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Technical Report on Stratospheric Ozone Depletion in Europe: an integrated economic and environmental assessment

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This Report has been prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO under contract with the Environment Directorate-General of the European Commission.

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Abstract

The economic assessment of priorities for a European environmental policy plan focuses on twelve identified Prominent European Environmental Problems such as climate change, chemical risks and biodiversity. The study, commissioned by the European Commission (DG Environment) to a European consortium led by RIVM, provides a basis for priority setting for European environmental policy planning in support of the sixth Environmental Action Programme as follow-up of the current fifth Environmental Action Plan called 'Towards Sustainability'. The analysis is based on an examination of the cost of avoided damage, environmental expenditures, risk assessment, public opinion, social incidence and sustainability. The study incorporates information on targets, scenario results, and policy options and measures including their costs and benefits.

Main findings of the study are the following. Current trends show that if all existing policies are fully implemented and enforced, the European Union will be successful in reducing pressures on the environment. However, damage to human health and ecosystems can be substantially reduced with accelerated policies. The implementation costs of these additional policies will not exceed the environmental benefits and the impact on the economy is manageable. This requires future policies to focus on least-cost solutions and follow an integrated approach. Nevertheless, these policies will not be adequate for achieving all policy objectives. Remaining major problems are the excess load of nitrogen in the ecosystem, exceedance of air quality guidelines (especially particulate matter), noise nuisance and biodiversity loss.

This report is one of a series supporting the main report: *European Environmental Priorities: an Integrated Economic and Environmental Assessment*. The areas discussed in the main report are fully documented in the various *Technical reports*. A background report is presented for each environmental issue giving an outline of the problem and its relationship to economic sectors and other issues; the benefits and the cost-benefit analysis; and the policy responses. Additional reports outline the benefits methodology, the EU enlargement issue and the macro-economic consequences of the scenarios.

Technical Report on Stratospheric Ozone Depletion

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Reports in this series have been subject to limited peer review.

The report consists of three parts:

Section 1:
Environmental assessment
Prepared by G.J.M. Velders (RIVM), H. Slaper (RIVM)

Section 2:
Benefit assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

Section 3:
Policy assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

References
All references made in the sections on benefit and policy assessment have been brought together in the Technical Report on Benefit Assessment Methodology. The reference made in the section on environmental assessment follows at the end of section 1.

Contents

1. Environmental assessment

1.1 Introduction

A description of the state of the ozone layer and the causes and effects have recently been discussed in Europe's Environment (1998) and in the EU98 report (1999). Extensive overviews of the current scientific understanding of ozone depletion and the effects are given in the EC report European Research in the Stratosphere (EUR, 1997), in the UNEP/WMO Scientific Assessment of Ozone Depletion: 1998 (WMO, 1999), and in the UNEP Environmental Effect of Ozone Depletion 1998 Assessment (UNEP, 1998). We refer to these reports for detailed information.
In this chapter a short description of the issue, relevance and policies of stratospheric ozone depletion is given. The DPSIR-chain is described with emphasis on the impact indicator "excess skin cancer incidence". Several scenarios are calculated for this indicator and the benefits of the international policies are shown. Finally the interaction of this theme with other environmental themes is discussed.

1.1.1 Short background of stratospheric ozone depletion

The stratospheric ozone layer is a diluted veil of ozone gas that stretches from about 10-40 km above the ground. There is a natural balance between ozone production and destruction. Ozone depletion is caused by man-made emissions of chlorine and bromine compounds, but not all compounds with chlorine and bromine affect the ozone layer to the same extent. The longer the atmospheric lifetime of a compound the more of it can enter the stratosphere and contribute to ozone depletion. The chlorine and bromine compounds that cause significant depletion of the ozone layer are CFCs, carbon tetrachloride (CCl_4), methyl chloroform (CH_3CCl_3), HCFCs, HBFCs and halons, all of which are completely of anthropogenic origin. They are used as coolant, foam blowing agent, aerosol propellant, cleaning agent and fire extinguisher. The ozone layer can also be depleted by methyl chloride (CH_3Cl) which comes mainly from the oceans and methyl bromide (CH_3Br) which comes from natural and anthropogenic sources. Other substances such as nitrous oxide and water vapour also participate in the natural process of ozone destruction. The use of CFCs and halons, in particular, has led to an increase in the concentration of chlorine and bromine in the stratosphere. These compounds are chemically very stable and are not degraded in the troposphere. In the stratosphere they are dissociated by the short-wave radiation from the sun and release chlorine and bromine, which then take part in chemical chain reactions. A single chlorine or bromine atoms can destroy many thousands of ozone molecules before being removed from the stratosphere. The natural balance between production and loss of ozone is therefore shifted towards a lower concentration of ozone.

Four distinct regions can be identified with respect to stratospheric ozone depletion: the Antarctic, the Arctic, mid-latitudes in the Northern and Southern hemisphere and the tropics.
The largest decreases in total ozone (the amount of ozone in a column that reaches from the ground to the top of the atmosphere) of 60-70% occur every year, since the beginning of the 1980s, in spring (Sept.-Nov.) over Antarctica; known as the ozone hole. Since the beginning of the 1990s decreases of 30-40% in the ozone layer have been seen in spring (Feb.-Mar.) over the Arctic. At mid-latitudes depletions in total ozone of 2-5% per decade are observed since the beginning of the 1980s. No trend in total ozone is seen over the tropics.

Meteorological processes can cause variations in the ozone layer on time scales from days to years. Large volcanic eruptions, as for example from Mt. Pinatubo in 1991, can cause an extra depletion of ozone for several years.

With a full compliance of the Montreal Protocol and its amendments and adjustments, it is expected that the ozone layer will be at its minimum around 2000 and start recovering after that. A full recovery is not expected before approximately 2050.

1.1.2 DPSIR-chain

Stratospheric ozone depletion starts with the production of ODSs (Ozone Depletion Substances). Shortly after production they are used for a range of applications (see Table 1.1).

Table 1.1 Usage of ODSs in the EU 1986-1995 in ODP tonnes per year. Source: KPMG.

Application	*Group*	*1986*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*
Aerosols	I[a]	141,786	49,815	2,341	15,308	14,379	13,598	6,419	20
	VIII[f]	0	145	227	256	277	264	213	157
Refrigeration	I	28,752	31,144	28,805	29,891	30,007	34,096	1,677	210
	II[b]	-	62	56	41	43	45	18	1
	III[c]	676	523	814	530	350	200	10	10
	VIII	0	1,583	1,636	1,620	1,734	1,868	1,885	2,341
Foam	I	85,370	95,138	83,106	74,526	57,592	46,360	13,347	0
	VIII	0	132	503	847	1,154	1,611	2,858	4,187
Solvents	I	45,039	45,414	40,859	34,470	2,386	20,088	8,321	28
	VIII	0	0	6	2	24	143	380	691
Fire extinguishant	III	42,700	46,211	40,298	35,491	26,765	20,895	0	0
Other	IV[d]	-	26,608	23,522	11,189	7,404	3,156	1,905	0
	V[e]	-	12,871	12,262	10,513	9,105	6,716	5,637	4,425
TOTAL	All	344,323	309,646	253,435	214,684	176,220	149,040	59,670	12,070

[a] Group I = CFC-11, CFC-12, CFC-113, CFC-114, CFC-115.

[b] Group II = CFC-13, CFC-112.

[c] Group III = Halon-1211, Halon-1301, Halon-2402

[d] Group IV = Carbon tetrachloride

[e] Group V = 1,1,1-trichloroethane

[f] Group VIII = HCFC-22, HCFC-123, HCFC-124, HCFC-133, HCFC-141b, HCFC-142b

Emission to the atmosphere takes place immediately in the application, e.g. in the production of open foam or as solvent, or up to a large number of years with e.g. refrigeration or fire extinguishers. The production, use and emission can be considered as the Driving force (D). The production and use of ODSs is at the moment governed almost completely by the international policy measures. The future state of the ozone layer will therefore be largely determined by the natural processes in the atmosphere that destroy ODSs and by the Montreal Protocol, and only slightly by the future production and use of ODSs. The production, sales (use) of most ODSs has decreased to almost zero in the EU and most other developed countries (Europe's Environment, 1998; EU98 (1999). There is some concern about two new solvents, bromochloromethane and N-propyl bromide, with ODPs of 0.15 and 0.026, respectively. No information is available about the production, sales and atmospheric concentration of these solvents.

After being emitted in the atmosphere the ODSs directly contribute to the concentration in the troposphere. It takes on average approximately 3 years before the ODSs are transported to the stratosphere and can contribute to the ozone depletion. The tropospheric concentrations of several ODSs decrease since a few years as a direct result of the international policies. The atmospheric concentration of HCFCs and halons are still increasing; the latter contrary to earlier expectations. (For methyl bromide there is no measerable trend). The weighted sum of all ODSs is the Pressure indicator (P). The amount of total ozone is the State indicator (S).

A thinner ozone layer results immediately in an increase of UV radiation at ground level, which can lead to a variety of adverse impacts (I) on aquatic and terrestrial ecosystems, food chains, and human health. Among the adverse effects on human health are increases in skin cancer incidence, cataracts, and possibly an impairment of the immune system (see the UNEP effects assessment; UNEP, 1998). The Montreal protocol and its amendments and adjustments and the EC Counsel regulations are the Responses (R).
Effects for terrestrial ecosystems include possible damaging effects for plants and microbes, but these organisms also have protective and repair processes. Terrestrial ecosystem responses to increases UV-B are evident primarily in interactions among species, rather that in the performance of individual species. Effects for aquatic ecosystems include possible adverse effects on the growth, photosynthesis and reproduction of phytoplankton, thus affecting the food web. There are no good dose effect relations available for terrestrial and aquatic ecosystems (UNEP, 1998)
Increases in UV-B radiation negatively affect the physical and mechanical properties of polymers, but conventional photostabilizers are likely to mitigate the effects.

1.1.3 Policy agreements and compliance

The Vienna Convention in 1985 was the starting point for international policy agreements on the reduction of halocarbon emissions, and provided a framework for the restrictive protocols that came into action later-on. The

Montreal Protocol, in 1987, provided the first restrictive countermeasures, in which the production of the five major ozone depleting substances is restricted to 50% of the 1986 production levels by the year 2000. In view of the compelling evidence that ozone depletion was actually occurring, the restrictions were sharpened in subsequent Amendments: the London Amendments, which were agreed upon in 1990, the Copenhagen Amendments in 1992, the Vienna Adjustments in 1995, and the Montreal Amendments in 1997. The London Amendments aimed at a complete phase out of the primary ozone depleting substances by the year 2000, and the Copenhagen Amendments forwarded the complete phase out to the year 1996. Developing countries were allowed longer periods for phasing out the ozone depleting substances. In addition to the restrictions for the primary ozone depleting substances restrictions were also put on other ozone depleting substances. The main changes to the protocol agreed upon in Vienna (1995) and Montreal (1997) concern the phase out of HCFCs and methyl bromide; the latter now set at 2005 for developed countries.

The Montreal Protocol and its amendments and adjustments are implemented in 1994 by the EU in the Council Regulation EC No. 3093/94. This regulation is now being updated in the Council's common position (EC no. 19/1999) of 23 february 1999. This proposal (see Table 1.2) sets limits on the production of HCFCs (the Montreal Protocol only limits the consumption of HCFCs), tighter controls on the consumption and use of HCFCs and which prohibits the production and consumption of methyl bromide. Furthermore the sale and use of CFCs, halons, carbon tetrachloride, methyl chloroform and HBFCs is prohibited. Tighter import and export controls on ozone depleting substances are also proposed.

Table 1.2. Proposed tighter controls in the EU

Compound	Year	Montreal Protocol
CFCs, halons, CCl_4, CH_3CCl_3, HBFCs		Production and use prohibited
HCFC production	2000	freeze at 1997 level
	2008	65% reduction from 1997 level
	2014	80% reduction
	2020	85% reduction
	2026	production prohibited
HCFC consumption	1999	freeze on calculated consumption at 2.6% of CFC consumption in 1989 plus total HCFC consumption in 1989
	2001	freeze on calculated consumption at 2.0% of CFC consumption in 1989 plus total HCFC consumption in 1989
	2002	10% reduction from 2001 level
	2003	65% reduction
	2004	70% reduction
	2008	95% reduction
	2015	consumption prohibited
CH_3Br	1999	25% reduction on production and consumption at 1991 levels
	2001	production and consumption prohibited, with possible exemptions for critical uses

Source: Council's common position (EC no 19/1999) of 23 feb. 1999

All countries in the EU and the EU itself have ratified the Copenhagen Amendments of the Montreal Protocol and thereby also have to follow the Vienna Adjustments. As of May 2000, the Montreal Protocol has been ratified by 173 parties, the Copenhagen Amendment by 104 and the Montreal Amendment by 37. All the available information indicates that there is a good global compliance with the Montreal Protocol and its amendments and adjustments: the production and consumption of CFCs, halons, carbon tetrachloride and methyl chloroform decreased strongly since 1990.

There are reports on smuggling of CFCs into the EU and into the USA. The NGO Environmental Investigation Agency (EIA, 1997, 1998) estimates that illegal trade in CFCs currently amounts to some 30000 tonnes per year of which between 6000 and 20000 tonnes may occur in the European Union. 30000 tonnes equals 11% of the global production of CFCs in 1995. ODSs are still produced and will be produced in the near future for 'essential uses' agreed upon by the parties of the Montreal Protocol. At the moment these essential uses are mostly for metered dose inhalers, but in the future possibly also for fumigation in agriculture.

1.2 Method

1.2.1 Excess skin cancer incidence

A decrease in stratospheric ozone results in an increase in UV radiation reaching the surface and related adverse effects for humans, ecosystems and materials. One of the adverse effects for humans for which a quantifiable dose-effect relation exists is skin cancer. Questions are being raised regarding the extent of the risks involved and the future developments in relation to the international policy measures. A collaboration between atmospheric scientists and bio-physicists from the Netherlands (RIVM and University Utrecht) and the USA (NOAA) has lead to a new method for estimating future skin cancer risks in relation to emission scenarios for ozone depleting substances (Slaper et al., 1996). The method is based on an improved integrated source-risk model, which was previously developed at RIVM (Slaper et al., 1992). The improved model is used to evaluate excess skin cancer risks caused by ozone depletion in relation to various halocarbon emission scenarios.

The UV-chain model integrates dynamic aspects of the full source-risk chain. Starting with the production and emission of ozone depleting substances, the consequences for the ozone layer, subsequent changes in UV-irradiance and changes in skin cancer incidence are evaluated (Slaper et al., 1996). The carcinogenic UV-dose is ascertained by weighting of the ambient UV spectrum according to the carcinogenic effectiveness (De Gruijl and van der Leun, 1994). The last chain in the model consists of a dose-time-response model for skin cancer induction. The dose-time response models are derived from animal studies, but parameters are calibrated on the basis of epidemiological studies at different latitudes (Slaper et al., 1996). Differences in the timing of UV-driven processes (early or later stages) are incorporated into the present modelling (Slaper et al., 1996). Changes in behaviour, skin sensitivity, in cloud and aerosol load of the atmosphere are not taken into account. Furthermore, calculations are based on the present age distribution of the populations. Three major skin cancer types are considered: basal cell carcinoma (BCC), the most frequent but least aggressive, squamous cell carcinoma (SCC) and cutaneous malignant melanoma (CMM), the least frequent but most aggressive. Present skin cancer incidence is estimated to be around 1100 cases per million per year in NW-Europe. (Slaper et al., 1996).

1.2.2 Equivalent effective stratospheric chlorine

Emitted halocarbons are transported to the stratosphere, where they are photochemically broken down, releasing active chlorine and bromine atoms. These atoms can destroy ozone molecules by catalytical reactions. Halocarbons (CFCs, halons, HCFCs etc.) release active chlorine and bromine atoms at a different rate and have a different effect on the ozone layer. Bromine atoms are also much more active in ozone destruction than chlorine atoms (about 60 times). To account for these differences the Equivalent Effective Stratospheric Chlorine (EESC) quantity was used (Daniel et al., 1995), which takes into account the transport of the halocarbons from the troposphere to the stratosphere (in about 3 years), the different release rates of the atoms in the stratosphere and the larger effect of bromine atoms on ozone destruction compared with chlorine atoms. The EESC is considered to be directly proportional to a change in ozone column.

The evaluation of ozone column trends from measurements suggests that a downward trend started around 1975-1980, when chlorine levels were already elevated. In the UV-chain model we therefore assume that ozone depletion started after a threshold in effective chlorine loading was reached. Above this threshold a linear relation between chlorine loading and relative decreases in ozone columns is applied, and at very high chlorine levels ozone saturation of ozone depletion is inferred (Slaper et al., 1996).

1.3 Results

1.3.1 Excess skin cancer incidence

Five scenarios are evaluated for this study: No restrictions on halocarbon production (NR) (assuming that their would have been no policy measures at all), the Montreal Protocol (MP), the Copenhagen Amendments (CA), and two variations on the latter: a more restrictive scenario (CA+) not allowing a longer phase out period for developing countries, and a less restrictive scenario (CA-) where 30% of the developing countries do not comply with the restrictions. Figure 1.1 shows the relative increase in the yearly effective UV dose at 52° north latitude in the Netherlands as found using the UV-chain model for the five scenarios. The points in Figure 1.1 indicate modelled UV-doses based on observed changes in the ozone layer. Each point represents a three year running average of the UV-dose. The figure clearly shows that UV-doses in the 1992-1995 period are considerably higher than modelled for the five scenarios. This is possibly due to enhanced chemical breakdown of ozone, caused by the volcanic eruption of the Mt. Pinatubo in 1991. If we include these recent years in the calibration of the UV-chain model the risks would increase 20-40%. However, it is expected that the enhanced depletion will not continue for a prolonged period. A slow recovery of the ozone layer can only be expected in the CA and CA+ scenarios, which show a maximum UV increase around the year 2000 of +10% .

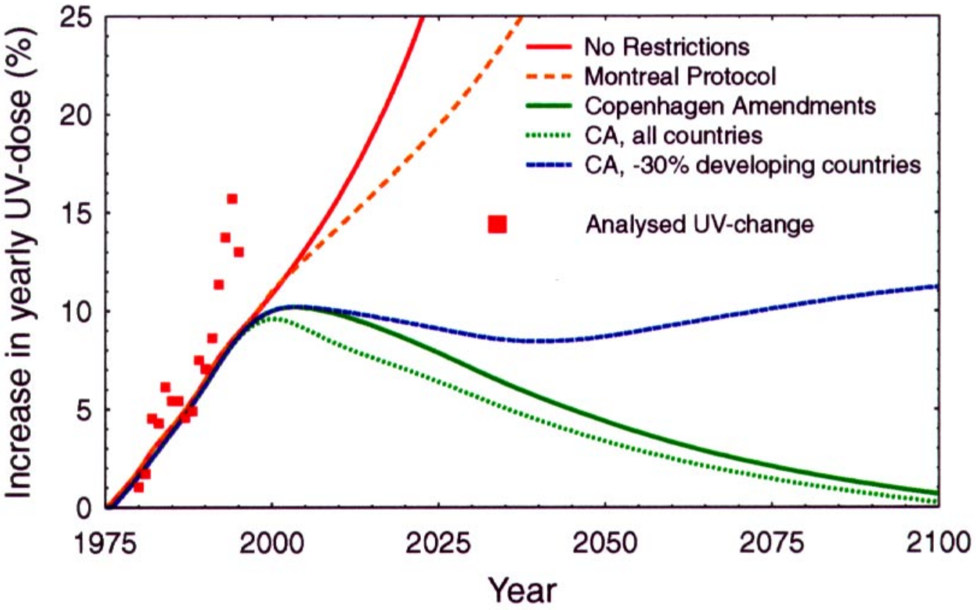

Figure 1.1. Relative increase in yearly effective UV dose received at ground level at 52° north latitude (NW-Europe), for each of the five scenarios. The squares give the three year averaged yearly dose derived from ozone observations (Slaper et al., 1998).

Figure 1.2 shows the excess skin cancer risks combining the changes in UV-exposure with the dynamical skin cancer models. Comparison of Figs. 1 and 2 indicate a 60-year delay between the exposure and risk peaks in the CA scenario. In the CA scenario the calculated number of excess cases caused by ozone depletion reaches about 47,000 per year in the EU15 in NW Europe in the year 2050.

Assuming a population of 360 million for the EU15 the number of excess skin cancer cases that can be avoided by complying with the CA-scenario (relative to the No Restrictions scenario) amounts to about 80,000 cases per year in 2050. This numbers increases 10-fold towards the end of the 21st century, due to the long delay times. Approximately 2% of the cases are fatal. These estimates of the excess skin cancer risks are probably conservative, because UV-levels in the 1990-1995 period are underestimated by the model, effects of ageing populations are not included, and trends in behaviour are not included.

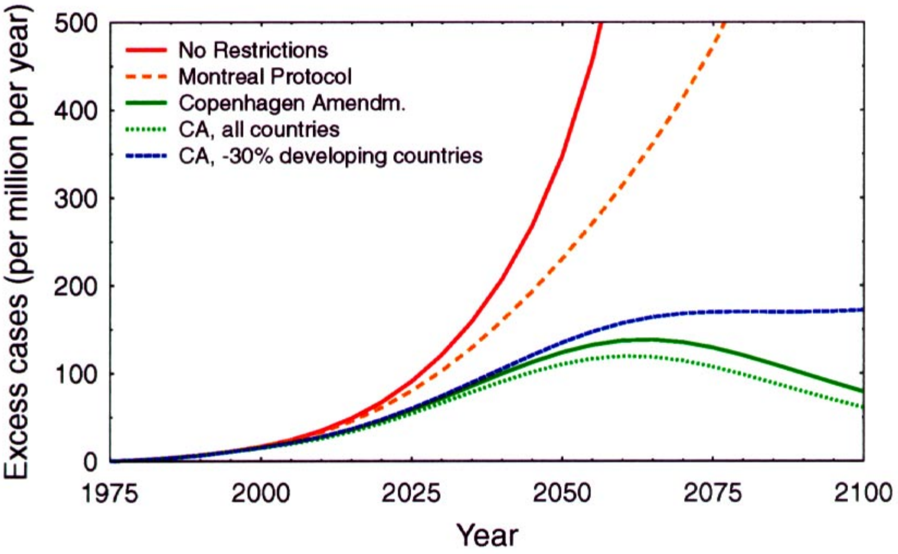

Figure 1.2. Excess incidences calculated for the population in NW Europe, incorporating the delay between exposure and the occurrence of tumours (Slaper et al., 1998).

Clearly uncertainties are involved in the modelling of all processes, from the production of ODSs to the excess cases of skin cancer incidence and related deaths. An uncertainty analysis has shown the statistical significance of the differences between the three main scenarios (NR, MP and CA). See Slaper et al.,. (1996) for details of the uncertainty analysis. The largest uncertainties are introduced in the steps from the effective chlorine in the stratosphere to ozone depletion and from UV increases to excess cases of skin cancer and to the deaths. The dose effect relations on which these calculations are based are not known accurately. These uncertainties have a large effect on the total calculated numbers, but a relatively small effect on the differences between scenarios. Using a statistical procedure, taking all the uncertainties into account, it is found that the calculated excess cases of skin cancer in the EU15 in 2050 (CA scenario) ranges from 40 to 250 cases per million per year with a best estimate of 125 (adapted from Slaper et al., 1996). The NR scenario ranges from 120 to 900 with a best estimate of 340 cases per million per year in the EU15 in 2050. The number of avoided cases (CA-NR) ranges from 70 to 650 with a best estimate of 215 cases per million per year.

The calculations of the increase in UV and excess skin cancer incidence, presented here, are derived for NW-Europe, i.e. they are based on the observed ozone depletion at northern mid-latitudes and on the sensitivity of the population in the Netherlands for skin cancer. We have used these calculations to derive the excess incidence for the whole EU15 by assuming that the relations hold for the whole EU15 and multiplying with the total population. Additional uncertainties are introduced by doing this. First, there are large differences in sensitivity to skin cancer between the North and South of Europe. Since there is only a good relation available between UV and skin cancer incidence for the Dutch population we have used this for the whole of Europe. Second, the calculations assume no changes in behaviour of the people, e.g. vacations, etc.

Geographical distributions over Europe of excess skin cancer incidence have been made based on the observed distribution of ozone depletion over Europe, but with the skin cancer sensitivity of the Dutch population. These calculations show small geographical differences over most of Europe, but with smaller values over Scandinavia. The calculations also show considerable year to year variation. Because of these uncertainties we only give numbers for the whole of the EU, not for individual countries.

The calculations presented here follow the follow the Copenhagen Amendments (1992) of the Montreal protocol. The more strict adjustments of Vienna (1995) and amendments of Montreal (1997) are expected to yield only slightly lower values for the excess skin cancer incidence (~10% in 2050). The largest steps in the phase out of ODSs have been obtained by the earlier amendments, with the largest associated benefits in terms of skin cancer incidence (Longstreth et al., 1998).

1.3.2 Equivalent Effective Stratospheric Chlorine

In Figure 1.3 the EESC is shown from the baseline scenario of WMO (1999). This scenario follows the latest amendments of Montreal (1997). Ozone depletion was first observed around 1980. The corresponding EESC value is 2 ppbv. It is now assumed that this value is a sort of threshold for ozone depletion. When the EESC drops below this value, no ozone depletion is expected anymore. The maximum EESC value was reached around 1998 and is expected to decrease since. A total recovery of the ozone layer is not expected before about 2050, when the EESC drops below 2 ppbv again.

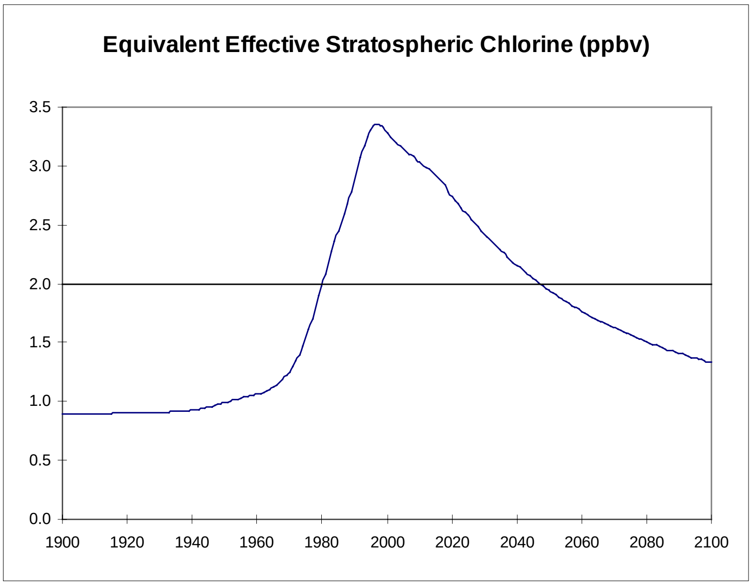

Figure 1.3. EESC (Equivalent Effective Stratospheric Chlorine) following the Montreal Amendments of 1997. (Baseline scenario of WMO (1999)).

Significant uncertainties are also introduced in the conversion from the policy measures in production of ODSs, which is partly based on reported production and sales information from companies. The estimation of the emissions from the production and sales of ODSs also introduces uncertainties (McCulloch and Midgley, 1998), although these are partly validated by comparison of the calculated tropospheric concentrations with measurements (WMO, 1999).
The data for the driving forces (production and consumption of ODSs) are from DGXI and based on data reported by producer companies. It has been shown that for most species the global amounts produced and emitted agree with measured concentrations of ODSs in the troposphere (WMO, 1999). Such an analysis is much more difficult on a continental scale and impossible on a country level, due to the long atmospheric life times of the ODSs (global nature of the problem). The uncertainties in the production and sales reported by DGXI are probably less than 10%. The global figures, which are needed to calculate the effects on the ozone layer, contain larger uncertainties. Up to the beginning of the 1990s, the global figures were dominated by production and consumption in developed countries. The production and consumption of manufacturers in most western countries is reported by AFEAS (1998). For the global figures, estimates have to be made for the production in other countries. The uncertainty in the production and consumption data is estimated at about 10%. Since the production in developed countries has almost stopped, the relative contribution of the other countries increases, which increases the relative uncertainty in the global figures.

The indicator Equivalent Effective Stratospheric Chlorine (EESC) is based on a calculation with a box model using reported production and emission data (WMO, 1999). The corresponding calculated tropospheric concentrations are in close agreement with the measured concentrations from the ALE/GAGE/AGAGE (Prinn et al., 1998) and NOAA/CMDL (Elkins et al., 1998) networks. Above a threshold, corresponding to the EESC in 1980, it is considered to be directly proportional to ozone depletion at mid latitudes. In the calculations it is taken proportional to the observed ozone depletion. The uncertainties in the indicator is estimated at 10%. A slightly different, but calculated analogously, indicator is used for the calculation of the UV change. This has no significant effect on the outcomes, since it is scaled to the observed ozone depletion and considering all the other uncertainties.

The future behaviour of the ozone layer depends largely on the natural processes that destroy ODSs in the atmosphere, due to the large global reduction in production and use of ODSs in the last years. WMO (1999) reports that with a full global compliance with the Montreal Amendments of 1997, the ozone layer is expected to be recovered (EESC below 2 ppbv) between 2033 and 2052 and most likely around 2048. Non compliance (illegal production and smuggle) can delay this with several years. The lower limit of about 2033 corresponds with an immediate total stop in all emissions and destruction of all ODSs contained in existing equipment. The recovery is than governed complete by natural processes in the atmosphere.

1.3.3 Interaction with other environmental issues

Climate change

Climate change may cause an increase in temperature in the troposphere and a decrease in temperature in the stratosphere. This decrease may delay the recovery of the ozone layer at the Arctic and Antarctic by several years, due to an increase in clouds in the stratosphere. The greenhouse gases methane and nitrous oxide may also affect stratospheric ozone by chemical interactions. This may have a positive or negative effect (Velders, 1997). The magnitude of this interaction is uncertain and depends on the emissions of methane and nitrous oxide and the chlorine concentration.

Aircraft emit nitrogen oxides (NO_x) directly in the upper troposphere and lower stratosphere. This is the only anthropogenic source of NO_x in these regions. The impact of the current fleet of aircraft on the observed ozone depletion is unknown but probably small. The effect of a possible future fleet of supersonic aircraft flying in the stratosphere on the ozone layer could be slightly negative, but with a considerable uncertainty range (Brasseur et al.,. 1998, and IPCC, 1999).

Increases in UV-B may affect the growth, photosynthesis and reproduction of phytoplankton Reductions in phytoplankton may result in a reduced uptake of CO_2 in the oceans (UNEP, 1998).

CFCs, and also the compounds used as replacement for CFCs, are potent greenhouse gases. The decrease in emissions of the CFCs reduces their contribution to the radiative forcing in the coming decades, but contribution of the HFCs and HCFCs will increase. Currently, the radiative forcing of all halocarbons (CFCs and related species) is approximately 0.28 W/m^2, compared with approximately 2.45 W/m^2 for the direct radiative forcing from the sum of all greenhouse gases.

Aquatic ecosystems

TFA (trifluoroacetic acid) is produced by the atmospheric degradation of several HCFCs and HFCs (substitutes for CFCs). TFA can accumulate in rivers, lakes and oceans and has moderate short-term toxicity. The levels of TFA currently produced by the atmospheric degradation of HCFCs and HFCs are estimated to be orders of magnitude below those of concern and make only a minor contribution to the current burden of TFA (UNEP, 1998).

Tropospheric ozone / air quality

UV-B radiation plays an important role in chemical processes in the troposphere and boundary layer. Model studies suggest that additional UV-B reduces tropospheric ozone in clean environments (low NO_x) and increases it in polluted areas (high NOx). Increased UV-B will increase concentrations of hydroxyl radicals in the troposphere and results in faster removal of pollutants (methane, carbon monoxide, HCFCs, HFCs etc.). These effects will be small and difficult to detect due to many other variable factors.

1.4 Conclusions

The international regulations to protect the ozone layer (Montreal Protocol) are working:
- The production, use (sales) and emissions of Ozone Depleting Substances (ODSs) have decreased significantly, both in the EU and globally.
- The total potential chlorine concentration in the troposphere is decreasing slightly since its maximum around 1994.

However,
- A complete recovery of the ozone layer is not expected before 2050. Over the Antarctic and Arctic extensive depletion of ozone will continue to occur in spring in the coming decades.
- Increased levels of UV radiation will continue. The associated damaging effects, for humans and ecosystems, are likely to persist beyond the depletion of the ozone layer.

Additional future control measures will help to restore further the ozone layer, although by amounts generally smaller than those already expected to be achieved by current regulations. The latest amendments of the Montreal Protocol limit the use of methyl bromide and HCFCs, while the new EU Council Regulation goes even further. There are a few not completely solved issues which can affect the recovery of the ozone layer:
- There is theoretically a relatively large potential for eliminating global halon and CFC emissions by stopping the production and destroying halons and CFCs used in existing equipment.
- Smuggling and illegal production of ozone depleting substances is estimated at 10% of the 1995 global production. These illegal activities will delay the recovery of the ozone layer by several years.
- Globally 173 countries have ratified the original Montreal Protocol of 1987, but only 104 have ratified the Copenhagen Amendments of 1992. The presented projections demonstrate the relevance of the global compliance with the Copenhagen Amendments.
- Developing countries must meet their commitments, beginning in 1999, in order not to jeopardise the reductions already achieved and the expected recovery of the ozone layer.

There are no major spill overs from and to other environmental problems. Potentially relevant are:
- An increase in CO_2 concentrations may delay the start of the recovery of the ozone layer by 10-30 years and cause an increase in ozone depletion in the Artic in spring for several decades.
- The effect of a possible future fleet of supersonic aircraft flying in the stratosphere on the ozone layer could be slightly negative or positive, but should not exceed a few percent.

UV-levels in NW Europe were surprisingly high in some recent years and continued ozone and UV-monitoring should establish the success rate of implementing the policy agreements. Comparing risks related to ozone depletion to other environmental risks requires consideration of the global aspects, the burden for future generations and the definition of risk groups, in terms of sensitivity and behaviour. Furthermore, other adverse UV effects and uncertainties in estimates should be considered.

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2. Benefit Assessment

2.1 Introduction

2.1.1 Public opinion

Euro barometer (1995) ranks 'global pollution' as the third most serious environmental problem, with 40% of respondents placing it in the most serious or second most serious category. This is a slight drop from the second place ranking in 1992. Variance about this ranking is quite wide: there is an eighth ranking in Ireland and a seventh in France, and a second ranking in Luxembourg. Ranked by percentage very worried or quite worried about threats "world wide", ozone layer depletion ranks equal first with tropical forest loss.

2.1.2 Expert opinion

GEP et al. (1997) assesses expert opinion on environmental issues. "Ozone" clearly refers to stratospheric ozone rather than tropospheric ozone but is included within the general category of climate change. Climate change was ranked second as a priority issue after development and population change, with 23.7% of respondents making it the first or second most important issue. However, this relates to all respondents to the questionnaire world wide. The ranking by respondents from Northern and Southern Europe remains the same, but Southern Europeans cite water scarcity and pollution as their first ranked problem. Overall North + South Europe ranking for climate change is 28%, higher than the global average.

2.2 Scenario benefit estimation

Due to the absence of scenarios, this section is devoted to the evaluation of benefits for the existing policy measure, i.e. the full implementation of the Montreal Protocol and its Amendments.

The benefits of this policy are assumed to be equal to the avoided skin cancer damages only. The benefit estimate results are summarised in Table 2.1.

Table 2.1 Summary of benefit estimates: discount rate 4%

Benefit of Baseline scenario over 'No Restrictions' Scenario € million	Confidence
12,000 Annuity: 534	Moderate: Main uncertainty is the figure for incidence of skin cancer. VOSL figure, valid due to age distribution of cancer incidence Understatement because: (i) Consideration given to NW Europe cancers only. (ii) Cases of cataracts are omitted (iii) Impacts to fisheries, agriculture and materials are omitted.

Suitable indicators and valuation estimates required for further research in this area are identified as follows:

- distance to goal of Montreal Protocol Amendments;
- non-cancer morbidity;
- changes in marine ecosystem productivity;
- cost per skin cancer avoided, and
- cost per non-cancer morbidity case avoided.

Methodology valuation of skin cancer

The approach adopted here is to estimate the number of skin cancers under the relevant scenarios, find the avoided skin cancers, value these in monetary terms and express the results in present value terms using 1990 as the base.

However, the scenarios are modified. This is because the TD and baseline scenarios converge. The 'maximum feasible reduction' (TD) is already in place through the London and Copenhagen Amendments to the Montreal Protocol. Thus, the value of avoided skin cancers due to the Montreal Protocol is estimated by using a “Copenhagen scenario” and a 'No restrictions' scenario (i.e. what would have happened without the Montreal Protocol and the Amendments). The time horizon used in this analysis is also changed because the impacts of the policies in place are not readily discernible much before 2050. Accordingly, we take 2050 as benchmarks. Excess skin cancers for EU15 are given in Table 2.2.

Table 2.2 Excess skin cancer rates: 1990-2050. NW Europe[1]

	Skin cancer cases per million per year		
	1990	*2020*	*2050*
Baseline scenario: Copenhagen Amendment	5	50	125
No restrictions	5	75	340

Source: RIVM (1999)

RIVM (1999) estimate excess skin cancers by multiplying the NW-Europe risk of incidence by the EU population. NTUA population projections are used up to 2030. For the years after 2030, the trend of the UN medium projections applied to NTUA 2030 figures is used. The picture is shown in Table 2.2. Growth rates in cancer incidence are estimated to be 7.3% p.a. during 1990-2050 in the unrestricted case and 5.5% p.a. in the Copenhagen control case.

Types of skin cancer incidences

There are two types of skin cancer considered and only some cancers will be fatal. Non-melanoma cancers (NMCs) dominate, they are a function of prolonged exposure and have a low risk of fatality. Whereas melanoma cancers (MC) are less well understood and may result from acute exposures (e.g. sunburn). MCs generally have a high fatality risk.

US EPA (1987) suggests that 99.5% of avoided excess cancers would have been non-melanomas and 0.5% melanomas. They go on to suggest, that of the 0.5% melanomas, 24% result in mortality, whereas only 1% non-melanomas result in mortality. The current study adopts these figures. A sensitivity analysis is conducted using a higher melanoma fraction at 10%, as suggested by Diffey (1992).

Estimated deaths and cancers in NW Europe are given in Table 2.3.

Table 2.3 Avoided deaths and cancers in NW Europe 1990 – 2050

		1990	2020	2050	Growth rates (p.a.)
Baseline scenario: Copenhagen	all cancers	1822	19,478	44,826	5.5%
No restrictions	all cancers	1822	29,218	121,927	7.3%
Avoided cases	all cancers	0	9739	77,101	-
	total deaths	0	109	860	
	total NFCs	0	9630	76241	

Avoided deaths given in Table 2.2 are found using the US EPA (1987) fractions, where MCs account for 0.5% of cancers and NMCs account for 99.5%. For example, let C = cancers.

Deaths from melanoma cancers: = 0.24 x 0.005 C = 0.0012 C
Deaths from non-melanoma cancers: = 0.01 x 0.995 C = 0.00995 C.

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[1] NW Europe = EU15 plus Norway

Total deaths are therefore equal to 0.01115 C and total non-fatal cancers (NFCs) are equal to 0.98885 C

RIVM data indicate that the risks are distributed across NW Europe fairly evenly if there are no restrictions, except for Finland and Sweden where incidence rates are 40-50% below average rates. Ireland also has a reduced incidence rate compared to the EU-wide average.

Valuing Health Impacts

Since skin cancer deaths are relevant for all age groups in the population we adopt the value of a statistical life (VOSL) for the general population. This is € 2.6 million (1990 prices), adjusted to 1997 prices using the deflator 1.274 gives a VOSL of € 3.31 million. However, the fatalities in question occur over the whole period 2000-2050 and thus the VOSL relevant to 1990 will not be relevant to the whole period. Rather, we would expect VOSL to rise as incomes rise. The effect of income growth is captured by introducing a rising relative price of risk aversion of 0.5% per annum.

For non-fatal cancers (NFCs) we require the willingness to pay to avoid the onset of skin cancer. Unfortunately, there are few WTP studies that are relevant. Table 2.4 summarises the available estimates.

Table 2.4 Economic valuation of non-fatal cancers

Study	Country	€ per NFC (1997 prices)	Comment
Rowe et al., 1994	USA	156,000	NFCs generally, based on COI
ExternE	Europe	450,000	Source unknown
Viscusi, 1995	USA	1,640,000	Lymph cancers
Bryant, 1992	Australia	600- 16,000 (a) 7,000-150,000 (b)	Skin cancers, COI Skin cancers, CVM
Aimola, 1998	Italy (Sicily)	50,000 (1) 90,000 (2) 500,000 (3) 730,000 (4)	Lung cancer Uterus cancer Prostate cancer Leukaemia
Murdoch & Thayer, 1990	USA	31,000	Skin cancers

Rowe et al. (1994) adopt values based on the US costs of treating cancers ('cost of illness' or COI) and then multiply this by 1.5 on the basis that, where COI and WTP studies are available, WTP appears to be 1.5 times the COI. This procedure is clearly not satisfactory since there are few studies, which estimate COI and WTP. Moreover, the Rowe et al.,. COI value dates from the mid-1970s. Their valuation is just 6% of the VOSL they use. Adopting that ratio here would give the WTP to avoid a cancer equal to € 156,000. Rowe et al.'s confidence interval gives a 50% probability to this central value, a 33% probability to a value one half of this, i.e. € 78,000 and 17% probability to a high value of twice the central value, i.e. € 312,000. But these estimates relate to non-fatal cancers generally, and not to skin cancers.

ExternE (personal communication) now uses a figure of € 450,000 for a non fatal cancer, i.e. some 17% of the VOSL, but it is unclear how this sum has been derived. Nor does it appear to be relevant to skin cancers, the vast majority of which are fairly easily operable.

Viscusi (1995) conducts a computer experiment in which respondents are able to trade off ill-health against risk of death in an automobile accident. His results (for the USA) suggest that a curable lymph cancer would be valued at some 63% of the VOSL, which, in this case, would give a value of € 1.64 million, about four times the suggested ExternE figure. Once again, however, lymph cancer and skin cancers are not very comparable and use of the Viscusi figure would result in too high a set of estimates. Aimola (1998) uses the contingent valuation method to elicit cancer risk valuations from a small sample of the population in Sicily.

The cancers in question were prostate, uterus, leukaemia and lung cancers. All are more dramatic than non-melanoma skin cancers and carry significantly higher risks of death with the possible exception of prostate cancer. Once again, then, the estimates are likely to overstate the relevant WTP to avoid a non-fatal skin cancer.

The only WTP study directly relevant to skin cancer is by Murdoch and Thayer (1990). They estimate WTP using a “defensive expenditures” approach, i.e. by looking at changes in expenditure on sun protection products. They find that the total damages from anticipated increases in non-melanoma cancers are about one half of the 'cost of illness' measure used by the US Environmental Protection Agency at the time. In undiscounted form, their estimates can be shown to result in a value per case of some \$30,000[2]. However, most of the cases occur well into the future. In 1997 terms this would be \$37,000 or some € 31,000. We adopt a round figure of € 30,000 as being applicable to the year 2000. In the absence of other information we apply this figure to non-fatal melanomas as well, which is clearly a conservative assumption.

Monetised Avoided Cancers

A monetary estimate of the avoided skin cancer cases due to the Montreal Protocol and its Amendments is found by comparing a “No restrictions” scenario to the “Copenhagen” scenario. The following steps are made in order to estimate the present value of the health damage avoided.

Step1: Adjust VOSL and WTP values for years greater than 1990 to allow for rising relative price of risk aversion, where 0.5% is the annual percentage increase in the relative price of risk avoidance.

VOSL: in any year t (>1990) $= 3.31$ million x $(1.005)^t$ [t=0 in 1990]

Since the WTP value of 30,000 is for the year 2000, this value must be decreased for the years 1990-1999, but increased thereafter as follows:

WTP: in any year t (>2000) $= 30{,}000$ x $(1.005)^t$ [t=0 in 2000]

in years t (<2000)= 30,000 divided by $(1.005)^{10-t}$ [t=0 in 1990]

Step 2: Estimate number of deaths and NFCs in all years for both scenarios

No restrictions scenario: 7.3% is the annual increase in the number of cancers (whether fatal or not). Thus, deaths in any year t (>1990) are 20 x $(1.073)^t$, where 20 is the number of deaths in 1990 (i.e.1821 x 0.01115). NFCs in any year t (> 1990) are 1801 x $(1.073)^t$, where 1801 are NFCs in 1990 (i.e. 1821 x 0.98885).

Copenhagen scenario: 5.4% is the annual increase in deaths and NFCs in any year, 1990-2050. Deaths and NFCs are found following the same methodology given above.

Step 3: Calculate avoided cancers in all years

Avoided cancers in all years are found by subtracting the “Copenhagen” scenario from the “No restrictions” scenario.

Step 4: Monetise avoided cancers

Multiply the deaths and NFCs in all years by the corresponding VOSL and WTP respectively.

Step 5: Present value of monetised avoided cancers

The present value of the monetised avoided cancers, base year 1990 is estimated using a 4% discount rate. The result is given in Table 2.5. Another means of presenting the results is in terms of annuities, i.e. the annual sums which, when discounted, would result in the present values shown in Table 2.5. Annuities are also reported in Table 2.5.

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[2] Estimated by taking their estimated 2.96 million extra cases and an undiscounted defensive expenditure of \$87.7 billion.

Table 2.5 Present value and annuitised value of damage to NW Europe, 1990 base

Discount rate	Deaths	NFCs	Total
Present Value 4%	6.85×10^9	5.23×10^9	12.1×10^9
Annuitised Value 4%	-	-	0.53×10^9

Other Health Impacts

Estimates of the impact of UV-B on cataracts have been made, but are highly uncertain. It is suggested that each 1% decrease in ozone is associated with a 0.5% increase in cataracts (Longstreth et al., 1995).

Changes in immune function are also suspected but no quantitative relationship appears to exist. The effects on increasing infectious disease incidence "could be significant" (Longstreth et al., 1995).

Sensitivity analysis

Assumptions have been made throughout this study. Some may have a significant effect on the results, while others will only make a minor difference. This section examines what happens to the benefit estimates if the assumptions are changed.

Column 1 in Table 2.6 presents the current assumptions used in the analysis of stratospheric ozone depletion and the results achieved with these assumptions are given in column 2. Changes in these assumptions are given in column 3 and the quantitative effects are given in column 4.

Table2.6 Key assumptions and estimated results of changing these assumptions.

Current Assumption	Current estimate € billion	Revised assumption	Revised estimate € billion
Excess skin cancers in 2050, EU15. Baseline: 125 No restrictions: 340	12.1	Baseline: 40-250 No restrictions: 120-900	low: 6.0 high: 30.0
Risk of MC and NMC US EPA (1987) 0.5% melanoma cancer (with 24% mortality)	12.1	Diffey (1992) 10% melanoma cancer (with 24% mortality)	25.4
Population forecast: UN medium trend	12.1	NTUA trend	20.1
4% discount rate	12.1	2% discount rate 6% discount rate	29.9 5.2
4% discount rate: annuity	0.534	2% discount rate: annuity 6% discount rate: annuity	0.861 0.324

Note that all values are present values based on 4% discount rate unless otherwise indicated.

Dose response functions for ozone layer depletion

Non-melanoma skin cancers are either basal cell carcinomas (BCC) or squamous cell carcinomas (SCC). BCC represents around 80% of non-melanoma cancers but most non-melanoma deaths are due to SCC. Estimates of the 'amplification factor', i.e. the increase in skin cancers for each 1% decrease in ozone, are 3.0±0.8% for SCC and 1.7±0.5% for BCC, or 2.0±0.5% when combined. Thus a 10% decrease in average ozone concentration would be associated with a $10 \times 2.0 = 20\%$ increase in non-melanoma cancers. Taking 1.2 million new cases pa, this amounts to 250,000 new cases every year for a 10% depletion of ozone (Longstreth et al., 1995).

Melanomas. Dose response functions are far less certain for melanoma cancers.

References

References in the sections on benefit and policy assessment have been brought together in the Technical Report on Benefit Assessment Methodology.

3. Policy assessment

3.1 Policy Package

3.1.1 Key issues

The European Union has met the targets so far required under the Montreal Protocol. Phase out of CFCs was achieved one year ahead of the Copenhagen deadline (1994 as opposed to 1995); the EU has adopted a phase-out deadline of 2015 for HCFCs rather than the 2030 date required under the Copenhagen Amendment; and the Vienna Amendment target for methyl bromide of a 25% reduction was expected to be met at the beginning of 1999 as opposed to 2001. In these respects, then, the EU "over-complies" with the Montreal Protocol. However, at least the first one of the following recommended actions is worth considering further:

- Ensure acceleration of the Article 5 countries
- Reduce illegal imports of ODS
- Continue efforts for over compliance of Montreal Protocol.

3.1.2 Recommended policy initiatives

Accelerated compliance by Article 5 countries.

Since the EU is typically over-complying with the Montreal Protocol and its Amendments, probably the major task ahead is bringing developing countries further "on board" and accelerating their phase out of ODS. The current procedure for dealing with the developing countries is via the Multilateral Fund, which meets the incremental costs of ODS substitution on a project-by-project basis. Desai and Mathur (1996) suggest that the project approach is too slow and costly for really accelerated progress. They recommend establishing competitive bid auctions for the Fund's grants, that developing countries set firm targets for ODS and that they also consider introducing market-based instruments to comply with the Protocol.

Based on ARC (1997), Table 3.1 gives the average cost per tonne of CFCs, total cost and quantity of CFCs reduced for further compliance with the Montreal Protocol by Article 5 countries.

Table 3.1 Average cost and total cost for CFC and Halon emissions reduction

Present value Discount rate: 5%	Average cost € per tonne (1997 prices): A	Total cost € billion (1997 prices): B	Quantity (million tonnes) C = B/A
CFCs			
Aerosols	420	1.0	2.40
Foams	4116	2.6	0.63
Refrigeration	5578	40.0	7.18
Solvents	2369	1.8	0.78
Sterilants	1200	0.08	0.7
Halons	*3100**	0.25	0.081
HCFCs	2428	6.0	2.52
Methyl Chloroform	1756	6.9	3.92
Carbon Tetrachloride	1546	1.3	0.81
Methyl Bromide	1848	0.9	0.50
Total		*61.0*	*18.89×10^6*

* based on marginal cost estimate. The exchange rate is assumed to be $1=€ 0.84.

ARC (1997) suggest that the accelerated compliance of LDCs, should result in roughly a 19 million tonne reduction in ODS. The weighted average cost per tonne of ODP can be found by dividing the total cost by total quantity, i.e. €$_{97}$ 3230. Given that these reduction measures should be financed through the Multilateral Fund and that in 1991-98, EU-15 contributions amounted to some 39% of world contributions to the Fund, the EU's share of the costs would be € 24 billion.

The benefit / cost ratio of the accelerated compliance of LDCs, is large at 3.3:1. For details *see below*.

Reduce illegal imports of ozone depleting substances (ODS)
Illegal imports of ODS, appear to be more a matter of concern in the US than in the EU. However, the problem of illegal imports can be resolved by means of detection and penalties if offence do occur. The very high level of penalties (fines plus imprisonment) in the USA suggests a strong policy. The main source of the illegal trade appears to be China (EIA 1997, 1998, 1999).

Continue efforts for over compliance of Montreal Protocol
The EU should continue to over-comply with the Montreal Protocol at a time when the 'slack' in the original adjustments is being reduced. There appears to be no need for additional EU policies to address EU compliance at this stage but the need may re-emerge early in the 21st Century. Brack (1996) reports that some of the EU compliance has been achieved by reducing stockpiles of CFCs. Once these stockpiles are reduced, further reductions must come from reductions in production. If so, the US experience with a CFC tax is encouraging as is the tradable allowance scheme, although such schemes may take time to introduce. Other suitable measures include refund schemes with taxes on other refrigerants / fire extinguishers to help recover and establish banks of CFCs / halons.

ARC (1997) show that the global net present value of benefits due to the Montreal Protocol are € 2020 billion and the B/C ratio is estimated to be 11. For details see below.

3.1.3 B/C ratios for policy initiatives

Where possible, we estimate the benefits and costs for the recommended policy initiatives, given above.

Accelerated LDC compliance with Montreal Protocol
Based on the information provided by ARC (1997) given in Table 3.1, we estimate the benefit cost ratio of bringing Article 5 countries on board with accelerated compliance to the Montreal Protocol. The B / C ratio for ODS control by Article 5 countries is large.

Costs
The present value of costs (discount rate: 5%) to the EU15 for bringing Article 5 counties on board with accelerated compliance is given by: EU15 contributions to Multilateral Fund (EU share of world costs) multiplied by the weighted average cost per tonne of ODP multiplied by the quantity reduced. I.e. (0.39 x € 3230 x 18.9 x 10^6 = € 23.8 x 10^9.

Benefits
The present value of benefits of accelerated compliance by Article 5 countries, allowing for EU's share of responsibility is given by: world benefit per tonne of ODS depletion multiplied by the EU share of world costs multiplied by the quantity of ODS reduced: I.e. (€ 10,765 x 0.39 x 18.9 x 10^6 = € 79.4 x 10^9).

World benefit per tonne of ODS depletion
The world benefit per tonne of ODS depletion is the sum of total annual health benefits and non-health benefits from accelerated compliance of Article 5 countries divided by the annual ODP weighted tonnage reduction of ODSs. The world benefit per tonne of ODS is estimated based on the results of ARC (1997), by the following procedure:

Health benefits from accelerated compliance of Article 5 countries
ARC (1997) present the health benefits of the Montreal Protocol in terms of numbers of avoided health cases avoided. These are reported in Table 3.2.

Table 3.2 Ill health cases avoided due to Montreal Protocol

Health effect	Total number of cases avoided thousand	No of cases avoided per year thousand
Non-melanoma cancer	19,100	262
Melanoma cancer	1,500	21
Fatal cancers	330	4.5
Cataracts	129,100	1770

The total world-wide ODP weighted[3] reduction in emissions of ozone depleting substances is reported to be some 309.1 million tonnes over the period 1986 - 2060, or approximately 4.18 million tonnes per annum. A monetary valuation of the avoided health cases is found by multiplying the number of cases avoided by the relevant WTP to avoid that health case. The unit values for damages to health are assumed to be:

Table 3.3 WTP to avoid fatal and non-fatal cancers and cataracts

Health effect	Unit damage value € (1997)
Non-melanomas	30,000
Melanomas	30,000
Fatal cancers	3,310,000
Cataracts	722

Multiplying the number of cases per year by the unit values for damages to health gives the total damage value of approximately € 24.6 billion.

Non-health benefits from accelerated compliance of Article 5 countries

ARC Research Consultants (1997) also estimate the non-health benefits of emissions reduction to be approximately € 400 billion in present value terms (discount rate is 5%). This present value can be re-expressed as an annuity using the formula:

$A = PV / a$

Where $a = [\,1 - (1+r)^{-t}] / r$. For r= 5% and t=73, a = 19.43. Hence, annuitised non-health benefits of the Montreal Protocol are approximately: € 20.5 billion.

Total health + non-health benefits from accelerated compliance by Article 5 countries

From the calculations above, total health and non-health benefits of the Montreal Protocol are estimated to be approximately: € 24.6 billion plus € 20.5 billion = € 45 billion. Dividing this by the annual ODP weighted tonnage reduction of 4.18 million tonnes, suggests that unit damage values are approximately: € 10,765 per tonne of CFC11 or € 10.7 per kilogram.

Benefit / Cost ratio

The comparison of the costs and benefits (present value) of accelerated compliance by Article 5 countries shows that:

PV (costs) to EU15:	€ 24 billion
PV (benefits) to world:	€ 79 billion
B/C ratio:	3.3

Note: the benefit estimates include avoided damages to health (i.e. avoided fatal and non-fatal skin cancers) and avoided damages to agriculture, fisheries and materials.

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[3] Weights are relative to a tonne of CFC11.

Continued over compliance of Montreal Protocol

Available data permits the estimation of a B/C ratio for the Montreal Protocol, the results confirm that the existing policy is economically efficient.

Applied Research Consultants, ARC (1997) estimate the global costs and benefits of the Montreal Protocol. ARC (1997) give monetised global benefits for reduced economic damage to fisheries, agriculture and materials. However, the health benefits are not given a monetary value. Thus, EFTEC estimates the monetary value of health benefits by taking the ARC estimates for numbers of reduced skin cancers (fatal and non-fatal) multiplied by the relevant VOSL (€ 3.31 million, (1997 price), WTP to avoid a non-fatal skin cancer (€ 30,000) or WTP to avoid cataracts (€ 722). Table 3.4 sets out the global benefits, the costs and net global costs. The B/C ratio for the Montreal Protocol is estimated at 11, which suggests that the existing measure passes the benefit cost test and is therefore economically efficient. Note that all monetary values are given in present value terms, the base case discount rate is 5%.

Table 3.4 Global benefits and costs (present value) due to the Montreal Protocol

Global benefits			
	Reduced cases of / damage to:	Cases thousand	$€_{97}$ billion
Health:	non-melanoma skin cancers	19,100	573
	Melanoma skin cancers	1,500	45
	skin cancer fatalities	335	1109
	Cataracts	129,100	93
Other	fisheries, agriculture, materials	-	400
TOTAL			2220
Global costs			
	costs of eliminating the use of ODSs		200
Global net present value of benefits			2020
B/C ratio for Montreal Protocol			**11**

Source: EFTEC adaption of ARC Applied Research Consultants (1997) for Environment Canada.

3.2 Policy assessment

This section brings together the information presented earlier to form an assessment of the suggested policies according to the policy selection criteria. Although there is no further internal policy recommendation due to over-compliance with Montreal Protocol and Amendments, we suggest that there is a need to accelerate compliance with the Montreal Protocol by Article 5 countries.

3.2.1 Causal criterion

Table 3.5 presents the driving forces behind the stratospheric ozone depletion problem, the underlying causes are also identified.

Table 3.5 Driving forces and underlying causes of stratospheric ozone depletion

		Underlying cause		
		MF	IntF	ImpF
D1	Industrial production of ODSs			
D2	Use of ODSs in refrigerators, foam blowing, aerosols and solvents			X
D3	Slow development and adoption of substitutes for HCFC			X

X = main underlying cause, MF = market failure, IntF = intervention failure, ImpF = implementation failure. Note that for D1 and D2, the main causes are due to growth in real income.

Within EU underlying causes are addressed, as shown by over-compliance. Risks relate to the failure of LDCs to make the necessary substitutions, which in turn depend on compensation for incremental costs under the Multilateral Fund.

3.2.2 Efficiency criterion

In general, the benefit-cost ratios for the control of ozone depleting substances, are large.

Montreal Protocol
Global costs and benefits are estimated by ARC (1997), see Table 3.4. The B/C ratio for the Montreal Protocol is estimated at 11, which suggests that the existing measure passes the benefit cost test and is therefore economically efficient.

NW Europe benefits of the Montreal Protocol: The benefits to NW Europe in terms of avoided fatal and non-fatal skin cancers, due to the Montreal Protocol, between 1990 and 2050 are estimated, as a present value: € 12 billion (where; the discount rate is 4% and 1990 is the base year). The benefit estimates are an underestimate because they consider NW Europe fatal and non-fatal cancers only, cases of cataracts are omitted. The impacts to fisheries, agriculture and materials are also omitted.

Uncertainties are expected to be great. The main uncertainty is the figure for skin cancer incidence, whilst the use of VOSL is valid due to the age distribution of cancer incidence (i.e. all ages are affected).

At the time of writing, EU15 costs for the Montreal Protocol were not available.

A comparison of the benefits to the world, due to EU 15 action, with the costs to the EU15, as a share of world costs, shows that further control of ODSs, through Article 5 countries accelerated compliance, is justified in benefit cost terms. I.e. the B/C ratio is greater than unity, at 3.3. See Table 3.6.

Table 3.6 Benefits, costs and B/C ratios for the accelerated compliance of Article 5 countries to the Montreal Protocol

Present value: Discount rate = 5%	€ billion
Costs to EU15 (as share of world costs)	24
Benefits to world (due to EU15 action)	79
B/C ratio	*3.3*

Benefits include avoided damages to health, agriculture, fisheries and materials (for details see section *2*: Benefit assessment).

Cost effectiveness
Article 5 countries will not comply without compensation for incremental costs of substituting ODSs, hence this is the only realistic option.

Public opinion
Euro barometer (1995) shows that 69% of respondents believe that decisions of the environment should be taken at the Community level, rather than at national level. It also shows that most Europeans are prepared to change their consumption behaviour as a step to slow down or perhaps even stop the deterioration in the environment as a whole. Although public opinion regarding the issue of stratospheric ozone depletion control is not known with certainty, the results of the Euro barometer (1995) suggest that the European population may be in favour of further contributions to the Multilateral fund in order to encourage the accelerated compliance of Article 5 countries to the Montreal Protocol.

3.2.3 Administrative complexity

Administrative complexity is low due to the existence of specially designed institutions, i.e. the Multilateral Fund. This suggests the success of full implementation is high. The sole issue is the “political will” of contributing countries.

3.2.4 Equity criterion

The accelerated compliance of Article 5 countries with the Montreal Protocol, meets the equity criterion since LDCs do not pay for the incremental costs and hence are no worse off than they would be without action. Also they get improved health and ecosystem benefits, and probable transfer of technology benefits.

3.2.5 Jurisdictional criterion

Stratospheric ozone depletion is a global issue and hence EU acting together provides the most efficient solution. Action should therefore continue to be centralised. Additional gains from CFC trading.

Macroeconomic effect

Details of all macroeconomic effects are presented in Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface .

All references in the sections on benefit and policy assessment have been brought together in the Technical Report on Benefit Assessment Methodology.