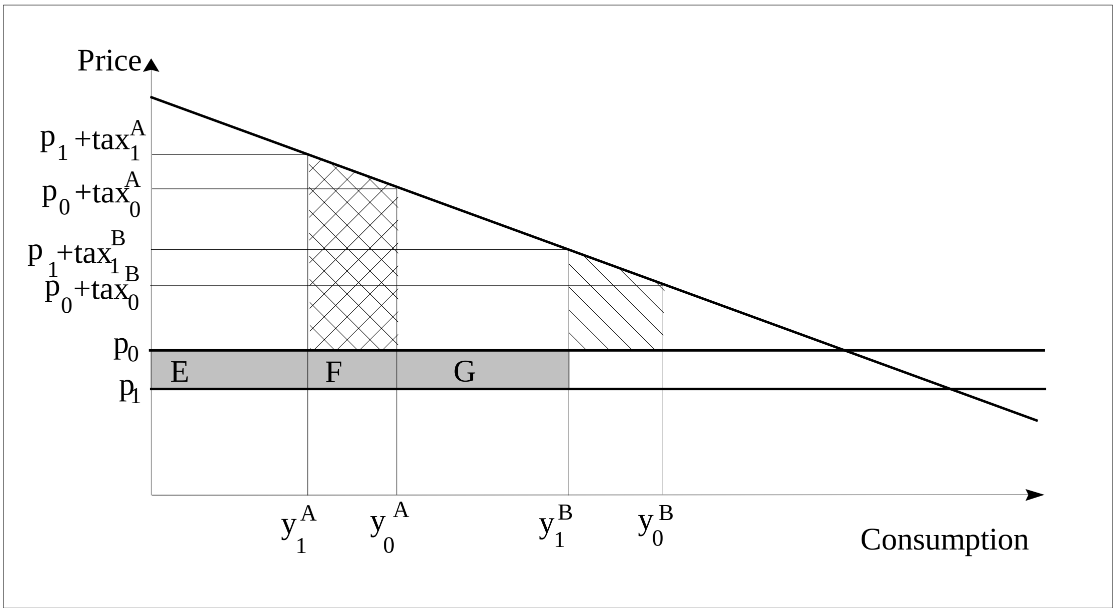
Let us now assume that this country is committed to reducing its consumption of fossil fuels from y_0 to y_1. As in the case of the net exporter of fossil fuels this is brought about by the introduction of a tax on consumption. Contrary to the case of the net-exporting country it is not clear whether the importing country will experience a net gain or loss from the implementation of the climate agreement. Due to the price decline in the market for fossil fuels the producers' profit is reduced to the lower cross-hatched triangle, and the consumers' surplus is reduced to the upper cross-hatched triangle. However, we should include the quadrangle containing B, C, E, G, and H on the income side because it represents the revenue from taxation of fossil fuels. Consequently, whether the country will experience a net gain or

[9] Use of the term dead-weight-loss in this chapter could be criticized because the taxes are introduced to correct for an externality. From a shortsighted, national point of view the term 'dead-weight-loss' could be used as an approximation.

[10] The scales of the axes in Figure 5.1 and Figure 5.2 should be interpreted as different in these two figures.

a net loss depends on whether the area I is larger than the sum of E and H. If the price fall and the net import are relatively large, we are talking about a substantial terms-of-trade gain and E and H will be large. On the other hand, if the domestic demand for fossil fuels is relatively inelastic, for example, due to few possibilities for substitution, the area I will be large.

Figure 5.3 An illustration of the dead-weight-loss from fossil fuel taxation in the case of no taxes at the starting point (country B) and in the case of a considerable fossil fuel tax at the starting point (country A).



In the above examples it was assumed that there were no fossil fuel taxes before the implementation of the climate agreement. The level of the fossil fuel taxes in the reference situation, however, is essential to the magnitude of the costs of the implementation of a country's commitments. The importance of the level of fossil fuel taxes in the reference situation is illustrated in Figure 5.3. For the sake of this example, let us assume that we have two countries, A and B, which are identical except that country A has lower fossil fuel consumption (y_0^A) due to a higher fossil fuel tax. We also assume that these two countries do not have any indigenous fossil fuel production, but are committed to reduce their emissions by the same amount; that is, from y_0^A to y_1^A and from y_0^B to y_1^B. Finally, we assume that this is part of a climate agreement which causes the fossil fuel price to drop from p_0 to p_1. Country A then has a terms-of-trade gain equal to the area E. The tax *increase* gives rise to a dead-weight loss extension equal to the cross-hatched area. As a result, the net gain from the climate agreement is equal to the area E minus the cross-hatched area. Correspondingly, country B has a net gain equal to the shaded area (E+F+G) minus the hatched area. This example illustrates the more general rule that the marginal increase in dead-weight loss of increased taxation is higher, the higher the tax is in the first place; while the level of the fossil fuel taxes and the terms-of-trade gains from lower fossil fuel prices in the world market are inversely related.

In the above comments to Figure 5.1 and Figure 5.2 some important components in the complete set of costs and benefits of a climate agreement are ignored in order to simplify the discussion. In the numbered paragraphs below some comments on these components are given:

1. According to previous discussion, increased dead-weight loss should be expected as one of the consequences of a climate policy. However, this is a result of the simplifying assumption that there is only one type of fossil fuel. In reality there are three, basic fossil fuel types and these are again applied in several different sectors and in different qualities. If the tax rates vary among the different applications and types, it is likely that the taxation policy is not optimally designed in the first place.[11] The typical taxation pattern is that petrol is heavily taxed while most other oil products and coal and gas are not as heavily taxed, if taxed at all. When that is the case, dead-weight loss will not necessarily be increased when a cost-effective climate policy is implemented. We will see examples of this in the following sections.
2. If the emission reduction commitments are met by the use of fossil fuel taxation, public revenue will be affected. Increased revenue enables the governments to reduce other taxes ('recycle' the revenue) and, consequently, the dead-weight loss from traditional taxation. Therefore, the revenue generated through the implementation of a climate policy should be seen as an element which reduces the costs of the climate policy. The higher the marginal excess burdens of taxation, the more weight should be given to the revenue generating effect.[12] As an example, let us reconsider Figure 5.2 in the case where the excess burden of taxation is 0.5. The implementation of the climate policy in this country generates a revenue equal to the size of the quadrangle containing B+C+G+E+H, which we denote R. This could be 'recycled' in order to reduce distortionary taxes. In our case such a tax reduction would increase the efficiency in the economy and thereby the total

[11] In this case "optimally" is interpreted as what is optimal from a narrow, short-term national view, ignoring the climate change externality of fossil fuel combustion.

[12] Almost all taxes distort behavior of households and firms. With the exception of taxes which correct for external effects such as environmental harm, such distortions generate lower efficiency in the economy as a whole and consequently reduced national income. The marginal excess burden of taxation (MEB) is a short expression for costs in the form of reduced national income from a marginal increase of public revenue brought about by increased distortionary taxes. There is a vast amount of literature on MEB with the estimates varying between 0.0-1.0. One half is a point estimate in good accordance with the literature, however. See for example Ballard et al. (1985) and Jorgensen and Wilcoxen (1993). The MEB of taxation is equal to marginal costs of public funds minus 1.

value of the production by half the quadrangle R. This means that the country will experience a net loss only if the area I minus the area E+H is larger than half of the quadrangle R.

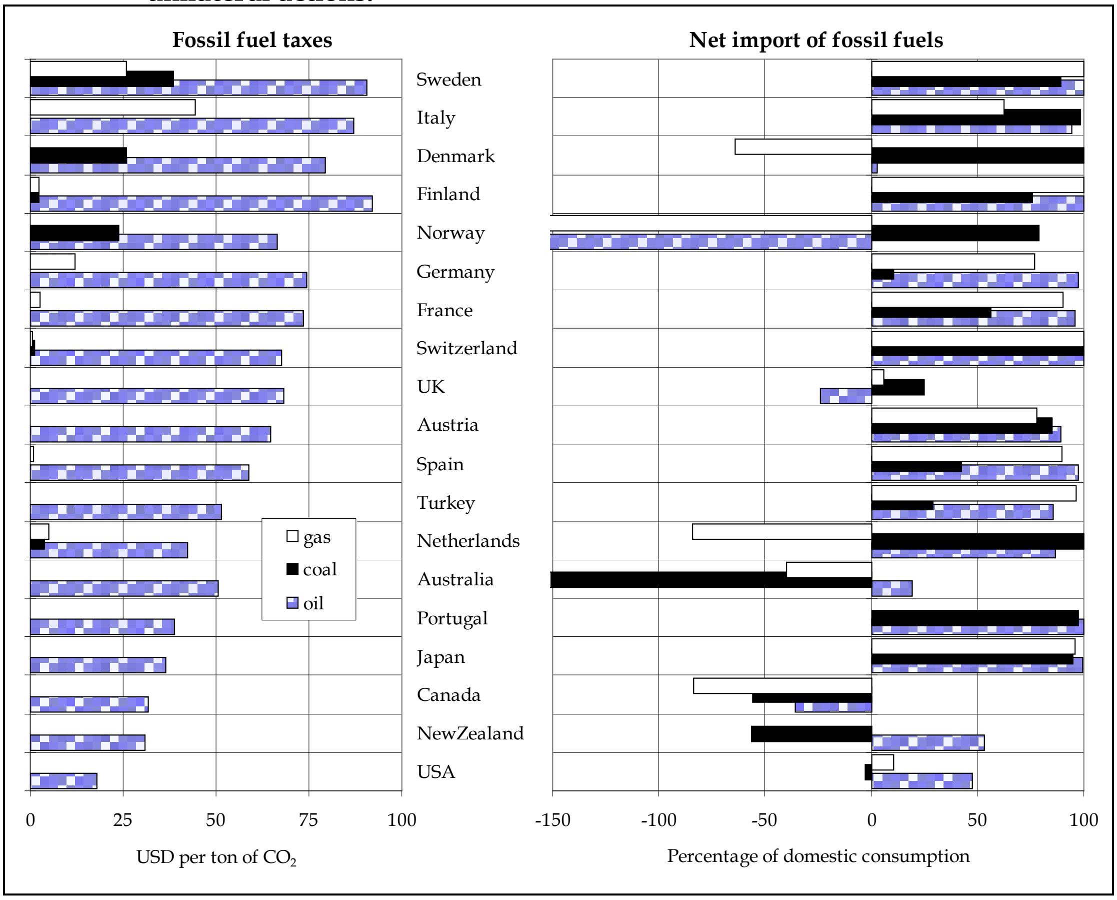
3. The implementation of a climate policy in the OECD countries will not only alter the terms-of-trade in the fossil fuel markets. The increased energy prices (paid by consumers) will be reflected in increased prices of products produced by intensive use of energy; for example, iron, steel, and non-ferrous metals such as aluminum. These effects, together with general changes in demand and supply patterns caused by the relative price changes, will alter terms-of-trade in several other directions than those mentioned above. Some countries, for example, will experience net terms-of-trade improvements from this, while others will experience deteriorated terms-of-trade. These secondary terms-of-trade effects further modify the burden sharing consequences in relation to the simplified schemes used in the illustration above.

Modifying points 1 and 2 could be illustrated by the case of the USA and Sweden. If we look at Figure 5.5 we find Sweden at the top of the "Fossil fuel taxes" chart. This is due to the relatively high taxation of coal, gas and oil consumption in this country. At the bottom we find the United States with no taxation of natural gas or coal and, on average, relatively low taxes on oil products. The costs these two countries will experience if they take unilateral actions to reduce their CO_2 emissions, measured in reduced welfare as a percentage of GDP, are shown in Figure 5.4. The figure assumes that the taxation of the fossil fuels is efficiently designed.[13] The solid lines represent the welfare loss if benefits from revenue recycling are not assumed.[14] The calculations indicate that in this case the USA could reduce its emissions of CO_2 by about 5% without any welfare loss. The corresponding figure in the case of Sweden is only about 2%. The more rapid increase in the welfare loss in Sweden is due to the high tax level in this country in the first place which gives rise to a higher marginal dead-weight loss, see the comments to Figure 5.3.

[13] To be more precise; the solid lines represent the case where the MEB is assumed to be zero.
[14] The calculations are done with the model documented in Holtsmark (1996).

Figure 5.3 Fossil fuel taxes and imports in OECD 1993

Figure 5.4 Abatement costs as percentage of GDP in the USA and Sweden assuming unilateral actions.



* Some numbers concerning Norway (oil -1316% and gas -864%) and Australia (coal -215%) exceed the scale of the diagram. The tax rates include all taxes on consumption except value added taxes(VAT). Sources: ECON (1995) and OECD (1995).

The broken lines represent the welfare losses in the cases where there are assumed to be significant benefits from revenue recycling.[15] A noteworthy result is that just the implementation of an efficient taxation of fossil fuels under this assumption means a 15% reduction of emissions of CO_2 in the USA. Notice that the broken line in the chart of the USA starts at 15%. Further reductions in the USA imply reduced welfare compared to the efficient taxation situation, but the emissions could be reduced by slightly more than 35% in the USA before there will be a net loss compared to the reference situation. The situation is quite contrary in Sweden. Due to the relatively high fossil fuel taxes in the first place, there is not a corresponding potential for increasing the tax revenue by increasing the fossil fuel taxes. The numerical examples illustrated in Figure 5.4 underline the importance of the level of the fossil fuel taxes for a country's abatement costs.

5.3 Characteristics of the current situation

Figure 5.5 provides the average level of the sum of all taxes implemented on fossil fuels in a selected number of the OECD countries. The tax levels and structures vary substantially, but the typical pattern is high taxes on oil and low or no taxes on coal and gas. Together with Italy, the Nordic countries have the highest taxes on oil products.

From an efficiency point of view the uneven level of the taxes levied on the three different fuels is remarkable. The taxation pattern, however, is even more inefficient because Figure 5.5 hides the fact that there is not a uniform taxation of oil for different applications in the OECD countries. About half the oil used in countries belonging to the OECD is for transportation, and it is this part of the oil consumption that is mostly taxed. Oil, on the other hand, used in industry production, is taxed at much lower rates, if such use is taxed at all.

In addition to the inefficient taxation of fossil fuel consumption, there are considerable subsidies to production of coal in Germany, and to some extent in the UK and Spain (see ECON, 1995).

Figure 5.5 also presents the size of the net imports of the fossil fuels in the selected OECD countries as a percentage of total domestic consumption. These numbers have relevance in an analysis of the distribution of costs of a climate agreement (Figure 5.1 and Figure 5.2). Norway is an exceptional case because of its large production of natural gas and oil relative to its consumption. Therefore, among the OECD countries Norway is a very vulnerable party as far as repercussions from a climate agreement affecting the fossil fuel markets are concerned. The negative effects on the Norwegian economy from falling fossil fuel prices are further exaggerated since the fossil fuel production in Norway, through taxation of resource rent and direct public ownership, represents a substantial part of the total public revenue.

5.4 Principles, schemes and tools for the distribution of climate measures across countries

No matter what approach is taken by a climate agreement or the types of commitments specified, there will be drawbacks and obstacles. Every possible agreement will therefore represent a compromise between crossing interests. It will for example be difficult if not impossible to reach an agreement that imply a cost-effective distribution of emission

[15] In these numerical examples the MEB is assumed to be 0.4 in both countries. This assumption not only alter the measured welfare loss, but also the taxation policy of the two countries. The model used in these numerical examples makes the strong assumption that the countries always implement an efficient climate policy. When

Table 5.1 List of possible agreement scenarios*

Scenario	OECD emission reduction in percentage	MEB of taxation**	Type of agreement
1A 1B	20 40	0.0*** 0.0***	The OECD countries are committed to keep total fossil fuel taxes (ignoring VAT) above an agreed upon level
2A 2B 2C	20 40 20	0.0*** 0.0*** 0.4	Equal national emission reductions (in percentage)
3B	40	0.0***	Equal welfare reductions in percentage of GDP

* The reference situation is 1993 and the model is simulated as if we are still in 1993. See comment below.

** MEB can be taken into account in different ways in the model simulations and this could cause confusion. The point is that in all scenarios except scenario 2C, the national governments are assumed to maximize a welfare function which does not include benefits from revenue recycling. This should be interpreted as assuming that the national governments design their policies as if they believe that the MEB is zero. Scenario 2C on the other hand assumes that the national governments maximize welfare functions that include benefits from revenue recycling and that they believe the MEB is 0.4.

*** When benefits from revenue recycling are presented later in this chapter there is an underlying assumption that the MEB is 0.4.

reduction commitments and at the same time will be considered as fair by all parties. It is therefore likely that an agreement will represent a give and take between the demand for cost-effectiveness and a fair distribution of commitments.

As pointed out in section 5.1 we direct the focus towards two types of agreements: agreements specifying QELROs and agreements specifying commitments concerning the taxation of fossil fuels. In the next section we discuss an example of an agreement which implies a cost-effective approach in the sense that a certain emission reduction target for the OECD area as a whole is reached through coordinated, efficient taxation of fossil fuel consumption. Specifically, instead of complete harmonization of the taxes, we assume that the agreement analyzed, specifies minimum taxes. That means that the participating parties are assumed to be committed to implement these minimum taxes if the level of them exceed the current fossil fuel taxes. In section 5.6 we follow up with an analysis of an agreement which commits the participating parties to equal percentage emission reductions. In section 5.7 we also analyze how the different national quotas should be specified so as to induce equal welfare reductions in the percentage of GDP.

the MEB is assumed to be larger than zero, a consequence is that the countries' taxation of fossil fuels is different compared to the case where the MEB = 0, because more emphasis is put on revenue generation.

The characteristics of the different agreement scenarios are listed in Table 5.1. Some results are presented in diagrams below. Detailed simulation results are found in Annex A5. A remark should be made on the choice of time for the scenarios. The model is calibrated to fit OECD data for 1993. In the Berlin Mandate the years 2005, 2010 and 2020 are mentioned as possible time frames for an agreement. Despite the fact that it is likely that the economies of the OECD countries and their role in the world economy will have changed substantially before reaching these points in time, we simulate the model as if we are still in 1993. This is done to make the simulation results more transparent. To simulate the model through 2005, 2010, and 2020 would require making several assumptions about the development in the different OECD countries and in the rest of the world between 1993 and these points in time. Such assumptions will always be weak and speculative, yet at the same time have crucial implications for the results. Choosing 1993 as the base year and the starting point for all the simulations make the simulation results as easy to interpret as possible. In the interpretation you must keep in mind that characteristics of the situation in 1993 are likely to have changed substantially before, for instance, 2005. One important factor, for example, will be the increased importance of non-OECD countries in the world economy in the next century. For an elaborate discussion of these changes, see DFAT and ABARE (1995).

As with all applied, numerical models the results of our simulations are closely linked to the model framework and the set of assumptions. Therefore, all results must be interpreted with care. Rather than giving any final answers, the results must be seen as a step in the process leading towards an increased understanding of this issue.

5.5 A cost-effective agreement as a reference situation

As a starting point we will analyze an agreement with a cost-effective approach where the fossil fuel taxes measured in USD/ton of CO_2 emissions are harmonized across the participating countries.[16] Full harmonization would implies however that several countries should reduce their oil taxes and it would be somewhat peculiar to analyze such an agreement. Instead, we assume that the agreement introduce *minimum* tax levels. In other words, we assume that an agreement is reached which commits the OECD countries to

[16] To be more precise, this is only cost effective if the MEB of taxation is zero in all the participating countries. As long as the MEB of taxation and demand patterns are different among the parties it is cost effective to vary the emission tax policy across parties (cf. Holtsmark, 1996). On the other hand, it is unrealistic that a climate agreement could commit the parties to introduce different emission taxes. In the presented model simulations labeled as ‘cost-effective’ the sum of the national welfare indicators, which do not include benefits from revenue recycling, is maximized.

Table 5.2 Minimum required fossil fuel taxes measured in USD/ton of CO2 in scenarios 1A and 1B in the three world regions.

	Scenario 1A			Scenario 1B		
	Oil	Coal	Gas	Oil	Coal	Gas
Europe	38.25	26.71	32.85	61.22	50.48	54.38
North America	38.25	26.71	25.96	61.22	50.48	50.67
Pacific	38.25	26.71	30.56	61.22	50.48	54.50

investigate all their fossil fuel taxes and to apply tax increases or new taxes where the taxes in total are found to be smaller than the minimum taxes specified in the agreement.

Although several problems concerning implementation and control of such an agreement will arise, problems of this type will probably also be important in relation to a protocol specifying QELROs. Our main interest in this report however, are the burden sharing consequences. Advantages and disadvantages in connection to transparency and control have to be further investigated.

Table 5.2 shows the minimum tax levels in two scenarios, 1A and 1B, of agreements that commit the parties to held fossil fuel taxes above the agreed upon level. In scenario 1A, where the CO_2 emissions from OECD countries in total are reduced by 20%, the parties are committed to charge taxes on oil consumption of at least USD 38.25 per ton of CO2 and on coal consumption of at least USD 26.71 per ton of CO2 . The substantial difference between these two required minimum taxes is due to the strategic role of the OECD in the fossil fuel markets and the assumption that the welfare of only the OECD countries is maximized in a cost-effective way. The fact that the OECD area imports a larger share of its oil consumption than of its coal consumption is one of the factors behind this result. This type of tax-rate differentiation will generate relative price changes in the fossil fuel markets that favor the OECD countries.[17]

The taxation on natural gas is modeled in a somewhat more complicated manner. While the model assumes that there are world markets for oil and coal, three regional markets (North America, Europe, the Pacific) for natural gas are modeled to accommodate for high transportation costs. Hence, because it is assumed that a climate agreement is formulated in such a way that the sum of the welfare indicators of the OECD countries is maximized, the minimum required gas taxes differs among these three regions. The relatively low gas taxes in North America are due to the fact that the USA and Canada do not import gas from countries not taking part in the agreement. The OECD countries in Europe and the Pacific are on the other hand net importers.

If we compare Table 5.2 with Figure 5.5 we see that in scenario 1A the taxes on oil consumption must be adjusted upwards in only a limited number of countries where these taxes are low in the current situation (1993). On the other hand, taxes on coal and gas must be increased substantially (or introduced) in most of the OECD countries.

The left diagram in Figure 5.6 shows the emission reductions in scenario 1A as a percentage of the CO_2 emissions in the reference situation. The uneven distribution of emissions reductions which will follow from a cost-effective agreement is evident. Due to the high fossil fuel taxes in Sweden, for instance, it is not cost-effective that this country take further actions if the target is to reduce OECD emissions by 20%. The USA, UK and Australia, on the other hand, should reduce their emissions by more than 20% due to the low and inefficient fossil fuel taxes and the relatively intensive use of coal in these countries in the reference situation.

The diagram on the right in Figure 5.6 shows the changes in the welfare indicators measured as a percentage of the GDP brought about by the implementation of the climate agreement analyzed in scenario 1A.[18] The dark gray bars represent the welfare changes before the net public revenue increase is recycled into the economy.[19] Norway is at the bottom of this chart despite the limited emission reduction commitment placed on this country (as indicated in the left chart). This result is due to Norway's special role as a small country highly dependent on fossil fuel exports (cf. Figure 5.5). It is also due to the fact that that the climate agreement in this scenario is estimated to reduce producer oil prices by 3.1% and the producer price on natural gas in the European market by 5.6% (cf. Table 5.3).

The other three participating parties with significant welfare losses are the USA, Canada and Australia. This is mainly due to low fossil fuel taxes in the reference situation. In the cases of Canada and Australia, it is also related to their considerable fossil fuel exports. When several of the other countries experience limited welfare losses and even net gains, the reason is

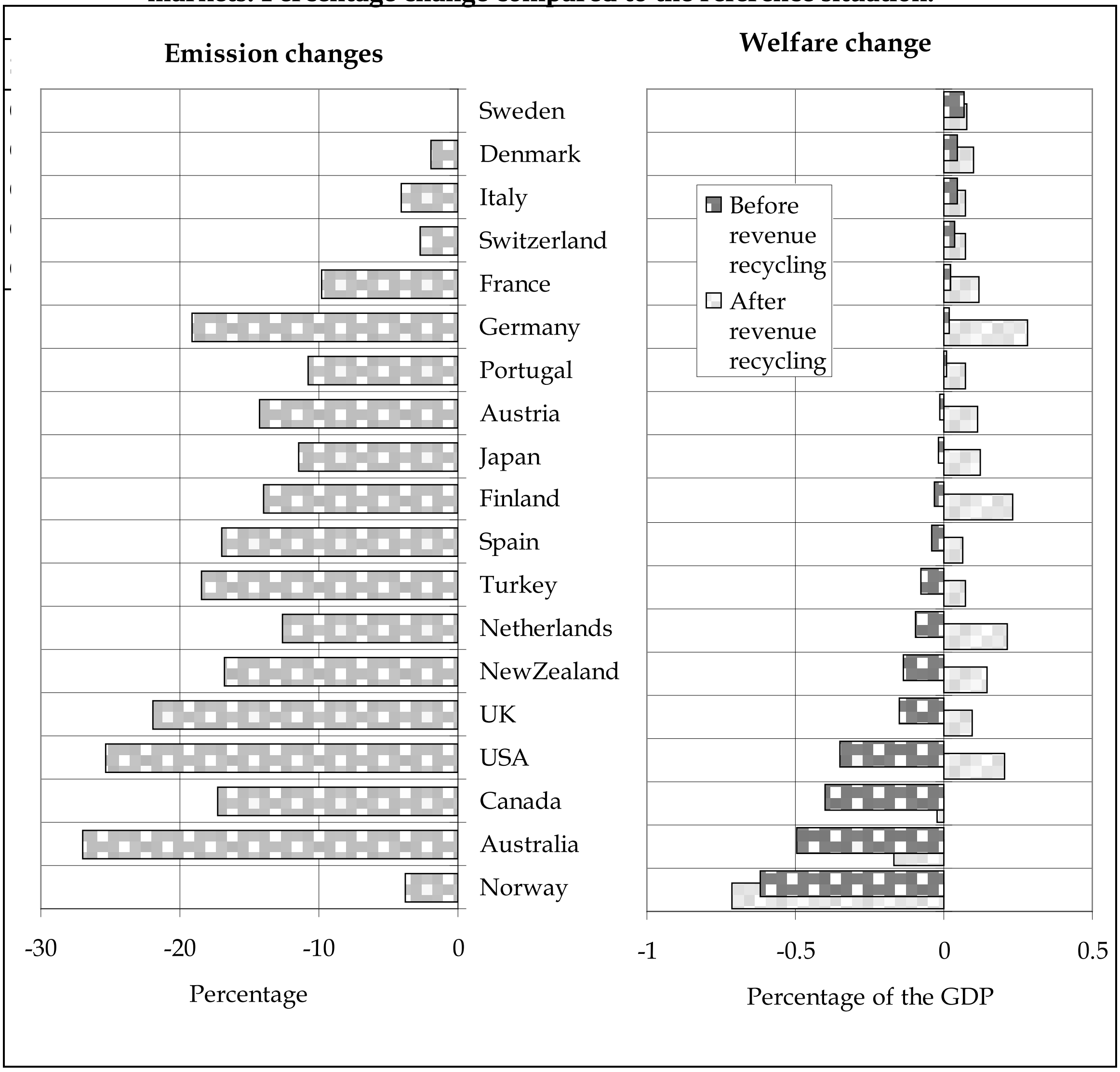
[17] If we are talking about a protocol to FCCC such differentiation of the tax rates in favor of OECD is, of course, totally out of the question. It could be an option, however, if the annex II countries in the OECD, independent of the FCCC process, take some sort of coordinated action.

[18] In section 5.2 it is illustrated how climate agreements will cause both income losses and reduced consumer surplus in the different countries. The model simulations provide estimates of these losses. The term 'welfare reductions' is defined as the sum of the income loss and the reduction in consumers surplus.

[19] For an explanation of the term 'revenue recycling', see the comments in point 2 on page 96.

Figure 5.6 Scenario 1: 20% emission reduction through uniform fossil fuel taxes

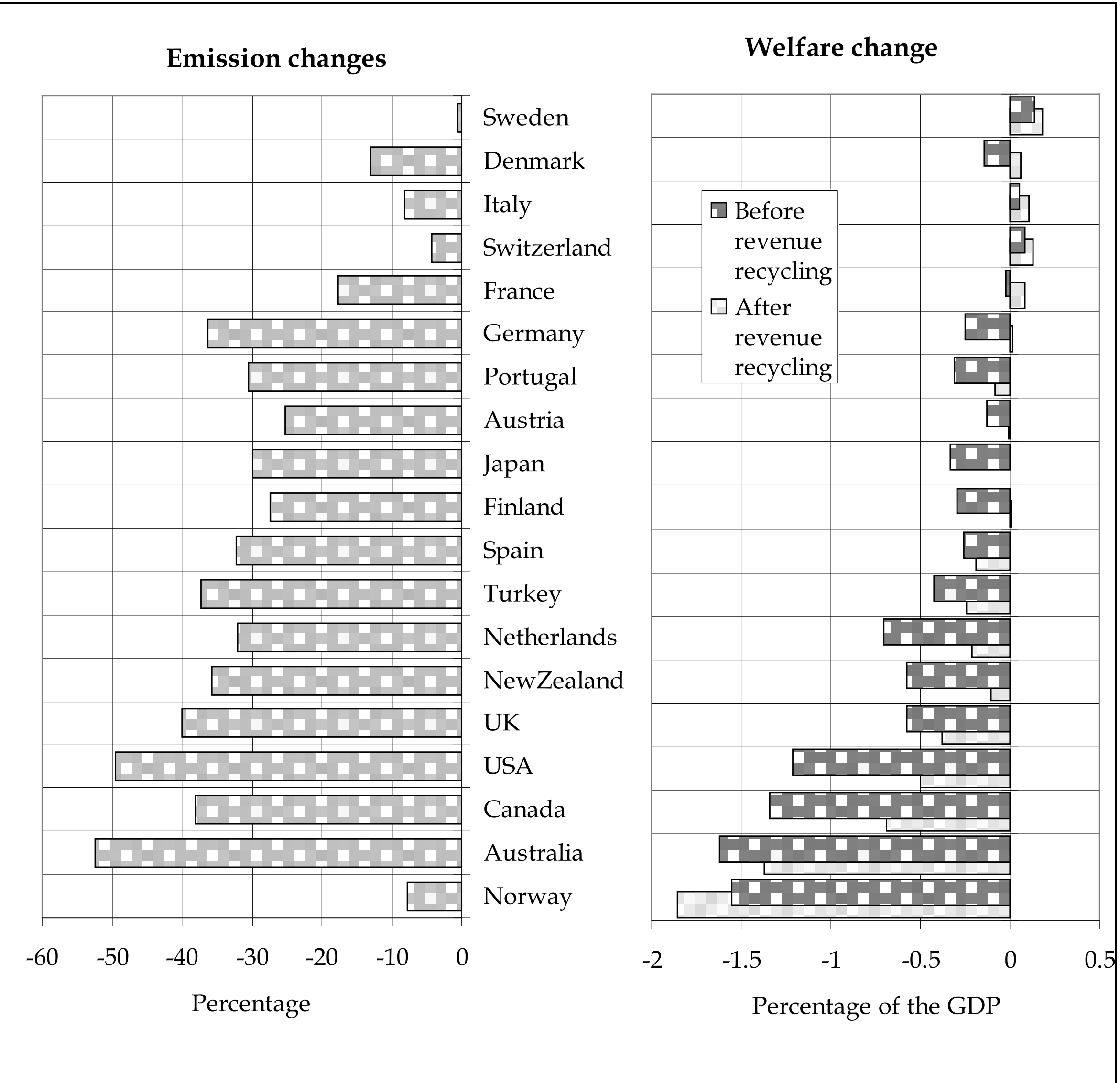
Table 5.3 Fossil fuel prices in the world markets and the regional gas markets. Percentage change compared to the reference situation.



partly that the terms-of-trade effects from lower fossil fuel prices are considerable due to high import shares.

The light gray bars in Figure 5.6 represent the changes in the welfare indicators taking into account that revenue generated could replace or reduce other taxes.[20] If these taxes distort economic behavior, such revenue recycling will increase the efficiency of the national economies. The simulations indicate that an emission reduction of the size we are considering here is a “no regret” option for several OECD countries. The assumed size of the MEB are crucial for this result. Furthermore, it is based on the assumption that the OECD countries

Figure 5.7 Scenario 1B- 40% emission reduction through minimum fossil fuel taxes.



coordinate their actions in order to obtain the underlying terms-of-trade gains. The terms-of-trade changes partly explain the negative welfare effects for Norway, Australia and Canada even when revenue recycling is taken into account.

The Norwegian public sector receives a large part of the profit in the off shore oil and gas production through taxation and direct ownership. The reduced gas and oil prices in scenario 1A reduces the profit in this sector and, therefore, the Norwegian public revenue. This reduction is estimated to be larger than the increased revenue from increased taxation of

[20] The welfare indicators maximized in scenarios 1A and 1B do not include benefits from revenue recycling. The light gray bars represent the changes in the welfare indicators that include benefits from revenue recycling. This is done by assuming that the marginal excess burden (MEB) of taxation is 0.4 in all the countries. Concerning the USA, a MEB of taxation of 0.4 is in accordance with Jorgensen and Yun (1990) who found that the MEB of the US tax system as a whole is 38 cents per dollar of revenue raised. This estimate is uncertain, (cf. for example Ballard et al., 1985), and is also likely to differ among the OECD countries.

fossil fuel consumption. This explains why the welfare reduction in the case of Norway is larger when benefits from revenue recycling is included than in the case where such benefits are not included.

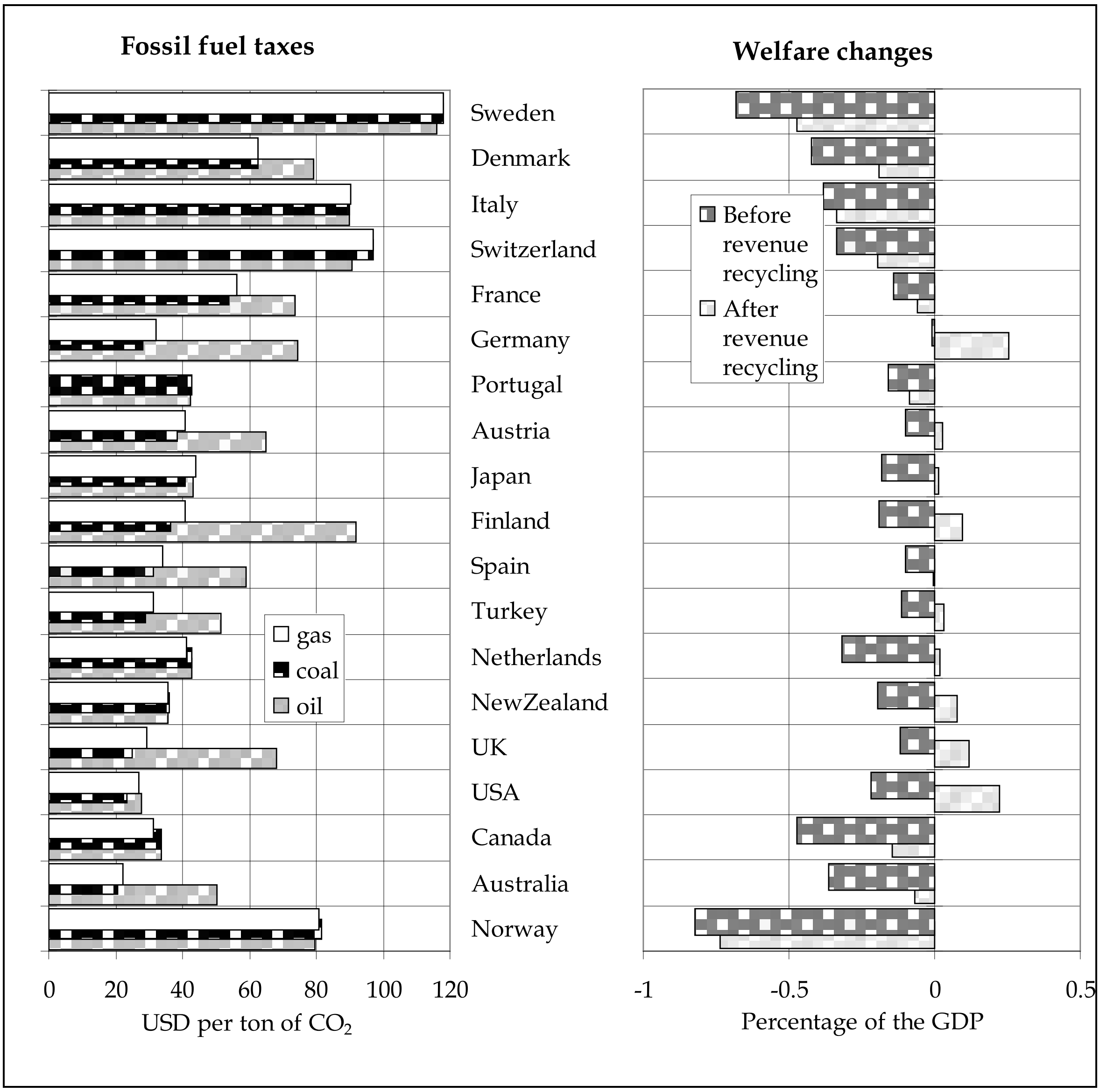
In scenario 1B the total emissions of CO_2 from the OECD countries are reduced by 40% through an agreement which, as with scenario 1A, implies minimum levels for fossil fuel taxes (cf. Table 5.2). There are no dramatic changes in the emissions reduction pattern compared to scenario 1A, apart from a slightly more even distribution of the emission reductions (cf. Figure 5.7). The non-linear relationship between emission reductions and welfare reductions, however, is evident from the substantial increase in the welfare losses. This is related to the increasing marginal dead-weight loss from taxation when tax rates are increased (cf. the comments to Figure 5.4 on page 98). A remarkable feature, when we compare the results with scenario 1A, is the tendency towards reduced gaps between the welfare changes before and after the inclusion of the benefits from revenue recycling. This is related to the relationship between revenue and tax rates which, as a simplification, could be said to have a “Laffer-curve property”.

Due to a predicted reduction in the oil and gas prices of 8.4% and 9.8%, respectively, Norway is the country with the largest welfare loss in scenario 1B. The world market price of coal is predicted to fall 16% and that drop in price partly explains the substantial welfare loss for Australia.

We are now able to draw some preliminary conclusions from scenarios 1A and 1B. It is obvious that a cost-effective agreement, which commits the OECD countries to certain minimum levels for fossil fuel taxes, will imply substantial welfare losses to some countries, especially Australia, Canada, and the USA, at least in the case with 40% emission reduction. Several other countries will experience only small losses or even net gains. This distribution of costs should be seen in relation to the per capita emissions in the current situation, which are considerably above average in the three countries mentioned. Countries that have already implemented substantial fossil fuel taxes will have an advantage in this type of agreement.[21] However, such taxes could reflect that these countries on a unilateral basis have implemented abatement measures. It seems reasonable to credit such initiatives in a climate agreement.

[21] Norway experiences substantial welfare losses in scenarios 1A and 1B despite relatively high fossil fuel taxes in the reference situation.

Figure 5.8 Scenario 2A - 20% uniform emission reductions.



5.6 Emission constraints and uniform percentage reductions

As pointed out in the introduction to this chapter, much of the focus in the AGBM process has been towards an agreement setting quantified emission restrictions. Rather than providing an elaborate discussion about possible problems with implementation and control, we will assume that such an agreement could be implemented. Our attention is on the distribution of the costs.

In scenarios 2A and 2B, all OECD countries are committed to reduce their emissions of CO_2 by 20% and 40%, respectively (cf. Table 5.1). It should be emphasized that these emission reductions are accomplished through replacement of the current fossil fuel taxation by a policy giving priority to efficiency. Nevertheless, as in scenarios 1A and 1B, the tax rates are not in any cases adjusted downward. [22]

A first result of scenario 2A, evident from Figure 5.8, is that the fossil fuel taxes measured per unit of CO_2 are harmonized within the different small countries with negligible market power in the fossil fuel markets. Where the oil taxes were high in the first place, however, there is not complete harmonization and there is no tendency towards harmonization *across* countries. In the larger countries, or countries with substantial interests in the fossil fuel markets, the taxes are further adjusted to take advantage of their market power. This is evident for instance in the case of the USA and Canada, which have opposing interests in the North American gas market. These interests are reflected in their fossil fuel taxation policies predicted in scenarios 2A and 2B (cf. Figure 5.8 and Figure 5.9).

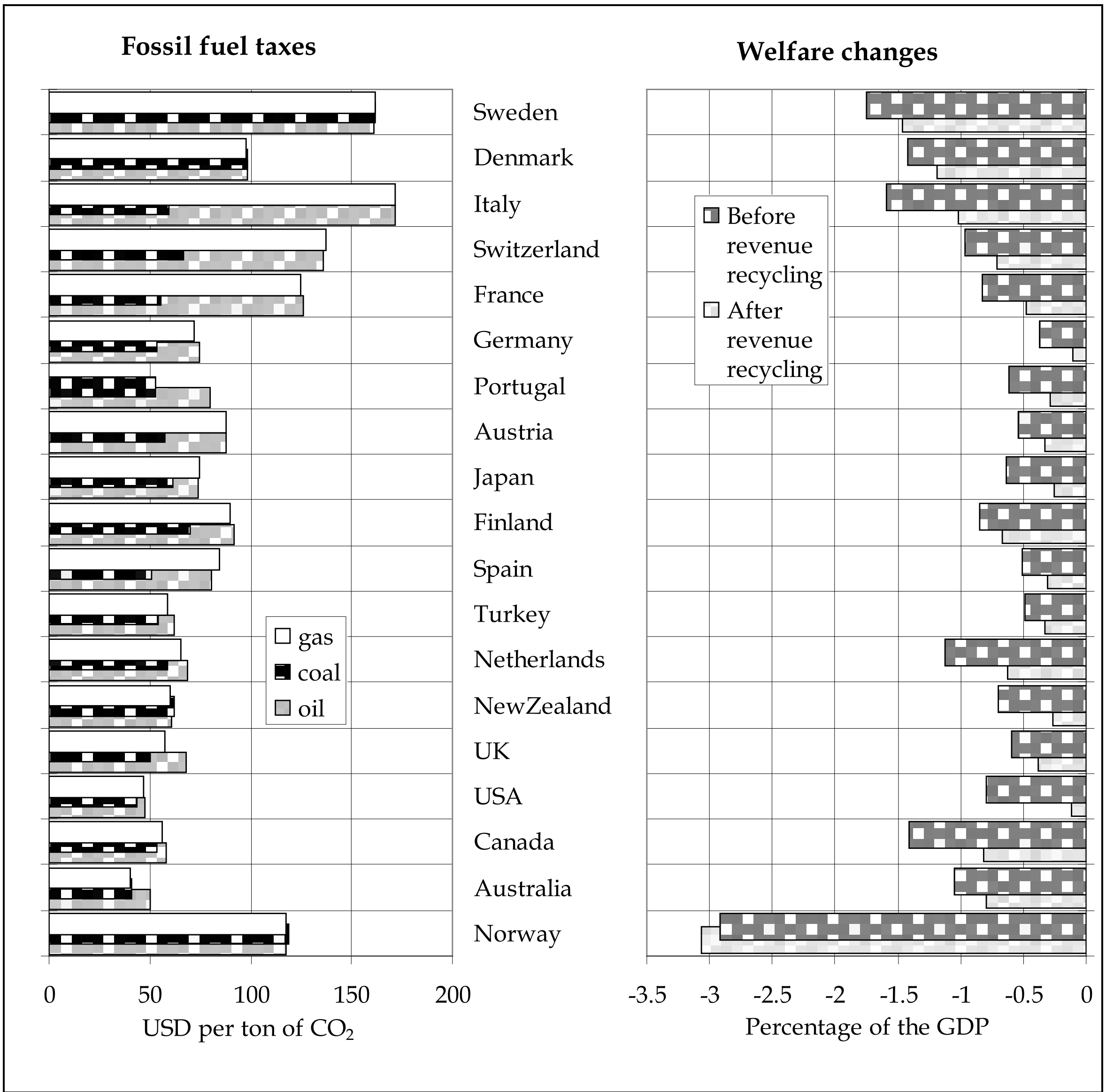
The costs, measured by the reductions in the model's country-specific welfare indicators, are quite differently distributed compared to scenario 1A. The relatively large welfare losses in countries like Sweden, Denmark, Italy and Switzerland to some extent reflect the high fossil fuel taxes in the reference situation. Other factors, such as the carbon intensity in the reference situation, also play a role here. Denmark's intensive use of coal, for instance, is contrasted by the fact that some coal taxes have already been introduced in this country. The fact that coal in Germany is not taxed in the reference situation, explains a large part of the difference between the outcomes of Denmark and Germany. Germany could reach its 20% reduction commitment simply by the introduction of a more efficiently designed fossil fuel taxation system.

The Netherlands is a country with substantial welfare loss in scenario 2A. This is due to a terms-of-trade loss (natural gas price in Europe drops 7.3%) and high domestic abatement costs due to low coal consumption and high gas consumption in the reference situation.

The relatively small welfare loss in Norway is due to the fact that the oil price is approximately unchanged in scenario 2A. The reason for this development is the reduced oil taxes in several countries.

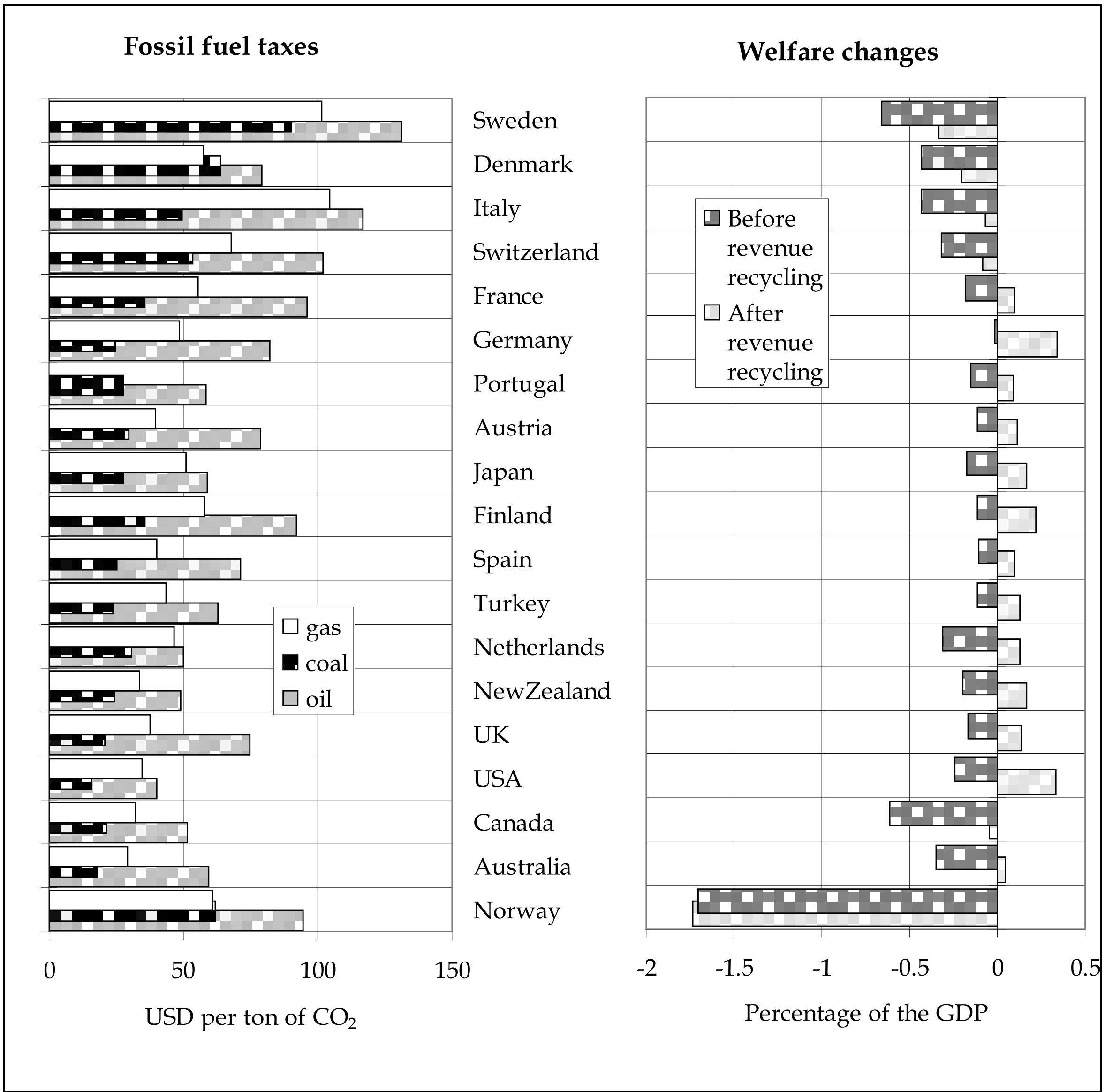
[22] Each OECD country maximizes a welfare indicator with respect to the tax rates on the consumption of oil, coal and gas subject to the emission constraint and the constraints that the fossil fuel taxes must be at least at the level of the reference situation. The governments take their market power in the fossil fuel markets into account, but do not take into account that they could also affect the responses of other countries. The welfare indicators which are maximized in scenarios 2A and 2B do not include benefits from revenue recycling. If the welfare indicators which include such benefits where maximized, the fossil fuel taxation policies would have been designed in a different way (cf. Holtsmark (1996) for an analysis of that case).

Figure 5.9 Scenario 2B - 40% uniform emission reductions.



Before we give a few comments on scenario 2B, we will make some remarks on scenario 2C. As with scenario 2A, scenario 2C is based on a possible agreement that commits the OECD countries to reduce their CO_2 emissions by 20%. The difference between the scenarios lies in the specification of the maximized welfare functions; in scenario 2C they include benefits from revenue recycling. Despite the lack of unquestionable empirical information and the fact that the size of these benefits is uncertain and probably vary across countries, we have assumed that revenue recycled in all the countries increases the welfare indicator by 40% of the amount of revenue which is recycled.[23] Although it is important to underline the limited empirical basis for this assumption, some indications of the importance of revenue recycling can be given.

Figure 5.10 Scenario 2C - 20% uniform emission reductions - political weight on revenue recycling



As reflected in Figure 5.10 the new choice of objective function changes both the behavior and the distribution of costs significantly. The domestic harmonization of fossil fuel taxes in scenario 2A is replaced by taxation patterns with a tendency towards higher oil taxes and lower taxes on coal and gas, with higher public revenue as a result. The simulation points out that a 20% CO_2 emission reduction is a "no regret" option in several OECD countries, with the largest return in the USA and in Germany. A major part of this, however, is due to terms-of-trade gains from the price drop in the fossil fuel markets. A background simulation not documented in this report shows that if these price reductions had not taken place, that means assuming that the supply is perfectly elastic, the net gains almost vanish or turn negative in

[23] This corresponds to assuming that the MEB is 0.4 in all OECD countries (cf. footnotes 12 and 15).

countries like Japan, Austria, Finland, Spain, and Turkey. On the other hand, in that case the Norwegian welfare loss would be reduced from 1.7% to about 0.2% of the GDP and the Canadian loss would change to a net gain.

In scenario 2B, as in scenario 2A, we are assuming that the participating countries maximize welfare functions which do not include benefits from revenue recycling. The emission reductions are increased to 40%, and the welfare losses are consequently quite considerable in a number of countries. Norway has the largest welfare loss due to the price drops in the fossil fuel markets. Sweden, Denmark and Italy also experience substantial welfare losses in this scenario. The noteworthy welfare losses of Australia, Canada, and the Netherlands are related to the significant price drop in the fossil fuel markets in this scenario, cf. Table 5.3.

A striking observation is that the welfare losses of the USA and Germany, in the case when benefits from revenue recycling are taken into account, are less than 0.15% of the GDP. These, and the other results from the simulation model, must be interpreted in a long-term perspective. If such emission reductions had to be carried out on a short-term basis the costs would have been much larger.

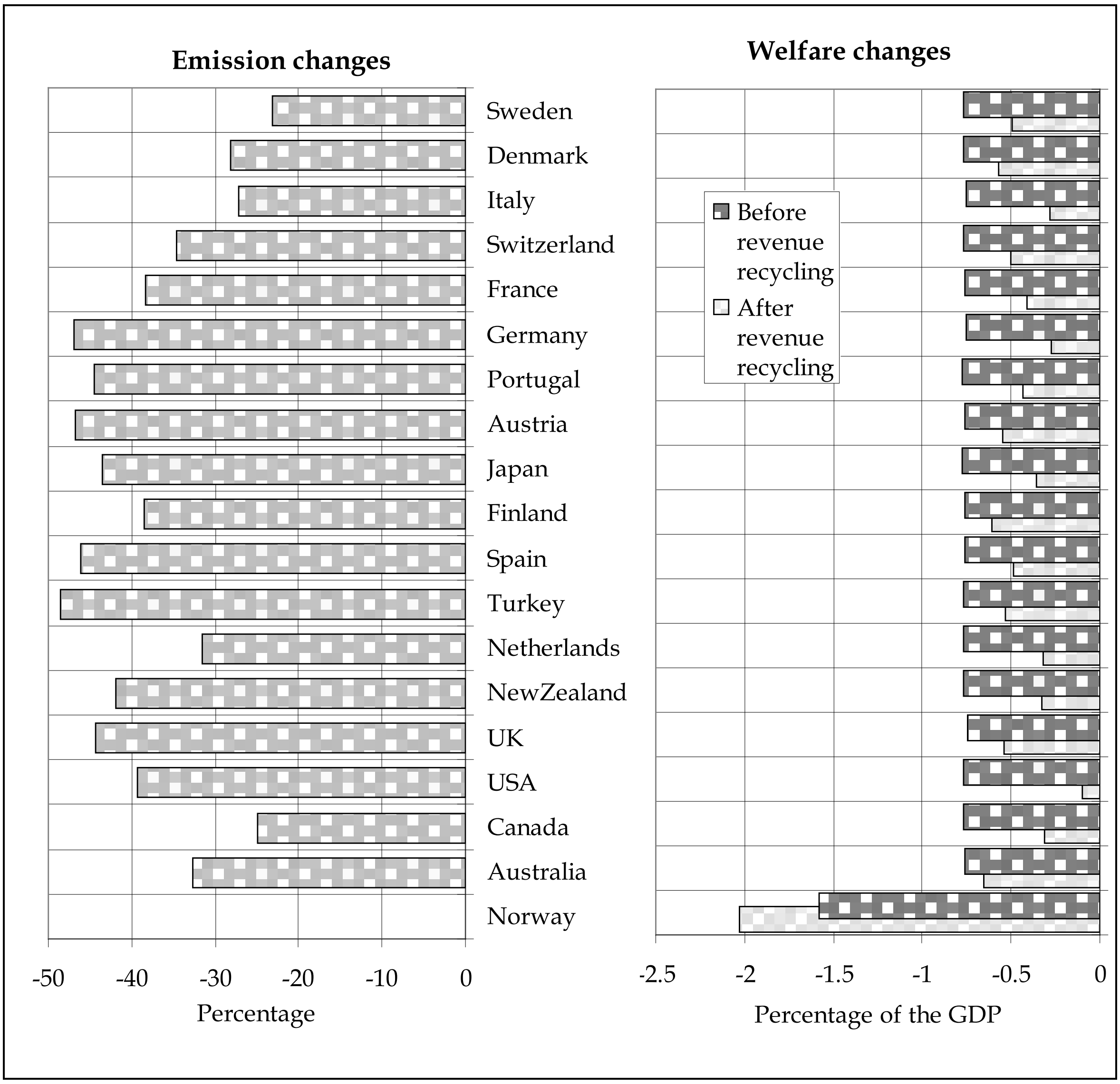
5.7 Welfare-adjusted emission reduction commitments

Section 5.5 focused on a possible protocol which commits the participating parties to implement certain *policies*. More specifically, the section analyzed efficiency and burden sharing properties of agreements setting minimum levels for the national fossil fuel taxes. Section 5.6 focused on agreements committing the parties to equal percentage reductions of their CO_2 emissions. The distribution of the costs is totally different in these two major types of agreements, but they share the characteristic that this distribution, by some of the parties, might be found unacceptable.

To solve for such types of problems, there have been some proposals of a third type of agreement which imply national emission quotas adjusted to account for differences in abatement costs. An example of such an agreement is analyzed through a simulation labeled scenario 3B. In this scenario total OECD emissions of CO_2 are reduced by 40% relative to the reference situation. The emission reductions are distributed in such a way that the welfare losses are equal when measured as a percentage of the GDP.

One exception in this scenario is for Norway, which is assumed to have no commitments. The reason is that Norway’s main welfare loss is likely to be connected to a price drop in the

Figure 5.11 Scenario 3B - welfare adjusted emission reductions



fossil fuel markets, not domestic abatement measures. Therefore it is difficult to fit Norway into this type of scheme.

The emission reduction commitments are shown in the left diagram of Figure 5.11. A surprising result is that the emission reduction commitment of the USA is slightly below the average of 40%. Nevertheless, the welfare loss, when taking benefits from revenue recycling into, account is very small in the case of the USA. Hence, if the welfare indicator that includes benefits from revenue recycling had been used as the basis for the emission reductions, the emission reduction in the USA would have been larger and above the average of 40%.[24] In general; the variation in the welfare indicators that include benefits from

[24] A background simulation not presented here shows that if the welfare indicator that includes benefits from revenue recycling had been used, the emission reduction of USA would have been 44%.

revenue recycling indicates that if this welfare indicator had been used as the basis for the emission reductions, it would have resulted in a different set of emission reduction commitments. Some parties will gain from a change of the welfare indicator and others will lose. This clearly shows how difficult it will be to have an agreement of this type. Several critical assumptions in this type of model simulation are always open for discussion. For instance, if benefits from revenue recycling are to be included, a question arises about how to calculate these benefits in the different countries.

5.8 Joint Implementation under the Climate Convention

Referring to the mitigation of climate change and limiting emissions of greenhouse gases, the FCCC states that "… These Parties may implement such policies and measures jointly with other Parties…" (Article 4.2.a). This type of cooperation is usually referred to as Joint Implementation (JI).

A general definition of JI is a cooperation between two or more parties to the FCCC with the aim to fulfill their national commitments to reduce GHG emissions. The idea is that such cooperation would be more cost-effective in achieving a reduction in GHG emissions since abatement costs seem to vary substantially from country to country. It also means that mitigation investments in a JI system could be undertaken in those countries where such investments are cheapest compared to the GHG abatement effect (see Torvanger et al., 1994).

The first COP in Berlin in the spring of 1995 agreed to a pilot JI phase until the year 2000 to gain knowledge and develop the mechanism. During this phase no credits will be given to countries that invest in abatement projects in other countries (host countries). The alternative term Activities Implemented Jointly was introduced during this COP and specifically refers to such cooperation in the pilot phase until the year 2000. After the year 2000 an operational JI phase with established rules and crediting can begin if such a plan is supported by all parties to the FCCC. For this purpose methods and procedures to handle measurement and control problems must be developed. These problems relate to issues such as base-year definition and climate effect measurements as well as the status of 'no regrets' projects. Furthermore there is a question if JI funding is additional or not.

In the context of the AGBM negotiations and burden sharing, JI will mostly be of interest after the year 2000 if and when the mechanism is established and credits for investing countries are allowed. Given crediting, JI could contribute to reduced national abatement costs for countries where domestic emissions reduction efforts are expensive. This would increase the level of cost-effectiveness at both the national and international level. The potential cost saving depends on the groups of countries included in the JI system. The largest JI potential is probably found in developing countries, Eastern Europe and Russia. In the first period after the year 2000, JI projects involving Annex I countries (i.e. OECD countries, East European countries and Russia) are likely to be more acceptable for all parties to the FCCC than projects in non-Annex I countries (i.e. developing countries). Implementation of favorable JI projects in the pilot phase and development of appropriate institutional arrangements will, however, increase the confidence in JI and increase the likelihood of involving all countries in JI projects, which would, ultimately, increase the global cost-saving potential.

With this perspective an operational JI system after the year 2000 could contribute to reducing the climate policy costs of high-cost countries, and could thus make these countries willing to accept larger commitments. These increased commitments could increase the ambition level of the OECD with respect to emissions reduction target. The closer an agreement is to equal emission reductions across countries, the more interesting options such as JI become because they have the potential to reduce the cost for high-cost countries. On the other hand the JI option is uncertain since it depends on acceptance from all FCCC parties for crediting after the year 2000. The cost saving potential is also somewhat uncertain since we do not know if and when JI projects in developing countries will be accepted.

5.9 Tradable emission quotas

In sections 5.6 and 5.7 we analyzed agreements which were assumed to specify national emission quotas, and we implicitly assumed that these quotas were non-tradable. The possibility of trading quotas will have consequences both for efficiency and for the distribution of costs and benefits.

In simple markets for emission quotas it is clear that the introduction of quota-trading will not make any participants worse off. The reason is that quota trading is made on a voluntary basis and the participants are free to not take part in the trading. Nevertheless, in the case of national CO_2 quotas the introduction of quota-trading could make countries worse off. We explain the reason below.

In a situation with fully competitive markets, a system with tradable CO_2 quotas would theoretically secure a cost-effective solution and there would be only winners compared to the situation where the quotas were non-tradable. In practice the market for quotas could not be characterized as competitive. This is due to the fact that there are some large countries within the OECD that would have significant power in the market for quotas. The United States, for example, stands for nearly half of the OECD emissions. As long as one or more participants in a market have significant market power, it is unlikely that the equilibrium will be cost-effective.

If this lack of cost-effectiveness was the only problem, all countries would still be at least as good off after the introduction of trade, as before. The reason why some countries could lose from the introduction of tradable quotas, is related to the repercussions from the markets for fossil fuels. The transfer of quotas by trading is likely to change the relative prices of the fossil fuels and thereby the terms-of-trade gains and losses.

As an illustration, let us assume that the introduction of trade leads to increased emission reductions in countries with a relative coal-intensive fossil fuel consumption. Consequently, trading quotas could bring about a reduced demand for coal and an increased demand for oil and gas. This would affect the prices in the markets for fossil fuels, increasing the export income of Norway for example, while coal-exporting Australia could lose.

Originally our intention was to use the simulation model to elaborate this, but due to the complexity of the issue, the model has to be improved and expanded to be able to thoroughly analyze this question.

5.10 Conclusions

Although the greenhouse problem is caused by anthropogenic emissions of several climate gases, the main focus in this chapter has been on CO_2 . There are several reasons for this. First of all, CO_2 is considered to be the most important climate gas. Thus, it is likely that commitments to reduce CO_2 emissions will be an important part in a possible agreement at COP-3.

With the help of a numerical model, we have analyzed three basically different types of agreements. First, we analyzed an agreement which committed the Annex-I countries to implement certain policies, here specified as minimum levels for domestic fossil fuel taxes (1A and 1B). Then we analyzed agreements which implied uniform, quantitative emission restrictions (2A, 2B and 2C). Finally we explored a possible agreement where the specified quantitative emission reductions where adjusted so as to secure a fair distribution of the welfare losses (3B).

A first conclusion is that, irrespective of the type of agreement we are talking about, the welfare losses are quite small despite considerable emission reductions. The terms-of-trade gains that Annex I countries will experience, especially the possibility to coordinate their actions and take advantage of their role in the fossil fuel markets, is a factor explaining this result.

A second conclusion is that the level of the fossil fuel taxes in the situation before a climate agreement is implemented is important for the national abatement costs. The marginal abatement costs are likely to be high in countries with high fossil fuel taxes due to a high marginal dead-weight loss in this situation. At this point, the benefits from revenue recycling, which are difficult to estimate, are important in the valuation of abatement costs. With high taxes in the first place, increased tax rates are likely to bring about small amounts of revenue. This is contrary to the situation in countries with small fossil fuel taxes, where increased tax rates are likely give larger increases in the revenue. In general, if there are large costs in the form of efficiency losses related to revenue collection, high fossil fuel taxes will be crucial in the valuation of the abatement costs.

A third conclusion is that inefficient taxation of fossil fuels in the first place enables some countries to reduce their CO_2 emissions to some extent with net benefits, a so called “no regret” option. Such countries could meet their commitments just by the introduction of a more efficient system for the taxation of fossil fuels.

The conflicting interests between the fossil-fuels-exporters and the net-importers among the Annex I countries are apparent. Norway’s special strategic interests due to this country’s role as producer is of course striking but should not be surprising due to the importance of oil and gas production in this country’s economy. Some of the other fossil fuel exporters - Canada, Australia, UK, and the Netherlands - will experience, in different ways and to varying extent, corresponding terms-of-trade losses. However, these losses are of minor importance to their economies compared to the situation in Norway.

If it is possible to reach and implement a climate agreement which implies commitments towards the implementation of certain policies, such agreements would have several advantages. As far as burden sharing is concerned such agreements imply that credits are given to countries that have already implemented a national climate policy. One of the disadvantages of quantitative emission restrictions is that it is difficult to reach consensus on how to adjust the different national quotas in order to give proper weight to this type of considerations. Differentiation of national quotas based on national circumstances must ultimately be based on numerical calculations. However, such calculations could always be improved or be made the object of discussion. Consequently the probability for reaching this type of agreement might be small.

ANNEX A5

Table A.1 Emission changes as a percentage of the reference emissions.

Scenarios	1A	1B	2A	2B	2C	3B
Australia	-27.0	-52.3	-20.0	-40.0	-20.0	-32.7
Austria	-14.3	-25.3	-20.0	-40.0	-20.0	-46.7
Belgium	-13.2	-27.7	-20.0	-40.0	-20.0	-40.3
Canada	-17.3	-38.1	-20.0	-40.0	-19.7	-24.8
Denmark	-2.0	-12.9	-20.0	-40.0	-20.0	-28.1
Finland	-14.0	-27.4	-20.0	-40.0	-20.0	-38.5
France	-9.8	-17.7	-20.0	-40.0	-20.0	-38.4
Germany	-19.2	-36.4	-20.0	-40.0	-20.0	-47.0
Greece	-20.3	-38.0	-20.0	-40.0	-20.0	-40.6
Ireland	-19.5	-37.8	-20.0	-40.0	-20.0	-42.5
Italy	-4.1	-8.2	-20.0	-40.0	-20.0	-27.1
Japan	-11.5	-29.9	-20.0	-40.0	-20.0	-43.5
Luxembourg	-17.3	-32.3	-20.0	-40.0	-20.0	-36.6
Netherlands	-12.6	-32.0	-20.0	-40.0	-20.0	-31.6
New Zealand	-16.8	-35.8	-20.0	-40.0	-19.9	-41.9
Norway	-3.8	-7.8	-20.0	-40.0	-20.0	2.4
Portugal	-10.8	-30.4	-20.0	-40.0	-20.0	-44.5
Spain	-17.0	-32.3	-20.0	-40.0	-20.0	-46.1
Sweden	0.6	-0.6	-20.0	-40.0	-20.0	-23.2
Switzerland	-2.7	-4.2	-20.0	-40.0	-20.0	-34.6
Turkey	-18.4	-37.3	-20.0	-40.0	-20.0	-48.5
UK	-22.0	-40.0	-20.0	-40.0	-20.0	-44.3
USA	-25.3	-49.4	-20.0	-40.0	-20.0	-39.2

Table A.2 Welfare changes as a percentage of the GDP in the reference situation. Benefits from revenue recycling are *not* taken into account.

	1A	1B	2A	2B	2C	3B
Australia	-0.49	-1.62	-0.36	-1.05	-0.35	-0.76
Austria	-0.01	-0.13	-0.10	-0.54	-0.11	-0.76
Belgium	0.00	-0.29	-0.16	-0.76	-0.16	-0.76
Canada	-0.40	-1.34	-0.47	-1.41	-0.61	-0.77
Denmark	0.05	-0.15	-0.42	-1.42	-0.43	-0.77
Finland	-0.03	-0.29	-0.19	-0.85	-0.11	-0.76
France	0.02	-0.02	-0.14	-0.83	-0.18	-0.76
Germany	0.02	-0.25	-0.01	-0.37	-0.02	-0.76
Greece	-0.16	-0.65	-0.19	-0.74	-0.08	-0.76
Ireland	-0.11	-0.55	-0.14	-0.62	-0.08	-0.73
Italy	0.04	0.05	-0.38	-1.59	-0.43	-0.76
Japan	-0.02	-0.34	-0.18	-0.64	-0.18	-0.77
Luxembourg	-0.07	-0.51	-0.18	-0.98	-0.06	-0.76
Netherlands	-0.10	-0.70	-0.32	-1.12	-0.31	-0.76
NewZealand	-0.14	-0.57	-0.20	-0.70	-0.20	-0.76
Norway	-0.62	-1.55	-0.82	-2.92	-1.71	-1.58
Portugal	0.01	-0.31	-0.16	-0.61	-0.15	-0.77
Spain	-0.04	-0.25	-0.10	-0.51	-0.11	-0.76
Sweden	0.07	0.14	-0.68	-1.75	-0.66	-0.76
Switzerland	0.04	0.08	-0.34	-0.96	-0.32	-0.76
Turkey	-0.08	-0.42	-0.11	-0.49	-0.11	-0.77
UK	-0.15	-0.58	-0.12	-0.59	-0.17	-0.75
USA	-0.35	-1.21	-0.22	-0.79	-0.24	-0.76

Table A.3 Welfare changes as a percentage of the GDP in the reference situation. Benefits from revenue recycling *are* taken into account.

	1A	1B	2A	2B	2C	3B
Australia	-0.17	-1.37	-0.07	-0.80	0.05	-0.65
Austria	0.11	-0.01	0.03	-0.33	0.12	-0.55
Belgium	0.24	0.10	0.10	-0.31	0.27	-0.38
Canada	-0.02	-0.69	-0.15	-0.82	-0.05	-0.31
Denmark	0.10	0.06	-0.19	-1.19	-0.21	-0.57
Finland	0.23	0.01	0.10	-0.67	0.22	-0.61
France	0.12	0.08	-0.06	-0.47	0.10	-0.41
Germany	0.28	0.02	0.26	-0.11	0.34	-0.28
Greece	0.03	-0.59	0.00	-0.71	0.12	-0.79
Ireland	0.16	-0.27	0.12	-0.45	0.22	-0.46
Italy	0.07	0.11	-0.34	-1.02	-0.07	-0.28
Japan	0.12	0.00	0.01	-0.26	0.16	-0.35
Luxembourg	0.27	-0.23	0.15	-0.59	0.32	-0.40
Netherlands	0.21	-0.21	0.02	-0.62	0.13	-0.32
NewZealand	0.14	-0.11	0.08	-0.27	0.17	-0.33
Norway	-0.71	-1.85	-0.74	-3.07	-1.73	-2.03
Portugal	0.07	-0.08	-0.09	-0.29	0.09	-0.43
Spain	0.06	-0.19	0.00	-0.31	0.10	-0.49
Sweden	0.08	0.18	-0.47	-1.47	-0.33	-0.49
Switzerland	0.07	0.13	-0.19	-0.71	-0.08	-0.50
Turkey	0.07	-0.24	0.03	-0.32	0.13	-0.53
UK	0.10	-0.38	0.12	-0.38	0.14	-0.54
USA	0.20	-0.50	0.22	-0.12	0.34	-0.10

Table A.4 Average oil-taxes in USD/ton of CO_2.

Scenario	Baseline	1A	1B	2A	2B	2C	3B
Australia	50.5	50.5	61.2	50.5	50.5	59.4	36.8
Austria	64.8	64.8	64.8	64.8	87.8	78.9	97.4
Belgium	49.4	49.4	61.2	49.4	74.6	65.0	70.3
Canada	31.7	38.2	61.2	33.5	57.9	51.5	40.9
Denmark	79.4	79.4	79.4	79.4	98.1	79.4	80.4
Finland	92.0	92.0	92.0	92.0	92.0	92.0	88.1
France	73.5	73.5	73.5	73.5	125.8	96.0	122.4
Germany	74.4	74.4	74.4	74.4	74.4	82.2	101.9
Greece	65.7	65.7	65.7	65.7	65.7	65.7	63.4
Ireland	55.2	55.2	61.2	55.2	55.4	55.2	63.8
Italy	87.0	87.0	87.0	90.0	171.9	116.9	134.2
Japan	36.5	38.2	61.2	43.4	74.0	59.0	81.7
Luxembourg	67.1	67.1	67.1	67.1	77.5	67.1	73.0
Netherlands	42.4	42.4	61.2	42.9	68.5	50.2	56.9
New Zealand	30.8	38.2	61.2	35.6	60.4	49.0	63.1
Norway	66.6	66.6	66.6	79.6	117.3	94.6	66.6
Portugal	38.7	38.7	61.2	42.3	79.6	58.2	87.6
Spain	58.9	58.9	61.2	58.9	80.8	71.2	97.1
Sweden	90.7	90.7	90.7	115.9	161.4	131.2	125.6
Switzerland	67.6	67.6	67.6	90.5	136.3	102.1	126.3
Turkey	51.5	51.5	61.2	51.5	61.8	63.1	78.9
UK	68.2	68.2	68.2	68.2	68.2	74.9	70.7
USA	18.1	38.2	61.2	27.7	47.4	40.2	46.6

Table A.5 Average coal-taxes in USD/ton of CO2

Scenario	Baseline	1A	1B	2A	2B	2C	3B
Australia	0.0	26.7	50.5	20.4	41.1	17.9	36.3
Austria	0.0	26.7	50.5	38.6	57.4	29.8	63.7
Belgium	0.0	26.7	50.5	40.0	65.7	29.8	69.9
Canada	0.0	26.7	50.5	33.6	53.5	21.3	41.0
Denmark	25.9	26.7	50.5	62.4	98.1	63.6	80.4
Finland	2.2	26.7	50.5	36.3	70.2	35.9	68.9
France	0.0	26.7	50.5	53.9	55.4	35.7	53.9
Germany	0.0	26.7	50.5	28.0	53.7	24.7	56.3
Greece	0.0	26.7	50.5	26.4	53.0	26.5	54.3
Ireland	0.0	26.7	50.5	27.4	55.3	26.6	55.3
Italy	0.0	26.7	50.5	89.8	59.2	49.6	57.2
Japan	0.0	26.7	50.5	40.7	61.3	27.6	61.9
Luxembourg	0.0	26.7	50.5	30.6	57.8	30.4	54.4
Netherlands	3.9	26.7	50.5	42.7	58.7	30.5	56.7
New Zealand	0.0	26.7	50.5	35.9	61.8	24.4	63.0
Norway	23.9	26.7	50.5	81.7	118.5	61.7	23.9
Portugal	0.0	26.7	50.5	42.7	52.5	28.0	54.0
Spain	0.0	26.7	50.5	31.1	50.7	25.0	50.9
Sweden	38.4	38.4	50.5	117.9	161.7	90.0	125.5
Switzerland	1.2	26.7	50.5	97.2	66.7	53.4	62.7
Turkey	0.0	26.7	50.5	28.8	53.8	24.0	57.7
UK	0.0	26.7	50.5	24.9	50.2	21.0	52.6
USA	0.0	26.7	50.5	23.6	43.6	15.8	42.8

Table A.6 Average gas-taxes in USD/ton of CO_2

Scenario	Baseline	1A	1B	2A	2B	2C	3B
Australia	0.0	30.6	54.5	22.3	40.5	29.0	35.7
Austria	0.0	32.8	54.4	40.8	87.7	39.5	97.3
Belgium	0.0	32.8	54.4	41.4	75.7	47.8	70.4
Canada	0.0	26.0	50.7	31.2	55.9	32.4	39.1
Denmark	0.0	32.8	54.4	62.7	98.0	57.6	80.2
Finland	2.2	32.8	54.4	40.8	89.7	58.1	88.1
France	2.8	32.8	54.4	56.3	125.0	55.4	121.6
Germany	12.1	32.8	54.4	32.1	72.2	48.3	90.7
Greece	0.0	32.8	54.4	0.0	0.1	0.0	0.1
Ireland	0.0	32.8	54.4	30.3	55.3	46.3	63.8
Italy	44.5	44.5	54.4	90.2	171.8	104.3	132.0
Japan	0.1	30.6	54.5	44.0	74.9	51.2	80.9
Luxembourg	0.0	32.8	54.4	33.8	70.6	45.9	66.5
Netherlands	5.1	32.8	54.4	41.1	65.3	46.6	55.1
New Zealand	0.0	30.6	54.5	35.8	60.3	33.8	62.9
Norway	0.0	32.8	54.4	80.6	117.4	61.0	0.0
Portugal	0.0	32.8	54.4	0.0	0.0	0.0	0.0
Spain	0.9	32.8	54.4	34.2	84.4	40.0	96.8
Sweden	25.8	32.8	54.4	117.9	161.7	101.4	125.5
Switzerland	0.6	32.8	54.4	97.2	137.3	67.9	125.2
Turkey	0.0	32.8	54.4	31.5	58.9	43.6	78.8
UK	0.0	32.8	54.4	29.3	57.4	37.7	70.1
USA	0.0	26.0	50.7	27.0	47.1	34.9	45.8

NATIONAL CIRCUMSTANCES OF SELECTED OECD COUNTRIES AND THE BERLIN MANDATE NEGOTIATIONS

Summary

In this chapter we analyze some national circumstances of selected OECD countries and their possible implications for the AGBM negotiations. These circumstances are energy structure, emissions structure, abatement cost estimates, and impacts of some uncertainty aspects. Coalition building during negotiations is likely to be more dependent on relative emissions abatement costs than anticipated climate change impacts. However, countries that perceive the climate change impact uncertainty to be large are likely to accept higher commitments to reduce emissions than countries where the perceived level of uncertainty is lower. A main tentative conclusion is that the achievable outcome of the negotiations is determined by two groups of countries, those that have a relatively low concern for climate change and low abatement costs on the one hand, and those that have a relatively low concern for climate change and high abatement costs on the other hand. The second tentative conclusion is that the level of success for the negotiations depends on the ability to introduce flexibility in the proposed burden sharing system with respect to giving concessions both to 'cost sharing' and 'emissions reduction sharing'.

Introduction

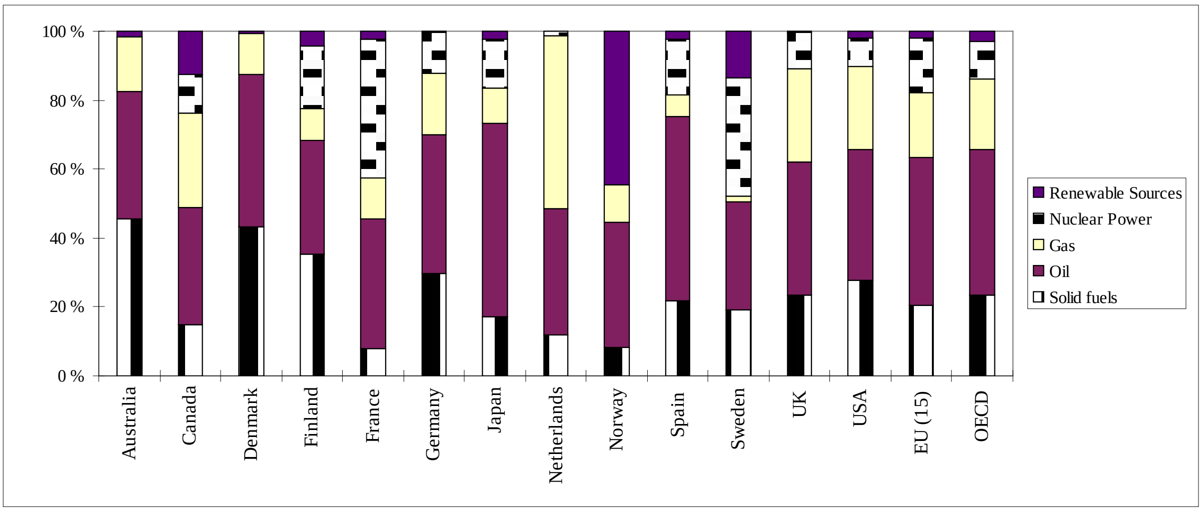
The purpose of this chapter is to analyze the negotiation game on the Berlin Mandate between the group of OECD countries with a focus on heterogeneity, that is differences in national circumstances, and some aspects of uncertainty.

Even if the AGBM negotiations focus on strengthened commitments for Annex I countries to reduce their emissions of climate gases, it is likely that the OECD countries with the exception of Mexico and the Czech Republic (i.e. Annex II countries) will have to take most of the burden in the next few years.[1] The remaining Annex I countries, which are Russia and countries in Eastern Europe undergoing the process of transition to a market economy, will eventually later have to take on a larger burden according to their economic development.

Given parties that are heterogeneous with respect to economic structure, energy structure, resource base, geography and climate, and furthermore given uncertainty of different characteristics attached to possible climate impacts in these countries, the idea is to analyze the influence of these circumstances on the position of the parties in the negotiations, and how these positions might influence the negotiations and their outcome.

[1] The negotiations are carried out by the Ad Hoc Group on the Berlin Mandate (AGBM).

Figure 8.1 Percentage share of different energy sources, 1993 (OECD, 1995a)



The chapter starts out with a brief survey of carbon dioxide emissions, energy structure and abatement costs estimates for a selection of OECD countries. These data are selected based on availability and relevance for the countries' position in the climate negotiations, in particular with respect to consequences for marginal abatement costs compared to other OECD countries.[2] The next section presents an analysis of how specific national properties with respect to uncertain abatement costs and future climate change impacts could influence countries' willingness to take on costly commitments to reduce GHG emissions, or to prefer minor commitments and a 'wait and see' solution. We have chosen to leave out an assessment of climate impact vulnerability in theses countries due to the many uncertainties and problems involved in estimating such figures. Instead we include a general analysis of the influence on negotiations from the participating countries' level of concern for climate change in the last section.

An assessment of vulnerability of OECD countries due to sea level rise and impacts for agriculture is presented by Rowlands (1995). The author uses this assessment in addition to abatement cost estimates to undertake a classification of countries according to national interests in negotiations. The classification divides countries into a group of 'pushers', which should favor ambitious climate policies, 'intermediates', and 'draggers', where the latter group should resist ambitious climate policies.

Against this background we present a classification of the selected group of OECD countries according to predicted interest for cost sharing solutions, such as 'equal cost per capita', as compared to emission reduction sharing solutions, such as 'equal percentage reduction'. The hypothesis is that countries with relatively high marginal emissions abatement cost prefer ‘equal cost per capita’ since they then will have a better control of cost implications of commitments accepted and are likely to face lower costs than under the alternative ‘equal percentage emission’ agreement type. On the other hand countries that have a relatively low marginal emissions abatement cost prefer ‘equal percentage reduction’ since such agreements probably mean moderate costs for these countries. Under a ‘equal cost per capita’ agreement they would probably face commitments involving higher costs. In the final section the same country typology is employed to analyze the AGBM negotiations to illustrate possible solutions and the achievable set. The achievable set of the negotiations can be defined as the set of all possible outcomes of the negotiations that are acceptable and individually rational to all parties. Thus all parties have incentives to participate and accept the outcome as long as it is contained in the achievable set.

A survey of selected OECD countries

The selection of OECD countries in this survey consists of 13 countries and EU(15).[3] These countries are Australia, Canada, Denmark, Finland, France, Germany, Japan, Netherlands, Norway, Spain, Sweden, UK, and USA. These countries are chosen according to size within OECD and as representatives of groups and geographical regions within OECD.

In this survey we examine percentage shares of different energy sources, CO_2 emissions per capita and per unit of GDP, in addition to percentage contribution of energy related CO_2 emissions by economic sector, and estimated CO_2 emissions abatement costs. The national figures are compared to the OECD average if the latter figure is relevant and available. Finally, some other national circumstances that might influence the position of the countries in the negotiations are discussed.

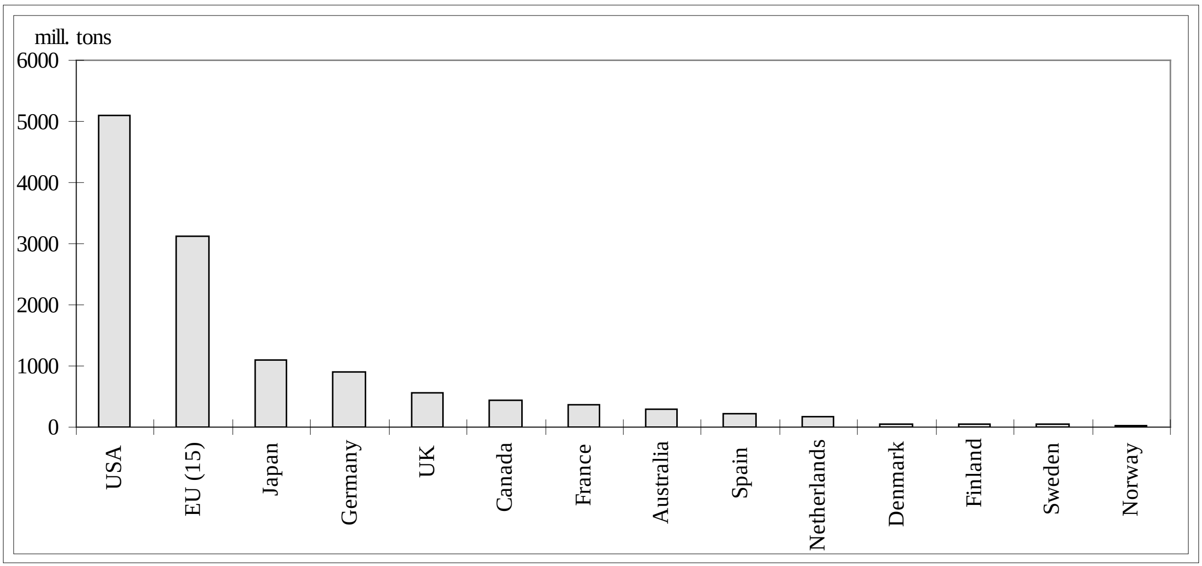
Percentage share of different energy sources

The percentage share of different energy sources in 1993 for the selection of OECD countries is shown in Figure 8.1, where the OECD average is included for comparison.

[2] A similar survey of Nordic countries is presented in Ringius, Torvanger and Meze (1996).

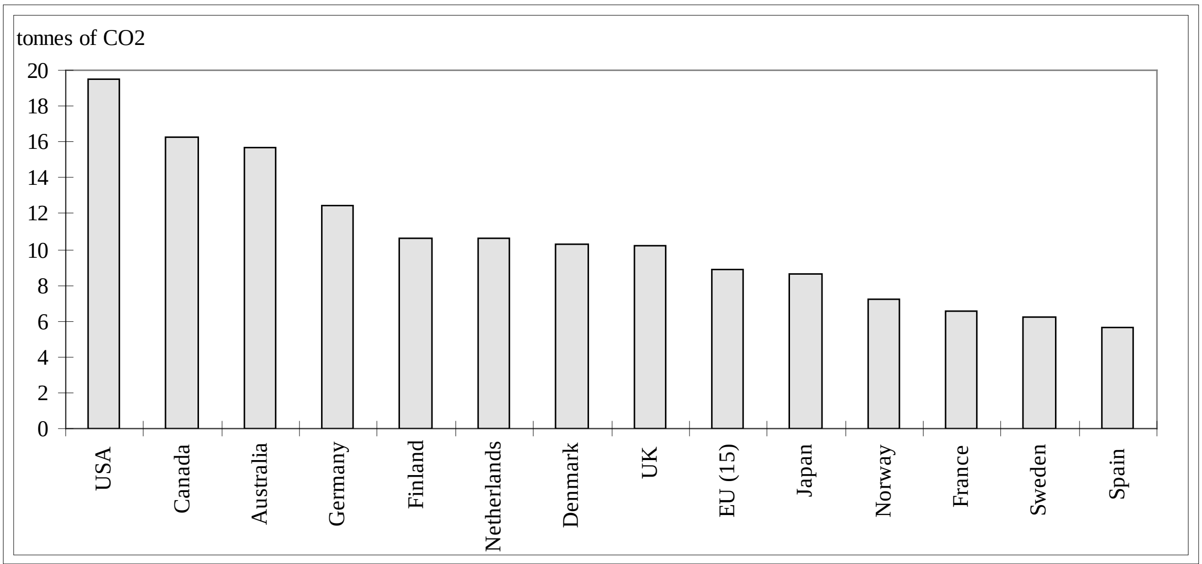
[3] EU(15) represents the European Union before Austria, Finland and Sweden became members, where altogether 15 countries were members of EU.

Figure 8.2 Energy related CO_2 emissions, 1993 (OECD, 1995a)



Let us assume that a relatively high share of solid fuels (mainly coal) contributes to a relatively low marginal CO_2 emissions abatement cost since other energy sources of lower carbon content like gas and oil can be substituted for coal. Relatively higher is in terms of comparison with the OECD average, and with some consideration of EU(15). Likewise, a low gas share should contribute to a relatively low marginal emissions abatement cost since the gas share could probably be increased. On the other hand a high share of renewable energy sources (and nuclear power) contributes to a relatively high emissions abatement cost since they are carbon free and cannot be readily expanded.

Figure 8.3 Energy-related CO_2 emissions per capita, 1990 (OECD and IEA, 1994)

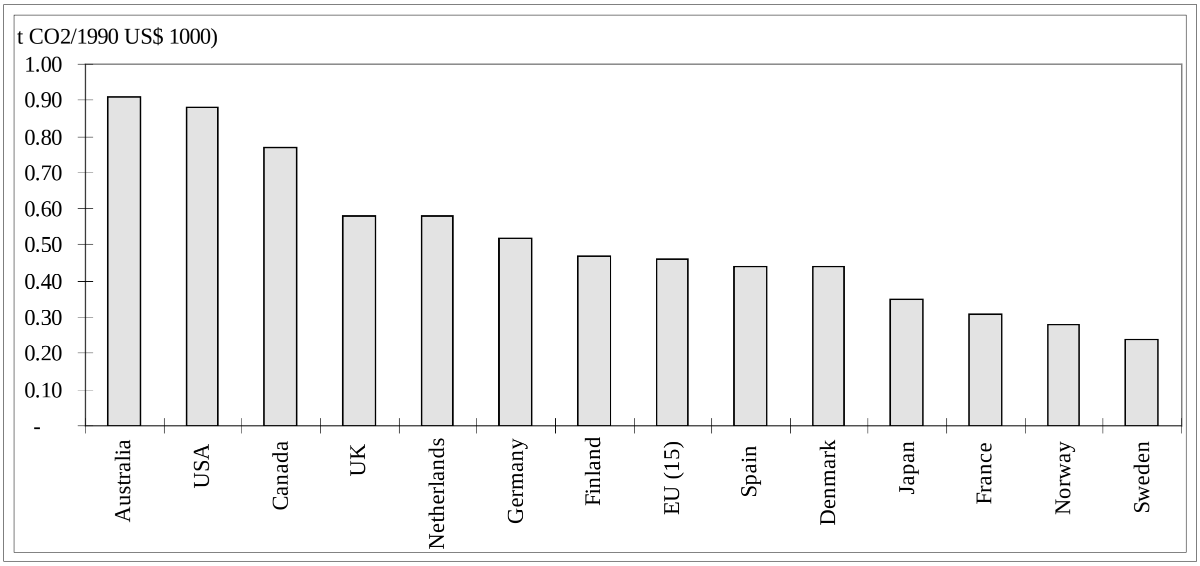


Given such considerations of national energy structures, we find that Canada, France, Japan, Netherlands and Norway are likely to have relatively high marginal emissions abatement costs, whereas Australia, Denmark, Finland, Germany, Spain, Sweden and USA are likely to have relatively low marginal emissions abatement costs.

CO_2 emissions

Energy related CO_2 emissions in mill. tons in 1993 are given in Figure 8.2, where the countries are ordered according to decreasing emission level. In Figure 8.3 and Figure 8.4 CO_2 emissions are given in per capita terms (1990) and per unit of GDP (1992), respectively. The OECD average in

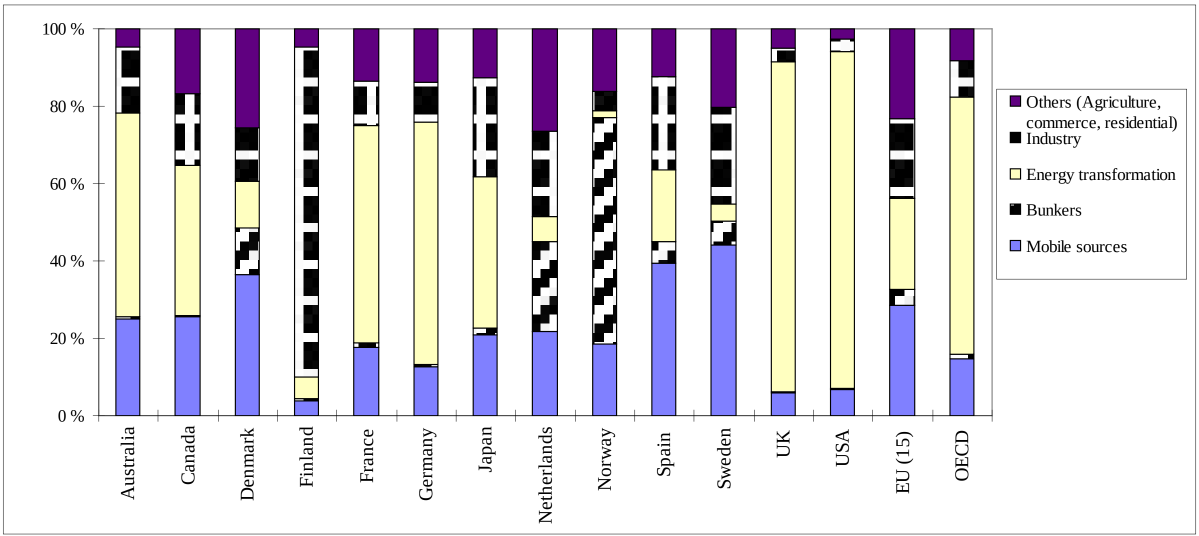
Figure 8.4 Energy-related CO_2 emissions per unit of GDP, 1992 (OECD and IEA, 1995b)



included for comparison.

From the figures we see that emissions in per capita terms is highest for USA, Canada, Australia and Germany. Emissions are lowest for Spain, Sweden, France, Norway and Japan. When it comes to energy related CO_2 emissions per unit of GDP there are some, but no dramatic, changes to the ranking of countries. The highest emission levels are now represented by Australia, USA, Canada, UK and Netherlands, whereas the lowest emission levels are represented by Sweden, Norway, France and Japan. The CO_2 emission level per unit of GDP can be looked upon as a measure of the national level of energy efficiency. In addition the emission level depends on the energy structure

Figure 8.5 Percentage contribution of energy-related CO_2 emissions by sector, 1993 (OECD, 1995a)



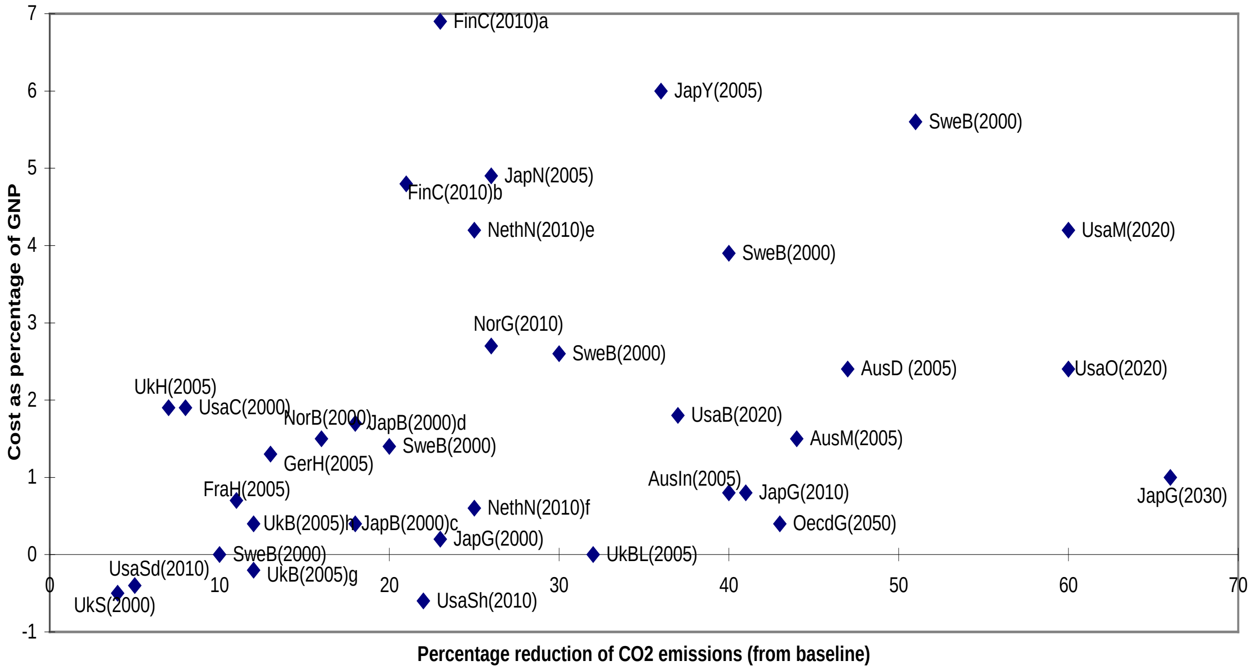
(i.e. the share of different energy sources discussed above) and the structure of the national economies, since a large share of carbon-intensive sectors in GDP would contribute to a high emission level in per unit of GDP terms. To the extent this emission level indicates the level of energy efficiency, these data suggest that the potential for energy efficiency improvements is largest for Australia, USA, Canada, UK, Netherlands and Germany. Thus the data could indicate that the marginal emissions abatement cost is relatively low in these countries.

Percentage contribution of energy related CO_2 emissions by economic sector

The percentage contribution of energy related CO_2 emissions in 1993 by sector is presented in Figure 8.5. Once more the OECD average is included for comparison.

We assume that the fuel-switching potential from high-carbon energy sources to low-carbon energy sources is highest in the energy transformation and industry sectors, and lowest in the transportation sector. Given these assumptions high energy transformation and industry sector shares and a low transportation share indicates a relatively large potential for emissions reductions through fuel switching, which contribute to a relatively low marginal emissions abatement cost. By the same argument low energy transformation and industry shares and a high transportation share contribute to a relatively high emissions abatement cost. From such a perspective and examining Figure 8.5 we find that Australia, Canada, Denmark, Norway, Spain, Sweden and EU(15) are likely to have relatively high marginal emissions abatement costs, whereas Finland, UK and USA are likely to have

Figure 8.6 CO_2 emissions abatement costs as percentage of GDP from top-down studies (IPCC, 1995a)



relatively low marginal emissions abatement costs.

Comparing energy structure and emissions structure

Comparing the suggested relative emissions abatement cost from the examination of energy structure in Figure 8.1, emissions level per unit of GDP in Figure 8.4 and emissions structure in Figure 8.5, we find that there are similar results for about one third of the countries, but some deviation in the results for the other countries. However, if we give some emphasis to the importance of the energy structure in Figure 8.1 compared to the emissions data, meaning that we pay extra importance to the potential for fuel-switching between energy sources compared to the somewhat more vague indications of level of energy efficiency, we come up with a result for most of the countries. Thus we find that Canada, France, Japan, Norway are likely to have relatively high marginal emissions abatement costs, whereas Australia, Denmark, Finland, Germany, UK and USA are likely to have relatively low marginal emissions abatement costs. Netherlands, Sweden and Spain seem to have marginal emissions abatement costs at some intermediate level.

CO_2 emissions abatement costs estimates

A survey of emissions abatement cost studies are presented in Figure 8.6, Table 8.1and Table 8.2. Figure 8.6 is taken from the draft for the new IPCC report (IPCC, 1995a), but where we have left out other countries than the selected group of OECD countries. The emissions abatement level is presented as a percentage of base year emissions and plotted against the cost measured as percentage of GNP. From the large number of American studies in a separate figure in the IPCC draft we have chosen six studies which represents some extreme and average estimates for target years until 2020.

Table 8.1 Top-down abatement cost studies

Country	Author (year)	Key[4]	CO_2 reduction from base year	Cost as GNP impact
Australia	Dixon et al. (1989)	AusD (2005)	47%	2.4%
Australia	Industry Commission (1991)	AusIn (2005)	40%	0.8%
Australia	Marks et al. (1990)	AusM (2005)	44%	1,5%
Finland	Christensen (1991)	FinC (2010)	23%,21%	6.9%,4.8%a,b
France	Hermes-Midas (992. Karadeloglou)	FraH (2005)	11%	0.7%
Germany	Hermes-Midas (1992. Karadeloglou)	GerH (2005)	13%	*13%*
Japan	Ban (1991)	JapB(2000)	18%,18%	0.4%,1.7%c,d
Japan	Goto (1991)	JapG (2000,2010,2030)	23%,41%,66%	0.2%,0.8%,1%
Japan	Nagata et al. (1991)	JapN (2005)	26%	4.9%
Japan	Yarnaji et al. (1990)	JapY (2005)	36%	6%c
Netherlands	NEPP (1989)	NethN (2010)	25%, 25%	4.2%,0.6%e,f
Norway	Bye, Bye & Lorentsen (1989)	NorB (2000)	16%	1.5%
Norway	Glomsrød et al. (1990)	NorG (2010)	26%	2.7%
OECD	GREEN (1992)	OecdG(2050)	43%	0,4% GDP
Sweden	Bergman (1990)	SweB(2000)	10%,20%,30%, 40%,51%	0%,1.4%,2.6%, 3.9%,5.6%
UK	Barker (1 993)	UkB (2005)	12%	-0.2%,+0.4%g,h
UK	Barker & Lewney (1991)	UkBL (2005)	32%	0%
UK	Sondheimer (1990)	UkS (2000)	4%	-0.5%
UK	Hermes-Midas (1992: Karadeloglou)	UkH (2005)	7%	1.9%
US[5]	DRI (1992)	UsaD(2020)	37%	1,8%
US	CBO-PCAEO,DRI (1990)	UsaC	8%	1,9%
US	Manne (1992)	UsaM(2020)	60%	4,2%
US	Oliveira-Martins, et al.(1992)	UsaO(2020)	60%	2,4%
US	Shackleton et al. (1993)	UsaSh (2010)	22%	-0,6%
US	Shackleton et al. (1993)	UsaSd (2010)	5%	-0,4%

a,b Unilateral action and global action.
c,d Tax case and regulation case.
e,f National policy scenario and global policy scenario.
g,h GNP gain when OECD tax levied with VAT reduced to maintain revenue neutrality; GNP loss when tax used to reduce the PSBR.
Source: IPCC (1995a).

4 The letters in the Key refer to the country and author.

5 This is a selection of US-studies from IPCC (1995a). Some average cost studies are selected together with outlying studies with respect to abatement cost and reduction level. Studies with a later target year than 2020 are left out.

Table 8.2 Bottom-up abatement cost studies

Study	Country	Percentage abatement compared to base year until (year)			Cost (as per cent of GDP)
		2005/2010	2015/20	2025/30	
IPSEP1993	EC(5)		>26-58	>60	zero
FRG Enquete 1992	FRG	30			zero
Mills et al. 1991	Sweden	>35			zero
COHERENCE 1991	UK	10			zero
UNEP 1993	Denmark	>21		>45	zero
Unader-ETSAP 1993	Norway	10; 20			0,65%; 0,95%
Kram-ETSAP 1993	Sweden			20	0,47%

Source: IPCC (1995a), Unander (1993) and Kram (1993).

All these are top-down studies, which means that they are based on macro-economic models. Each study is represented in the figure, and the country and target year is specified. Table 8.1 presents the same studies listed according to country. The available number of bottom-up studies is much smaller than top-down studies, and these are listed in Table 8.2. In addition to the data in the table in IPCC (1995a) we have included two ETSAP-studies (Unander, 1993 and Kram, 1993). The results of the bottom-up studies in Table 8.2 are mostly reported as the percentage reduction of CO_2 emissions compared to the base year that is possible to realize at negative or zero cost by a target year. The OECD countries represented are Germany, Sweden, UK, Denmark, and Norway in addition to EC(5).

We notice that there is quite some variation in the emission estimates, and in particular for some of the countries. For some of our selected OECD countries no abatement cost studies are available (Canada and Spain). Once again the difficulties involved in comparing estimates based on different models and assumptions should be emphasized. A further difficulty in comparing the estimates is represented by the variation in target year.

Some other relevant national circumstances

A number of other national circumstances may be relevant for the short-term or long-term marginal abatement cost of a country, or might at least influence the interests and position chosen by a country in the AGBM negotiations. A few such circumstances are: i) present climate policy choices and

Table 8.3 Classification of OECD countries according to marginal emissions abatement cost

Low cost	Average cost	High cost
GER, UK, USA	AUST, CAN, DK, FIN, FRA, NL, SPA	JAP, NOR, SWE

measures; ii) comparative advantages and export potential for a country with respect to new energy efficient technologies, and iii) policy choices and measures in other areas (such as coal subsidies to support regional settlements dependent on coal mining).

Classification of countries according to abatement cost

Based on the survey of energy structure, emissions structure, abatement cost estimates, and model estimates from chapter 5, we proceed to make a classification of the selected OECD countries according to marginal emissions abatement costs in three groups, one group of high cost countries, one group of low cost countries, and one group of average cost countries. The classification is shown in Table 8.3. For some of the countries there is some variation in relative abatement cost depending on national circumstance in terms of energy structure, emissions structure, abatement cost estimates, or uncertainty aspects. In these cases we have made a subjective evaluation based on the presented data and other available sources.

Impact of climate effects, cost structure and uncertainty on a country's interest

Economic structure, the pattern of energy use, etc., give rise to different emission intensities across countries. How these differences affect the estimates of the costs of emissions control depend somewhat on the assumptions made in different studies, but it seems that the cost can be explained mainly from the energy efficiency of each country, and the energy structure, which indicates the possibilities for substitution between energy sources.

The costs of emission control may be important for the making of coalitions in climate negotiations. As pointed out in chapter 4, however, also considerations of benefits may be decisive in this respect. In this section the model described in section 4.2.2 is applied to provide some examples of how national properties, such as the cost structure, anticipated benefits, etc., may affect each country's optimal climate policy. The calculations will also be used to study the cost of a climate agreement which diverges from what each country considers to be optimal. The importance of uncertain factors will also be discussed. The calculations are meant merely as illustrations of how an analysis of

Table 8.4 Alternative cases

Concern for climate change	Abatement costs	
	High	**Low**
Medium/high	A	B
Low	D	C

country interests might be carried out, and provide some hypotheses of interest for further analysis.

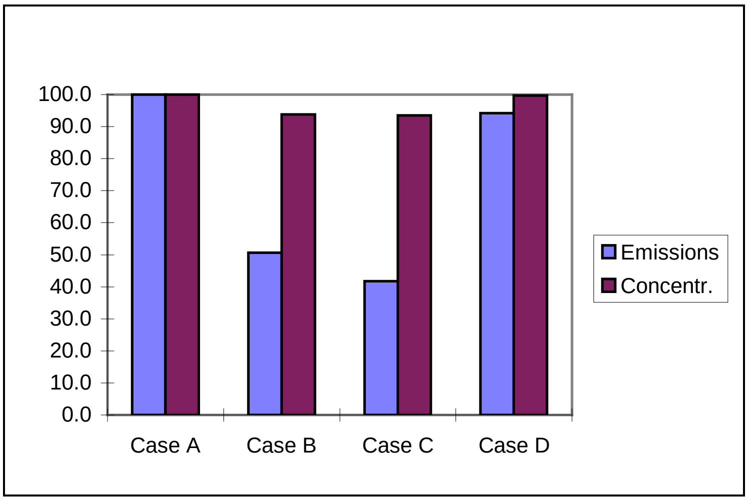
In order to make the cases, or "countries", as comparable as possible, we consider similar economies, comparable with that of Norway, through which the parameter choices of the model were calibrated. We distinguish four cases, which are roughly described in Table 8.4

The distinction of abatement costs affects the adjustment costs of investments in abatement. High costs are represented by the base case studied in chapter 4. Lower abatement costs implies, first, that the cost of investing each unit of abatement capital is a little more than 20% lower in the low-cost alternative, and, second, that the marginal cost of the investment-rate is lower. This means that installation of abatement capital is cheaper, which may be explained by the possibilities of installing well-known energy saving technologies, or by the possibilities of substituting energy with lower emissions of CO_2 for energy with high emissions. Thus, the high and low abatement cost alternatives may represent countries with different energy structure and energy efficiency.

The optimal choice of policy will also depend on the anticipated benefits of an international agreement on climate change. Because of the vast uncertainties in estimates of such benefits, it may be more appropriate to denote these benefits as the concern for climate change. However, within the framework of the model, this concern has to be expressed in terms of damage of climate change. The medium/high-concern cases correspond to the damage assumed in the base case discussed in chapter 4, thus making case A equal to this base case. The damage depend both on the temperature sensitivity at $2\times CO_2$ and on the percentage reduction in GDP resulting from this increase in average temperature. Assuming a temperature sensitivity at 2.5°C, the high-medium cases (A and B) implies a damage at 2.5 to 3% of GDP. The low concern cases (D and E) implies a damage between 1.5 and 2% of GDP.

It is not straightforward to make comparisons of optimal policies between countries with different

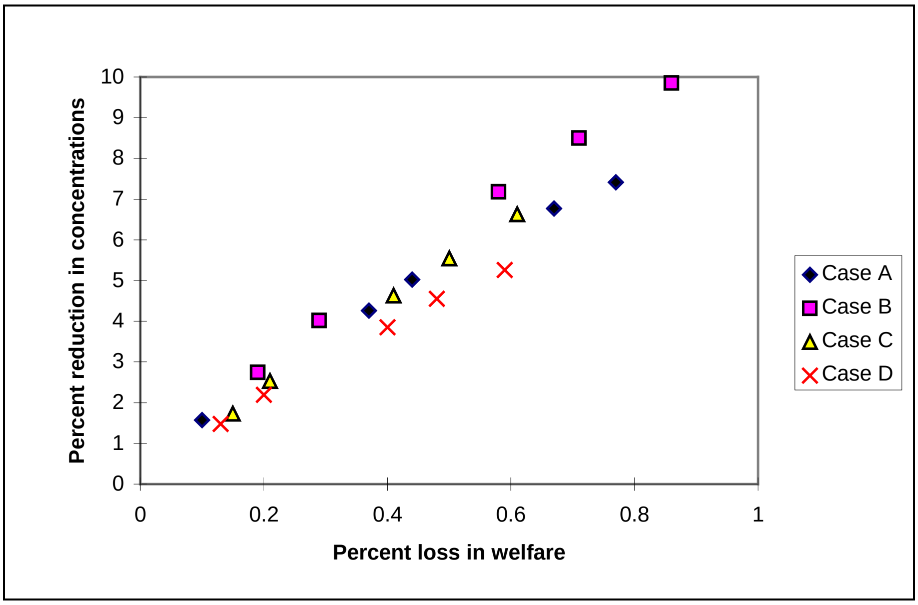
Figure 8.7 Contributions from emissions and concentrations of greenhouse gases in 2045. Case A = 100.



national characteristics, and there are many alternative ways to measure the differences. In the following, we compare the optimal policies under the assumption that the total value of capital (productive and abatement) is the same in all alternatives in 2045. A weakness with this requirement is that cases C and D, where the damage of climate change is low, have to build up equally much capital as in cases A and B. Thus, one may say that it implies that in cases C and D one is better prepared for the years to come after 2045. We will focus on the reductions in emissions and in concentrations of greenhouse gases in 2045, and compare the effects on total welfare over the period 1995 to 2045. Figure 8.7 compares the level of emissions and concentrations in 2045 for the four cases under optimal policy.

The emissions contributed to 6.5 ppmv in case A (=100), and the level of concentrations were 549.5 ppmv. (=100). While the emissions differ considerably between the four cases, the level of concentrations deviates by less than 10% between the highest and the lowest alternative. The reductions in cases B and C are results of the low abatement costs. It may be surprising that the cases with low concern end up with lower emissions and concentrations than the cases with high concern. This is because of the focus of the terminal year. The low damage cases are characterized by a rapid consumption growth. Thus, to meet the requirement of terminal capital, the initial consumption level in these cases has to be low. This results in a much higher level of investment in productive capital from the beginning, and thereby higher growth in production and emissions. Thus, the need for abatement occurs at an earlier point in time, because the emissions sooner reach the level where they

Figure 8.8 Percentage loss of welfare by percentage reductions in concentrations in 2045 compared with optimal policy

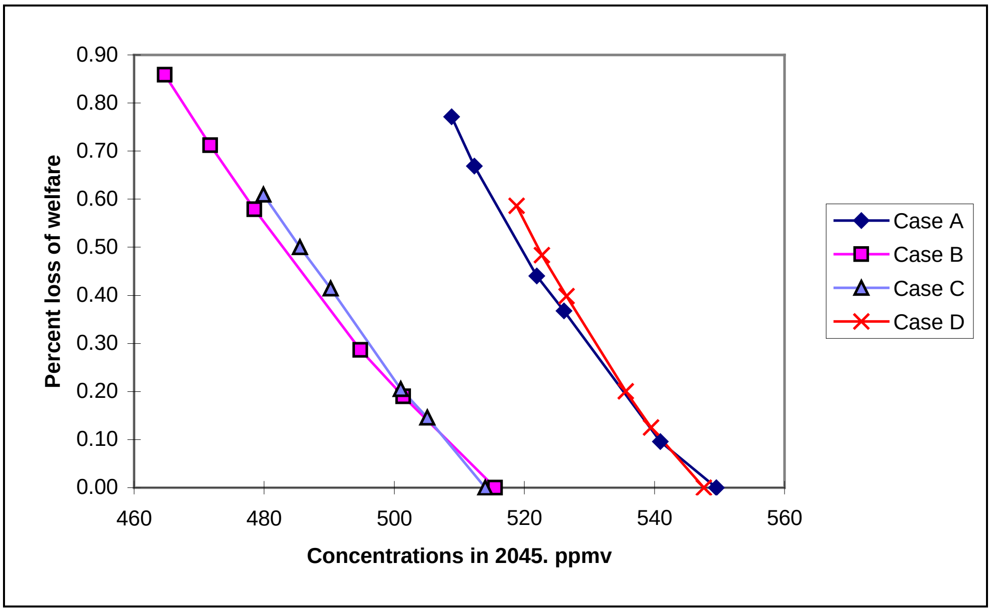


exceed the natural rate of decay for greenhouse gases.

One may interpret the emissions and concentrations displayed in Figure 8.7 as each country's position prior to negotiations. The position is developed under the assumption that all countries has to reduce their annual emissions by the same rate as the country in question. We may take this principle of burden sharing to be the one which the countries have agreed to follow. Thus, if the optimal policy for country A (case A) implies a 35% reduction in emissions in 2030 compared with no abatement, it assumes that all other countries do the same. All the four countries in this example comes up with different wishes for the optimal policy. Thus, an agreement will leave some, or all, parties worse off than each country's their first-best agreement. The question is therefore what the cost of a different policy is. Figure 8.8 displays the costs in terms of percentage loss of welfare over the whole period 1995-2045 of more aggressive negotiated targets for the concentrations than what each of the countries consider to be optimal. These targets are expressed as reduction in concentrations measured in per cent of optimal concentrations in 2045. The time profiles for investments in abatement are about the same as for optimal policy.

In spite of the different concerns and substantially different abatement costs, it seems as if a focus on percentage reduction in concentrations compared to the individual, optimal choice, may level out some the potential conflicts between the countries. In all the cases a 10% reduction in concentrations

Figure 8.9 Percentage loss of welfare in cases A - D at alternative targets for concentrations in 2045.



in 2045 implies a welfare loss at about 1%. There are different reasons for this result. One is that the focus on concentrations rather than emissions means that the amount of emissions to reduce is about the same in all the cases. Moreover, an increase in the level of abatement must be compensated by a reduction in consumption growth, which must be counteracted by enhancing the initial level of consumption in order to meet the requirement on terminal capital. The cost, measured in total welfare over the whole period, is therefore substantially moderated when comparing the four cases. In fact, this effect is stronger in the calculations above than the sole effect of abatement costs. As a supplement to the cost curves in Figure 8.8, we add that in order to achieve 4-5% reduction in the concentrations, the initial consumption level had to be increased by approximately 1.2% in cases A and D, which indicates a considerably lower rate of consumption growth. In cases B and C, a 0.4% increase in initial consumption was sufficient to obtain the same reduction in concentrations.

One may discuss the relevance of focusing on percentage reductions in concentrations. Each country has defined its own optimal level of concentrations, and countries that find it optimal to reduce the concentrations more than others are not given any credit for the abatement they do as a consequence of their optimal strategy. Some have therefore suggested to assess a target for absolute level of concentrations. Figure 8.9 shows the cost curves for the four cases of achieving alternative levels of concentrations in 2045.

The grouping of interests now becomes quite clear. As was indicated above cases A and D face similar costs when deviating from their optimal policy, and the same applies for cases B and C. In other words, the calculations indicate that the cost of abatement may be decisive for explaining common interests among countries, while different concern for climate change have no decisive impact. The figures show that to meet the optimal policy of cases B and C, the welfare loss of cases A and B amount to between 0.8 and 1% of the total welfare for the period. One reason why differences in the concern for climate change seems to be insignificant for the explanation of country interests, may be that the damages are quite small within the period we consider, at least in the first half of the period. As was discussed above, the natural rate of decay for greenhouse gases seem to be of more importance for the policy in this period.

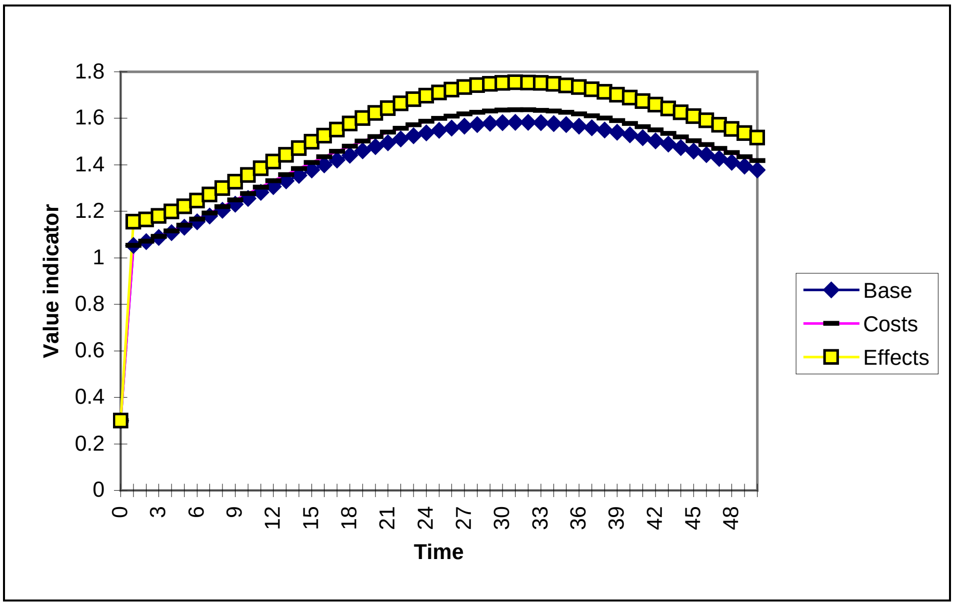
Uncertainty

Till now, we have assumed full certainty with respect to future climate change impacts and abatement costs. One of the main challenges in climate policy is to adapt to the uncertainties of climate change. Some of the uncertainties may be represented explicitly in the model presented and some are disregarded or embedded in simplified expressions. It is likely that our intuitions about a sound climate policy is substantially affected by our attitude towards the uncertainties of climate change. On the other hand, models usually analyze the topic under an assumption of certainty. Recommendations about climate policy may be due to this assumption. For instance, the familiar economic advise to delay actions, which was confirmed in the previous section, may be due to the fact that we assume that we know for certain what the consequences of our actions today are. We may thus plan our allocations between abatement and consumption, and how to distribute this activities over time, under full knowledge about the climate effects. Many would say that the main problem of designing a climate policy is thereby disregarded.

A complete analysis of climate policy under uncertainty would require an own paper. As discussed in chapter 4, however, it is possible to include uncertainties in the model used above by defining the evolution of state variables as stochastic processes. In this study, stochastic terms are attached to the evolution of abatement capital and to the concentrations of greenhouse gases. These are solved as two separate cases, interpreted as uncertain climate costs and uncertain effects of climate change, respectively. The model is solved by maximizing expected welfare over the time horizon. The solution is given in terms of the expected optimal paths for the state variables, control variables and endogenously determined prices.

Thereby, we may find how the expected paths are affected by uncertainty, but cannot say how the

Figure 8.10The value of abatement capital in base case, with uncertain costs and uncertain effects.



paths eventually turn out. The decisions at each point in time will depend on how and when the uncertainty is resolved, which means they will depend on the state variables in each year. Thus, we cannot say in which year abatement investments will approach a given level, only when we expect it to be approached. Abel and Eberly (1994) have shown that investment decisions under uncertainty can be fully analyzed by the properties of an adjustment cost function alone if capital prices are provided. Uncertainty as such will only have an impact on the capital prices. By developing the expected path for the price of abatement capital under optimal policy, it is possible to analyze the investment decision, and how the decisions are affected by uncertainty. A higher capital price means that the decision maker is expected to yield a higher benefit from his investments. As we consider abatement capital, this means that abatement is expected to be higher. What decision to take, eventually, depends on the actual states at the time of decision. In addition, a number of other factors are important, such as the degree of irreversibility of the investment decision. To install capital equipment with few alternative applications are clearly more critical than to install capital that can be sold at nearly full price if the benefits of the investments turn out less than expected. A change in the value of abatement capital may also be regarded as a shift in the expected timing of investments, compared to the certainty case. A higher value of abatement capital thus indicates a precautionary action.

Figure 8.10 shows the evolution of shadow prices of abatement capital in the certain base case and in the two cases of uncertainty. The result thus shows that the expected timing of abatement policy will be advanced both when the costs are uncertain and when the effects of climate change is uncertain compared with the certainty case. It is somewhat surprising that uncertain climate costs tend to stimulate a precautionary policy towards climate change. The explanation is that this uncertainty has two effects which affect the price of abatement in opposite directions. One effect is due to the curvature of the adjustment costs. Uncertainty implies that the expected costs of abatement are higher than the costs of expected abatement, which tend to reduce the price of abatement capital and thereby to retard investments in such capital. But the uncertainty about abatement costs also implies that consumption becomes uncertain, because these costs are decisive for “what is left” to consumption out of GDP. This effect is therefore determined by the curvature of the welfare function. In the cases studied here, the latter effect is stronger than the first one, and the “precautionary” policy thereby occurs.

Uncertain effects of climate change contribute to an increase in the expected value of abatement capital, and is therefore expected to advance the timing of a climate policy. This result is in accordance with intuition. The strength of these effects is, however, worth to mention. The assumptions made about the uncertainty of abatement costs implies that about 65% of the annual investments deviates by +/-5 per cent from the expected level, which is quite high. The assumptions about the uncertainty of the effects imply that a deviation within an interval of +/- 2.5% per year from the expected level for 65% of the “observations”, which is moderate. Still, the effect on the price of abatement capital from uncertainty in effects of climate change is significant. This indicates that countries which consider the effects of climate change to be highly uncertain will try to advance actions to mitigate climate change compared with countries less concerned about these uncertainties. The conflicts of interest between these groups of countries may be considerable.

The significant difference between a study of optimal policy and similar traditional approaches is that the optimal policy approach recommends a considerably higher level of optimal abatement in each year. When there is uncertainty about the effects of climate change, this difference becomes even larger. Regarding a comparison of climate costs between countries, these results indicate how biased comparisons of costs or benefit-cost ratio may turn out compared with an evaluation of the optimal policy. This may be vital in order to explain positions taken by different countries in climate negotiations, and to analyze possibilities of coalition forming.

The achievable set of the AGBM negotiations

To accept the outcome of the negotiations and commit itself to emissions abatement all OECD parties must find that this option is better than the best alternative actions, such as leaving the negotiations or trying to reduce the ambition level for OECD to the extent possible, that is reducing the emission reduction target. For simplicity we assume that only two alternatives exist. The first alternative is an agreement where all OECD countries participate, and where the common target is ambitious and implies costly commitments for participating countries. The second alternative is no agreement. For the purpose of this analysis the no agreement alternative can also be interpreted as an agreement with a very low ambition level for the common target, which would lead to emissions close to a business-as-usual scenario, and thus not influence national policies, and only involve commitments of minor costs.

We now turn to the second dimension in the negotiations we focus on, namely the national concern for future climate change. By national concern for future climate change we think of government and general public's interest in the protection of the global climate system. Such interest may be motivated by anticipated climate change impacts and related costs (or benefits), but may also be motivated by a genuine concern for the global climate system as a collective good for present and future generations. According to section 8.3 the level of perceived uncertainty related to climate change impacts may be important for a country's level of concern for climate change and what climate policy it prefers. Thus perceptions of uncertainty can be one of the factors that explain coalition building of countries with similar interests in the negotiations. Countries that perceive the level of uncertainty to be high will tend to more concerned for climate change and be willing to accept higher commitments. We assume that OECD countries can be divided into two groups, those that are more than average concerned for future climate change and those that are less than average concerned. However, since we find that classification of OECD countries in such groups would be speculative given the available data, we limit the discussion to a general analysis of the structure of the negotiations.

This discussion can be compared to the results from the analysis of Rowlands (1995). He finds that Denmark, Germany and Netherlands based on national interests and commitments shown through climate policy actions should be 'pushers' in the negotiations, whereas Finland, France and Spain should be 'draggers'. Australia, Canada, Japan, Norway, Sweden, UK and USA should be 'intermediates'.

In particular for Norway, but also for other concerned countries with high cost, the fundamental issue will be to influence the AGBM negotiations to move in direction of ‘cost sharing’ rather than ‘emission reduction sharing’, since this probably would mean commitments involving relatively lower costs for these countries.

One obvious obstacle for such a strategy besides differing interests between OECD countries, is the limited availability of abatement cost studies at the national level, and difficulties involved in making such cost estimates comparable across modeling approaches and countries.

We now introduce the concept of the *achievable set*, which can be defined as the set of possible agreements that makes all countries better off participating compared to not participating and having no agreement (or an agreement of no real influence on total OECD emissions and national policies). Given this setting the achievable set can be interpreted as a condition for all countries to be individually rational. Consequently no country could gain from not participating since this would mean no agreement, in which case all countries would be worse off.

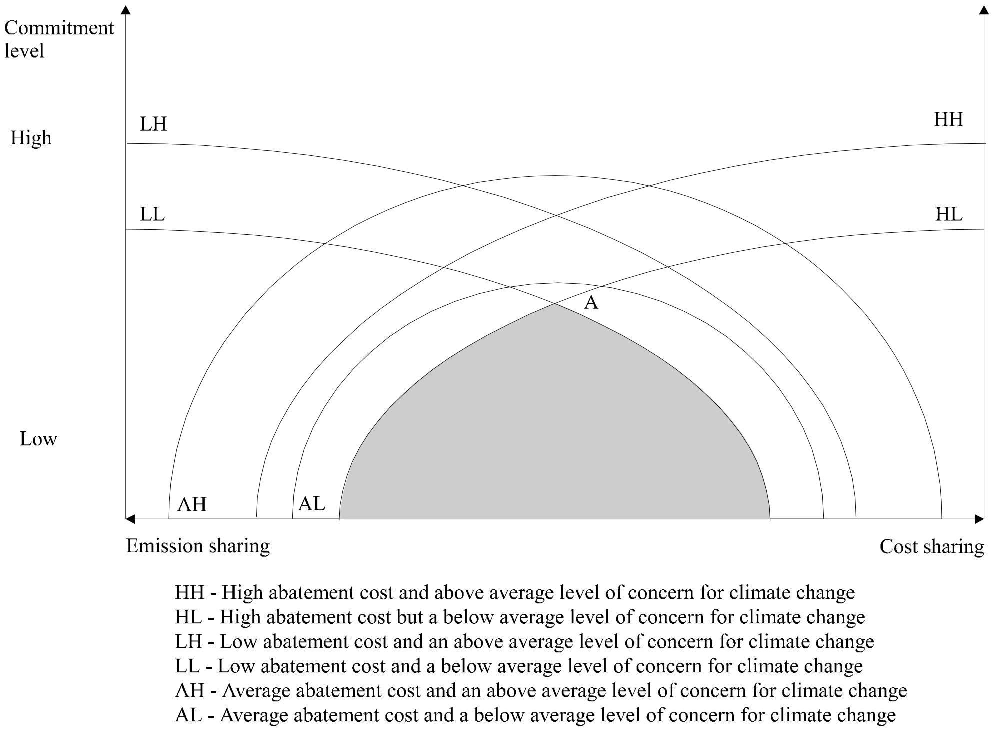
Based on the classification of countries in the last section we introduce a new notation for these groups of countries:

HH - countries that have a high abatement cost and above average level of concern for climate change;
HL - countries that have a high abatement cost but a below average level of concern for climate change;
LH - countries that have a low abatement cost and an above average level of concern for climate change;
LL - countries that have a low abatement cost and a below average level of concern for climate change;
AH - countries that have an average abatement cost and an above average level of concern for climate change; and finally
AL - countries that have an average abatement cost and a below average level of concern for climate change.

Earlier in this chapter we proposed a hypothesis according to which countries with a high marginal abatement cost would be inclined towards a system of ‘cost sharing’ to be able to control the cost implications of the commitment accepted. In a ‘cost sharing’ agreement type they are likely to face lower costs than under the alternative ‘emission reduction sharing’ agreement type. On the other hand countries that have a relatively low emissions abatement cost would prefer a system of ‘emission reduction’ since such agreements probably would mean moderate costs for these countries. Under a ‘cost sharing’ agreement they would probably face commitments involving higher costs.

This dimension of relative abatement cost and system preference is combined with the level of concern for climate change and commitment level for reducing emissions within OECD and is

Figure 8.11 The achievable set of negotiations



shown in Figure 8.11.[6]

Thus we assume that a country that is above average concerned about climate change is also inclined to take on a relatively high commitment or cost share to reduce emissions. The commitment level of a country can also be interpreted as concern for climate change impacts in the country. The six groups of countries defined above are each represented by a curve in the figure. The assumption is that the HH countries of high cost and above average concern will be willing to accept a higher commitment the closer the proposed burden sharing system comes to 'cost sharing'. Likewise for the HL group that are somewhat willing to accept commitments, but this curve is below the HH curve. From the same line of reasoning the LH curve is above the LL curve, and both groups are the more willing to take on commitments the closer the proposed burden sharing system is to 'emission reduction sharing'. The curves for the last two groups of average abatement cost countries have a hill shape and are found in the middle of the figure since these countries are assumed to prefer some intermediate burden sharing system between 'emission reduction sharing' and 'cost sharing'. As for the other groups the AL curve is below the AH curve.

[6] Emissions can either refer to carbon dioxide emissions or to 'gas packages' containing carbon dioxide and other climate gases expressed in carbon dioxide equivalents with the help of GWPs.

From this figure we can draw some interesting tentative conclusions on the setting of the AGBM negotiations and the likely achievable set of these negotiations. We assume that one of the objectives of the negotiations is to reach as high a commitment level as possible for the involved countries. In the figure this translates into finding the highest point contained in the achievable set. Checking out the figure we find that the achievable set is determined by the area below all the curves. The achievable set can be interpreted as a condition for all countries being individually rational, thus preferring to participate if the alternative is no agreement. Thus the achievable set is the area described by the left-hand side of the HL curve and the right-hand side of the LL curve. The point A represents the intersection of these two curves. We also note that the HH, LH, AH and AL curves does not determine what is achievable in the negotiations. The achievable solutions and the highest possible commitment level, represented by A, is determined by the LL and HL groups. Thus the countries of below average concern for climate change, and low or high abatement cost determine the achievable level of commitment in terms of emissions abatement target for the OECD group. It should be observed that A is not necessarily the Pareto optimal solution, since we cannot rule out the possibility that all countries could be better off choosing a commitment level below A.[7] However, A shows the maximum achievable commitment level and target for the OECD group.

From the figure we also see that the achievable target can be increased if the level of concern in the LL and/or HL groups are increased. Such changes of concern can be activated by new research and predictions for future climate change and impacts, confer the new IPCC report (IPCC, 1995a). The achievable target could also be increased through ‘side payments’, where the countries that have a higher than average concern for climate change compensates a higher commitment level of countries that have a lower than average concern. Such compensation could take many forms, such as relating AGBM negotiation positions to positions in agreements for other international environmental problems, but seems to have a low political feasibility between OECD countries. On the other hand compensation schemes would add an complicating factor to the negotiations.

The point A also determines the ‘optimal mix’ of ‘cost sharing’ and ‘emissions reduction sharing’ in terms of an agreement or proposed burden sharing system. An important challenge during the negotiations will be to introduce flexibility with respect to this dimension in the process (which is represented by the x-axis in Figure 8.11), such that a menu for choosing different levels and combinations of ‘cost sharing’ and ‘emission reduction sharing’ in one burden sharing system is developed. As an illustration we can think of three agreement types, where the first is of the ‘emission sharing’ type, the second of the ‘cost sharing’ type, and a third type that represents the mid-section of the x-axis in the figure. Given these three agreement types the argument is that the

7 A solution is Pareto optimal if it is not possible to reallocate commitments between countries such that any country is made better off without making at least one other country worse off.

mid-alternative (i.e. the third type) would be most promising for the negotiations to move in direction of. This agreement type would be a mix of the other two types and give concessions both to ‘cost sharing’ and ‘emissions reduction sharing’.

A general option is to favor differentiation among OECD countries where different economic situations and national circumstances is accounted for, see FCCC and AGBM (1995). One way of doing this is burden sharing rules based on national circumstances, which we have discussed in chapter 7. However, there is a tradeoff in terms of adding complicating factors in the negotiations. One more option to reduce abatement costs of high cost countries outside of the AGBM negotiations is Joint Implementation under the FCCC. There is, however, some uncertainty associated with Joint Implementation, confer section 5.8

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INTERGENERATIONAL WELFARE EFFECTS

Summary

Because of the long lifetimes of the most important climate gases and the delay in the climate response, the analysis of policies to mitigate climate change imposes strong assumptions about the distribution of costs and benefits between generations. To base intergenerational distribution on one single ethical principle will always have some consequences that could have been better handled by another principle. A minimum requirement for sustainable development is equity among generations. However, equity usually leads to much less total welfare than would have been possible. A maximum welfare principle may, however, lead to economic recession in the very long run. The weaknesses of the intergenerational aspect of analysis of climate change suggests that recommendations for policies with consequences in the very long term are interpreted with care. A discussion of these aspects is useful, however, in order to identify the most urgent issues to be examined.

The main focus in this report is on the distribution of climate policy measures between countries - that is *intra*generational distribution. In this chapter we will elaborate on the question of *inter*generational equity. The question of intergenerational equity in climate policy is highlighted by the time lag between policy actions taken today and the future atmospheric concentration of GHGs and potential welfare losses created by climatic changes. Such intergenerational equity considerations are reflected in the principles of the FCCC, as summarized in Article 2:

> "The ultimate objective of this Convention ....is to achieve,.., stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such level should be achieved .....to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

There seems to be a consensus and explicit recognition on the need for intergenerational equity on a global level. In the FCCC the notion of sustainable economic development is emphasized as a principle for distribution between generations. The FCCC focuses especially on the protection of food production, in that it gives special attention to securing basic needs for present and future generations. It is, however, quite unclear how these principles should be implemented. Can the concept of sustainable economic development give any guidance for the practical implementation of climate policy?

As we will show in the next paragraph, the notion of sustainable development is a rather vague concept. Moreover, it is stated in the FCCC that climate policy should *not* aim at solving problems related to equity in general. Thus, considerations of equity in relation to climate policy applies only to the extent that climate change, or actions to mitigate climate change, affects aspects of equity. The question we ask is: "how can sustainable development as a principle for distribution between generations serve as a guideline for the assessment of what a fair effort may be now in order to reduce climate change in the future".

The concept of 'sustainable development

The concept of 'sustainable development' was placed on the political agenda by the World Commission on Environment and Development (WCED) through its report Our Common Future.[1] The WCED defined sustainable development as a development that "meets the needs of the present without compromising the ability of future generations to meet their own needs".

The concept of sustainable development has proved to be too vague and ambiguous

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[1] World Commision on Environment and Development (1987).

to give concrete guidance for political decision-making. There has, however, been many suggestions for definitions or interpretations to make the notion more precise and operational.[2] The concept has e.g. been formalized within economic models of optimal development, and the implications of different interpretations and ethical assumptions have been analyzed and discussed. [3] The studies show that it is difficult to make the concept of sustainable development operational and to analyze it within a formal framework without loosing central issues of importance in relation to fairness and justice. The concept should therefore be kept relatively open.

One step towards a definition, provided by Asheim (1993), is "sustainability is a requirement of our generation to manage the resource base such that the average quality of life that we ensure ourselves can potentially be shared by all future generations" or that "development is sustainable if it involves a non-decreasing average quality of life".[4] The notion 'quality of life' is supposed to include everything that influences the situation in which people live. It is intended to capture both material consumption and the importance of health, culture and nature. By resource base we mean the total value of stocks required for production in the economy.[5] To analyze the problem of distribution of welfare between generations it is common to distinguish between natural capital (resource- and environmental assets) and manmade capital (both real and human capital). In a sustainable economy the total value of these capital stocks should be non-decreasing. Although it is easy to concur with this general principle, many difficult questions need to be answered before it can be implemented.

Ideally, the concept of sustainable development should give guidance for both the goals for climate policy and for the distribution of abatement costs between generations. However, there are many problems in connection with intergenerational welfare comparisons: preferences of future generations are unknown, there are huge uncertainties about the future economic and environmental development, the benefits of climate policy, technological development, etc. As such uncertainties will never be totally eradicated, implementation of intergenerational

[2] Pezzey (1992), for instance, mentions more than 60 different proposals for definitions of 'sustainable development'.

[3] See e.g. Asheim (1993), Chichilnisky (1993), and Beltratti, Chichilnisky and Heal (1993).

[4] See Asheim, 1993 p. 4-5.

[5] An economy can be both a global economy and a national economy.

equity aims based on the concept of sustainable development presupposes agreement on simplified, but often controversial, assumptions about such variables.[6] The academic debate on sustainability has paid much attention to the possibility of substitution between natural- and manmade capital. The question was brought up for discussion in the early 1970ies. It was argued then that the steadily increasing exploitation of the world's non-renewable resources would lead to a gradual extinction of resources which are essential for the existence of the human kind. This exploitation thereby deprived future generations the possibilities of achieving the same opportunities as the present generation. The economist's response to this view is that expresses a too rigid view on the possibilities of substitution. The argument is that a relative shortage of essential resources will be reflected in market prices. When the stock of natural resources decline, their market prices will increase, and lead to a substitution towards alternatives. The core of the discussion is therefore the question of how far the concept of sustainable development can allow for substitution between manmade capital and natural capital.

The FCCC establishes the responsibility for descendants in general. Article 3.1 summarize this issue.

> "The parties should protect the climate system for the benefit of the present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibility and respective capabilities."

Thus, the present generation has a responsibility for future generations. However, the FCCC gives different responsibilities within the present generation, but is not very clear as to what extent available environmental and natural resources may be exploited today. This is clearly not only a question of facts, to which one can provide scientific answers. Ethical aspects, especially those related to our concern for generations to come are also important in this respect. For instance, there is no doubt that exploitation of natural resources has contributed significantly to welfare during the history. Therefore, it is pointless to prohibit any substitution between natural resources and manmade capital to take place in the future. On the other hand, the historical experience does not necessarily give us any guidance as to how far depletion of natural resources should go. For instance, it does not tell us anything whether the concern for future generations are properly represented in the

[6] The precautionary principle give some guidelines for how to handle such uncertain situations, but this guidelines is rather general and the precautionary principle seems also to be difficult to make operational.

observations, such that our own concern can be revealed from these observations.

Other criteria of intergenerational distribution

In contrast to intragenerational distribution there is only a few principles for distribution between generations that is mentioned in the literature. We will focus on two criteria; the utilitarian criterion and the so-called maxi-min criterion. Both criteria are well known welfare criteria, and frequently used in economic analyses. The utilitarian suggests that the right social alternative is the one that maximizes the sum of welfare over all generations, with or without discounting. The maxi-min welfare criterion suggest that the right social alternative is to allocate resources to the least wealthy, and is thereby an egalitarian one. The utilitarian criterion is the most commonly used criterion in optimal economic growth analyses. One reason for this, demonstrated by Solow (1974), is that the maxi-min criteria could be an obstacle for economic development.

Both the utilitarian and the maxi-min criteria may be compatible with the definition of sustainable development. A sustainable development could be both totally egalitarian or involve increasing welfare over time. Hence, several types of development might be sustainable. Sustainable development is just a requirement that our generation is not making future generations worse off than we are. However, Dasgupta and Heal (1979) shows that a utilitarian welfare criterion will always lead to a welfare path that sooner or later approaches zero if exhaustible resources are applied in production and cannot be replaced. In such an economy, the utilitarian criterion is therefore not in concordance with sustainable development. It is, however, difficult to point at essential non-renewable resources that are necessarily depleted because of climatic change. On the other hand, several of the essential natural resources, such as cultivable soil, are renewable contingent on a proper management. To design such a management may require a full integration of the dynamics of both the economy and the ecology.

Comparisons of economic and environmental effects over time - the discount rate

Policy recommendations from economic analyses are heavily based on assumptions about how economic and environmental effects that occur at different points in time are compared. The assumptions are usually rooted in standard choices which are not, and cannot be, discussed in detail every time they are chosen. However, conventions are usually set within certain contexts. For instance, the time perspective of economic analyses seldom exceeds 25 years. Assumptions about the rate of return and the welfare function, appropriate within such a time perspective, may be utterly restrictive when the time perspective extends to 250 to 300 years. While the time perspective in economic analysis usually can be considered by reference to the preferences of presently living people, analysis of climate change will necessarily raise the question of how to compare "our own" preferences with those of generations to come. In this perspective, the standard assumptions about comparisons over time, such as the choice of welfare function, requires a critical examination. Many factors of decisive importance for the choice of climate policy, distributions of commitments among countries, and timing of actions relates directly to assumptions about the sharing of responsibilities between generations.

The simplest, and most common, way to compare economic values over time is to choose a rate of discount. IPCC (1995b) suggests in the executive summary a discount rate applied for the analysis of climate policies in the range 1.5 to 6%. This means that the present value of a climate measure that yields a 1 mill. USD benefit 100 years ahead ranges from nearly

2 950 USD to nearly 226 000 USD, even if the benefit is assessed with accuracy under full certainty. Apart from being nearly useless as a recommendation, it also indicates that the cost of climate change mitigation, and principles for sharing it among countries, may be significantly affected by the choice of discount rates, because the time profile of costs and benefits which face different countries differs. The question, therefore, is what set of assumptions forms the basis for the choice of this rate?

The standard economic approach to intertemporal allocation of resources over time follows the well-known Ramsey rule or some version of it. The Ramsey rule is basically theoretical, and developed within a very general model. However, it provides the benchmark for any discussion about economic comparison of goods and services which occur at different points in time. In very general terms, the Ramsey rule can be expressed as follows:

> Intertemporal equilibrium is characterized by equality between the marginal social return on capital and the cost of postponing consumption.

The social return on capital is equal to the marginal productivity of capital adjusted for the social loss due to externalities. In many cases the marginal productivity of capital can be observed by the return on private investments. For some categories of capital, for instance capital expended on public services, social return is harder to observe. In the model described in chapter 4, the social return on abatement capital is equal to the marginal reduction in abatement costs, for instance because of learning, plus the marginal value of lower emissions. The first component might be observed, but its contribution to the social return is probably small. The second term is very difficult to observe.

The marginal social return on capital is likely to change in the long term. It may be difficult to make a choice of this rate over a long period of time, and sometimes inconsistent if studying economies with externalities. In such cases it may be more appropriate to try to assess the cost of postponing consumption. Then, social and ethical considerations is taken into account as well. In the simplest growth model, the cost of consumption postponement is determined by two terms. One is the rate of impatience, which is included in the social welfare function of most economic models. The other is the rate of consumption growth adjusted for the intertemporal elasticity of substitution. The latter term has not been subject to much controversy. It reflects the fact that reduced consumption today enables more consumption at a later point in time. However, the elasticity of intertemporal substitution relates directly to the concern for future generations, by reflecting the emphasis on intergenerational equity in the social welfare function. The higher elasticity the higher weight on intergenerational equity.

The most controversial term has been the rate of impatience, which assumes that the utility of a given magnitude of consumption is higher, the sooner it is consumed. As a consequence, the consumption of the present day generation is given a higher weight than future generations in the welfare function. The discussion of how impatience relates to the rate of return stems from the 18th century, and some argued as late as in the 1950-ies that the existence of interest rates could be explained by people's impatience alone, that is, they required something in compensation for not consuming at once. Schelling (1994) discusses ethical aspects of a rate of impatience in the social welfare function, and cannot find any reason for including it. In a multiple period setting there is in principle no difference between intergenerational distribution and intragenerational distribution. His polemic question is why an explicit distribution-factor should be attached to intertemporal allocation of resources when no-one dears to attach such a factor to intragenerational allocation.

Many economists oppose this view. Manne (1994) argues that time-series data confirm the existence of a rate of impatience. Taking the Ramsey rule as his point of departure, he cannot in fact find good reasons for choosing a rate lower that 2%. In his study of Rawlsian preferences, Solow (1974) points out that intergenerational equity is likely to lead to higher level of consumption today and lower future consumption compared with an optimal development, even when preferences exhibit impatience. The reason is that welfare optimization takes into account the possibility of setting aside resources (investments) in order to enhance consumption later.

There may be many reasons why time-series data confirm a rate of impatience. Dasgupta and Heal (1979) show that one reason may be the uncertainty attached to the date of death. Another reason is that it is not straightforward to assess the aggregate social return on capital, because it includes the value of e.g. externalities and social return on public investments (cf. the results of the model analyzed in chapter 4). The rate of impatience thereby fills the gap between an observed rate of return and acceptable assumptions about the instantaneous welfare function.

One may, however, ask whether the standard separation between the rate of impatience and consumption growth adjusted for the elasticity of intertemporal substitution provides a sufficient expression for the value of postponing consumption. This separation is due to the choice of intertemporal welfare function, which presumes that preferences over time can be appropriately represented by the sum over the instantaneous utilities at each point in time over a given period, weighed by the rate of impatience (additive utility). To apply instantaneous preferences as the point of departure for a description of intertemporal preferences is appealing because it is easier to set up criteria for such a welfare function from intuition. The question is whether the timing of events, for instance the consumption path itself, may have direct impacts on the preferences. If so, there is a good chance that the standard additive utility-function is inappropriate.

One apparent example of such a dependency of time in consumption is habit formation, which indicates that growth is better than recession. Habit formation means that the utility of a given consumption level depends on whether the level in former periods were higher or lower than the present consumption level. Another example is that decision makers are probably not indifferent as to when uncertainty resolves over time. When faced with alternative sequences of lotteries, it is likely that those lotteries which give early resolution will be preferred to those with a late resolution. Additive utility does not allow for such considerations, because it is impossible to separate between risk attitude and propensities to allocate consumption over time. When applying an additive utility function for a test of properties in time series data, therefore, one does not know what stems from intertemporal substitution and what stems from risk aversion.

Koopmans (1960) established a utility function which allowed for dependency between consumption at different points in time. In later years, his so-called recursive utility has been applied to deal with the problems of habit formation and choices over lotteries where the uncertainty resolves at different points in time. In long-term analysis, and especially in the case of climate change, a better understanding of these aspects may contribute significantly to the question of discounting. To our knowledge, however, no-one has addressed the problem of climate change within such a framework.

Intergenerational comparisons - what can be said?

There is no doubt that questions related to intergenerational comparisons represent major challenges to the creation of a global climate policy. How we choose to emphasize the welfare of our descendants will not only have an impact on the timing of actions, but will also affect the distribution of commitments among present living people, for instance by its direct influence on the choice of climate policy measures. However, there are no concise tools available for making intergenerational comparisons. This is partly because ethics will remain a vital aspect when comparing ‘now' and ‘the future'. To obtain general acceptance for political or philosophical ideas worldwide, such as those expressed by the concept of sustainable development, it is required that a rather wide range of interpretations is allowed for. This is why such concepts may give little guidance for a scientific treatment of the problem. Another reason for the lack of concise tools is the exceptionally long-term aspect of climate change. The basis for economic theory, for instance, is not developed within such a perspective. A number of methodological problems can be identified, and further elaborated on. An improvement of the methodological basis will provide policy-makers with a more appropriate tool for comparisons of intergenerational distribution.

Despite these shortcomings, the conventional wisdom has some important messages to give. The most important are, firstly, that substitution between different kinds of national capital stocks, such as manmade and natural capital, will in general contribute to the welfare for future generations. A gradual extinction of given stocks will usually be reflected in market prices. The problems relate to stocks not being subject to economic transactions, or to unanticipated shocks that may occur. Secondly, the question of distribution between the present and future generations is not only a question of the emphasis placed on intergenerational equity. Perhaps more important is the potential of economic growth. Avoided consumption implies that the ground is prepared for consumption growth. Thus, a myopic altruism may have an environmental effect opposite to the one intended.

7. PARTICIPATION IN A CLIMATE PROTOCOL AND BURDEN SHARING RULES

Summary

This chapter focuses on the issue of equity in the context of climate change. It is explicitly assumed that fair sharing of the burden of reducing greenhouse gas emissions is quickly becoming an essential issue in the on-going climate protocol negotiations. The first part of the chapter discusses some important relationships between emission reduction targets and coalition-building as well as relationships between abatement cost and countries' willingness to cooperate in reducing greenhouse gas emissions. The second part of the chapter explores the role which burden sharing rules, formulae and equity principles could play in reaching an agreement on a climate protocol. This part discusses a number of concepts of equity, examines three specific burden sharing rules and formulae, and presents cost calculations on the burden sharing rules. The chapter concludes by discussing whether burden sharing rules could facilitate agreement among the OECD countries on how to share the total cost of reducing greenhouse gas emissions.

7.1 Introduction

Governments are at present in the process of examining how a future climate protocol could reduce the total cost of greenhouse gas reduction, and how it could realize a fair distribution of abatement cost across countries and among regions. Some Annex I parties are much concerned about the future distribution of the cost of reducing greenhouse gas emissions because they expect that emission reduction measures might entail considerable cost and that the abatement cost might be distributed in an uneven manner across Annex I parties. In order to achieve a climate protocol, it is clearly important how a protocol will determine the size of the total abatement cost and affect the international distribution of abatement cost across countries.

This chapter explicitly assumes that achievement of fairness and equity - more particularly, a fair burden sharing - is an essential issue in the ongoing climate protocol negotiations.[1] The chapter focuses on how the Annex I parties, specifically the OECD countries, might agree to share the total cost of reducing greenhouse gas emissions. Two issues are considered particularly important when countries decide whether to cooperate in emission reduction, namely the size of a total commitment for the OECD group of countries and the distribution of the commitments to reduce emissions among the OECD countries.

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[1] There exist a rather extensive literature about fairness and equity in the climate change context. For a review, see Lasse Ringius et al. 'Climate Policy, Burden Sharing and the Nordic Countries: Present State of Analysis and Need for Further Analysis', *CICERO Report* 1996:2.

As discussed in the next section, greenhouse policies are highly interdependent and individual governments' policy choices have significant consequences for group-formation processes in the climate protocol negotiations. Each government is dependent upon if, how, and to what extent other governments intend to reduce global warming. The third section discusses some important relationships between global emission abatement targets, total abatement cost, and participation. The fourth section will discuss the relationship between the cost share of each country and its willingness to participate, especially the significance of achievement of equity when distributing commitments to reduce greenhouse gas emissions, and defines the concept of burden sharing. The first section of part 2 will discuss specific equity principles and burden sharing rules. In the second section, three burden sharing rules and formulae are explored and the distributive effects of their implementation are clarified. The third section will draw conclusions regarding the roles which rules and principles might play in reaching agreement on a climate protocol.

7.2 PART I

7.2.1 Anatomy of the Climate Protocol Negotiations

The challenging and complex nature of the climate protocol negotiations has to do with the fact that the global climate system is a collective, or public, good.[2] It is in the collective and global interest that all countries cooperate, but it is in each country's self-interest not to participate while others cooperate to protect the climate system. No single country can alone protect the global climate system, but individual countries benefit when others cooperate but they do not.

The classical problems associated with the provision of collective goods are free-riding and under-provision of the collective good. Problems of collective action are aggravated at the international level due to the absence of world government institutions, few possibilities for sanctioning, and limited opportunities for monitoring and enforcement when countries do not comply with their environmental commitments. Collective goods may, however, be provided by resourceful and powerful countries. Alternatively, they might use of force, side-payments and even 'bribes' in order to induce other countries to cooperate. However, small homogeneous groups of countries may in some circumstances succeed to cooperate and discourage free-riding.

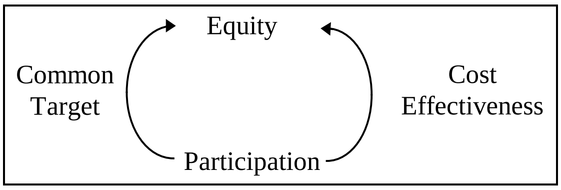
[2] Alternatively, the climate system could be conceived of as a renewable natural resource (but only if long time scales are considered). With minor qualifications, the above observations are also valid for renewable natural resources.

Recently concerns for equity, fairness and burden sharing have resurfaced in the global climate policy process.[3] Some of the many concepts of equity that have been suggested in the context of global warming are discussed below in section 7.3.1. Although equity is often perceived to be a diffuse and complex issue, it is here suggested that the political significance of achieving equity and the emerging 'need' for fair burden sharing in the global warming context can at least partly be understood by taking into account three other issues, namely participation, common emission reduction targets, and cost-effectiveness.

Figure 7.1 depicts some fundamental relationships between equity, participation, common emission targets, and cost-effectiveness. The right-hand arrow indicates that a relationship exists between how cost-effectively emissions are reduced, the number of participating countries and equity. Since there is a large variation in GHG emission reduction costs across countries, see chapters 4 and 8, cost-effectiveness would mean larger reductions in some countries than in others. If countries with relatively inexpensive abatement options would have to bear the abatement costs alone, it is unlikely that they would participate and other countries would accordingly have to pay 'their' share of the total abatement cost to encourage participation from as many countries (in which emissions reduction is less costly) as possible. As the left-hand arrow indicates, there also exists a relationship between the amount of GHG emissions reduced, the number of participating countries and equity. Emission reduction undertaken in a few countries might be sufficient if the common emission reduction target is rather modest, but an ambitious target can only be achieved if many countries reduce their GHG emissions. Because of significant national differences which *inter alia* cause very uneven abatement costs across countries, broad participation almost inevitably would result in demands for a fair sharing of the burden of reducing GHG emissions. Relationships between equity, common emission targets, participation and cost-effectiveness are examined in part 1. Furthermore, as shown in part 2, there exists a dynamic relationship between equity and cost-effectiveness.

[3] Concerns about the global distribution of abatement costs were evident from the early beginnings of the global climate policy process in the late 1980s. Developing countries refused to incur the cost of solving the global warming problem. As it was emphasized, they had not caused the global warming problem and they were accordingly not responsible for its solution. Developing countries also emphasized that they have less means available for such purposes. In fact, North-South issues seriously jeopardized an agreement on the climate convention.

Figure 7.1 Relationships between equity, participation, cost-effectiveness and common emission targets



With respect to the climate protocol negotiations among the Annex I group of countries and the ‘need’ for burden sharing, two issues should be noted at the outset. Firstly, the issue of responsibility for the historical cumulative emissions of greenhouse gases, i.e. the historical emissions added over time, has so far not played an important role in these negotiations. Secondly, neither has the issue of adverse climate change impacts (e.g. flooding of coastal areas or ecosystem damage due to temperature increase) played a significant role in the climate protocol negotiations. For such reasons, those two issues are not examined here and they are not reflected in the burden sharing rules examined in this chapter.[4] It is reasonable to assume that climate protocol negotiations conducted within the Annex I group of countries are likely to be less complex than if developing countries were participating in the negotiations; developing countries would probably focus mostly on the historical emissions of greenhouse gases, and on the adverse effects of climate change, especially in developing countries.

It should be noted in addition that the climate protocol negotiations primarily concern the OECD countries. Although the Berlin Mandate declares that all Annex I parties shall strengthen their commitments to reduce greenhouse gas emissions, the protocol negotiations primarily take place among OECD countries because the economies in transition for the time being are considered unlikely candidates for a climate protocol.[5] Many groups could possibly be formed among the high number of countries participating in the global climate policy process and existing groups of political and economic importance, such as the European Union, could be likely candidate groups for negotiating a climate protocol. It is quite likely that problems in creating a negotiation group on the climate protocol would jeopardize the negotiation process. The existence of a rather small, more homogeneous negotiation group

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[4] Ian Rowlands has examined the development of climate policies using the so-called interest-based explanation suggesting that a country’s policy is determined by the balance of the costs and benefits of climate change policy. The damage costs of climate change are included in the study. See Ian H. Rowlands (1995) ‘Explaining National Climate Change Policies’, *Global Environmental Change* 5(3): 235-49. For the interest-based explanation more generally, see Detlef Sprinz and Tapani Vaahtoranta (1994) ‘The Interest-Based Explanation of International Environmental Policy’, *International Organization* 48(1): 77-105.

[5] See the FCCC, Article 4.6.

should therefore be acknowledged as an important first step in the climate protocol negotiations.[6] However, while the Berlin Mandate urges the Annex I group to strengthen their commitment, it cannot be safely assumed that this group can reach an agreement on a climate protocol. To illustrate some of the relationships depicted in Figure 7.1, possible group-formation processes in the climate protocol negotiations are examined below.[7]

7.2.2 Relationship between Global Emission Abatement Targets and Participation

Countries that set an ambitious emission reduction target and intend to reduce a significant amount of total global greenhouse gas emissions necessarily have to adopt a set of tough and stringent climate measures and policies. The European Union, for example, has recently suggested that the atmospheric concentration of CO_2 should be less than 550 ppmv.[8][9] Stabilization at a level lower than 550 ppmv, which according to the IPCC would result in a temperature increase of around 2 degrees, would require global emissions to be less than 50% of current levels of emissions. Draconian abatement measures would be necessary to reach this policy goal and the cost would clearly be prohibitive if the European Union alone were to achieve this common emission reduction goal.[10] Furthermore, assuming for a moment that the EU in fact could achieve this ambitious goal, abatement cost would become exceedingly high and political and technical feasibility surely would become scant at the point where easy and inexpensive opportunities for emission reduction would no longer be available. This example illustrates the existence of one direct relationship between total abatement target and the willingness of countries to protect the global climate system, namely that small groups of countries setting an ambitious common abatement target will incur prohibitively high

[6] The Berlin Mandate is evidence that the Annex I countries have now agreed to ‘go first’ in controlling greenhouse gas emissions. Thus, the first Conference of the Parties (COP-1) confirmed what some studies already had predicted, namely that the climate regime is likely to develop in a sequential fashion: the first phase, similar to the present one, is one in which no countries have legally binding commitments, the second phase is one in which most if not all Annex II countries will acquire legally binding commitments, phase three is the phase where all Annex I countries have legally binding commitments, and, finally, phase four is the phase in which all countries have legally binding commitments. For the phases in the development of the climate regime, see A. Torvanger, et al. 'Joint Implementation under the Climate Convention: Phases, Options and Incentives', *CICERO Report* 1994:6, pp. 2-5.

[7] Some scholars assume that coalition-building of some kind is necessary to move the climate negotiations forward. For a discussion of winning coalitions in the global climate policy process, see James K. Sebenius, ‘Designing Negotiations Toward a New Regime: The Case of Global Warming’, *International Security* 15(4): 110-148.

[8] Statement of the Representative of Italy on Behalf of the European Union. 6 March 1996.

[9] An atmospheric CO_2 concentration twice the preindustrial level (commonly referred to as $2xCO_2$) is commonly used to compare estimates of global warming. According to the IPCC, atmospheric CO_2 concentrations have increased from about 280 ppmv in pre-industrial times to 358 ppmv in 1994. Ppmv (parts per million by volume) is an unit for mixing ratio (or concentration) that gives the number of molecules of a gas per million molecules of air.

abatement cost. It is therefore unlikely that small groups of countries will for long pursue an ambitious common target.

But a large group might be able, in theory, to achieve the emission reduction goal of the European Union. Individual members of the group will be able to reduce less if they could agree to divide up the total amount of emission reduction and distribute smaller individual contributions among themselves. Everything else being equal, it is therefore less costly for individual countries that attempt to realize a significant common emission reduction target within a large group.[11] Individual countries can contribute less when others also contribute towards the same goal, and the bigger the group the less each individual country needs to contribute. Accordingly, countries will attempt to add as many countries as possible to their efforts to reduce global warming. In regard to the climate protocol negotiations, countries intending to halt global warming will want as many OECD countries as possible to join them in their efforts. The individual country will accordingly prefer that all OECD countries join a climate protocol. However, as discussed below, out of concern for national goals and national goods some countries might not be willing or able to pursue a less ambitious national climate policy even though this would result in more total emission reduction.

A quite different situation occurs when countries pursuing an ambitious climate policy attempt to get other countries which are more reluctant to follow their lead and thus achieve a considerable common emission abatement target. Some countries might be genuinely concerned about global warming, and others might hope to provide political leadership in the climate protocol negotiations.[12] So-called leaders will attempt to build a big group of committed countries as such a group will be able to reduce a considerable amount of total greenhouse gas emissions. By creating international climate regulation or policy, leaders might also hope to protect their economies against unilaterally imposed abatement cost. To build a big group of OECD countries committed to a legally binding climate protocol, leaders might attempt to persuade others of the necessity of halting global warming. Alternatively, they might use force, side-payments, or 'bribes'.[13] They might also use their market power to push other

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[10] For a discussion of the 550 ppmv scenario, see IPPC 'The Science of Climate Change'. Prepared by Working Group I. Technical Summary for Circulation at SBSTA/AGBM, February/March 1996, pp. 20-2.

[11] In addition, a larger group of countries may have more national and collective options, a fact which might increase technical and political feasibility. This topic is not discussed here but has been considered within the OECD/IEA Joint Project on National Communications under the Framework Convention on Climate Change. See 'Policies and Measures for "Common Action"'. Initial Report, 18 August 1995.

[12] In the early 1970s, the United States was concerned about ocean dumping of waste and provided essential leadership in the process creating the global ocean dumping regime. See Lasse Ringius (1992) 'Radwaste Disposal and the Global Ocean Dumping Convention: The Politics of International Environmental Regimes', unpublished Ph.D. dissertation, the European University Institute, Florence, Italy.

[13] Oran R. Young, 'Political Leadership and Regime Formation: on the Development of Institutions in International Society', *International Organization* 45(3): 281-308.

countries to reduce greenhouse gas emissions in a more aggressive manner. In this way leaders might succeed to create a group of OECD countries that accepts the conditions of a rather aggressive climate policy being presented in the form of a protocol. However, it is unlikely that leaders will for long be willing to unilaterally pursue an ambitious climate protection policy. When it is not possible to create a rather large group of OECD countries, leaders should be expected to abandon such policy if they incur considerable economic cost as a result.

In other situations there will not exist any such direct relationships between a common emission abatement target and willingness of countries to participate. Thus, national concerns and motivations might make some countries unilaterally embark upon an ambitious climate policy. For example, some countries might expect their energy-conservation industry to profit if the future puts more emphasis on conservation of energy, while others might be under pressure from environmental non-governmental organizations (ENGOs) and public opinion. Significant implications for the climate protocol negotiations follow in both situations since countries will be little concerned about whether other countries take similar steps, or whether they in fact take an effective step towards slowing global warming. Especially when they in reality only are concerned about achieving national goals and national goods, such countries will oppose a lowering of their climate policy ambitions and refuse to under-reduce emissions. Moreover, they will therefore not attempt to build a bigger group of OECD countries as described above. Although a bigger group would reduce a larger total amount of emissions, they will not support other countries which pursue less ambitious climate policies. Countries falling into this category would insist on primarily achieving their domestically-identified emission target.

Should such a situation occur, OECD countries will form groups around different emission reduction targets and perhaps around specific climate policies and measures. Some nations might not even join a group. It also seems plausible that conflict may occur between groups supporting different climate policies or targets. Conflict might likewise result when groups favoring different climate objectives attempt to enlarge, or when groups protect themselves against economic and other consequences of rival groups' climate policies. Serious rivalry or incongruity will result in stalemate, with consequences for the regime-building process. For example, the European Union hoped that the United States and Japan in 1992 would adopt a climate policy similar to its policy but the European Union's proposal for a climate policy did not receive the support of the United States during the last phase of the negotiations on the FCCC. The European industry, which feared that the European Union policy would mean unfavorable trade effects and reduced international competitiveness subsequently withdrew its political support for the European Union climate policy. This sequence of events caused a loss of momentum in the regime-building phase.

A quite different situation occurs when only a few countries set a modest emission reduction goal. Some OECD countries might not be overly concerned about the global warming problem. Others might fear that their industry or economy will be disadvantaged if a significant amount of emission reductions is undertaken. Public opinion might not be in favor of ambitious climate policy in some countries, while others might not be able to follow a feasible and economically acceptable way to emission reductions. For all such reasons, countries will identify a rather modest emission reduction goal which primarily reflects existing national opportunities and constraints in respect to greenhouse gas emission reduction. A modest emission reduction goal could be achieved by a few OECD countries, but countries will have no significant incentives for building a bigger group. It is therefore unlikely that a big group of OECD countries will emerge in a situation where only some few OECD countries pursue a modest climate policy. Moreover, no significant reduction in total global emissions will result.

In conclusion, there exist some rather strong relationships between the ambition of greenhouse policies - and therefore the total amount of greenhouse gas emission that is reduced - and likely group-formation processes in the protocol negotiations. It is most likely that a big group of OECD countries is built when politically and economically powerful countries pursue a rather ambitious emission reduction goal which results in more than negligible abatement cost. It is less likely that a big group of OECD countries will be established when few OECD countries pursue a modest emission reduction goal. Neither is it likely that a big group of OECD countries will be built when few OECD countries pursue an overly ambitious emission reduction goal, given existing constraints and opportunities.

As discussed in chapter 8, however, there have so far been no indications that any of the politically and economically powerful countries are acting as a leader in the climate protocol negotiations. Moreover, most countries seem to be concerned mostly about national goals and national goods. In such a situation, the issue of fairness and equity becomes even more prominent. Below follow some introductory observations regarding how countries may agree to divide up the total amount of emission reduction and distribute individual commitments among each other.

7.2.3 Relationships among Cost, Willingness to Cooperate and Burden Sharing

Given a specific emission reduction target, it is reasonable to assume that countries will attempt to reduce their abatement costs as much as possible. They will in other words strive to be cost-effective. The greater the abatement costs, the greater the incentive is to find cost-effective ways to reduce emissions. Everything else being the same, countries that find emission control is too costly choose either to reduce fewer emissions or reduce no emissions at all. However, the evolving global climate policy process faces governments with additional challenges.

Many analysts and international relations scholars would expect that countries only will cooperate in protecting the global climate system to the extent that they improve, or at least maintain, their economic and political position relative to other states.[14] In the most extreme version of this view, countries will attempt to systematically take advantage of others that incur economic costs due to abatement policies. Individual countries will take advantage of opportunities to improve their economies and economic welfare vis-a-vis other countries. Individual countries might be more concerned about economic growth and employment than about protection of the global climate system which will further reduce their willingness to cooperate. Following this, more permanent forms of international cooperation to protect the global climate system will be extremely hard to realize since countries necessarily have to protect themselves against others. Climate protection cooperation will only occur when rather homogenous countries undertake a modest level of policy coordination that does not jeopardize their economies and create opportunities for some to profit at the expense of others.

In a less extreme version of this view, countries are willing to incur abatement cost when others also incur such costs. The willingness of countries to cooperate will depend upon whether it is possible to achieve an equal cost distribution across countries. By building a global climate change regime, moreover, countries might be able to protect their economies and at the same time influence global climate policy.[15] They will take action to defend their economies and economic welfare against those who try to benefit at their expense. It should be noted, furthermore, that some countries already have identified domestic climate policies which are more ambitious than the global climate policy. This could indicate that they might be willing to accept some minor relative losses. Consequently, there might exist a certain well-defined area of possible climate policy agreements and countries might prefer to reach one agreement inside this area rather than no agreement at all.

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[14] Kenneth N. Waltz (1986) *Theory of International Politics*, in Robert O. Keohane (ed.) *Realism and Its Critics*, pp. 27-130. New York: Columbia University Press. Joseph M. Grieco (1990) *Cooperation Among Nations: Europe, America, and Non-tariff Barriers to Trade*. Ithaca: Cornell University Press.

[15] Marc A. Levy et al. (1995) 'The Study of International Regimes', *European Journal of International Relations* 1(3):267-330.

Burden sharing refers to the way in which a group of countries benefiting from a collective good agrees to share the costs of providing the collective good.[16] As mentioned already, the global climate system is a collective good. International and global collective goods can, however, be provided when a group of countries agrees to make the contributions that are necessary to collectively provide the good. This will necessitate negotiations and the cost to each individual country of providing the collective good will have to be negotiated among countries. This is because collective goods cannot be provided through the market system; the 'price' of collective goods is not determined by the market. The costs of providing a collective good can be interpreted as a change in economic welfare and can be measured in terms of gross domestic product (GDP) loss, gross national product (GNP) loss, or in gross national expenditure (GNE) reduction.

An individual country's willingness to pay or contribute to a collective good will be determined by how much it values the good as well as the willingness of other countries to contribute. Moreover, even though countries all may value the collective good and some countries perhaps value the good more than others, the issue of achieving proportional contributions from countries is essential in negotiations that are concerned with collective goods. Burden sharing is achieved when countries manage to work out a distribution of commitments that they perceive is in conformity with their concept(s) of equity. The commitments should consequently be thought of as being 'proportional contributions' from countries to the collective good, in this case the global climate system. There exist a number of definitions of fairness or equity, however. The most prominent ones are discussed below in section 7.3.1.

The climate protocol negotiations have shown that some governments are very concerned about the cost of emission reductions and are eager to explore opportunities for reducing GHG emissions in a cost-effective manner. Importantly, as governments also have been eager to emphasize, abatement costs vary considerably across countries. Economic sector structure, national energy policies, available energy sources, and efficiency of generation and use of energy are the most important explanations for this. Also, differences exist among OECD countries with respect to public concern over the adverse effects of global warming and with respect to political support for intervention in energy markets and technologies. There are furthermore differences across countries in regards to strength and competence of government ministries and agencies involved in climate protection. The existence of considerable national differences significantly complicates the climate protocol negotiations.

[16] Among the social sciences, it is the discipline political science that has paid most attention to the issue of burden sharing, especially in international relations studies. Interestingly, international relations studies employ

It is evident that some countries might incur higher costs than others if a climate protocol does not adequately reflect important dissimilarities among countries. To illustrate, it has been estimated that Australia would experience an annual loss of 0.79% in Net Domestic Product from stabilizing its own CO_2 emissions at the 1990 level while the European Union would only suffer a loss of 0.19%.[17] It should therefore be expected that countries will oppose a climate protocol which adopts uniform targets and objectives in the form of the same percentage emission reduction in all countries regardless of their respective national circumstances. A policy of equal percentage cuts in each country, e.g. a 10% cut in emissions in year 2020 compared to emission levels in 1990, is an example of the 'symmetric' approach.[18] It is therefore important to explore alternative and perhaps more fair ways to distribute the burden of emission reduction across OECD countries. It should be noted, however, that some countries fear that burden sharing rules and formulae might complicate or prolong the climate protocol negotiations.[19]

7.3 PART II

7.3.1 Equity Principles and Burden Sharing Rules

The FCCC and the Berlin Mandate explicitly refer to a number of concepts of equity. According to the first framework convention principle: 'The Parties should protect the climate system for the benefit of present and future generations of humankind, *on the basis of equity* and in accordance with their common but differentiated responsibilities and respective capabilities'.[20] Consequently, parties should observe the principle of intergenerational equity, discussed in chapter 6, and they should furthermore acknowledge their difference in regards to capacity to pay. With respect to the latter principle, the FCCC distinguishes explicitly between developed and developing countries and stresses several times that parties should

concepts from economics when they conceptualize and analyze issues related to burden sharing.

[17] Andrew Chisholm and Alan Moran, 'Carbon Dioxide Emissions Abatement and Burden Sharing among the OECD Countries', *Tasman Institute Occasional Paper* B26, June 1994, p. 6.

[18] Generally, this approach means that countries agree to do 'the same thing'. For a discussion of symmetric agreements, see Edward A. Parson and Richard J. Zeckhauser, 'Equal Measures or Fair Burdens: Negotiating Environmental Treaties in an Unequal World', pp. 81-113 in Henry Lee (ed.) *Shaping National Responses to Climate Change* (Wash. DC: Island Press, 1995).

[19] For example, according to a German intervention delivered to the third round of negotiations within the Ad Hoc Group on the Berlin Mandate (AGBM-3): 'We recognize, of course, that there are other ways of approaching the concept of equity, such as a differentiation of targets. However, we foresee enormous practical difficulties and obstacles in identifying the relevant factors affecting the emissions of different greenhouse gases, in deriving corresponding indicators, in generating reliable and comparable data needed, and last but not least, in weighting these indicators. The selection of indicators as well as their relative weight is highly arbitrary, with results differing substantially (...)This approach would mean even more complicated and lengthy negotiations without necessarily ensuring a more equitable outcome.' Statement by Cornelia Quennet-Thielen, German Delegation, 6 March 1996.

[20] Article 3.1. (Italics added).

take 'into account their common but differentiated responsibilities'.[21] Thus, the FCCC refers to the principle of vertical equity discussed below.

Furthermore, when Annex I countries develop emission reduction policies and measures, they should do this in such a way that these are 'taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable growth, available technologies and other individual circumstances, as well as the need for *equitable and appropriate contributions* by each of these Parties to the global effort'.[22] Clearly, the FCCC puts heavy weight on the issue of equity, especially with respect to the differences between developed and developing countries, but also with respect to difference among Annex I countries. The latter concern is the focus of the principle of horizontal equity, also discussed below. Nevertheless, the equity principles embedded in the FCCC are yet to be translated into abatement policies and measures. If the parties could agree on how to operationalize one or several equity principles, this could perhaps be reflected in a protocol, or another legal instrument, through a differentiation regime. But the FCCC lacks explicit mechanisms for achieving equity between OECD countries, in the sense of sharing the costs equally amongst countries with a similar capacity to pay.

Equity criteria or equity principles refer to a more general concept - or rather, one among several general concepts - of distributive justice or fairness.[23] There is no commonly accepted definition of equity, but the positions of countries participating in the climate protocol negotiations seem to some extent to be influenced by their concern for achievement of fairness and equity. Also, equity principles can serve as a benchmark against which countries evaluate and compare national commitments to reduce greenhouse gases. Concern for equity does not mean that countries are not also concerned about cost-effectiveness.

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[21] Article 4.1.

[22] Article 4.2. (Italics added).

[23] A. Rose (1992) 'Equity Considerations of Tradable Carbon Emission Entitlements', in UNCTAD *Combating Global Warming*, Geneva.

Table 7.1 Selected equity principles and related burden sharing rules

Equity principle	Interpretation	Example of implied burden sharing rule
Egalitarian	Equal rights of people to use the atmospheric resources	Reduce emissions in proportion to population
Sovereignty	Current rate of emissions constitutes a status quo right now	Reduce emissions proportionally across all countries to maintain relative emission levels between them
Horizontal	Similar economic circumstances have similar emission rights and burden sharing responsibilities	Equalize net welfare change across countries (net cost of abatement as a proportion of GDP is the same for each country)
Vertical	The greater the ability to pay the greater the economic burden	Net cost of abatement is inversely correlated with per person GDP
Polluter pays	Carry abatement burden corresponding to emissions (eventually including historical emissions)	Share abatement costs across countries in proportion to emission levels

Source: Based on Rose (1992), DFAT and ABARE (1995), Bureau of Industry Economics (1995), Burtraw and Toman (1992).

A number of concepts of fairness and equity have been identified in the context of global climate change.[24] The most prominent ones are summarized in Table 7.1.[25] The egalitarian principle or the egalitarian theory is concerned with equality. In the context of global climate change, this principle would imply that every individual has the same right to use the atmosphere and should be allowed the same right to emit greenhouse gases. This principle would mean that emission permits be distributed to individuals, not governments, and each individual would be entitled to exactly the same amount of permits.

The sovereignty principle implies that each individual, or entity, is guaranteed some rights and resources. The principle of sovereignty is commonly observed in international environmental treaty-making and institution-building, and countries supported that the

[24] As mentioned earlier, the issue of responsibility for the historical cumulative emissions of greenhouse gases has so far not played an important role in the climate protocol negotiations. The issue is therefore not reflected in the burden sharing rules examined in this chapter. For burden sharing rules taking into account the responsibility for cumulative emissions, see, for example, Ian H. Rowlands, 'International Justice and Global Climate Change', mimeo, London School of Economics and Political Science, 1996.

[25] An additional distinction can be drawn between procedural fairness, i.e. whether all countries are able to participate effectively in the climate change negotiations, and consequential fairness of allocation, i.e. whether the outcome of the global climate policy process is considered fair. The above does not examine procedural equity.

principle of sovereignty was laid down in the FCCC.[26] One possible interpretation of the sovereignty principle would be equal percentage emission reductions in all countries, e.g. countries stabilize their emissions at 1990 levels in 2020 or another across-the-board type of policy.

The principle of sovereignty resembles to some degree the principle of horizontal equity which calls for all persons in the same group to be treated equally. The principle implies equal treatment of the members that belong to a group. The principle of horizontal equity would require the equalization of the burdens of abatement cost across nations or an equal percentage reduction in welfare.

Vertical equity is intended to make improvement for those with less resources relative to those with more resources. Progressive income taxation is a well-known example of application of the principle of vertical equity. However, while many such examples of use of the vertical principle exist, there exists no obvious set of rules to follow when dividing individual countries into different groups, and specific rules may be somewhat arbitrary. Vertical equity refers to the capacity to pay and implies greater economic burden to be carried by richer countries. This is illustrated, for example, by the Montreal Protocol on Substances That Deplete the Ozone Layer which distinguishes between the developed and developing countries. The latter group is, because of its 'basic domestic needs', entitled to delay its compliance with the control measures specified in this protocol by ten years. In effect, a transition period is allowed for developing countries in order to lessen the burden imposed on them.[27] As already mentioned, such a principle is explicitly referred to in the FCCC: 'The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a *disproportionate or abnormal burden* under the Convention, should be given full consideration'.[28]

The polluter pays principle implies that the burden is distributed in accordance with an individual's contribution of emissions. The amount to be paid by polluters increases as

[26] According to one of the FCCC's preambles: 'States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction'.

[27] See Richard E. Benedick, *Ozone Diplomacy: New Directions in Safeguarding the Planet* (Harvard University Press: Cambridge, Mass. 1991).

[28] Article 3(2). (Italics added).

emission levels rise.[29] Uniform carbon tax across countries could be advocated as an example of this principle, but there might be difficulties in using the polluter pays principle in a burden sharing arrangement. For a discussion of the principle, see chapter 4.

Equity principles should be distinguished from specific burden sharing rules and so-called formulae. A formula defines ‘national emissions entitlements, or changes from the status quo, on the basis of national characteristics such as population, GDP, current emissions, or factors plausibly associated with national responsibility, sensitivity, or need for various emitting activities’.[30] Specific burden sharing rules and formulae might correspond to one or more of the equity principles discussed above. Rules and formulae will identify the individual country’s emission entitlements or its amount of emission reduction. Similar to the cost of each individual country of providing a collective good, also concrete burden sharing rules would have to be developed through negotiations among countries. It is likely that more than one concrete policy or measure can satisfy a particular equity principle.

It should be noted that some equity criteria can be consistent with more than one burden sharing rule, and particular burden sharing rules or formulae can be consistent with more than one equity criterion.[31] For example, a population based rule assigning emission permits on a per capita basis would be consistent with the egalitarian principle with its equal per person emissions and with the sovereignty principle where emissions are cut back proportionally on a per capita basis.

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[29] For discussion, see M. Grubb (1995) ‘Seeking Fair Weather: Ethics and the International Debate on Climate Change’ *International Affairs* 71 (3): 490.

[30] Edward A. Parson and Richard J. Zeckhauser, ‘Equal Measures or Fair Burdens: Negotiating Environmental Treaties in an Unequal World’, in Henry Lee (ed.) *Shaping National Responses to Climate Change* (Wash. DC: Island Press, 1995), pp. 99-101.

[31] A. Rose ‘Equity Considerations of Tradable Carbon Emission Entitlements’, in UNCTAD *Combating Global Warming*, Geneva.

Table 7.2 Data on OECD countries (except Island, Mexico, Czech Republic), 1993

	CO_2 emissions (energy related, mill. tons)	GDP (bill. 1990 USD)	population (in 1000)	CO_2 emissions/GDP (in kg CO_2/1990 USD 1000)	GDP/capita (USD)	CO_2 emissions per capita (tons)
Australia	283	309.3	17840	915	17337	15.9
Austria	57	166	7990	343	20776	7.1
Belgium	113	196.8	10010	574	19660	11.3
Canada	443	573.8	29100	770	19718	15.2
Denmark	59	134	5200	440	25769	11.3
Finland	55	118.3	5090	470	23242	10.8
France	368	1205	57960	310	20790	6.3
Germany	897	1718	81410	520	21103	11.0
Greece	74	69	10350	1072	6667	7.1
Ireland	33	50	3560	660	14045	9.3
Italy	408	1109	57100	368	19422	7.1
Japan	1091	3094	124960	350	24760	8.7
Luxembourg	11	11	380	1000	28947	28.9
Netherlands	171	294.6	15400	580	19130	11.1
New Zealand	28	47	3460	596	13584	8.1
Norway	32	114.5	4337	280	26401	7.4
Portugal	46	69	9860	667	6998	4.7
3Spain	223	500.9	39140	440	12798	5.7
Sweden	52	218.2	8770	240	24880	5.9
Switzerland	43.2	223.3	6940	190	32175	6.9
Turkey	150	173	59490	867	2908	2.5
UK	558	971	58375	580	16634	9.6
USA	5095	5765	260730	880	22111	19.5

Sources: OECD (1995a); OECD (1995b).

It should be noted in addition that burden sharing rules might not be equally operational. They might be static and focus on one point in time, for example, population or land area, or they might be more dynamic, indicating cumulative emissions, development, future growth rates, etc. Rules might be concerned with a single criterion, such as population, GDP or costs, or they might combine different criteria, e.g. emissions per capita or abatement costs as a percentage of GDP. A recent theme among analysts is to examine how several combined criteria could be incorporated into a single multi-criteria burden sharing rule.[32] Rules or formulae may be expressed in absolute terms, for example reduction of emissions by 20% relative to the 1990 levels, in relative terms like uniform percentage abatement per capita or

[32] See Yasuko Kawashima, 'Differentiation of Quantified Emission Limitation and Reduction Objectives (QELROs) according to National Circumstances: Introduction to Equality Criteria and Reduction of Excess Emission'. Paper presented at 'Informal workshop on quantified limitation and reduction emission objectives', 28 February 1996, in Geneva.

Table 7.3 CO_2 emissions, population and GDP as percentage of OECD total (except Island, Mexico, Czech Republic).

	CO_2 emissions	GDP	population
Australia	2.8	1.8	2.0
Austria	0.6	1.0	0.9
Belgium	1.1	1.1	1.1
Canada	4.3	3.3	3.3
Denmark	0.6	0.8	0.6
Finland	0.5	0.7	0.6
France	3.6	7.0	6.6
Germany	8.7	10.0	9.3
Greece	0.7	0.4	1.2
Ireland	0.3	0.3	0.4
Italy	4.0	6.5	6.5
Japan	10.6	18.1	14.2
Luxembourg	0.1	0.1	0.04
Netherlands	1.7	1.7	1.8
New Zealand	0.3	0.3	0.4
Norway	0.3	0.7	0.5
Portugal	0.4	0.4	1.1
Spain	2.2	2.9	4.5
Sweden	0.5	1.3	1.0
Switzerland	0.4	1.3	0.8
Turkey	1.5	1.0	6.8
UK	5.4	5.7	6.7
USA	49.5	33.7	29.7

Sources: OECD (1995a); OECD (1995b).

equal emissions per unit of GDP, or in marginal terms, such as equal marginal abatement cost.[33]

7.3.2 Rules for Distribution of Burden among OECD Countries.

This section explores different kinds of burden sharing rules and formulae. The intention is not to advocate any of these burden sharing rules in particular but solely to explore different types of formulae and examine how they distribute the abatement costs across the OECD. The results indicate which national circumstances that are important when a country's share of emission reduction would be determined. While a number of equity principles were discussed in the previous section, this section focuses on achievement of horizontal equity because this principle is adopted by the FCCC and because theories of international environmental cooperation expect that the OECD countries would be concerned that a burden sharing formula distributes cost evenly across the OECD.

[33] Marginal cost of abatement can be defined as the cost of the last unit of carbon emissions reduced. One consequence is that the more energy efficient an economy is (e.g. Japan), the more it costs to increase energy efficiency and reduce emissions further, because the marginal cost of abatement for the country is high.

Three burden sharing rules or formulae are explored. It is assumed that the overall level of abatement remains 20% of total 1993 OECD emissions but the required targets in individual countries change. It is described how each formula will distribute the burden across the OECD countries and how much individual countries will have to reduce in order to contribute their share of the total amount of emissions reduced by the OECD. It is furthermore calculated how costly the three formulae would be for individual countries, and the total cost for the OECD is also calculated. All OECD countries (except Iceland, the Czech Republic and Mexico) are examined.[34] For absolute and relative figures on population, GDP and CO_2 emissions in OECD countries, see Table 7.2 and Table 7.3, respectively.

The distribution of the emission reduction commitments following from the implementation of Formula I, II and III will imply a certain distribution of abatement costs. The components of the abatement costs are generally described in chapters 4 and 5. Chapter 5 uses a numerical model to estimate how the implementation of different types of climate agreements would distribute abatement costs across the OECD countries. The model is used here to estimate how Formula I, II and III distribute abatement costs across OECD countries and the level of cost-effectiveness within the OECD achieved by them.

Furthermore, to compare the formulae and the resultant cost distributions, the welfare changes following a 20% reduction in each OECD country are included as a reference case (see Fig. 7.2).[35] This case resembles the policy proposal made by the German delegation at the AGBM-3 in March 1996 in Geneva.[36] The case corresponds to scenario 2A in chapter 5 where some further comments on the results are given. One conclusion from scenario 2A is that uniform reductions are likely to be seen as unfair from the viewpoint of countries with high abatement costs. Also, the welfare loss for the OECD is 0.21% of GDP if each country cuts its emissions with 20%. In the following some examples of applications of the formulae are discussed with the help of some figures. Detailed results are presented in Annex A7 of this chapter.

Formula I

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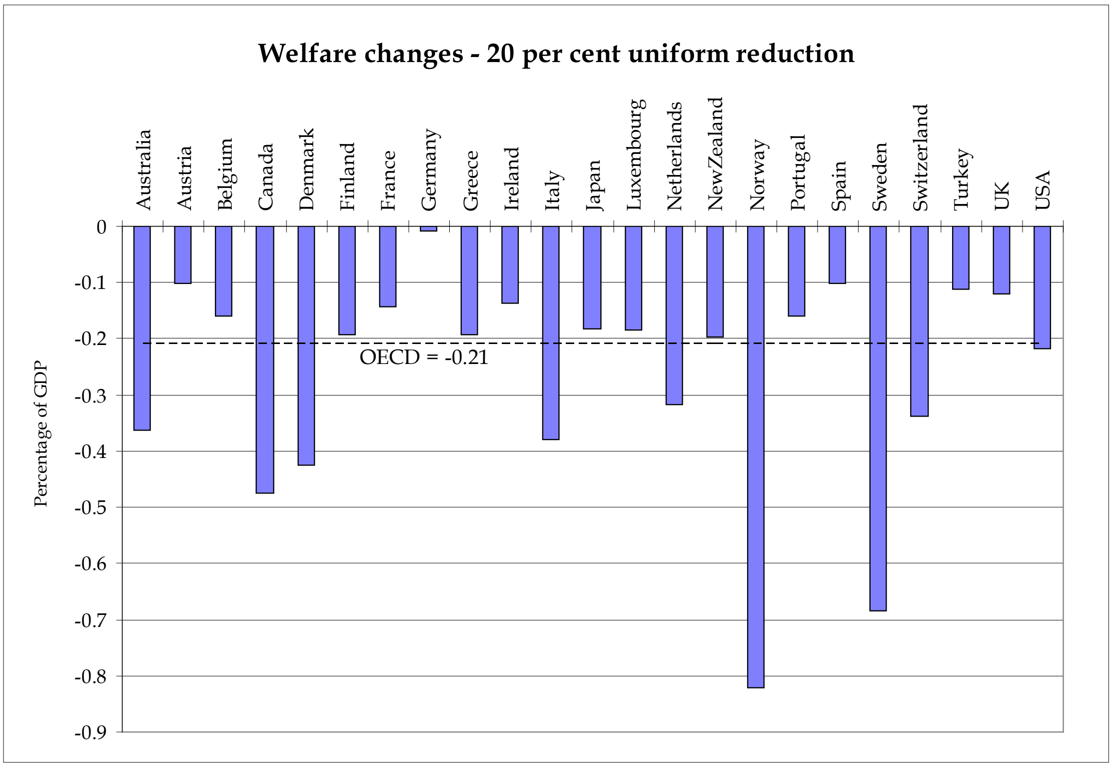
[34] It has not been possible to obtain comparable data on Iceland. Mexico and the Czech Republic are not included since they have only recently become members of the OECD and are not included in the Annex I group of countries.

[35] See chapter 5 for the definition of the concept of welfare change.

[36] Germany proposed a 10% reduction in CO_2 emissions by the year 2005, and a 15-20% reduction by the year 2010, both against the base year of 1990. Statement by Cornelia Quennet-Thielen, German Delegation, 6 March 1996.

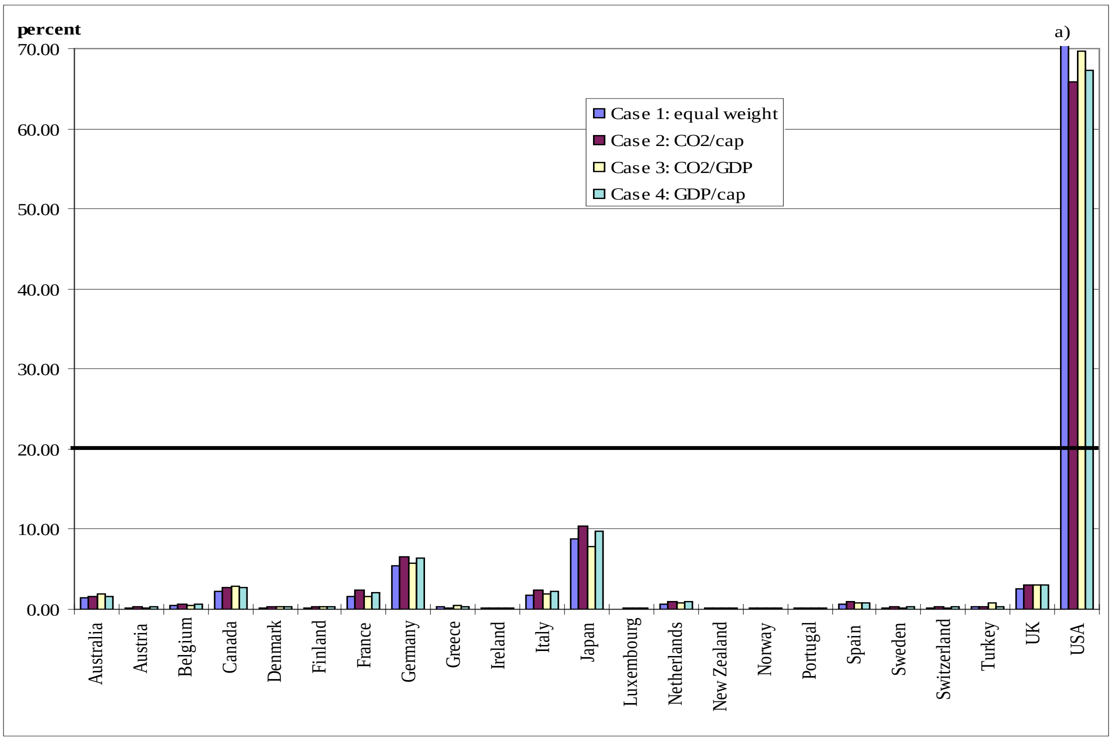
Figure 7.2 Welfare changes in percentage of GDP from a 20% uniform emission reduction



A number of quantitative burden sharing rules could be constructed. Formula I is based on the premise that a country which is identical to the average OECD country, so to speak, should reduce its emissions with exactly 20%.[37] A country which exceeds the OECD average with respect to one or more of four variables should reduce its emissions with more than 20%. Similarly, if a country is below the OECD average with respect to one or more of the variables its target will be below 20%. Formula I's four variables are CO_2 emissions per capita, GDP, CO_2 emissions per unit of GDP and GDP per capita. The variables can be understood as proxies for emission entitlements, size of countries, energy efficiency, and wealth. Each variable is given a weight, and the sum of the weights is 100. The variables are listed in Table 7.2.

[37] The formula is: $Y_i = \{w_A\ A_i/A + w_B\ B_i/B + w_C\ C_i/C + w_D\ D_i/D\}\ Z$, where Y_i is the percentage emission reduction target for country i, A_i is emissions per capita for country i, B_i is GDP for the same country, C_i is emissions per unit of GDP for the same country, and D_i is GDP per capita for this country. A, B, C and D represent OECD averages for the same variables. The weights for the variables are represented by the w-weights, and where the sum $w_A + w_B + w_C + w_D = 100$. Z is a scaling factor which is determined so as to make the total emissions abatement for OECD equal to 20% (Z varies between 0,0965 and 0,1218 in different scenarios).

Figure 7.3 Formula I. Emission reduction as percentage of OECD reduction



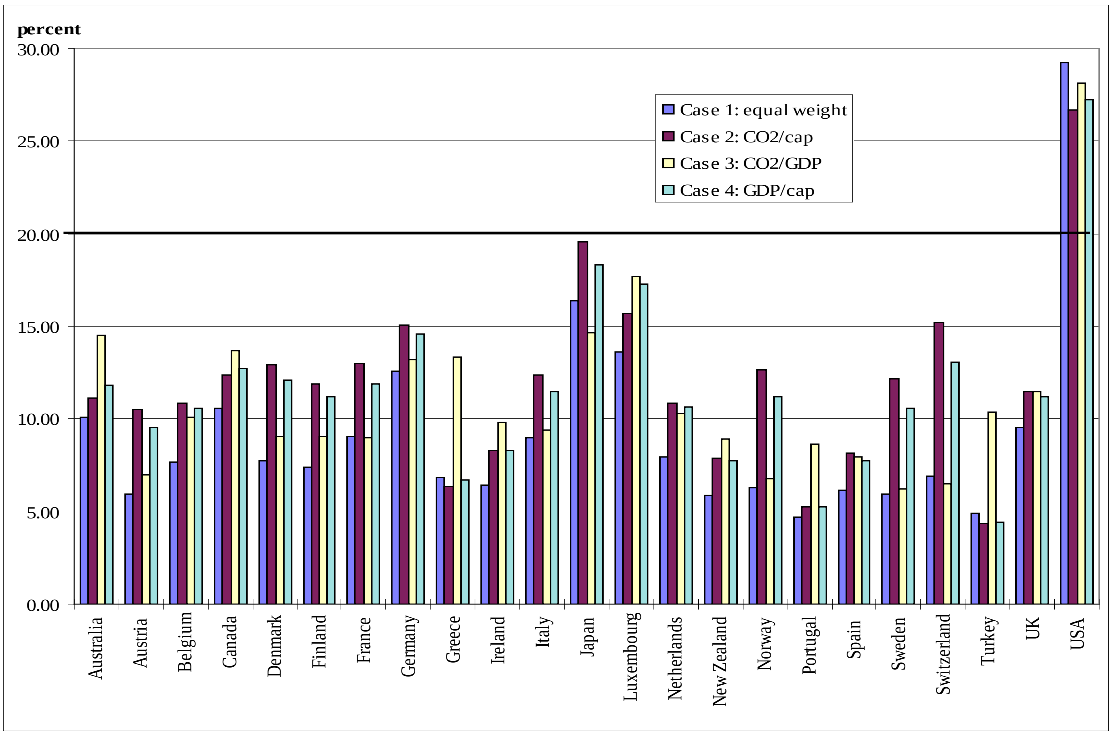
a) Emission reduction as a percentage of OECD for USA: Case 1: 72%.

Four ways to distribute weights on the variables, referred to as Case 1, 2, 3, and 4, are calculated.[38] The base case gives equal weight, namely 25, to the four variables. In each of the three other cases an additional weight of 55 or 70 is given to one variable, and the other three variables have weights of either 10 or 15. The results presented in Figure 7.3 show each OECD country's percentage reduction share of the total emission abatement target of OECD. In Figure 7.4, the results of Formula I are presented as percentage reduction in each country's emissions.

Figure 7.3 shows that the countries that make the largest reductions in the four cases are United States, Japan, Germany and Canada. United States reduces from 66% to 72% of OECD's total emission reduction, Japan reduces from 8% to 10%, Germany from 6% to 7%, and Canada reduces from 2% to 3%. Norway, Sweden and Denmark each account for between 0.1% to 0.4% of total OECD reductions. Table 7.3. shows that the United States is responsible for about 50% of total OECD emissions. However, according to Formula I, the

[38] Case 1: 0,25*(CO_2/cap+GDP+CO_2/GDP+GDP/cap);
Case 2: 0,55*CO_2/cap+0,15*(GDP+CO_2/GDP+GDP/cap);
Case 3: 0,55*CO_2/GDP+0,15*(CO_2/cap+GDP+GDP/cap);
Case 4: 0,7*GDP/cap+0,1*(CO_2/cap+GDP+CO_2/GDP).

Figure 7.4 Formula I. Emission reduction as percentage of national CO_2 emissions (OECD reduction 20% of 1993 level).

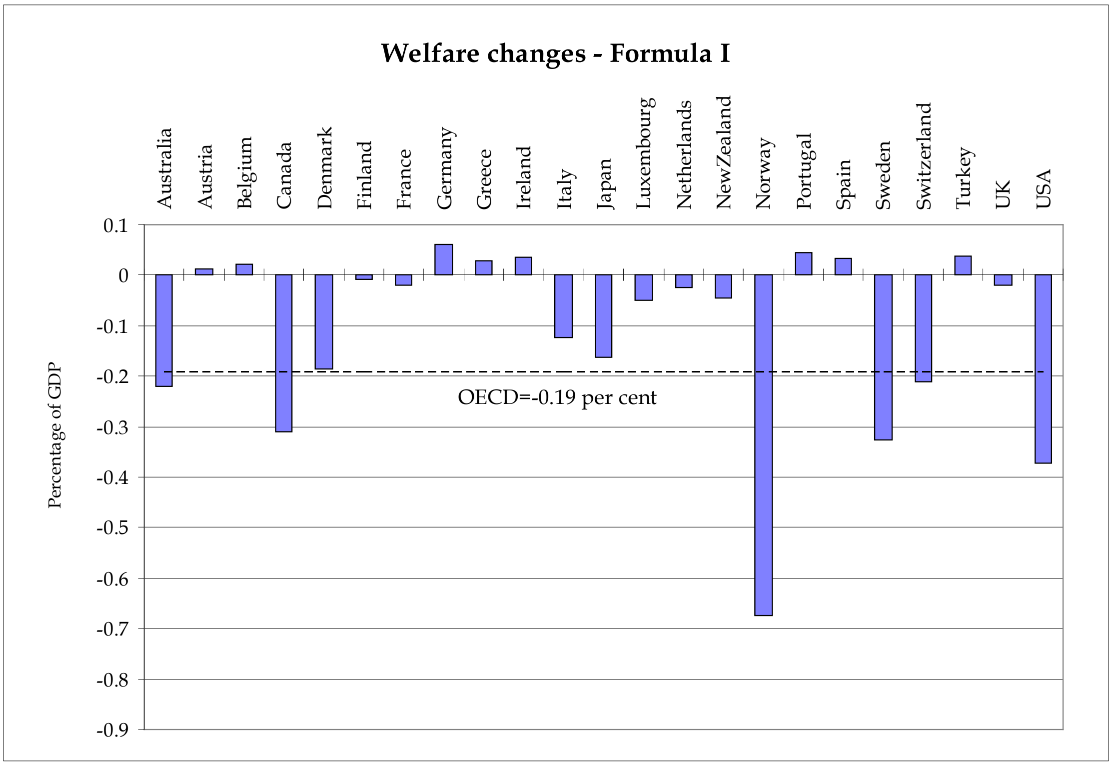


United States has a relatively larger share of emission reductions than its share of total OECD emissions.

To achieve the 20% reduction in total OECD emissions, as Figure 7.4 shows, the United States reduces its present emissions from 27% to 29% and Japan reduces from about 15% to 20%. Furthermore, Luxembourg reduces from 14% to almost 18%, Germany from 13% to 15%, and Canada from 11% to 14%.

It is evident that putting different weights on the variables results in considerable differences in the amount of emissions reduced by countries. In Case 1, the United States reduces its emission with 29%, Japan reduces its emission with about 16%, and Germany and Luxembourg reduce their emission with 13% and 14%, respectively. In this case most countries, except United States, reduce at a relatively low level compared to Case 2, 3 and 4. Case 2 puts more emphasis on countries' emission per capita and, as a consequence, the United States reduces about 27% of its emissions, Japan reduces almost 20%, and Germany, Luxembourg, and Switzerland reduce slightly above 15%. For the majority of wealthy European countries and Japan, Case 2 results in considerable emission reductions relative to Case 1, 3 and 4, while the United States reduces less. Case 3 puts emphasis on energy efficiency as measured by how much a country emits relative to the size of the economy. Case 3 results in considerable reductions in relatively poor countries such as Turkey, Greece, Portugal and Ireland, but also in Australia, Canada and New Zealand, and in Luxembourg. In this case, Turkey reduces 10%, Greece 13%, Portugal 9% and Ireland 10%, while Australia reduces 15%, Canada 14%, New Zealand 9%, and Luxembourg 18%. Case 4 results in larger emission reductions in countries with high GDP per capita, and therefore with more capacity to pay, and results in relatively larger reductions in relatively wealthy European countries and in Japan, but less reductions in the United States. The United States reduces its emissions by

Figure 7.5 Welfare changes in percentage of GDP from implementation of Formula I.



27%, and Sweden, Norway, Denmark and Canada reduce their emissions between 11% and 12%. Japan reduces about 18% of its emissions.

Returning to the issue of horizontal equity, it could be argued that Case 3 is unfair to relatively poor countries, and that Case 1 and 4 are favorable to most European countries, but unfair to the United States. Of these four cases of Formula I, therefore, Case 2 represents the most equitable distribution of emission reductions across OECD countries. Consequently, the cost implications of Case 2, which implies that the United States reduces slightly less while almost all other relatively wealth OECD countries reduce more, are estimated.

In Figure 7.5, Norway, the United States, Sweden, Canada, Switzerland and Australia experience the largest welfare loss in percentage of GDP. The welfare loss of the United States is explained by its large emission reduction. The large welfare loss of Sweden and to some extent Norway is related to the high taxes on fossil fuels in these countries in the reference situation which result in high marginal abatement costs (see discussion in Chapter 5). The Norwegian welfare loss is also related to a price drop of 7.3% in the European natural gas market.[39] Canada's welfare loss is almost as big as the welfare loss of the United States despite the fact that Canada reduces much less than the United States. This result must be seen in relation to those two countries' role in the fossil fuel markets, especially the North American gas market. The United States is assumed to impose taxes on natural gas consumption of 31 USD/ton CO_2 in this scenario and the price of natural gas drops by 27.1% in the North American gas market.

Significantly, the model simulation shows that a number of countries will experience net welfare gains from the implementation of this type of burden sharing formula, especially Germany receives large net gains.

The total welfare loss amounts to 0.19% of the total GDP of the OECD area. Hence, Formula I is more cost-effective than the reference case's uniform reductions resulting in a total welfare loss of 0.21%. This is due to the large reductions in USA which, according to the model, has relatively low marginal abatement costs.

Formula II

Formula II is based on each OECD country's percentage share of population, CO_2 emissions and GDP of the OECD total. For the variables used in Formula II, see Table 7.3. Again, weights are given to each of the three variables.[40] Case 1 puts equal weight on the three variables, but the other three cases give low weight to population.[41] Case 2 puts more weight

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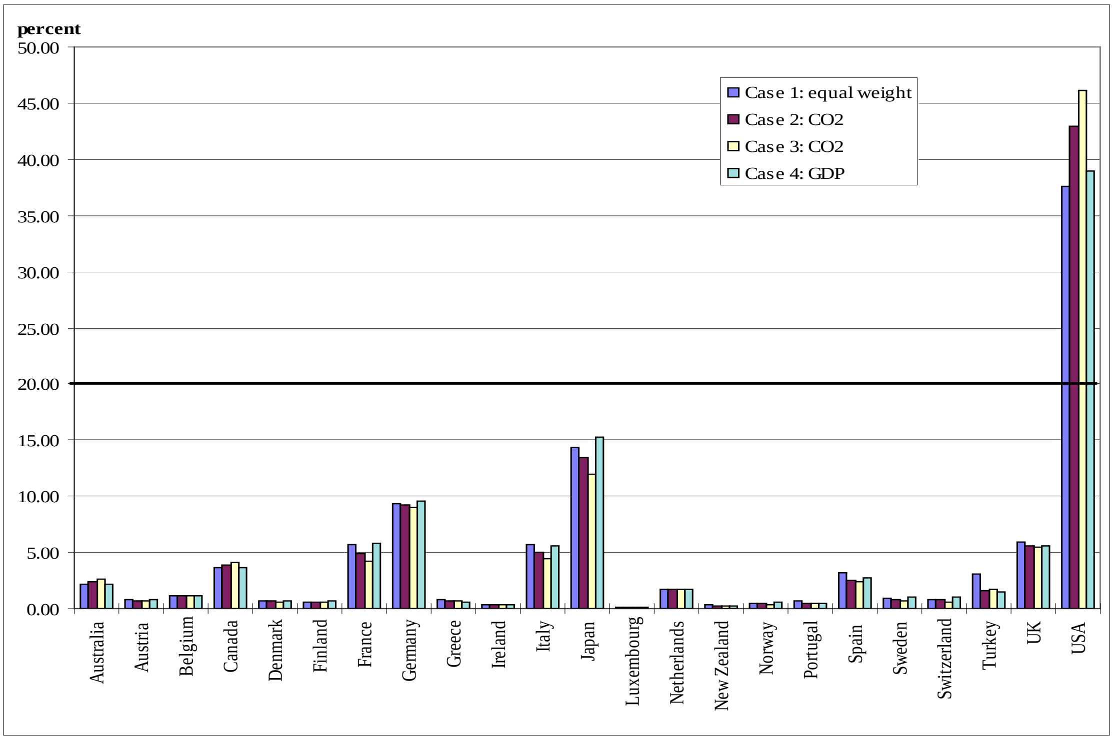
[39] The oil price is almost unchanged in this scenario and explains the relative small welfare loss of Norway. This result is connected to the assumption that the OECD countries introduces efficient taxation of fossil fuels which means reduced taxes on oil products in several countries.

[40] The formula is $X_i = \{w_E E_i + w_F F_i + w_G G_i\}$, where E_i is the percentage population share of country i, F_i is the percentage CO_2 emission share of the same country, and G_i is the percentage GDP share of the country. The sum of the w-weights is equal to 1.

[41] Case 1:1/3*(CO_2+pop+GDP);
Case 2: 0,05*pop+0,6*CO_2+0,35*GDP;
Case 3:0,05*pop+0,8*CO_2+0,15*GDP;
Case 4: 0,05*pop+0,35*CO_2+0,6*GDP.

Figure 7.6 Formula II. Emission reduction as percentage of OECD reduction

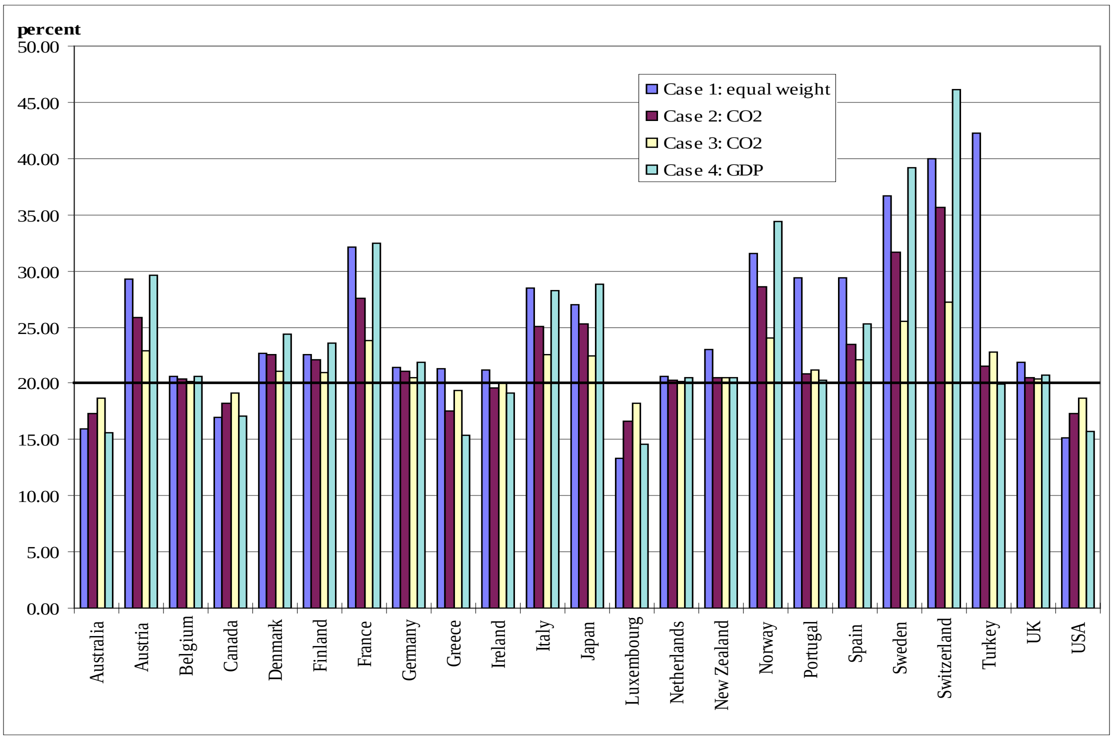


on CO_2 emissions and some weight on GDP, and Case 3 increases the weight on CO_2 emissions some, but reduces the weight on GDP. Case 4 puts most weight on GDP, less weight on emissions, and little weight on population. The results are presented in Figure 7.6 as each country's percentage of OECD total, and Figure 7.7 shows the percentage reduction needed in national emissions.

Figure 7.6 shows how much the OECD countries reduce emissions if they agree to implement Formula II. As the United States reduces less than under Formula I, other countries reduce relatively more emissions. The United States reduces between 38% and 46% of the total OECD emission reduction, Japan reduces between 12% and 15%, Germany reduces between 9% and 10%, while France, Italy and Great Britain reduce between 4% and 6%. Also the Scandinavian countries reduce more emissions, namely between 0.5% and 1% each of the OECD total.

Figure 7.7 shows the reductions in the OECD countries' emissions that follow from implementing Formula II and the overall target is to reduce 20% of 1993 total OECD emissions. Different weights are given to the three variables. Again, it is evident that putting different weights on the variables results in considerable differences in the amount of emissions countries reduce. In Case 1, the biggest cuts are made by countries with large

Figure 7.7 Formula II. Emission reduction as percentage of national CO_2 emissions (OECD reduction 20% of 1993 level).

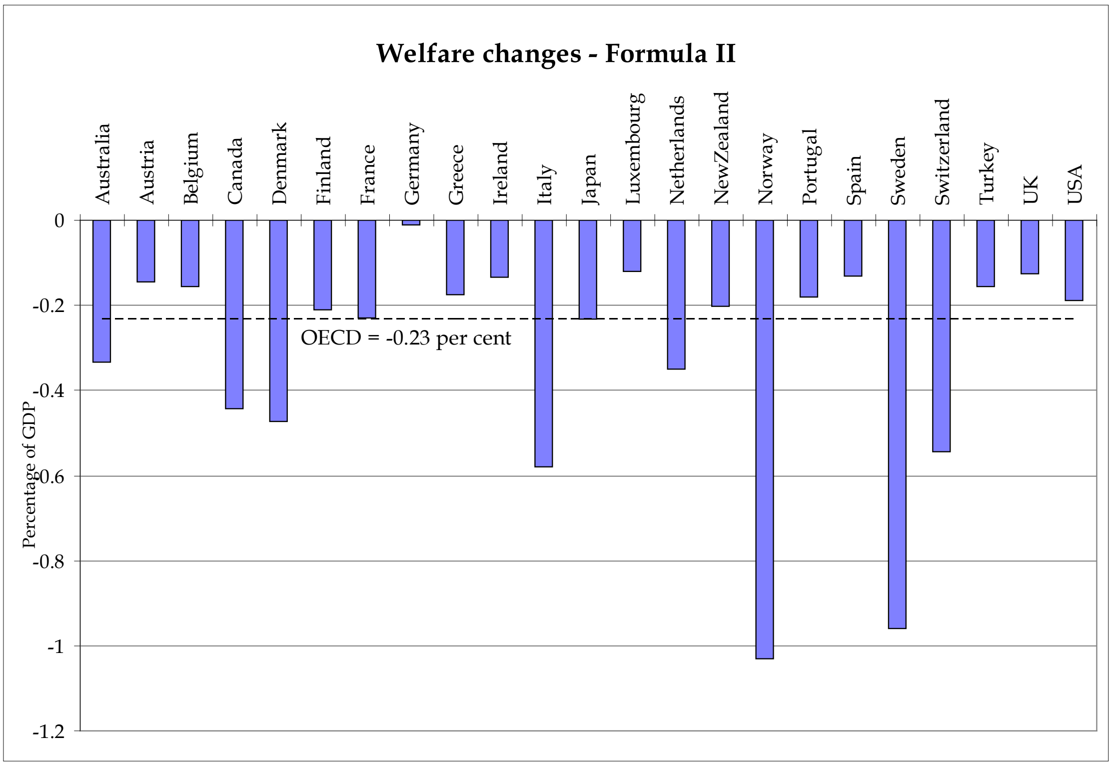


populations and modest emissions, and in relatively rich and energy efficient countries. Case 1 results in very high reductions in Turkey, and Austria reduces with 29%, France 32%, Italy 29%, Japan 27%, New Zealand 23%, Norway 32%, Spain 30%, Sweden 37% and Switzerland 40%. However, it results in relatively less reduction in the United States, Australia, Canada, and Luxembourg, by 15%, 16%, 17%, and 13%, respectively.

In Case 2 the differences in how much countries reduce emissions are generally smaller. Austria, Denmark, Finland, France, Germany, Italy, Japan, Norway, Portugal, Spain, Sweden, Switzerland and Turkey all reduce at a level higher than the average 20%, whereas Australia, Canada and the United States reduce below 20%. Some of the relatively poor OECD countries also reduce below 20%.

Case 3 further increases the weight on emissions compared to Case 2. Australia, Canada, Luxembourg and the United States, as well as Greece, Ireland, Portugal and Turkey, increase their reductions some. Austria, Belgium, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland and Britain reduce less relative to in Case 2.

Figure 7.8 Welfare changes in percentage of GDP from implementation of Formula II.

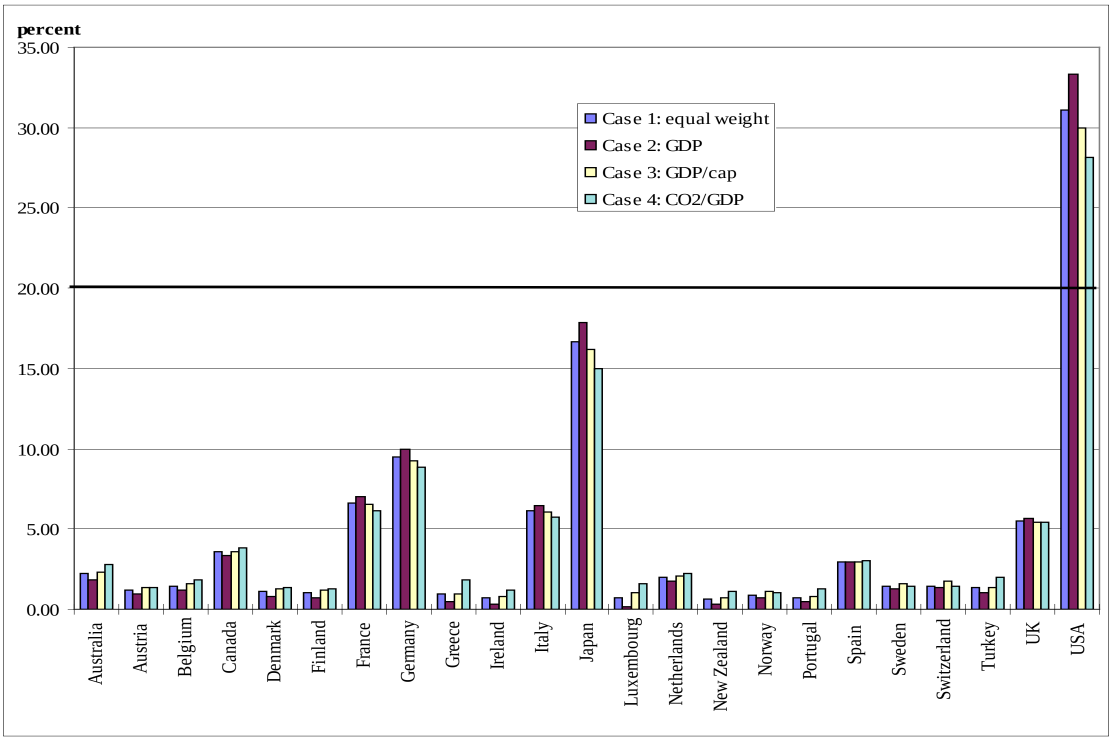


In Case 4, relatively wealthy and energy-efficient countries cut their emissions most. Case 4 implies considerable reductions in Austria, Denmark, Finland, France, Germany, Italy and Japan, and especially in Norway, Sweden and Switzerland. Less reductions are made in Australia, Canada, Greece, Luxembourg, Portugal, Turkey and the United States.

When comparing these four cases, it could be argued that Case 3 is most fair as it results in the most equal percentage distribution of emission reductions across OECD countries. Case 1 and 4 result in relatively high emission reductions in some countries and similarly low emissions reductions in others. Case 3 results in a more equal distribution of percentages relative to Case 2. Because Case 3 best conforms with the horizontal equity principle, the welfare implications of this case are calculated.

Relative to Formula I, Formula II gives rise to quite different quantitative emission reduction commitments. This is reflected in the welfare changes that follow from the implementation of the commitments (see Fig. 7.8). First of all, it is noteworthy that Formula II produces a less cost-effective solution compared to Formula I; the total welfare loss for the OECD is 0.23% of GDP, as compared to 0.19% in Formula I, and 0.21% in the reference case. This is because Formula II shifts some emission reductions from USA on to especially France, Italy, Sweden,

Figure 7.9 Formula III. Emission reduction as percentage of OECD reduction



Norway and Japan. The result is a transfer of commitments from a country with low marginal abatement costs, such as the United States, to countries with substantially higher abatement costs, such as Norway and Sweden. At the same time, the bigger reduction commitment for Germany results in a larger amount of relatively low-cost reductions is realized.

To conclude, under Formula II, Norway, Sweden, Italy and Switzerland are committed to reduce their emissions by a higher percentage than the OECD average and their welfare losses consequently are high. This formula could be said to have relatively unfair burden sharing consequences when judged against the principle of horizontal equity. In addition, it is less cost-effective. However, Formula II could to some extent satisfy the principle of vertical equity since most of these countries have high GDP per capita and therefore a higher capacity to pay (see Table 7.2).

Formula III

Formula III includes GDP, emissions per unit of GDP, and GDP per capita. Except CO_2 per capita, the same variables were included in Formula I. Weights that sum up to 100 are given to each variable. The weighted sum of the variables is calculated for each country and it is divided by the sum over all OECD countries.[42] In this way the percentage share of the OECD total is calculated for each country. In Case 1, the three weights are equal to 33,3.[43] The other cases put more weight, either 60 or 80, on one of the variables, and the weights on the other variables are either 20 or 10. In Figure 7.9 the estimated share of abatement commitments are shown as percentage of the OECD total. Also, the implications of the 20% reduction of total OECD emissions target are presented as percentage reduction in each country's emissions (see Figure 7.10).

In general, compared to Formula I and II, in Formula III the United States contributes less emission reduction and other countries significantly more. Figure 7.9 shows that the United States reduces between 28% and 33% of total OECD emissions, Japan reduces between 15% and 18%, and Germany reduces no more than 10%. France, Italy, and Great Britain reduce between 6% and 7%, while Spain, Canada and the Netherlands contribute with less emission reductions. However, the Scandinavian countries reduce between 1% and 2%.

Figure 7.10 shows that Sweden reduces between 51% and 64% its emissions, Norway between 45% and 72%, Austria between 36 and 49%, and France reduces between 34% and 39%. Because of its exceptionally high emissions per GDP and CO_2 emissions per capita, Luxembourg reduces its emissions between 29% and 295%! Italy and Japan reduce their emissions with more than 28%, and Denmark and Finland also make substantial reductions. However, Australia, Canada, and the United States reduce less than 20% of their emissions.

The distribution of emission reductions in Formula III is entirely different from the distribution in Formula I and II. This is reflected in the welfare changes found by the use of the model (see Fig. 7.11). Sweden, Switzerland, Norway and Italy experience welfare losses far above the average. This is basically a result of the large emission reduction commitments for those countries, but it also reflects the large marginal abatement costs in these countries.

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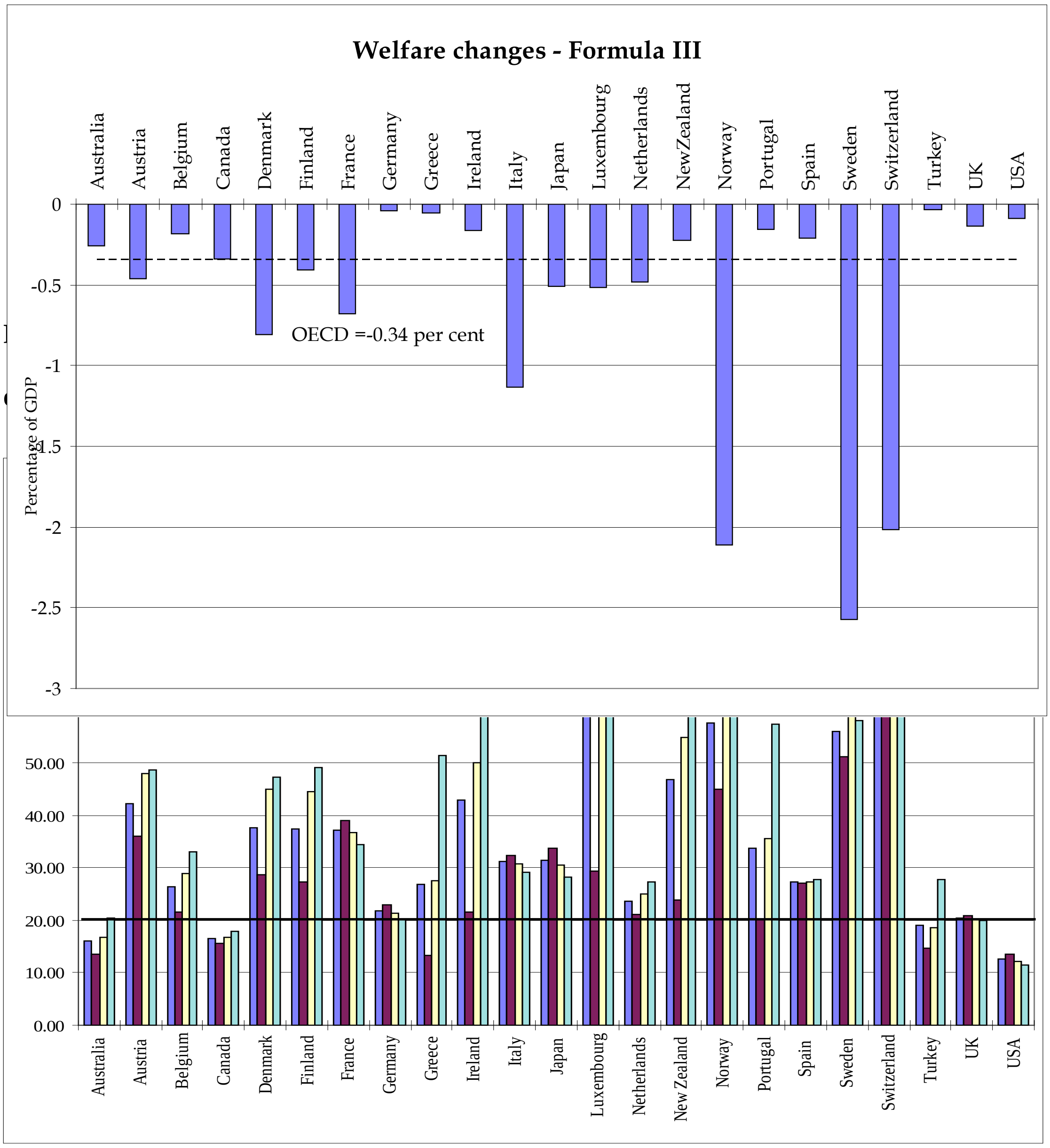
[42] The formula is $V_i = \{w_B B_i + w_C C_i + w_d D_i\}/ \Sigma_j \{w_B B_j + w_C C_j + w_d D_j\}$, where B_i is GDP for country i, C_i is emissions per unit of GDP for the same country, and D_i is GDP per capita for this country. The w's are weights that sum up to 100. The divisor represents the sum over all OECD countries. Due to the different units of the variables the scale of the data is adjusted so as to make the range (i.e. the lowest value up to the highest value found for different countries) comparable across the variables. One example of this is that the GDP figures are divided by 100.000 since they are much larger than the other variables.

[43] Case 1: 33*(GDP+CO_2/GDP+GDP/cap);
Case 2: 10*(GDP/cap+CO_2/GDP)+80*GDP;
Case 3: 20*(GDP+CO_2/GDP)+60*GDP/cap; Case 4: 20*(GDP+GDP/cap)+60*CO_2/GDP.

Figure 7.11Welfare changes in percentage of GDP from implementation of Formula III.



b) Emission reduction for Luxembourg as a percentage of national emissions: Case 1: 139%, Case 3: 187%, Case 4: 296%.

With regard to cost-effectiveness Formula III results in a burden sharing arrangement with large total abatement costs; the total welfare loss is 0.34% of GDP for the OECD area. In comparison, the welfare loss of Formula I and II are 0.19% and 0.23%, respectively. The high costs follow from the large commitments of some of the Nordic countries, Italy, Japan, Switzerland and France, where abatement costs usually are high, whereas the emission reductions are small in USA, Canada and Australia where the abatement costs are low.

7.4 Conclusions

This chapter began by observing that the distribution of the costs of emission reductions across Annex I countries is becoming an essential issue in the negotiations on a climate protocol. Countries are at present concerned that they might have to bear high costs of emission reductions which, in addition, might be unevenly distributed across the OECD countries. Theories of international environmental cooperation predict that countries will be concerned about the cost distribution of emission control and, in the absence of firm leadership by politically and economically powerful countries, achievement of fairness and equity will become significant issues in the climate protocol negotiations. Attention was also drawn to the fact that the FCCC underlines the significance of equity between developing and developed countries and, in addition, equity among OECD countries.

Some suggestions have been made that all Annex I countries should cut greenhouse gas emissions by the same percentage or that they should stabilize their emission levels in some future year relative to their emissions in a specific base year. As illustrated, such symmetric or non-differentiated approaches could distribute abatement costs very unevenly. Instead differentiation among countries and a possible differentiation regime appears to be more attractive to some countries. This chapter has explored three alternative formulae to distribute the commitments to reduce emissions among OECD countries. The examination goes further than simple burden sharing adjustment rules, e.g. per capita targets or equal percentage reductions. The formulae define how the OECD countries could share the burden of emission reduction, how much individual countries reduce their present emissions, and the subsequent welfare changes for each country. By varying the weights given to the variables in the formulae, their sensitivity were examined.

Unsurprisingly, the chapter demonstrates that the percentage distribution of commitments to reduce emissions does not adequately indicate the abatement cost distribution. However, it is apparent that none of the formulae could produce a burden sharing arrangement that equalizes the economic costs across the OECD, and Formula I, II and III could not satisfy the principle of horizontal equity in the FCCC. However, it is possible that these formulae could be adjusted, or other formulae could be introduced, so as to produce more equitable results. The outcomes of the three burden sharing rules were compared to a reference case in which each OECD country reduces its emissions with 20%. Formula I would be more cost-effective than the reference case, but Formula II and III would be less cost-effective.

Countries that negotiate a climate protocol perhaps will attempt to use ethical principles to persuade other countries that a particular proposal for a burden sharing rule is justified. Some expect that each party will emphasize principles and rules which favor its own position most and therefore will describe these as being the most fair and reasonable.[44] This claim is reasonable, but any country's wish to emphasize principles that obviously serve its narrow self-interest might be tempted by the need to create a burden sharing that is acceptable to others.[45] Undoubtedly, choosing a rule which could be accepted by all Annex I countries could complicate the climate protocol negotiations. In addition, any rule will raise complex issues regarding countries' narrow self-interest in minimizing their own abatement cost, on the one hand, and minimization of the total cost to the OECD on the other.

Fairness and equity, cost-effectiveness opportunities and flexibility are the main criteria which a burden sharing rule should satisfy. The issue of flexibility is relevant in case non-OECD countries shall later become parties to an international arrangement defining legally binding commitments to reduce greenhouse gases. Wide participation of countries is important; if not, the outcome of emission reduction will be negligible. A rule that is able to adapt to changes in the capacity of countries to pay, to technology and energy efficiency developments, and to population changes would be attractive. But a simple and robust burden sharing rule or formula perhaps would be more attractive and, importantly, be more politically feasible. Thus, simplicity might enable faster negotiations but might not be able to satisfactorily address different national circumstances.

[44] H.P. Young and A. Wolf (1992), 'Global Warming Negotiations: Does Fairness Matter?', *Brookings Review:* 46-51.

[45] Note that this assumes that countries are concerned about reducing global warming.

ANNEX A7 RESULTS FROM BURDEN SHARING RULES, EMISSION CHANGES IN PERCENTAGE

FORMULA 1

emiss. reduction as a % of OECD-reduction

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Japan	Luxembourg	Netherlands	New Zealand
Case 1: equal weight	1.4	0.2	0.4	2.3	0.2	0.2	1.6	5.5	0.2	0.1	1.8	8.7	0.1	0.7	0.1
Case 2: CO2/cap	1.5	0.3	0.6	2.7	0.4	0.3	2.3	6.6	0.2	0.1	2.4	10.4	0.1	0.9	0.1
Case 3: CO2/GDP	2.0	0.2	0.6	2.9	0.3	0.2	1.6	5.8	0.5	0.2	1.9	7.8	0.1	0.9	0.1
Case 4: GDP/cap	1.6	0.3	0.6	2.7	0.3	0.3	2.1	6.3	0.2	0.1	2.3	9.7	0.1	0.9	0.1

Percentage reduction in national emissions

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Japan	Luxembourg	Netherlands	New Zealand
Case 1: equal weight	10.1	6.0	7.7	10.5	7.7	7.4	9.1	12.6	6.8	6.5	9.0	16.4	13.6	7.9	5.9
Case 2: CO2/cap	11.1	10.5	10.8	12.4	12.9	11.9	13.0	15.1	6.3	8.3	12.4	19.6	15.7	10.9	7.9
Case 3: CO2/GDP	14.5	7.0	10.1	13.7	9.1	9.0	9.0	13.2	13.3	9.8	9.4	14.7	17.7	10.3	8.9
Case 4: GDP/cap	11.8	9.6	10.6	12.7	12.1	11.2	11.9	14.6	6.7	8.3	11.5	18.3	17.3	10.6	7.7

FORMULA 2

Emission reduction as a percentage of OECD-reduction

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Japan	Luxembourg	Netherlands	New Zealand
Case 1: equal weight	2.2	0.8	1.1	3.7	0.6	0.6	5.7	9.3	0.8	0.3	5.6	14.3	0.1	1.7	0.3
Case 2: emissions	2.4	0.7	1.1	3.9	0.6	0.6	4.9	9.2	0.6	0.3	5.0	13.4	0.1	1.7	0.3
Case 3: emissions	2.6	0.6	1.1	4.1	0.6	0.6	4.2	8.9	0.7	0.3	4.5	11.9	0.1	1.7	0.3
Case 4: GDP	2.1	0.8	1.1	3.7	0.7	0.6	5.8	9.5	0.6	0.3	5.6	15.3	0.1	1.7	0.3

Emssion reduction as a percentage of national-reduction (if OECD reduces by 20% from 1993 level)

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Japan	Luxembourg	Netherlands	New Zealand
Case 1: equal weight	16.0	29.3	20.6	17.0	22.7	22.5	32.1	21.4	21.3	21.2	28.5	27.0	13.4	20.6	23.0
Case 2: emissions	17.3	25.9	20.4	18.2	22.6	22.1	27.6	21.1	17.6	19.6	25.1	25.3	16.6	20.3	20.5
Case 3: emissions	18.7	22.9	20.2	19.1	21.1	21.0	23.7	20.5	19.3	20.0	22.5	22.5	18.2	20.2	20.5
Case 4: GDP	15.6	29.6	20.6	17.1	24.4	23.6	32.5	21.9	15.4	19.2	28.2	28.8	14.6	20.5	20.5

FORMULA 3

as % of OECD emission reduction

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Japan	Luxembourg	Netherlands	New Zealand
Case 1: equal weight	2.2	1.2	1.5	3.6	1.1	1.0	6.7	9.5	1.0	0.7	6.2	16.7	0.7	2.0	0.6
Case 2: GDP	1.9	1.0	1.2	3.4	0.8	0.7	7.0	10.0	0.5	0.3	6.4	17.9	0.2	1.8	0.3
Case 3: GDP/cap	2.3	1.3	1.6	3.6	1.3	1.2	6.6	9.3	1.0	0.8	6.1	16.2	1.0	2.1	0.7
Case 4: emiss/GDP	2.8	1.3	1.8	3.8	1.4	1.3	6.1	8.8	1.8	1.2	5.8	15.0	1.6	2.3	1.1

as % of national emission reduction

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Japan	Luxembourg	Netherlands	New Zealand
Case 1: equal weight	16.1	42.3	26.4	16.5	37.6	37.4	37.2	21.8	26.9	43.0	31.1	31.5	138.7	23.7	46.8
Case 2: GDP	13.5	36.0	21.7	15.7	28.7	27.4	39.1	22.8	13.3	21.6	32.4	33.7	29.2	21.1	23.8
Case 3: GDP/cap	16.7	48.0	28.9	16.7	45.1	44.5	36.7	21.3	27.6	49.9	30.7	30.6	187.3	25.0	54.8
Case 4: emiss/GDP	20.3	48.7	32.9	17.8	47.3	49.2	34.3	20.2	51.4	76.0	29.1	28.3	295.8	27.3	81.8

FORMULA 1

emiss. reduction as a % of OECD-

	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
Case 1: equal	0.1	0.1	0.7	0.2	0.1	0.4	2.6	72.4
Case 2: CO2/cap	0.2	0.1	0.9	0.3	0.3	0.3	3.1	65.9
Case 3: CO2/GDP	0.1	0.2	0.9	0.2	0.1	0.8	3.1	69.7
Case 4: GDP/cap	0.2	0.1	0.8	0.3	0.3	0.3	3.0	67.3

Percentage reduction in national

	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
Case 1: equal	6.3	4.7	6.2	6.0	6.9	4.9	9.5	29.2
Case 2: CO2/cap	12.7	5.3	8.2	12.1	15.2	4.3	11.4	26.7
Case 3: CO2/GDP	6.8	8.6	7.9	6.2	6.5	10.4	11.5	28.1
Case 4: GDP/cap	11.2	5.3	7.7	10.6	13.1	4.4	11.2	27.2

FORMULA 2

Emission reduction as a percentage of OECD-

	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
Case 1: equal	0.5	0.7	3.2	0.9	0.8	3.1	5.9	37.6
Case 2: emissions	0.4	0.5	2.5	0.8	0.7	1.6	5.6	43.0
Case 3: emissions	0.4	0.5	2.4	0.6	0.6	1.7	5.5	46.1
Case 4: GDP	0.5	0.5	2.7	1.0	1.0	1.5	5.6	39.0

Emssion reduction as a percentage of national-reduction (if OECD reduces by 20% from

	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
Case 1: equal	31.6	29.4	29.4	36.7	39.9	42.3	21.8	15.2
Case 2: emissions	28.6	20.8	23.5	31.6	35.6	21.5	20.5	17.4
Case 3: emissions	24.0	21.2	22.1	25.5	27.2	22.7	20.4	18.6
Case 4: GDP	34.4	20.3	25.2	39.2	46.1	20.0	20.8	15.8

FORMULA 3

as % of OECD emission

	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
Case 1: equal	0.9	0.8	3.0	1.4	1.5	1.4	5.5	31.1
Case 2: GDP	0.7	0.5	2.9	1.3	1.3	1.1	5.7	33.3
Case 3: GDP/cap	1.1	0.8	3.0	1.6	1.7	1.4	5.5	30.0
Case 4: emiss/GDP	1.0	1.3	3.0	1.5	1.5	2.0	5.4	28.1

as % of national emission

	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
Case 1: equal	57.5	33.8	27.3	56.0	69.3	19.1	20.4	12.6
Case 2: GDP	45.0	20.2	27.0	51.2	63.1	14.6	20.8	13.5
Case 3: GDP/cap	72.2	35.5	27.2	63.5	81.7	18.6	20.1	12.1
Case 4: emiss/GDP	67.3	57.4	27.7	58.0	69.2	27.8	19.9	11.4

REFERENCES

Aaheim, H. A. (1995), 'Aspect of Burden-Sharing of Common Actions to Mitigate Climate Change', *CICERO Working Paper* 1995:2, Oslo

Aaheim, H. A. (1996a), 'Verdien av klimatiltak' (The Value of Climate Measures), *CICERO Report* 1996:1, Oslo.

Aaheim, H. A. (1996b), 'Investment in climate measures under uncertainty', forthcoming as *CICERO Working Paper*.

Abel, A. B. and J. C. Eberly (1994), 'A Unified model of Investment Under Uncertainty', *American Economic Review* 84(3), 1369-1384.

Asheim, G. B. (1993), 'Sustainability: Ethical Foundations and Economic Properties', mimeo, Norwegian School of Economics and Business Administration, Bergen.

Ballard, C. L., J.-B. Shoven and J. Whalley (1985), 'General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States', *American Economic Review* 75(1), 128-138.

Barrett, S. (1992), 'Acceptable Allocation of Tradable Carbon Emission Entitlements in a Global Warming Treaty' in UNCTAD, *Combating Global Warming*, Geneva.

Baumol, W. J. (1972), 'On Taxation and the Control of Externalities', *American Economic Review* LXII(3), 307-322.

Beltratti, A., G. Chichilnisky and G. Heal (1993), 'The Green Golden Rule and Sustainable Growth', *Working Paper*, Colombia University.

Benedick, R. E. (1991), Ozone Diplomacy: New Directions in Safeguarding the Planet, Harvard University Press, Cambridge, Mass.

Berg, E., S. Kverndokk and K. E. Rosendahl (1996), 'Market Power, International CO_2 Taxation and Petroleum Wealth', forthcoming as *Discussion Paper from Research Department*, Statistics Norway, Oslo.

Berntsen, T., I. S. A. Isaksen, W.-C. Wang and X.-Z. Liang (1996), 'Impacts of increased anthropogenic sources in Asia on tropospheric ozone and climate: A global 3-D model study', *Tellus* 48b, 13-32.

Bohm, P. (1993), 'Incomplete International Cooperation to Reduce CO_2 Emissions. Alternative Policies', *Journal of Environmental Economics and Management* 24, 258 -271.

Bohm, P. and B. Larsen (1994), 'Fairness in a Tradable-Permit Treaty for Carbon Emission Reductions in Europe and the Former Soviet Union', *Environmental and Resource Economics* No. 4, 219-239.

Bureau of Industry Economics (1995), 'Greenhouse Gas Abatement and Burden Sharing - An analysis of efficiency and equity issues for Australia', *Research Report* No. 66, Australian Government Publishing Service, Canberra.

Burniaux, J. M., J. P. Martin, G. Nicoletti and J. Oliveira Martins (1992), 'The Costs of Reducing CO_2 Emissions. Evidence from GREEN', *Working Paper* No. 115, Economics Department, OECD, Paris.

Burtraw, D. and M. A. Toman (1992), 'Equity and International Agreements for CO_2 Containment', *Journal of Energy Engineering* 118(2), August.

Charlson, R. J., J. Langner, H. Rodhe, C. B. Leovy and S. G. Warren (1991), 'Perturbation of the Northern Hemisphere radiative balance by backscattering from anthropogenic sulfate aerosols', *Tellus* 43A-B (4), 152-163.

Chichilnisky, G. (1993), *'What is Sustainable Development?'*, paper presented at the workshop of the Stanford Institute for Theoretical Economics.

Cline, W. R. (1992), *The Economics of Global Warming*, Institute for International Economics, Washington D.C.

Coase, R. H. (1960), 'The Problem of Social Costs', *The Journal of Law and Economics* III, 1-44.

Chisholm, A. and A. Moran (1994), 'Carbon Dioxide Emissions Abatement and Burden Sharing among the OECD Countries', *Tasman Institute Occasional Paper* B26, June 1994.

Dasgupta, P., and G. Heal (1979), *Economic Theory and Exhaustible Resources,* James Nisbet and Cambridge University Press, Cambridge.

Dean, A. (1993), 'What do Global Models Tell us About the Carbon Taxes Required and the Economic Costs Entailed in Reducing CO_2 Emissions?', in T. Kaya, N. Nakicienovic, W. D. Nordhaus and F. L. Toth (eds.), *Costs, Impacts and Benefits of CO_2 Mitigation*, CP-93-2 IIASA, Laxenburg.

DFAT and ABARE (1995), *Global climate change - Economic dimensions of a cooperative international policy response beyond 2000*, Department of Foreign Affairs and Trade and the Australian Bureau of Agricultural and Resource Economics, Canberra.

ECON Senter for økonomisk analyse (1995), 'Energy Taxes in the OECD', *ECON Report* No. 332.

Ekins, P. (1995), 'Rethinking the Costs Related to Global Warming. A Survey of the Issues', *Environmental and Resource Economics* 6(3), 231-277.

Fankhauser, S. (1995), *Valuing Climate Change. The Economics of the Greenhouse Gas,* CSERGE, Earthscan Publications Ltd. London.

FCCC and AGBM (1995), *'List of Issues Identified by Parties'*, mimeo, Ad Hoc Group on the Berlin Mandate, Second session, Geneva, 30 October - 3 November 1995.

Fuglestvedt, J. S. and T. Skodvin (1996), 'A comprehensive approach to climate change: Options and obstacles', *CICERO Report 1996:4*.

Fuglestvedt, J. S., I. S. A. Isaksen and W.-C. Wang (1996a), *'Estimates of Indirect Global Warming Potentials for CH4, CO and NOX'*, Climate Change (in press).

Fuglestvedt, J. S., T. K. Berntsen, I. S. A. Isaksen, H. Mao, X.-Z. Liang and W.-C. Wang (1996b), '*Climatic effects of NOx emissions through changes in tropospheric O_3 and CH_4, A global 3-D model study*', forthcoming.

Golombek, R. and J. Bråten (1994), 'Incomplete International Climate Agreements. Optimal Carbon Taxes, Market Failures and Welfare Effects', *The Energy Journal* 15(4), 141-165.

Golombek, R., C. Hagem and M. Hoel (1995), 'Efficient Incomplete International Climate Agreements', *Resource and Energy Economics* 17, 25-46.

Grieco, Joseph M. (1990), *Cooperation Among Nations: Europe, America, and Non-tariff Barriers to Trade*, Ithaca, Cornell University Press.

Grubb, M. (1995), 'Seeking Fair Weather: Ethics and the International Debate on Climate Change', *International Affairs* 71(3), 463-96.

Hammit, J. K., A. K. Adams and D. J. Wuebbles, 1996, 'A welfare-based index for assessing environmental effects of greenhouse-gas emissions', *Nature* 381(6580), 301-303.

Hoel, M. (1992), 'Carbon Taxes. An International Tax or Harmonized Domestic Taxes?', *European Economic Review* 36, 400-406.

Hoeller, P. and M. Wallin (1991), 'Energy Prices, Taxes and Carbon Dioxide Emissions', *Working Paper* No. 106, *Economics and Statistics Department*, OECD, Paris.

Holtsmark, B. (1996), 'Winners and Losers in a Climate Agreement', forthcoming as *Working Paper, CICERO,* Oslo.

Intergovernmental Panel on Climate Change (IPCC) (1990), *Climate change. The IPPC Scientific Assessment*, J. T. Houghton, G. J. Jenkins and J. J. Ephraums (eds.), Cambridge University Press, Cambridge, U.K.

Intergovernmental Panel on Climate Change (IPCC) (1992), *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, J. T. Houghton, B. A. Callander and S. K. Varney (eds.), Cambridge University Press, Cambridge, U.K.

Intergovernmental Panel on Climate Change (IPCC) (1994a), *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios,* J. T. Houghton, L. G. Meira Filho, J. Bruce, Hoesung Lee, B. A. Callander, E. F. Haites, N. Harris and K. Maskell (eds.), Cambridge University Press, Cambridge, U.K.

Intergovernmental Panel on Climate Change (IPCC) (1994b), *Guidelines for National Greenhouse Gas Inventories.*

Intergovernmental Panel of Climate Change (IPCC) (1995a), *Second Assessment Report*, Draft.

Intergovernmental Panel on Climate Change (IPCC) (1995b*), The Science of Climate Change*, Prepared by Working Group I, Technical Summary for Circulation at SBSTA/AGBM, February/March 1996.

Isaksen, I. S. A., Ø. Hov and E. Hesstvedt (1978), 'Ozone generation over rural areas', *Environmental Science & Technology* 12, 1279-1284.

Jorgenson, D. and P. Wilcoxen (1993), 'Reducing US Carbon Emissions. An Econometric General Equilibrium Assessment', *Resource and Energy Economics* 15(1), 7-15.

Jorgenson, D. and K.-Y. Yun (1990), 'The Excess Burden of Taxation in the US', *Harvard Institute of Economic Discussion Paper* No. 1528, November, Harvard University, Cambridge MA.

Kawashima, Y. (1996), *'Differentiation of Quantified Emission Limitation and Reduction Objectives (QELROs) according to National Circumstances: Introduction to Equality Criteria and Reduction of Excess Emission'*, paper presented at 'Informal workshop on quantified limitation and reduction emission objectives', 28 February 1996, in Geneva.

Koopmans, T. (1960), 'Stationary Ordinal Utility and Impatience', *Econometrica* 28(2), 287-309.

Kram, T. (1993), 'National Energy Options for Reducing CO_2 Emissions, Volume I: The International Connection - A report of the Energy Technology Systems

Analysis Programme / Annex IV (1990-1993)', *Report* ECN-C-93-101, Netherlands Energy Research Foundation ECN.

Kram, T. and D. Hill (1996), 'A Multinational Model for CO_2 Reduction', *Energy Policy* 24(1), 39-51.

Levy M. A. et al. (1995), 'The Study of International Regimes', *European Journal of International Relations* 1(3), 267-330.

Manne, A. S. (1994), 'The Rate of Time Preference. Implications for the Greenhouse Debate', *Energy Policy* 23(4/5), 391-394.

Manne, A. S., R. Mendelsohn, and R. Richels (1994), 'MERGE: A model for Evaluating Regional and Global Effects of GHG Reduction Policies', in N. Nakicienovic, W. D Nordhaus, R. Richels, and F. L. Toth (eds.): *Integrative Assessment of Mitigation, Impacts, and Adaptation to Climate Change,* CP-94-9 IIASA, Laxenburg.

Manne, A. S. and R. G. Richels (1991), 'Global CO_2 Emission Reductions - the Impacts of Rising Energy Costs', *The Energy Journal* 12(1), 87-107.

Nordhaus, W. D. (1991), 'To Slow or Not to Slow. The Economics of Global Warming', *The Economic Journal* 101(6), 920-937.

Nordhaus, W. D. (1993), 'Rolling the DICE: An Optimal Transition Path for Controlling Greenhouse Gases', *Resource and Energy Economics* 15(1), 27-50.

Organisation for Economic Co-operation and Development (OECD) (1974), *OECD Council*, 14. November 1974 C 223, Paris.

Organisation for Economic Co-operation and Development (OECD) (1995a), *OECD Environmental Data Compendium*, OECD, Paris.

Organisation for Economic Co-operation and Development (OECD) (1995b), *Energy Policies of IEA Countries, 1994 Review*, OECD, Paris.

Organisation for Economic Co-operation and Development (OECD) (1995c), *Energy Balance of OECD Countries,* 1992-1993, OECD/IEA, Paris.

Organisation for Economic Co-operation and Development (OECD) and International Energy Agency (IEA) (1994), *Climate Change Policy Initiatives - 1994 Update*, OECD and IEA, Paris.

Organisation for Economic Co-operation and Development (OECD) and International Energy Agency (IEA) (1995), *Policies and measures for 'Common Action' - Initial Report*, memo 18 August, OECD/IEA, Paris.

Parson, E. A. and R. J. Zeckhauser (1995), 'Equal Measures or Fair Burdens: Negotiating Environmental Treaties in an Unequal World', in H. Lee (ed.) *Shaping National Responses to Climate Change*, Wash. DC, Island Press, 81-113.

Peck, S. C. and T. J. Teisberg (1994), 'Optimal carbon emissions trajectories when damages depend on the rate of level of global warming', *Climatic Change*, 28, 289-314.

Pezzey, J. (1992), *Sustainable development concepts: an economic analysis* World Bank, Washington, D.C.

Pigou, A. C. (1920), *The Economics of Welfare,* London, 4th ed., 1932.

Ramsey, F. P. (1928), 'A Mathematical Theory of Saving', *The Economic Journal* 38(152), 543-559.

Ringius, L. (1992), *Radwaste Disposal and the Global Ocean Dumping Convention: The Politics of International Environmental Regimes*, unpublished Ph.D. dissertation, the European University Institute, Florence, Italy.

Ringius, L., A. Torvanger and E. Meze (1996), 'Climate Policy, Burden Sharing and the Nordic Countries: Present State of Analysis and Need for Further Analysis', *CICERO Report* No. 2, CICERO, Oslo.

Rose, A. (1992), 'Equity Considerations of Tradable Carbon Emission Entitlements', in UNCTAD *Combating Global Warming*, Geneva.

Rosendahl, K. E. (1994), 'Carbon Taxes and the Petroleum Wealth', *Discussion Paper* 128, Statistics Norway, Oslo.

Rowlands, I. H. (1995), 'Explaining National Climate Change Policies', *Global Environmental Change* 5(3), 235-249.

Rowlands, I. H. (1996), 'International Justice and Global Climate Change', mimeo, London School of Economics and Political Science, London.

Schelling, T. C. (1994), 'Global Decisions for the Very Long Term', mimeo.

Sebenius, J. K. (1991), 'Designing Negotiations Toward a New Regime: The Case of Global Warming', International Security 15(4), 110-148.

Solow, R. M. (1974), 'Intergenerational Equity and Exhaustible Resources', *Review of Economic Studies*, Symposium on the Economics of Exhaustible Resources, 29-45.

Sprinz, D. and T. Vaahtoranta (1994), 'The Interest-Based Explanation of International Environmental Policy', *International Organization* 48(1), 77-105.

Titus, J. (1992), 'The Cost of Climate Change to the United States', in S. K. Majumdar, L. S. Kalkstein, B. Yarnal, E. W. Miller and L. M. Rosenfeld (eds.), *Global*

Climate Change: Implications, Challenges and Mitigation Measures, Pennsylvania Academy of Science, Pennsylvania.

Tol, R. S. J. (1993), 'The Climate Fund - Survey on Literature on Costs and Benefits', *Working Document* W93/01, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Torvanger, A, J. S. Fuglestvedt, C. Hagem, L. Ringius, R. Selrod and H. A. Aaheim (1994), 'Joint Implementation Under the Climate Convention: Phases, Options and Incentives', *CICERO Report* No. 6, CICERO, Oslo.

Unander, F. F. (1993), 'CO_2 Emission Control in Norway. Results from IEA-ETSAP Annex IV', *Report* IFE/KR/E-92/008, Institutt for Energiteknikk, Kjeller.

United Nations Environmental Programme (1994), *UNEP Greenhouse Gas Abatement Costing Studies. Phase Two Report Part 1: Main Report,* UNEP Collaborating Centre on Energy and Environment, RISØ National Laboratory, Denmark.

Waltz, K. N. (1986), 'Theory of International Politics', in R. O. Keohane (ed.) *Realism and Its Critics*, 27-130, Columbia University Press, New York.

Weitzman, M. L. (1974), 'Prices vs. Quantities', *Review of Economic Studies* XLI, 477-491.

Weitzman, M. L. (1976), 'On the Welfare Significance of National Product in a Dynamic Economy', *Quarterly Journal of Economics* 90, 156-162.

Weitzman, M. L. (1994), 'On the 'Environmental' Discount Rate', *Journal of Environmental Economics and Management* 26(2), 200-209.

Wigley, T. M. L., J. A. Edmonds and R. Richels (1996): 'Economic and Environmental Choices in the Stabilization of Atmospheric CO_2 Concentrations', *Nature* 379, 240-243.

World Commission on Environment and Development (WECD) (1987), *Our Common Future*, Oxford University Press, Oxford.

World Meteorological Organisation (WMO) (1995), 'Scientific Assessment of Ozone Depletion: 1994', *Global Ozone Research and Monitoring Project Report* 37, World Meteorological Organization, Geneva.

Young, H. P. and A. Wolf (1992), 'Global Warming Negotiations: Does Fairness Matter?', *Brookings Review*, 46-51.

Young, O. R. (1991), 'Political Leadership and Regime Formation: on the Development of Institutions in International Society', *International Oraganization* 45(3), 281-308.

Young, O. R. (1994), *Equity in Theory and Practice*, Princeton University Press, Princeton and Chichester.