OZONE LAYER PROTECTION

COUNTRY INCREMENTAL COSTS

Edited by
Kenneth King
and
Mohan Munasinghe

Global Environment Facility (GEF)
and
The World Bank
Ozone Layer Protection
Country Incremental Costs

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funds to developing countries for projects and activities that aim to protect the global
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Council—its governing body. The GEF’s implementing agencies are the United Nations
Development Programme (UNDP), the United Nations Environment Programme (UNEP),
and the World Bank. In addition the World Bank is the Trustee of the GEF Trust Fund.
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FOREWORD

The World Bank's Environment Department promotes the development of practical methodologies for environmental costing and valuation. It does so in order to assist operational divisions of the Bank and other concerned organizations in applying these techniques. One of the methodologies pioneered and developed in the Bank is the calculation of the incremental costs of projects eligible for financing under the Multilateral Fund of the Montreal Protocol on Substances that Deplete the Ozone Layer. The Bank was motivated to establish this methodology because it is an implementing agency of the Multilateral Fund of the Montreal Protocol and has in fact used that methodology as the basis for its operations. Since then, we have broadened this methodological development effort in two ways: by examining the incremental costs of actions directed at other global environmental problems, and by examining the issues in calculating incremental costs at sector and country levels.

The Global Environment Facility (GEF) provides finances to eligible countries to phase out ozone-depleting substances, to reduce emissions of greenhouse gases, to protect biodiversity, and to reduce the pollution of international waters. (In fact, GEF, which has recently been restructured and replenished, is the interim operating entity of the financial mechanisms for the Framework Convention on Climate Change and the Convention on Biological Diversity.) These activities impose added burdens on countries already struggling to mobilize financial resources for national development priorities. That is, they impose "incremental costs." For this reason, GEF is keen to evaluate and extend the application of the pragmatic methodologies developed in the Bank for measuring such costs. In addition, GEF has its own program of policy studies—the Program for Measuring Incremental Costs for the Environment (PRINCE)—which will further develop and extend the Bank's initial work into the other focal areas of its operations.

GEF collaborates with several institutions in the framework of PRINCE. Many of these are regional centers of excellence in developing countries which undertake policy-related studies and act as focal points in their regions for the dissemination of training material on incremental costs. Other collaborators include various organizations involved in policy studies or research.

The papers in this collection cover the application of incremental cost methodologies to the issue of phasing out ozone-depleting substances in developing countries. They were first presented at the Workshop on Country-Level Incremental Costs of Phasing Out Ozone-Depleting Substances, jointly hosted by the Environment Department and the GEF in Washington, D.C., on November 30, 1993. The department had commissioned the studies from the firms that had applied the methodology in the course of preparing country
programs for the Multilateral Fund. The studies sought to test how well the methodology worked—not to make recommendations for operations in the countries in question, which is the objective of the country programs themselves. The department and the GEF jointly reviewed the studies and drew conclusions of a generic nature that will help the preparation of future country costing studies in ozone as well as other focal areas.

We are particularly gratified by the enthusiastic response of the organizations that have contributed their time and effort to this evaluation and by the successful collaboration between the World Bank and the GEF in carrying out this work.

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Chairman and Chief Executive Officer
Global Environment Facility

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Finally, we are most grateful to Rebecca Kary and Jay Dougherty of Alpha-Omega Services, Inc., and Stephanie Gerard for assistance in the editing and production stage, as well as to Judith Smith of Soleil Associates, who designed the cover for the series.
# Abbreviations and Acronyms

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>CBD</td>
<td>Convention on Biological Diversity</td>
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<tr>
<td>CEE</td>
<td>Central and Eastern Europe</td>
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<tr>
<td>CFC</td>
<td>chlorofluorocarbons</td>
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<td>CFCCOST</td>
<td>CFC Cost Model (developed by COWIconsult)</td>
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<tr>
<td>CIS</td>
<td>Commonwealth of Independent States (former U.S.S.R.)</td>
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<tr>
<td>CMEA</td>
<td>Council for Mutual Economic Assistance, also known as COMECON, and comprising Cuba, Mongolia, and Vietnam</td>
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<tr>
<td>COSCOM</td>
<td>Country Study Cost Model (developed by ICF Incorporated)</td>
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<td>CSFR</td>
<td>Czech and Slovak Federal Republic</td>
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<tr>
<td>CTC</td>
<td>carbon tetrachloride</td>
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<td>DIW</td>
<td>Department of Industrial Works (Thailand)</td>
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<tr>
<td>FCCC</td>
<td>Framework Convention on Climate Change</td>
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<td>FOB</td>
<td>free-on-board</td>
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<tr>
<td>GEF</td>
<td>Global Environment Facility</td>
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<tr>
<td>GHG</td>
<td>greenhouse gas</td>
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<td>GNP</td>
<td>gross national product</td>
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<tr>
<td>HCFC</td>
<td>hydrochlorofluorocarbon</td>
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<tr>
<td>HF</td>
<td>hydrofluoric acid</td>
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<tr>
<td>HFC</td>
<td>hydrofluorocarbon</td>
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<tr>
<td>IFCT</td>
<td>Industrial Finance Corporation of Thailand</td>
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<tr>
<td>LPG</td>
<td>liquefied petroleum gas</td>
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<tr>
<td>OLADE</td>
<td>Latin American Energy Organization</td>
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<tr>
<td>MAC</td>
<td>mobile air conditioner</td>
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<tr>
<td>MCF</td>
<td>methyl chloroform (1,1,1—trichloroethane)</td>
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<td>NOP</td>
<td>National Ozone Policy</td>
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<td>NPV</td>
<td>net present value</td>
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<tr>
<td>O&amp;M</td>
<td>operations and maintenance</td>
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<td>ODP</td>
<td>ozone-depleting potential</td>
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<td>ODS</td>
<td>ozone-depleting substance</td>
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<td>OORG</td>
<td>Ozone Operations Resources Group</td>
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<tr>
<td>PRINCE</td>
<td>Program for Measuring Incremental Costs for the Environment</td>
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<tr>
<td>PVC</td>
<td>polyvinylchloride</td>
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<td>TDRI</td>
<td>Thailand Development Research Institute</td>
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<tr>
<td>UAC</td>
<td>unit abatement cost</td>
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<td>UC</td>
<td>unconstrained demand</td>
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<td>UCCEE</td>
<td>UNEP Collaborating Centre for Energy and the Environment</td>
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<td>United Nations Environment Programme</td>
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INTRODUCTION

The Vienna Convention for the Protection of the Ozone Layer 1985 was the starting point for global cooperation to protect the stratospheric ozone layer. It was followed by the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987, the London Amendment in 1990, and the Copenhagen Amendment in 1992. However, complying with the Montreal Protocol and its Amendments does constrain industrial development and therefore adds to costs. These costs, the incremental costs, would be incurred by any country—developed, developing, or in transition—when it made special efforts that it would not otherwise have made, in order to comply.

At the time of the London Amendment it was recognized that the incremental costs incurred by developing countries would place a heavy burden on their development efforts. Therefore, the Multilateral Fund was established to channel resources from developed to developing countries to meet the agreed incremental costs of phasing out ozone-depleting substances (ODS). Likewise the Global Environment Facility (GEF), which also finances projects that phase out ODS, meets each incremental cost.

Both the Multilateral Fund and the GEF require a strategic framework for the activities they finance to demonstrate that overall phaseout of ODS will be accomplished. This framework is the Country Program, which sets out a national strategy and a program of proposed activities to meet the phaseout schedules set out in the Montreal Protocol. The overall cost of the phaseout is the country incremental cost of implementing the entire Country Program. Knowledge of the country incremental costs will help to prioritize and program activities and to estimate the aggregate resources required for a complete phaseout worldwide. Demonstrating the feasibility of this approach would also suggest useful approaches to other global environmental issues such as reducing greenhouse gas emissions.

The framework presented in Chapter 1 by King and Munasinghe was developed to estimate the country-level incremental cost. This framework has been applied in several developing countries and countries in transition. The purpose of the Workshop on Country-Level Incremental Costs of Phasing Out Ozone-Depleting Substances was to gather key analysts engaged in this work to review the framework and its practical application. They present the results of their work in India, Turkey, Jordan, and Zimbabwe (Chapter 2: Mason); Egypt (Chapter 3: Catanach); Thailand (Chapter 4: Widge, Radka, and Dillon); and Tunisia and Czechoslovakia (Chapter 5: Bendtsen).
These country studies all succeeded in applying the broad framework. Their modeling approaches differed, of course—simpler models were used when not all the stages of production, application, and consumption of ODS were represented in the country industrial structure. Full optimization was used in only one case, since in others the phaseout problem is highly constrained. A number of specific modeling issues and suggestions for further developing the data and approach also emerged from these studies and are summarized in Chapter 1. While it was not always possible to calculate the absolute level of country incremental cost with confidence, the relative costs of alternative program schedules were quite stable. In most countries the “accelerated schedule” is either the most cost-effective one or close enough to it, so that adopting it would be the preferred risk-management strategy.

As there are many similarities between ODS phaseout and international action on other global environmental issues (like greenhouse warming), many concepts and modeling approaches developed for the ozone depletion issue will prove to be useful in the analysis of those other issues. However, one of the most important lessons follows from the observation that incremental cost calculations for ODS phaseout appear to be highly constrained. This implies that there are few degrees of freedom and few opportunities to explore cost-effective solutions. To avoid this situation in dealing with other issues, it would be necessary to construct treaty targets, schedules, and eligibility requirements more broadly.

Kenneth King
Mohan Munasinghe
Country Incremental Costs of Phasing Out Ozone-Depleting Substances

Kenneth King and Mohan Munasinghe

Incremental Costs

UNDERLYING ALL RATIONAL DECISIONMAKING is the concept of the effect of each possible action. The situation expected to result from a course of action (the with situation) is compared to what might have been expected otherwise, in the absence of that action (the without situation). Explicitly or implicitly, the extra cost of the contemplated action is weighed against the added benefit that is expected.
The "extra" (or incremental) cost is the difference between the costs of the with (or alternative case) and the without (or baseline case). By comparing incremental costs and incremental benefits, the best decision may be made to proceed. In economic cost-benefit analysis, this decision rule is expressed by requiring that incremental benefits must exceed incremental costs for the action to be justified.

Many actions that help protect the global environment incur incremental costs. For example, the choice of more expensive (but non-ozone-depleting) technologies and chemicals to provide a given level of refrigeration yields a global environmental benefit in the form of protection for the stratospheric ozone layer. This global benefit has not been valued monetarily but has been judged implicitly to exceed the costs of phasing out ozone-depleting substances (ODS). Incremental costs are being incurred to protect global biodiversity, reduce the risk of climate change, and prevent the pollution of international waters.

The benefits of protecting the global or regional environment accrue to many nations, rather than only to the country that incurs the cost of the action. Although the action may be justified economically from the viewpoint of the entire global community, it may impose what Richard Benedick terms an "added burden" financially on a given country. However, by allocating at least this incremental cost to the international community as a whole, the country undertaking the action will be left no worse off financially. Cost sharing is particularly important to developing countries because they are unable to bear the financial burden implicit in protecting the environment. It was in light of this fact, and to make necessary resource transfers, that financial mechanisms such as the Multilateral Fund of the Montreal Protocol and the Global Environment Facility were set up.

Overall, we would like to minimize global incremental costs—that is, to achieve a given level of ozone-depleting substances (ODS) phaseout at the lowest cost to the world community. To achieve this in practice, disaggregate incremental costs may be considered at different levels: project, sector, and country. It is generally least costly to take action at the highest level, which is usually the country level. Alternately, in many cases, it is not even feasible to consider with or without actions at the project level because of the inherent linkages between projects and sectoral activities. Actions to phase out ODS production cannot be considered independently of actions to reduce dependency on ODS in various applications, because action to do one will impose costs on the other unless the two are dealt with simultaneously. Likewise, in the power sector, it is usually not possible to express a decision in the form of a choice between one individual project (e.g., a windmill) and another (e.g., a coal-fired power station). Rather, one needs to compare the respective integrated long-range power capacity expansion plans, of which each project forms a part.

Country-Level Incremental Costs

In this report we are concerned with calculating the country-level incremental costs of actions within developing countries to protect the global environment. Specifically, we are concerned with the method of calculation, the robustness of the calculation, and the usefulness of the results for determining least incremental cost strategies, sequencing investments, and measuring the "added burden." Country studies have been undertaken by many groups, such as the World Bank, the United Nations Environment Programme, and the United Nations Development Programme (ODS phaseout); the United Nations Environment Programme (biodiversity); and by the United Nations Development Programme
Collaborating Center for Energy and the Environment (UCCEE) and others on reducing the emissions of greenhouse gases. Although we do not address the specific requirements or procedures set out for the country studies or country programs required by the various global environmental conventions—the Montreal Protocol, the Framework Convention on Climate Change (FCCC), and the Convention on Biological Diversity (CBD)—the questions above are implicit in all such country studies.

**Incremental Costs of Phasing Out Ozone-Depleting Substances**

In an earlier paper (King and Munasinghe 1991), we established a framework for the ozone issue and described a way to calculate the incremental cost to both countries and firms of actions to phase out ozone-depleting substances. That paper was the basis for discussions with various consulting firms who subsequently undertook country-specific calculations in selected developing countries.

**Some Important Distinctions**

We made several distinctions (King and Munasinghe, Section II) in that paper in order to clarify what was meant by incremental costs in different settings. We reviewed these distinctions in the light of subsequent work and found that they continued to be useful—in fact, they can be used in other global environmental focal areas as well. Below, we restate the principal observations.

First, we distinguish between imposed costs and costs voluntarily accepted in order to mitigate the global environmental problem. Although imposed costs could also be examined in an incremental cost framework, this is not our specific intention here. The incremental costs which we examined are those that are incurred voluntarily by a country in order to prevent or at least mitigate the problem by removing its causes. That is, we are concerned with costs incurred through phasing out the ODSs—not the costs that are imposed anyway by adaptation to or damage resulting from ozone depletion, by international trade restrictions on nonsignatory or noncomplying countries, or by increases in the economic cost of producing ODS and ODS technologies for a shrinking international market.

A similar distinction may be drawn between the imposed costs of climate change (adaptation costs and residual damage, measured against a baseline of no climate change) and the costs of actions that reduce the risk of climate change (costs of actions that reduce net emissions of greenhouse gases, measured against a baseline of climate change but without any specifically global consideration being taken into account).

Although we distinguish the incremental costs of mitigation from those of adaptation, we do not de-emphasize the fact that the global environmental benefits of mitigation are shared, nor do we imply that imposed costs should not be compensated in some way. Our intention is rather to draw attention to the fact that analysis of these two types of costs must proceed in different ways. In this report we have chosen to deal with mitigation costs because the operational need for doing so is more urgent—given that mitigation is an ex ante (or more immediate) phenomenon while adaptation is ex post and will occur in the future.

Second, we distinguish the economic issue of the incremental cost from the financial policy issue of sharing that incremental cost. In this report we are concerned with the economic issues which can be considered independently of financial questions: the incremental cost itself is independent of who will finance it. Indeed, many countries not applying or eligible for financial assistance will nevertheless want to know the incremental economic costs of their actions.
The economic issue is rooted in the with-without dichotomy that underlies all rational decisionmaking, not only in the global environmental arena, or in the economic arena. To reach a decision, the incremental cost of the action (the difference between the cost with and without the action) needs to be compared with the incremental benefit, even if only implicitly, and whether or not either has been monetized.

This distinction between economic and financial issues is particularly important in the context of global environmental problems because the two issues have often been confused. The economic issue is a technical one. The incremental cost defines what a country would have to give up (trade off, sacrifice) in order to meet its commitments under a global environmental convention (to help protect the global environment). While the solution to this equation is not always immediately evident, finding the solution remains an important factor in decisionmaking.

Although the financial policy question may have some technical aspects (the likely response to incentives, for example), it will also be influenced by nontechnical considerations. The Global Environment Facility governing committee and the conferences of the global environment convention parties will have to consider the nontechnical considerations when they deliberate on the meaning of "agreed full incremental cost" or "agreed incremental cost" as the basis for international grant financing.

Third, we distinguish between financial costs and economic costs. Financial costs are relevant to enterprises and to the design of incentives for managing a phaseout. Country incremental costs are economic. The Multilateral Fund, which reimburses project incremental costs at the enterprise level, considers only the economic costs of projects to be eligible and specifically excludes transfer payments. (Implicitly, it is assumed that governments would waive the incremental taxes and duties, that lost subsidies would not be compensated, and that incentive structures would be the responsibility of the governments.)

Fourth, we distinguish project-level, sector-level, and country-level incremental costs. The project-level incremental cost arises from that part of the capital investment and operations and maintenance expenditures on the substitute plant that is incremental to the originally justified investment and operations and maintenance expenditures and from the economic loss associated with accelerated replacement of capital stock. Such project-level incremental costs are borne by economic agents, usually firms, parastatals, or government agencies. The economic incremental cost of an ODS phaseout can be calculated, usually by adjusting financial cost data to remove transfer payments and the effects of distortions. Typical adjustments will be for taxes and duties, subsidies, and excess profits due to structural imperfections.

The sector-level incremental cost arises when both production and user sectors exist, and it is necessary to consider sectorally balanced investment programs. Here a phaseout in one sector that is not matched in the other sector could increase overall phaseout costs. In such a case, the investments in production and user industries are not independent. Sector-level incremental costs were not explicitly considered in our original taxonomy, mainly because ODS phaseout is largely a cumulation of projects by individual enterprises and sector costs may not differ substantially from the sum of project costs. Sector costs in fact are better illustrated in other contexts such as power


2. See Agenda 21, Ch 33.16; Montreal Protocol (as amended) Article 10.3 (a); and Global Environment Facility (GEF) Instrument, paragraph 2.
system investment programs where system effects and system costs are more pervasive. In the power sector, it is seldom possible to consider project-for-project substitutions; instead, it is necessary to consider alternative integrated investment and operational plans. The sector approach also allows us to add policy alternatives to go beyond the simple addition of projects, which is the focus of the Montreal Protocol. Such policy alternatives could include industrial strategy for ODS phaseout, and carbon taxes for greenhouse gas (GHG) reduction. The country-level incremental cost will include not only the project, or sector, costs but also welfare losses and macroeconomic costs.

Originally we distinguished between expenditure and loss. At the project level this might be a useful distinction: the higher cost of substitutes and capital plant versus the loss due to accelerated replacement of capital plant. However, at the country level the distinction disappears, because it is necessary only to compare one overall cost stream with another. All economic loss due to accelerated replacement will be implicit.

**Top-Down and Bottom-Up Country Cost Calculations**

Ideally, the comparison of with and without cases would be performed in a general equilibrium framework to capture all the trade-offs and the full adjustment costs to the economy. For the ODS phaseout problem, this is generally unnecessary and may also be impractical. The assumptions are that it is unnecessary because (a) the overall adjustment cost is small relative to the whole economy; (b) the phaseout takes place over a relatively short time (about ten years, possibly less); (c) the costs are to be compensated at a project level as they occur; and (d) that countries generally would not be expected to change overall economic policy or industrial strategy in order to minimize the need for international compensatory payments or to meet their commitments.

For other global environmental problems, these assumptions may need to be reconsidered. For example, greenhouse gas emissions will not be phased out, but maintained at reduced levels indefinitely, and policy responses will be much more important. However, even for this problem, there may still be a need for bottom-up modeling of short-term responses that provide information about investment options. In fact, very few top-down models have been applied to this problem in developing countries.

For bottom-up calculation, we explicitly consider the level of services provided by ODS and ODS technologies and examine the incremental cost of alternative (non-ODS) technologies for providing the same type and level of service. If we used an equivalent approach to the climate change problem, we would hold the services of the power sector fixed while examining alternative (less GHG-intensive) forms of supply and demand management.

**The Incremental Cost Framework**

We calculate incremental cost using a bottom-up approach. Whether one is calculating project, sector, or country-level costs, the broad framework is the same.

**Scenarios**

It is critical that we first identify the scenario. The scenario is the set of all assumptions that are regarded as fixed—that is, not part of the strategies being evaluated. While a strategy determines the alternative course of action and is controlled by the government or other economic agents, a scenario, by definition, is not controlled but describes the other relevant features of the issue. The same scenario would therefore underlie both the baseline and the alternative cases described below. It is important not to confuse the scenario with the strategies that are being evaluated, because to do so can lead to error—such as comparing one strategy to another under different scenarios.
Different scenarios, representing different possible views of the future, can be used though to test the sensitivity of the incremental cost calculation to uncertain parameters, but in each case they should be applied to both the baseline and the alternative strategy.

**Domestic benefit**

It is necessary to identify the domestic benefit of the activity that is to be substituted or modified. An example of domestic benefit is the effect on the domestic health and economy caused by the production of a certain number of refrigerators of given capacity.

**Baseline**

It is then necessary to construct a baseline case. Some baseline cases may be trivial, in the sense that no activity would normally take place in the absence of global environmental considerations. Others may be more complex, and involve a program of investment and operations over a long period of time. Since the baseline will be counterfactual once an alternative has been implemented, it is even possible to consider various baselines corresponding to different scenarios, for example. It will be useful to make the underlying assumptions explicit, since some baselines may be more plausible or have more policy relevance than others. For instance, if the financial policy requires it, the baseline may need to incorporate any of the following: (a) the most economic way of achieving the identified domestic benefits, (b) consistency with national priorities, and (c) reasonable environmental protection standards. Alternatively, it may simply be the most likely outcome, including any inefficiencies, distortions, or non-economic considerations that the country is likely to have permitted.

In general, one of two baselines is usually implied: the “business-as-usual” baseline, which represents the continuation of existing policy, and the “optimal” baseline, which includes assumptions about whatever pricing policy reform and industrial restructuring would be suggested by the county’s own best interests. The impact of this choice could be substantial, because many economically attractive but unfinanced opportunities could also benefit the global environment (such as energy conservation, in relation to the global benefit of reduced GHG emissions).

The choice of baseline is restricted by the financing policy in the case of the Montreal Protocol, but is less specified in the case of the FCCC.

In the case of the Montreal Protocol financial policy, the baseline benefits are further limited by being described as “basic domestic needs” in the amount that existed at the time the Protocol was signed (1987). These limitations can be interpreted to mean that the production of ODS-dependent goods for export is not included in the baseline and that growth in the demand for ODS-dependent goods over time is not included beyond the point where additional capacity is required.

In the case of GHG reduction, many developed countries are working towards targets of the same form: emissions by a certain target date (such as the year 2000) will be limited to an amount equal to historical emissions in a base year (such as the year 1990), with future emissions reduced by a fixed percentage of these (possibly 20 per cent by the year 2020). However, developing countries have no specific commitments under the FCCC. It is also likely that GHG emission reductions will be measured against normal trends rather than base year emissions in order to provide for continued industrialization to increase living standards; that is, the baseline would include “normal” growth in emissions over time.
1. Country Incremental Costs of Phasing Out Ozone-Depleting Substances

**Technical options**

It is necessary to identify technical options for producing domestic benefits of the same type while at the same time providing global benefits.

**Alternative**

An alternative case needs to be produced which yields domestic benefits in the same amount as the baseline case which it is replacing. This means, for example, that in the ODS phaseout case, the same number of refrigerators or, in the global warming case, the same amount of electricity will need to be produced by the alternative strategy as is produced by the baseline strategy.

**Incremental cost**

Incremental costs (whether at project, sector, or country level) are calculated as the difference in cost between an alternative and a baseline case within the chosen scenario. A simple framework is provided in Table 1-1.

These costs will be distributed over time. In some years the incremental cost will be positive, but in others it may be negative. For example, in phasing out ODS in air-conditioning, there may initially be higher incremental capital costs due to the higher costs of substitute chemicals. On the other hand, in recycling ODS there would be incremental capital costs that are partially offset by future savings due to the lower volumes of ODS required. Likewise, in GHG reduction, capital costs of the alternative fuel may lead to initial incremental capital costs of fossil fuel replacement. These costs would be partially offset by future negative incremental costs due to the avoided baseline costs of the fossil fuel replaced. Often, the incremental cost is expressed as a single number: the net present value calculated on the basis of an appropriate discount rate. This is not always a necessary step, however, since the time profile of the incremental costs may be sufficient for reimbursement if this is also done as the costs are incurred rather than in advance.

**Global benefit**

It may be useful to calculate the incremental global benefit, as is shown symbolically above, even though it is certainly not a part of the calculation of incremental cost and it is usually not monetizable. In ODS phaseout, this is the amount of ODS phased out—also a time profile; in GHG reduction it is the GHG reduction; in the case of biodiversity conservation it is the conservation goal met. It is useful to calculate global benefits in order to make cost effectiveness comparisons. If a higher incremental global benefit is derived from the use of given funds in one activity or country than in another activity or country, it benefits the global environment more to devote the resources in the most cost-effective manner.

**Cases**

There are many possible cases that can be evaluated depending on how many scenarios (S), reflecting external uncertainties, need to be considered; how many baselines (B) are of interest to policy-makers; and how many alternatives (A), or strategies, are under consideration. The maximum number of cases (C) is multiplicative. For example,

\[ C = S \times B \times A \]

The actual number of cases that needs to be considered may be smaller if certain combinations are regarded as unlikely or unnecessary.

The number of alternatives itself depends on the number of phaseout schedules (D)—each of which must at least meet any broad commitment under a convention—and the policies (P) under consideration:

\[ A = D \times P \]
There is no prescription for the number that might be considered—this will be a matter of judgment in each case. In the section below entitled *Lessons for Other Global Environmental Focal Areas*, we consider the number of cases usually adopted for the work on country incremental cost of ODS phaseout.

**Incremental domestic benefit**

It may sometimes be useful to identify incremental domestic benefits, if any, that accompany the actions taken principally to benefit the global environment. Although care would be taken to match the baseline and alternative cases in terms of the baseline domestic benefits they produce (the situation shown in Table 1–1), there occasionally may be such additional domestic benefits that are not separable in this way.

In ODS phaseout, there are few incremental domestic benefits; one of these few is the nonseparable benefit of having testing facilities for non-ODS equipment that will also prove useful in general product testing. In GHG reduction, the reduction of domestic pollution loads (below the requirements and national priorities already built into the baseline) is an incremental domestic benefit that can be expected from reduced use of fossil fuel. In conserving biodiversity, the availability of increased biological resources for sustainable industries is a possible incremental benefit. As is the case for incremental global domestic benefits, incremental domestic benefits are not part of the calculation of incremental cost. However, the financial policy for sharing the incremental cost may specify that this incremental domestic benefit needs to be taken into account in some way.

**Benefits**

Different types of benefits have been the source of some persistent misconceptions. Therefore we restate briefly the types of benefit that can occur in the incremental cost framework.

- First, there is the baseline domestic benefit—the benefit served by the activity damaging to the global environment. This benefit need not be monetized, but should be clearly identified and quantified so that one can demonstrate that the proposed alternative produces at least the same benefit as the baseline it replaces. If this were not the case, the country could hardly regard the proposed activity as an alternative. Numbers of refrigerators produced is an example of a quantified but unvalued baseline domestic benefit that is maintained in the alternative case.

- Second, there are avoided baseline costs. These are not benefits in the strict sense at all, but are sometimes so regarded. In fact, they are an integral part of the calculation of incremental cost. The savings in ODS resulting from an investment in recycling is an example of an avoided baseline cost, which must be valued and used as an input to the calculation of the incremental net cost of recycling.

- Third, there are incremental domestic benefits. These are "side benefits," benefits that are not part of the baseline and therefore not a national priority. Such benefits do not usually exceed the incremental cost of the proposed action; on their own they do not justify the action economically. Nevertheless, if these incremental domestic benefits are tangible but inseparable from the global benefits, the financing policy may require some amount of cost sharing between the international financing mechanism and the country. This is an issue of financial policy.

- Fourth, there are incremental global benefits. These need not be monetized, and do not form part of the calculation of incremental cost.
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Country Incremental Cost of Phasing Out ODSs

Scenarios

Typically, a scenario will include the following assumptions:

- the growth in demand for the services provided by ODS or its substitutes—which forms the basis for estimating the baseline domestic benefits. Often high and low growth scenarios are used;
- the cost and availability of technical options; and
- the cost and availability of ODS and ODS technologies.

Usually, the scenarios below (two or three) have been defined only on the basis of the principal country-specific uncertainty: the growth in demand for ODS services, often linked to the rate of economic growth.

- High-growth scenario
- Reference growth scenario
- Low-growth scenario

The other factors are international rather than country-specific and could also be used to define scenarios and standardize assumptions with other groups working on similar questions. Usually, technical availability is agreed on the basis of expert technical opinion (such as the Ozone Operations Resources Group [OORG]) and alternative cost assumptions are used in sensitivity testing only around the reference scenario.

Domestic benefits

Benefits are identified in each of the user sectors. Although production is an integral part of the chain of technical processes for providing these benefits, care should be taken not to “double count” by including production of ODS as an benefit additional to that of consumption.

Baseline

For this work, only the “business-asusual” baseline is used because of the restrictions imposed by the Montreal Protocol. The Montreal Protocol, for example, effectively stipulates that the baseline (and the alternative) case include existing economic policy and industrial strategy, although this presumably does not exclude policy instruments specifically targeted to the phaseout (what we have termed National Ozone Policy).

In the case of GHGs, the importance of policy responses is likely to be much greater. For one thing, efforts to control the release of GHGs will span many decades and may even be indefinite. Long time horizons make it more likely that baselines will eventually incorporate economic policy reforms and industrial restructuring. For another, the costs of GHG reduction strategies are likely to be much higher than those of ODS phase-out and inefficiencies are less easily afforded. We return briefly to the question of policy responses in the section Incremental Costs of Economywide Policy Responses.

Technical options

In the case of ODS phaseout, there is a wide variety of non-ODS options for the existing applications (in refrigeration and air conditioning, foam blowing, aerosol propulsion, solvent cleaning, and fire extinguishing).3

Alternative strategies

Up to six alternative strategies could be considered, depending on both the schedule

3. The options are constantly changing as a result of technical developments. Technical assessments are made by bodies such as the Ozone Operations Resources Group, which advises the World Bank in its role as an implementing agency of the Multilateral Fund.
chosen and the policies adopted. The schedule could be characterized as:

- **Allowable.** In this schedule, actions are taken at the last possible opportunity consistent with an environmental commitment.

- **Accelerated.** In this schedule, actions are taken as soon as they are technically feasible in order to minimize ODS emissions by reducing them below the maximum permitted by the commitment schedule agreed to by the country when ratifying the Montreal Protocol.

- **Optimal.** In this schedule, actions are timed to meet the commitment at lowest incremental cost. (To determine the "optimal" strategy, one actually considers a large number of strategies and, through constrained optimization, selects the minimum cost solution.)

The policy options could be characterized as:

- **Efficient.** An efficient (comprehensive) combination of policies. This policy option was not considered because of the restrictions of the Montreal Protocol which explicitly ruled it out.

- **National Ozone Policy.** This policy option comprises an optimal set of specific policy instruments dedicated to the phaseout of ODS but set in a general policy context of existing industrial strategy and economic policy, either or both of which may be very suboptimal.

- **None.** This option means no new policy is adopted. In general, this would be an inefficient "response" that would increase the incremental cost of the phaseout.

For ODS phaseout calculations, three schedules, combined with only the National Ozone Policy strategy, were used, making a total of three alternatives.

- **Incremental cost.** For each of the chosen scenarios, baselines, and schedules, one can calculate an incremental cost in respect of each of these policy options above (King and Munasinghe, Section IV).

- **Minimum incremental cost.** The cost of actions that follow the efficient policy will be the lowest incremental cost of meeting the commitments.

- **Compliance cost.** This is the cost of actions that incur the lowest incremental cost subject to the constraint that economic policy and industrial policy are not altered. (This constraint is imposed by the Montreal Protocol.) However, efficient specific measures (National Ozone Policy) to assist the phaseout are assumed to be in place. In general, because of the additional constraints, the compliance cost will exceed the minimum incremental cost.

- **Adjustment cost.** The actions that are actually taken, whether efficient or not. Therefore the adjustment cost will generally be greater than the compliance cost.

**Cases**

- **Scenarios (s).** Generally three scenarios are considered: high growth, reference, and low growth. Other uncertainties are treated as additional scenarios around the reference scenario for sensitivity testing.

- **Baselines (B).** Only the "business-as-usual" baseline is used.

- **Alternatives (A).** Three schedules (D) are considered: accelerated, allowable, and optimal. Only one policy (P) is assumed: National Ozone Policy, which does not include changes in economic policy or industrial strategy.

- **Cases (C).** On this basis, the number of principal cases considered is nine:

  \[ C = S \times B \times A = S \times B \times (D \times P) = 3 \times 1 \times 3 = 9 \]

Since there is only one baseline considered, we can simplify the naming of such cases.
1. Country Incremental Costs of Phasing Out Ozone-Depleting Substances

using a two-dimensional matrix, as shown in Table 1–2.

**Terminology**

At this point we need to alert readers to the various uses of some of the terms we have used above; first, because this may lead to misidentification of supposedly comparable cases when different studies are compared, and second, because the loose application of some terms in the incremental cost framework can lead to confusion.

- First, we have reserved the term *scenario* to apply only to the context of the problem, not the outcome or the strategy. The scenario embodies the relevant exogenous parameters that are not subject to policy control and which remain the same whatever strategy is adopted. There may be various scenarios, however, that reflect the uncertainty about the external context.

- Second, we have used *baseline* in the sense required by incremental cost analysis to denote a strategy which does not take global environmental considerations into account.

- Third, we have used *reference* to qualify *scenario*. It could also be used to qualify *baseline*, since several baselines are possible.

**Special Features of the Incremental Cost Analysis of ODS Phaseout**

There will be a number of special features involved in calculating the incremental cost, which, as indicated above, will be a compliance cost.

The compliance cost is the minimum adjustment cost given the existing economic policy and industrial strategy. In principle it can be calculated from a least-cost plan of adjustment comprising an optimal National Ozone Policy and an optimal investment plan. The principle is to minimize the economic incremental cost subject to constraints defined by the obligations under the Montreal Protocol and the fixed policies. In essence, the problem is the same as that of developing a least-cost investment program for the power sector. ODS phaseout costs, like power supply costs, need to be evaluated in a time dimension. There are, however, some special features of the ODS calculation.4

**Disaggregation**

The demand for the services of existing ODSs must be disaggregated by ODS. There are seven groups of controlled substances defined by the Montreal Protocol, each with its own chemical properties, type of use, and sector of application. The solution is the sum of up to seven separate reduction strategies, since the Montreal Protocol does not permit trade-offs between the schedules of the different groups.

**Data adequacy**

There is a special difficulty with data. ODS phaseout is unlike the case of power and water development, where there are reasonably accurate demand forecasts and good technoeconomic data for costing alternative supply options at different scales of operation. In ODS phaseout:

- demand patterns and price elasticities have not been extensively researched;

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4. We originally regarded the choice about whether to include the imposed costs of the Montreal Protocol as a special feature. However, it seems worth preserving the distinction between reimbursement of mitigation costs and compensation for imposed costs. The scenario would thus be that the Montreal Protocol has been adopted by the rest of the world, at least to the extent that this will affect the international prices and availability of ODS, ODS technologies, and the ODS substitutes. At the time, we also noted that least-cost planning required that benefits be kept the same, although we are now less inclined to regard this as distinctive. Keeping benefits the same is also essential for incremental cost analysis.
rapid technical change will have a large but unknown effect on phaseout costs within the planning period;

- costs of substitutes from sources outside the country and from domestic producers affiliated with multinational corporations are not easily obtained; and

- the reductions in cost due to learning and scaling up of operations are not well known.

Distributed costs

Unlike in utility planning, the costs of ODS phaseout will be highly distributed among a variety of government agencies, producers, user industries, and consumers.

Matched pair calculations

Since the issue is incremental costs, the calculations have to be done in matched pairs of baseline and alternative cases, and not singly.

Case Studies

Background

Since the theoretical work had been done, a number of Country Programs had been prepared for the Multilateral Fund of the Montreal Protocol. These programs assist the preparation of individual projects which would be eligible for financing by providing an overall program of which they form part, and outline the recommended National Ozone Policy.

Our concern here is not with the country-specific recommendations as such, but with the feasibility of the methodology (particularly in the light of the special features outlined). The methodology is useful as a test of proposed National Ozone Policy, as a way of evaluating investment plans for ODS phaseout, and as an indication of resource needs for ODS phaseout. We would like to draw lessons not only for future ODS phaseout studies but also, to the extent this is possible, for studies on other global environmental issues.

The Environment Department therefore commissioned four consulting firms to describe, without any additional research, their applications of the methodology. The country observations were for the purpose of testing the methodology, and not for evaluating specific country situations or recommendations. The consulting firms and the countries they selected appear in Table 1-3.

Steps in Calculating the Incremental Cost

Scenarios

Essentially, the scenarios used by the case studies featured growth assumptions for the services of ODS based on “unconstrained” ODS consumption. In some cases, the scenario explicitly assumed the ozone issue had never evolved into the Montreal Protocol; that is, there were no restrictions in the country or anywhere else. The main impact of this assumption was that ODSs would be available at present real prices, whereas, in fact, prices might eventually rise\(^5\) as production falls below the levels for economies of scale, and international supplies might become unavailable. Strictly speaking, a scenario should set out the expected context for both the baseline and the alternative cases so that the incremental cost of decisions to implement the Montreal Protocol in the given country can be measured. Including the “no Protocol at all” situation in a scenario, it becomes unusable for this pure calculation since the difference in cost will also include what we termed the “imposed cost.” However, given the uncertainty of the forecast, this may not have much of an impact.

\(^5\) Prices might temporarily drop if demand is restricted before capacity is closed.
Unconstrained demand is generally projected on the basis of a base year consumption and a growth factor derived from population and economic or sector growth. A time horizon that is sufficiently long to allow the phaseout and all consequential costs to be adequately represented (20 or 25 years) was used. High and low forecasts were offered, sometimes with a reference or central estimate as well.

The main practical problem, as expected, was the unavailability of data even for the base year. This situation arises because it is necessary to have the data disaggregated by a phaseout group, and because it is desirable to have it disaggregated by application in order to make better projections. As noted by Bendtsen (in this volume) in the case of Tunisia, there are numerous minor applications and many small users, particularly in the solvents sector but also in the refrigeration sector with its multifarious servicing requirements. Import statistics and company data are not easily obtained, and surveys, which are time consuming, are often needed. Another problem is that the base year itself may have to be adjusted for unusual circumstances, such as those that prevailed in the late 1980s and early 1990s in the former Czechoslovakia and other central European and former Soviet republics when the earlier centralized planning and the Council for Mutual Economic Assistance trading systems were disintegrating.

Because the forecasts are not precise or certain, they cannot be used for direct reimbursement purposes. The actual development of demand would need to be reviewed over time for this to be assessed more accurately.

**Domestic benefits**

The proxy for the benefits of ODS services, which are held the same for both the baseline and the alternative, is the unconstrained ODS consumption. For each ODS application, the most plausible alternative technologies are matched.

**Baseline**

Implicitly, the case studies used the “business-as-usual” baseline.

**Technical options**

In each country, it was necessary to make judgments about the technical options, whether these were straight chemical substitutes, such as liquefied petroleum gas as a propellant and HFC-134a as a refrigerant; process changes, such as low-chlorofluorocarbon (CFC) foam blowing techniques and the use of recycling and recovery techniques; or product substitutes, such as mechanical pumps instead of aerosol sprays for cosmetic applicators and cardboard instead of foams for packaging. However, there is considerable uncertainty about which of the technical options included in the preparation of the alternative strategy will stand the test of time. The search for feasible alternatives is extensive, and recent successes have reduced the estimated global cost of the phaseout. Furthermore, some options are acceptable in one country but not in another (for example, methylene chloride for flexible foam blowing), and transitional substances themselves will have to be phased out one day. There is some disagreement on the starting dates for new technologies (although this could reflect country availability rather than uncertainty about international availability), market penetration rates, and reduction potentials.

**Alternative**

The alternative strategy is constituted by a sequence of investments in the technical options that are required or encouraged by the National Ozone Policy. As required, the economic policy and industrial structure are assumed to stay the same. Thus the savings that might accrue if small-scale, inefficient
production were to shut down in the transition are not included in the final calculation.

Accelerated, allowable, and optimal schedules were tested. In the case of Tunisia, the accelerated schedule was in any case only slightly more expensive than the optimal (least-cost) one, despite the fact that it is well ahead of the formal Montreal Protocol limits.6

**Incremental cost**

In the suggested framework, the total costs of actions are recognized where and when they occur in both the baseline and the alternative cases. The incremental cost is calculated only once, as the “compliance cost,” when the total cost of the baseline is subtracted from the total cost of the alternative. However, in none of the case studies did the analyst use this approach. Rather than two cases with data on total cost being entered, the analysts used a single “incremental” case with estimates of unit abatement costs (in other words, unit incremental costs) multiplied by the amount of ODS replaced.

This approach, using unit abatement costs, may work reasonably well for ODS phaseout, which is calculated from the bottom up and involves costs that are small relative to the economy as a whole. Much of the cost data is already in an “incremental” form: capital conversion costs, additional royalties and costs of patents and designs, the full costs of required technical assistance and institutional strengthening, and incremental unit costs on chemical substitutes. As Widge, Radka, and Dillon (in this volume) point out, care is needed to prevent “double discounting” the unit abatement costs when they are put back into a cost stream. This would not be possible to do in other focal areas if the alternatives are very different or where there are system or macroeconomic costs involved.

However, in the ODS transition, there will be some economic losses in the form of premature retirement of capital equipment and consumer appliances and also some benefits from the transition in the form of more modern equipment that is acquired earlier than it would otherwise have been. It is this aspect of the ODS phaseout problem that the unit abatement cost approach does not really cover. In the case studies, therefore, this issue was handled separately. Bendtsen (in this volume) argues that the cost of forced early retirement is extremely sensitive to the assumptions about the future availability of drop-in substitutes as well as the availability of ODS from recycling and reclamation. While the forced early retirement costs are be estimated for domestic refrigerators, they are ignored for other equipment because the costs are probably small (due to retrofitting) and because there is insufficient data available on the stock of equipment and its age and characteristics. The estimate of the early retirement costs for domestic refrigerators is based on the stock and age profile of refrigerators, the annual production, the rate of recharging, the average useful life of refrigerators, and the economic cost of refrigerators (taken to be price less tax).

**Cases**

The country studies either refer to explicit cases or implicitly use three alternatives with three scenarios, the latter perhaps in the form of sensitivity tests around a reference scenario based on a central estimate of unconstrained demand.

**Global benefit**

The incremental global benefit will be the physical reduction in the ODS emission achieved by the alternative over the baseline.

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6. The Country Program recommended that the accelerated schedule be adopted because the global benefits are substantially larger for little increase in cost, and because possible CFC price increases will make this identical to the optimal schedule.
1. Country Incremental Costs of Phasing Out Ozone-Depleting Substances

for each scenario. This could be expressed as a time profile of the reductions of the different ODSs. There is an unresolved issue about the means of aggregating different ODSs through a weighting factor such as the ozone depletion potential and of expressing the value in present value terms (for example, through a discount rate). The issue is unresolved because there is no agreed damage function for the emission of ODSs. This is not a practical issue because the Montreal Protocol specifies benefits in terms of the schedules; nor is it a serious economic issue in the present context, since global benefit is not a part of the incremental cost calculation and there is an implied commitment to phase out all ODSs. So generally, if approximate comparisons are needed, it would be sufficient to calculate the accumulated ozone-depleting potential- (ODP-) weighted but undiscounted ODS emission reductions relative to the baseline. One could, of course, determine the sensitivity of the results to different discount rates.

Once the schedule of actions has been determined, this can be done by first calculating for each ODS the annual emissions in the alternative case, subtracting the emissions of the baseline, and then totaling the sums of the differences over all the years and ODSs. The baseline emissions are the estimates of the scenario, or, in other words, the unconstrained demand.

\[ E_{\text{base}} = \text{Unconstrained Demand} \]

The emissions of the alternative case are found by reducing the unconstrained demand by an amount determined by the technical options. Catanach expresses the reduced emissions of the alternative case in the following formula:

\[ E_{\text{alt}} = E_{\text{base}} - \text{Conserve} - NIK - \text{Subs} + \text{New} \]

where:

- **Conserve** = material savings from recovery and recycling.
- **NIK** = not-in-kind substitutes for ODS
- **Subs** = ODSs replaced by in-kind alternatives
- **New** = new applications requiring ODS substitutes

To meet the restrictions of the Montreal Protocol, \( \text{New} \) may need to be zero.

Incremental global benefit =

\[ \sum \sum \text{ODP}(\text{ODS}_i) \times \left[ E_{\text{base}}(\text{ODS}_i,t) - E_{\text{alt}}(\text{ODS}_i,t) \right] \]

where: \( i = \) index for each ODS group, and \( t = \) index of time (e.g., years)

### Modeling Issues

#### Optimization

One of the models we used in this study (Bendtsen, in this volume) was an optimization model, whereas the others used iterative simulation. Optimization is an extremely powerful technique for testing ODS phaseout strategies (schedules and policies), including those for the phaseout of transitional substances, such as hydrochlorofluorocarbons (HCFCs). However, optimization may now be unnecessarily sophisticated for the ODS phaseout calculations, since the problem is highly constrained.

First, for those central and eastern European countries and former Soviet republics that will not be accorded the status of developing countries, the actual difference between the alternative phaseout speeds has all but disappeared due to the Copenhagen Amendments to the Montreal Protocol of November 1992. The following amendments significantly tightened the requirements: the required phaseout date for CFCs, methyl chloroform (MCF), and carbon tetrachloride (CTC) is January 1, 1996, and that for halons January 1, 1994. There are thus few alternatives but the accelerated phaseout schedule. For those developing countries that depend on imports of ODS, the phaseout of ODS in the developing countries will
effectively raise the price and reduce the availability of ODS along the developed country schedules.

In fact, three of the studies showed that the accelerated schedule was very close to being the optimal.

**Model Sophistication**

The models used in the case studies could be run on personal computers, and both Catanach (in this volume) and Mason (in this volume) mentioned that their models were spreadsheet based. In view of the requirements of the model, and the need for transparency, this seems an excellent choice. Modern spreadsheet programs offer good databases and scenario managers that facilitate computation with conceptual understanding.

**Supply-Side Modeling**

Mason describes experience with the modeling of a large integrated ODS system (India) which has production, user industries, and consumer applications. Simplified approaches were taken for countries with fewer elements, such as Turkey, which has a wide range of industrial activity that uses or supports the use of ODS but does not manufacture it, and Zimbabwe and Jordan, which also import the components used in equipment that contains ODS.

In general, though, the supply side was modeled less effectively than the user industry sectors. This is understandable for most developing countries, which are importers and users, but is more serious when there are major supply side options. The main reasons for having a good supply side model are the following:

- It helps to identify costs where they first occur. In an economic model, one is not interested in the incidence of the costs; in fact one assumes in this case that costs originally borne by the producers will eventually be passed on to consumers in the form of higher prices.
- It brings out the issue of importation versus production.
- It integrates supply with use. The production, industry use, and consumer use of ODS and ODS appliances form an integrated system. Where there are only independent uses, such uses can usually be evaluated separately in terms of their individual cost-effectiveness. But where they are all linked through an integrated supply chain, the analysis is more complicated. If the phaseout is not balanced, the rapid phaseout in one sector will impose costs on the others. For example, phaseout of production, assuming that imports cannot take up the slack, will impose costs on user industries which face a sudden rather than a gradual withdrawal of ODS.
- It allows the systematic exploration of the dominance of the costs of the early retirement of appliances when CFCs are no longer available for recharging (a fact noted by both Catanach and Mason). This dominance suggests that an accelerated schedule is preferred, especially in growing economies, because it limits the accumulation of capital stock and consumer durables that would eventually require replacement. However, an accelerated schedule may impose high initial costs of replacement, unless these can be contained in some way. This cost containment usually requires one or more of the following supply-related options:
  - that CFCs be recovered, recycled, and reclaimed in order to provide a continuous supply of CFC for appliance servicing but without the necessity for importing or producing them;
  - that drop-in substitutes are readily available; or
that retrofitting can be done easily and cheaply.

A model that adequately represents these supply-related options is needed if genuine least-cost planning is to be accomplished in the more complex economies such as Chile, India, and China. The costs of these options should be considered in the overall cost minimization.

- It allows further exploration of assumptions about, and actions to affect, the servicing of equipment. On the one hand, Widge suggests that the simulation of a "servicing tail"—that is, the use of ODS beyond the date of the phaseout in new equipment—is useful and was done for the Philippines and for the island of Taiwan (studies not included in the case studies here). On the other, Bendtsen notes that for Tunisia the result (choice of phaseout speed) is not sensitive to the assumed rate of servicing of domestic refrigerators. Perhaps the issue to explore further is not so much the choice of overall phaseout schedule (which in most cases seems robust), but the choice and cost-effectiveness of subsidiary strategies to further reduce the residual uses of ODS once the Montreal Protocol targets have been met.

Further Research Effort

Further research needs can be divided into studies of ODS phaseout and those involving the mitigation of other global environmental problems, which are less well defined. In relation to the ODS phaseout, we can consider the following findings and sensitivity analyses.

International price data

A major increase in ODS prices (as would seem likely as plants close) makes the accelerated schedule the least-cost one, thereby making it less necessary to study this aspect further with optimization techniques. Bendtsen regards a doubling of CFC prices as sufficient for this; Mason believes that the accelerated schedule already reduces the phaseout costs in India significantly and that in other reasonably open economies, like Jordan and Zimbabwe, the phaseout will be market-driven by its links to the accelerated phaseout in supplier countries. Widge notes that changes in the prices in ODS and substitutes attributable to the global phaseout will have substantial impacts on Thai industry and consumers; however, given the mixed baseline used (which assumes a "no-protocol" situation) the results in the Thai model are likely to be inconclusive. The rising cost of ODS will of course add to the costs of industry, but these are strictly baseline costs; the incremental costs of the substitutes will in fact decline in this situation.

Although it seems that the recommended strategies are robust, most of the case study authors call for more research on the projected costs of ODS and ODS substitutes because this will have a major impact on incremental cost. Bendtsen notes that the costs of ODS substitute technologies tend to become generic if world prices are used for the open economies: projected worldwide costs would therefore help project preparation, being both cost-effective and standardized. Catanach comes to a similar conclusion, and calls for identification of the supply costs (freight costs can then be estimated and added). Bendtsen also notes that operating costs tend to dominate the costs of the phaseout (except in the "allowable" scenario, where the costs of forced early retirement dominate, as expected) implying perhaps that it is the future costs of substitute chemicals in particular that are the important parameters.

While generic information would of course be useful, would help standardize country studies for comparative purposes, and would be most cost-effectively generated if prepared centrally (for example, for the Multilateral Fund), we doubt that this
alone would be as helpful as believed. As noted above, most of the case studies used unit abatement cost approach in their analyses, and this may have inappropriately suggested that incremental costs can be measured or projected on a purely generic basis. In our experience (World Bank and Montreal Protocol 1992), the unit abatement costs are far more sensitive to country-specific factors such as the utilization of capital equipment than on generic factors. Mason in fact makes an observation that seems to support our conclusion in relation to recycling: there is a major difference between the costs of recycling in a large repair shop, with centralized repairs, and those of small service shops that cater to on-site repairs.

**Country growth factors**

An increase in country-specific growth certainly adds to the incremental cost, but does not seem to alter the conclusion that the most appropriate phaseout schedule is the accelerated one. Catanach notes this in the case of Egypt; Bendtsen notes only that an increase in the growth rate raises the incremental cost. This suggests that further work on refining country growth factors will not help in strategy formulation, and since country incremental cost is not the basis of reimbursement, it would not help in estimating resource transfers either. To the extent that the Montreal Protocol limits reimbursement to the incremental costs in relation to capacity extant in 1987, growth projections are not very relevant for anticipating resource transfers. However, they would alert the country to the extent to which unfundable incremental costs are growing.

**Usefulness of the Approach**

**Phaseout schedules**

The methodology was able to demonstrate the relative costs of the alternative speeds of phasing out ODS. (In most countries, the accelerated schedule is either the most cost-effective or close enough to it that it is preferred as a risk management strategy.) That is, although the country incremental cost itself is difficult to calculate with any confidence, the framework and process yields important general results.

**Phaseout policy**

Typical measures constituting the recommended National Ozone Policy in the studies were: taxes, selective bans, standards, monitoring, joint government-industry committees, and information dissemination. Although Mason states that country incremental cost considerations may guide the timing of such measures, it was generally conceded that the measures themselves were not modeled explicitly but recommended on general economic efficiency grounds or because of their institutional feasibility. (Nevertheless, we expect that modeling of policy instruments will become much more important for other global environmental issues, such as the phaseout of GHGs, because of the longer time horizon over which the reduction takes place, the number and diversity of sectors in which action will be taken, and the pervasiveness of the measures.)

**Investment sequencing**

The models all set out the required sequence of investments in a transparent way; this was certainly a strength and by itself would have assisted the planning process. However, the analysts did not appear to have used their models to perform an optimal sequencing of investments. It is likely that they timed the investments on the basis of the availability of the options and the material balance required by the schedule that formed part of the proposed strategy. Bendtsen believes that the COW/consult model is not well suited to sequencing. Unlike the power sector, where central utility planning is the norm, the various
sectors where ODS will be phased out are characterized by the multiplicity of small, private undertakings. Competitive market forces often drive the phaseout, and an "optimal" sequence of investments may not be possible because it might disturb the current market shares of different companies. In many cases the data available are not adequate for determining such optimal sequences.

Lessons for Other Global Environmental Focal Areas

Other Global Environmental Focal Areas

In conclusion, it can be stated that global environmental problems are caused by actions in individual countries. The mitigation of those problems will lead to global benefits—reduced crop damage, reduced risk of climate change, and so forth. Economic mitigation—actions whose costs are less than the global benefits they produce—will nevertheless impose costs on the host country that are less than that country's own share of the benefits from that specific action. Therefore, for mitigation to take place, international commitment is necessary, and—in the case of developing countries which cannot afford the actions implicit in that commitment—international financing. International conventions provide financing for the incremental costs of such actions in developing countries in the case of three focal areas—ozone depletion, climate change, and loss of biodiversity. The Global Environment Facility, in addition to financing actions in those areas, also finances actions to prevent the pollution of international waters.

There are similarities and differences among these focal areas that may affect the ability to calculate the country incremental cost. The important aspects are listed in Table 1–4.

Incremental Cost Calculations

Scenarios

In climate change, the scenario will include such things as the demand for energy services, and the likely international prices for principal fuels and important technologies. Scenarios underlying the climate change problem are probably easier to treat than those for ozone depletion because energy, which is a significant factor driving climate change, has been the subject of such analysis for reasons of commodity and resource forecasts for many years. The specific factors that should be included in the scenarios underlying the other focal areas are not well known, partly because of the diversity of actions that could be involved in mitigation.

Domestic benefit

In climate change, the domestic benefits that will need to be preserved by alternative (low GHG-emitting technologies) will be energy-related; others will be food and transport services. One lesson from our studies of ozone depletion is that there will be difficulties in projecting these benefits from base years on the basis of growth factors. This is, first, because some base years will be unusual (especially those for central and eastern Europe around 1990, which is the commonly regarded base year for developed country emissions) and second, because compound country and sector specific growth over long time periods will be difficult to make with confidence.

The projected benefits for industries and agricultural concerns that are the source of land-based pollution of international waters will be similar in type to those used in ozone depletion because they will involve numerous competing firms and various polluting processes.

The projected benefits to be maintained in biodiversity protection measures will be particularly diverse, reflecting the diverse
nature of the interventions necessary. However, in some countries, land pressure is the main factor in biodiversity loss, and the domestic benefits of land use may be projectible.

**Baseline**

The baseline question will be much more problematic in the case of climate change and biodiversity loss than for ozone depletion. This is true, first, because of the long, possibly indefinite, time spans; second because there will be many more sectors involved than just a subset of the industrial sector; and third because the incremental costs will be much higher. Because of the scope for and costs of game playing, it is likely that more attention will focus on the specification of the appropriate baseline. The most important factor, of course, is whether this will be "business-as-usual" or be based on the assumption (more or less true in the long term) of policy reform. In the case of climate change, one policy variable will be most important: energy pricing.

In biodiversity loss, important policy variables will be the pricing of agricultural inputs and products, land tenure, and the incorporation of domestic environmental considerations into decisionmaking.

**Options and alternative strategies**

In climate change (at least in the energy area), many technical options will be similarly dependent on technical change. Examples of such technical options are in the areas of new and renewable energy technologies, demand side management techniques, and fuel switching. In this respect, the construction of alternatives from a menu of technical possibilities will be similar.\(^7\) Producing menus of options for biodiversity conservation will be less easy because so many options will not be straight technical substitutions but rather local choices such as siting alternatives and land use options.

The simple imposition of a constraint (such as a GHG emission constraint) on the optimization of investment and operations will lead to incremental costs—but incremental costs that are much higher than they need be. The most cost-effective response will require a careful choice of technical options and policies. This in turn will require an assessment of the future costs of new and emerging technologies. This has proved to be difficult in the focal area of ODS phaseout; it will be even more so in climate change and other areas where treaties and domestic policies are encouraging rapid technical innovation.

**Incremental cost**

Many of the incremental cost calculations for the ODS phaseout appear to be overconstrained. This implies that there are no degrees of freedom, nor opportunities to explore cost-effective solutions. In order to avoid this situation in other global environmental issues, it would be necessary to construct treaty targets, schedules, and eligibility requirements more broadly. Where responses are interconnected, integrated models will be necessary, as in the case of countries that have ODS production, user industry, and consumer applications.

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7. In current work on the power sector for the Program for Measuring Incremental Costs for the Environment, the Latin American Energy Organization (OLADE) is working with the power utilities of Colombia and Costa Rica to construct alternative power development plans that satisfy the same domestic needs (electricity demand) but at a lower emission of GHGs by using different technologies.
Bibliography


### Table 1–1: Scenario X

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Cost ($)</th>
<th>Domestic benefit ($)</th>
<th>Global benefit (avoided emissions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>$C_{Ah}$</td>
<td>DB</td>
<td>$- G_{Ah}$</td>
</tr>
<tr>
<td>Baseline</td>
<td>$C_{Base}$</td>
<td>DB</td>
<td>$- G_{Base}$</td>
</tr>
<tr>
<td>Increment</td>
<td>$(C_{Ah} - C_{Base}) &gt; 0$</td>
<td>0 (because benefits are held constant)</td>
<td>$(G_{Base} - G_{Ah}) &gt; 0$</td>
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</tbody>
</table>

### Table 1–2: Baseline: Business as Usual

<table>
<thead>
<tr>
<th>SCENARIO --&gt;</th>
<th>ALTERNATIVE</th>
<th>Reference</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allowable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal</td>
<td></td>
<td></td>
<td></td>
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### Table 1–3: Consulting Firms

<table>
<thead>
<tr>
<th>Firm</th>
<th>Principal author</th>
<th>Country cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>COWIconsult, Denmark</td>
<td>Ulla B. Bendtsen</td>
<td>Tunisia, Czechoslovakia (Comments on Ghana)</td>
</tr>
<tr>
<td>Touche Ross, United Kingdom</td>
<td>Caroline Mason</td>
<td>India, Turkey, Jordan, Zimbabwe</td>
</tr>
<tr>
<td>ICF Incorporated, United States</td>
<td>Vikram Widge</td>
<td>Thailand (Comments on Taiwan and the Philippines)</td>
</tr>
<tr>
<td>C. Catanach, United States</td>
<td>Charles B. Catanach</td>
<td>Egypt</td>
</tr>
</tbody>
</table>
Table 1-4: Country Incremental Costs of Protecting the Global Environment

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Ozone depletion</th>
<th>Climate change</th>
<th>Pollution of international waters</th>
<th>Loss of biodiversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imposed cost of global change</td>
<td>Food chains, crops, immune response, skin cancer</td>
<td>Storm frequencies, sea level, droughts and floods</td>
<td>Marine food chains</td>
<td>Species loss</td>
</tr>
<tr>
<td>Mitigation targets in convention</td>
<td>Phaseout schedules for each group of ODSs</td>
<td>No specific ones for developing countries</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Separate mitigation groups</td>
<td>Seven ODS groups with separate targets</td>
<td>Carbon dioxide, methane, and other GHGs</td>
<td>Yes (organotins, petroleum) but not formally classified</td>
<td>Numerous (various ecosystems and species)</td>
</tr>
<tr>
<td>Treaty financing mechanism</td>
<td>Yes; Multilateral Fund</td>
<td>Yes; GEF (interim)</td>
<td>No</td>
<td>Yes; GEF (interim)</td>
</tr>
<tr>
<td>Reimbursement for mitigation</td>
<td>Agreed Incremental Cost</td>
<td>Agreed Full Incremental Cost</td>
<td>Agreed Full Incremental Cost</td>
<td></td>
</tr>
<tr>
<td>GEF focal area</td>
<td>Yes; certain countries not covered by the Multilateral Fund</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Mitigation</td>
<td>Complete phaseout</td>
<td>Reduced emissions</td>
<td>Reduced pollution by certain compounds</td>
<td>Protection of ecosystems</td>
</tr>
<tr>
<td>Benefits proxy</td>
<td>ODS</td>
<td>GHG</td>
<td>Various chemical loads</td>
<td>No. Goals specified exogenously</td>
</tr>
<tr>
<td>Method of aggregation of benefits</td>
<td>Ozone depleting potential (ODP)</td>
<td>Global warming potential (GWP)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Incidence of costs</td>
<td>ODS producers; user industries; consumers; governments</td>
<td>Power and energy suppliers; farms; industries; transport</td>
<td>Farms (pesticide and fertilizer users); industries (toxic effluent); shipping (toxic cargo, ship waste); government (oil and chemical spill cleanup)</td>
<td>Government (conservation and protected area management); industry and agriculture (pollution); people (alternative land use)</td>
</tr>
</tbody>
</table>
Evaluation of Incremental Cost Methodologies for Phasing Out Ozone-Depleting Substances: Case Studies of India, Turkey, Jordan, and Zimbabwe

Caroline Mason

This chapter presents the main results of case studies of ozone-depleting substance (ODS) phaseout studies in four countries: India, Turkey, Jordan, and Zimbabwe.

1. The work was carried out by Touche Ross Management Consultants in response to a request from the Environment Department of the World Bank.
Before presenting these findings, it is helpful to distinguish between two principal categories of Article 5 countries:

- countries such as India that manufacture ODSs and have a wide range of industrial activity to use them;
- countries that import their ODSs. These countries can be further subdivided as follows:
  - countries such as Turkey that locally manufacture components (such as compressors) for use in equipment, as well as assembling finished goods (such as refrigerators) and using ODSs in some manufacturing processes (such as in foam blowing);
  - countries such as Zimbabwe and Jordan that also import the components for use in equipment that contain ODSs. There may be some industrial activity in assembling finished goods from the imported components, and some use of ODSs in manufacturing processes.

In this chapter, the focus on the methodology developed in India, a country with a complex industrial structure including ODS producers, equipment manufacturers, and end users. Simplified versions of this methodology were applied in Turkey, Jordan, and Zimbabwe, where there is no ODS production.

**Methodology Used to Calculate Country Incremental Costs**

The stages in the methodology used follow.

**Current Situation**

Base data for India were collected by an Indian consulting firm, drawing on government officials, published government sources, industry associations, and individual companies. Data was also collected independently by Touche Ross. The data varied in quality, consistency, and completeness. As far as possible, supply and demand side estimates were reconciled. From this data, we did the following:

- prepared an inventory of the ODSs being used in the country, including the annual consumption (in tons) of each;
- established the applications using ODSs, including quantities for the manufacture of new products and for recharging equipment during repair;
- determined the source of the ODSs, whether imported or locally manufactured;
- presented an outline of the industry structure in each sector; and
- estimated the stock of refrigeration and air conditioning appliances in the country and their approximate age profile.

**Future Demand**

Likely future demand for each ODS use was projected to the year 2010 (2015 for 1,1,1-trichloroethane) in the absence of any limitations imposed by the Montreal Protocol. The forecasts were kept simple, and were based principally on official population and economic growth projections. For India, both upper and lower bounds of likely growth were projected, based on different scenarios.

The resultant unconstrained demand forecasts provided the baseline estimate of the quantities of ODSs to be substituted if demand for products is to be fulfilled, thus maintaining the domestic benefit. Given the uncertainties associated with forecasting, especially so far into the future, the projections were only indicative of likely future trends.

**Montreal Protocol Phaseout Profiles**

In India, the phaseout dates expected to emerge from the London meeting of the Parties were used. In the other countries, the actual London Amendments were used.
Substitutes and Alternatives

Technical options, in the form of substitutes and alternatives that were likely to be adopted in India, were identified for each use based on expected best practice around the world at that time. By and large, the Indian companies studied did not have plans for phaseout. The unit costs and technically feasible timing for changeover were estimated from international sources, taking into account likely time lags for introduction into India. In more recent studies, the situation has changed, and some companies do have plans for phaseout. In these situations, we have also taken into account the existing plans of the companies involved, and the possible influences of their suppliers and any foreign collaborators.

Policy Measures

At the time of the India study, we anticipated that government action would be needed to drive phaseout. More recently, in countries where there are no producers of ODSs, market forces are proving to be powerful, while the government role is more limited. We built up an understanding of the industrial, environmental, legislative, and fiscal framework in each country, and of the broad economic policies and strategies. We considered the effectiveness of regulatory and fiscal measures already used and in use. From this overview, we identified and evaluated a range of policy measures (both market-based and command-and-control) available to the government to cause industry to take action. These included

- quotas on production or consumption of ODSs, either voluntary or enforceable by legislation;
- financial incentives to close ODS production capacity, to establish ODS substitute capacity, or to convert existing capacity to the production or use of substitute substances;
- assistance with technology transfer;
- taxes, excise or other, or import tariffs on ODSs or products, or subsidies or reduced taxes on non-ODS substitutes or products;
- direct financial support for recycling or recovery schemes; and
- publicity to inform users of the changes they face, and training to encourage good housekeeping practices.

Phaseout Alternatives

The current situation, future demand, Montreal Protocol limits, possible substitutes and alternatives, and available policy measures, were all drawn together to produce phaseout alternatives, or possible patterns of projected phaseout measured in tons of ODSs. We developed a suite of computer models that allowed modeling of each user sector individually, as well as allowing a combination of models to provide an aggregated country perspective. For each user sector in India, we assessed the likely response to the package of government measures. Figure 2-1 shows the estimate of the likely responses of the domestic refrigerator manufacturers in India to a suite of new taxes and regulations, which provide the stimuli first to introduce water blowing for the foam insulation, subsequently to switch to the hydrochlorofluorocarbon HCFC-123 as the foaming agent, and the hydrofluorocarbon HFC-134a as the refrigerant. Finally, in the absence of continuing chlorofluorocarbon (CFC) 12 supply, recharging of refrigerators that fail in service has to stop. The responses of each sector are additive to generate the country's overall CFC profile. Similarly, the phaseout profile for each group of substances was built up.

The timing of introduction of the measures affects the timing of responses. Different timings were modeled to investigate, for example, at the two extremes, the latest possible phaseout consistent with the Montreal Protocol schedules and the earliest phaseout that is practically possible.
Country Incremental Costs

The economic costs of phaseout comprise one-time capital costs, ongoing incremental operating costs, and the costs of forced early replacement of equipment reliant on recharging with ODSs. It is assumed as a baseline that industry continues to meet growing demand for ODSs and for products made with or containing ODSs by investing in additional production capacity as required. We estimated the country-specific economic cost of different phaseout profiles by calculating the annual incremental cash flows in current prices between the time of the study and 2010 (2015 for 1,1,1-trichloroethane) and presenting these calculations as the net present value. We then built up estimates of incremental unit costs for each sector (ODS producers, each of the user sectors, and consumers). The elements of the model are illustrated in Figure 2-2 and are described in more detail in the section on Modeling below.

For the ODS producers and users in manufacture, most additional costs will, in the long term, be passed on to the consumer of the product in the form of higher prices. However, the costing model identifies costs at the point at which they first arise, rather than at the point at which those costs are recovered from customers. To avoid double counting, costs incurred by producers are not also represented in the costing model as being borne by users or consumers in the form of higher prices. With this approach, those incremental costs which fall directly in the consumer sector and which are additional to the incremental costs incurred in the producer and user sectors are those arising either from changes in running costs of appliances or from the need to bring forward replacement of appliances which cannot be recharged because the recharge substance is no longer available. Early replacement has been modeled as a cash outlay of the full cost of a new appliance in the year of replacement and a cash saving of an equal amount in the year of natural replacement.

In ODS nonproducer countries, the additional cost of substitute chemicals over and above that of the ODSs they replace was modeled as an incremental cost per ton imported, rather than as the additional capital and operating costs associated with new chemical production capacity. A discount rate appropriate to the country (such as the government's real discount rate for major investment projects) was adopted in each case.

Preferred Alternative

Through an iterative process, we investigated what might constitute an optimal strategy for the government to pursue. Optimal in this context meant least-economic-cost to the country, taking into account practicalities of implementation. The phaseout timing module (see Figure 2-2) was varied to calculate the effect on the country incremental cost. Also, recycling options were considered to reduce the number of refrigerators that needed early replacement.

Sectoral Implications

We then worked back from overall country incremental costs to summarize the implications for each sector. It is at this stage that specific projects potentially suitable for assistance from the Multilateral Fund may be identified.

Modeling

The computer modeling used Lotus 1-2-3 on personal computers, with inter-linked spreadsheets on a modular basis as illustrated in Figure 2-2. For maximum flexibility, we used simple simulation techniques, rather than optimization techniques, to investigate the effects on national incremental costs of different phaseout timings.

We first entered annual growth percentages for each user sector, then developed alternative phaseout timings (consistent with the policy measures selected) and input these. These policy measures were used to reduce...
demand in the user sectors. In India, we then phased down production in the ODS producer sectors in line with these policy measures. In nonproducer countries, we assumed that ODS imports declined in line with declining demand. All prices were assumed to stay constant in real terms.

Investments in new production capacity (whether in the producer or user sector) were based on typical plant sizes in each country for that type of facility, even if this did not seem to represent the optimum economic size of increments.

Refrigeration and air conditioning appliance ownership at the time of each study was estimated in the light of data from industry. Typical failure, repair, recharge and replacement rates were established by discussions with local businesses. We modeled, for each type of appliance, the numbers and age of appliances in each year, adding new appliances in line with production figures, removing appliances from the population based on average life expectancy, and calculating demand for CFCs for recharge using typical recharge rates.

Very high costs will be associated with early replacement of refrigeration appliances when CFCs were no longer available for recharging. Therefore, we investigated the possibility of recycling to help meet the ongoing demand for recharge refrigerants. We estimated the volumes of CFCs likely to be available for recycling based on the appliances being scrapped in urban areas as they reach the end of their natural lives and the quantities likely to be recoverable from these machines. This defined supply. The recovered CFCs were assumed to be recycled, first to meet recharge demand for domestic refrigerators and then other appliances. Costs of the recycling operation were estimated from international sources combined with the structure of the local servicing organization.

Country-Specific Assumptions and Results

India

At the time of this study (January–May 1990), we assumed likely substitutes and alternatives for ODSs in India as set out in Table 2–1. The table also shows assumptions about the earliest dates that these substitutes and alternatives would realistically be available in India.

The unit cost assumptions used are given in the annex to this chapter. They were best estimates at the time of the study and are not necessarily still valid. Modeling included the producer sector, and the feedstock industries to this sector that would be impacted significantly by phaseout.

The particular difficulties experienced in India related to the complexity of the industrial structure in the country and the limited availability of data on price and demand. This ruled out any modeling based on price elasticities of demand. Inevitably, we had to make informed judgments in order to produce “order of magnitude” results.

We calculated cash flows for four cases: for high- and low-demand estimates with phaseout as late as possible consistent with the Montreal Protocol schedules (allowable) and as early as practical (accelerated). For the high-demand and accelerated phaseout case for Group I substances (CFCs), the cash flows were as illustrated in Figures 2–3, 2–4, and 2–5.

The rising cash flows in the producer reflected the ongoing higher costs of some substitutes and alternatives. In the user sector, there is a peak in the cash flows as facilities are converted to use the substitutes and alternatives, with some ongoing higher costs. In the consumer sector, there is a surge of costs as appliances are replaced prematurely. The corresponding (high-demand, accelerated phaseout) present values are presented in Table 2–2.
We investigated the opportunities to reduce the costs in the consumer sector by recycling CFCs. The effect on the economic cost to India (high-demand, accelerated phaseout) is presented in Table 2–3. The present values for all four cases modeled are provided in Table 2–4.

For the high-demand, accelerated phaseout case, the breakdown of costs between different sectors is shown in Figure 2–6. We did not run a large number of iterations to find the least-cost solution, although we established that early action led to much lower total incremental costs than delayed action.

The package of policy measures we adopted to drive this phaseout comprised a combination of market-based and command-and-control measures, selected for effectiveness given the characteristics of the Indian economy (including the widely distributed user sectors and incidence of corruption). The measures included:

- production quotas on CFCs 11 and 12;
- taxes on CFC-11 and CFC-12 to increase their prices to those of substitutes and alternatives;
- financial assistance to owners of non-swing CFC plants to adapt their units to make more HCFC-22;
- incentives to export HCFC-22 to improve capacity utilization;
- assistance to aerosol fillers to modify their facilities to use liquefied petroleum gas (LPG);
- prevention, through the licensing system, the construction of new capacity to build refrigerators using CFC-12 as the refrigerant; and
- legislation to ban uses in specified sectors.

Overall, we concluded that accelerated phaseout significantly reduced the economic costs to India by reducing the number of appliances that had to be replaced prematurely. This cost could be reduced further by the introduction of recycling to prolong the supply of CFC-12 for recharge.

**Turkey**

We found good awareness in industry of the need to switch to non-ODSs in the future, although some companies were waiting for the Government of Turkey to declare its policy before they act. In the refrigeration sector, some companies were already investigating details about the production of non-CFC products (including the manufacture of non-CFC compressors), and they were very aware of the need to remain competitive, especially in their export markets in Europe. In the aerosol industry, market forces had influenced the changeover to LPG propellants in many products. In the foam industry, concerns over costs of changeover and lack of experience in the use of alternative blowing agents were delaying change.

ODS use was more limited in Turkey than it was in India, and all ODSs were imported, mostly from Europe, but also from the United States, Brazil and Taiwan. Calculation of country incremental costs followed the same methodology as applied in India. Country incremental costs, expressed as net present values, for two cases are set out in Table 2–5. Optimum phaseout was defined as phaseout incurring the lowest country incremental cost, and allowable phaseout was defined as phaseout occurring as late as possible consistent with the Protocol schedules. The net present values (NPVs) are based on a discount rate of 10 percent real.

The effect of recycling programs on the early replacement costs is estimated in Table 2–6. The types of policy measures recommended for Turkey included:

- establishing a licensing system for ODS users and ODS import monitoring procedures;
- setting up a task force within the Ministry of Environment to develop voluntary agree-
ments within industry in order to establish specific end-use bans;

- increasing public awareness through publicity for ODS reduction technologies;
- introduction of a levy on ODSs to a level that makes the substitutes and alternatives look attractive; and
- the eventual banning of the use of ODSs in specific applications.

Given the extent to which the market is initiating phaseout, some of these measures may now be superfluous.

Three specific projects for submission for financial assistance from the Multilateral Fund were identified. These were all put forward by one of the major refrigerator manufacturers in the country, eager to work closely with the World Bank team. Interestingly, the other refrigerator manufacturers preferred to act independently and did not get very involved with the team. There was no attempt to seek out other projects, nor to prioritize them.

**Jordan**

Jordan is heavily dependent on imports. All its ODSs are imported, most from Europe and some from the United States. All the refrigerator manufacturers import their compressors and only assemble the appliances locally. All three companies reported that they would switch to CFC-free models in line with advice from their respective suppliers. Some very low-density foams were blown using CFCs, but companies will shift to slighter higher densities that do not require CFCs once CFCs are no longer available. Some aerosol fillers were using CFCs as propellants, but the companies concerned were seeking suitable LPG supplies. Change-over was being strongly market-led by the influence of developed world suppliers.

Policy recommendations to the Government of Jordan included:

- enhancing public awareness, including emphasis on conservation measures and substitute technologies;
- announcing a phaseout schedule;
- establishing a licensing system for ODS users to restrict distribution and encourage environmentally-responsible handling practices; and
- applying a levy on imported ODSs and setting up an import monitoring procedure for ODSs.

**Zimbabwe**

At the time of this study (December 1991), all ODSs were imported into Zimbabwe, with the majority coming from South Africa, Germany, and the United States. Components, such as compressors, were also imported. Suppliers seemed to be keeping their customers informed about plans for phaseout. Market forces, principally the expectation of dwindling supplies, were encouraging companies in Zimbabwe to plan for phaseout. We were told that substitution is commercially viable, in the sense that additional costs can be passed on to customers. There were concerns about foreign exchange availability to meet the additional costs of the non-ODS imports.

CFCs for recharge have been in short supply for some time, constrained by foreign exchange restrictions. However, we found no provision for maintaining a supply post-phase-out for recharge purposes. We anticipated that this would mean that the average household would have to replace its refrigerator about five years sooner than normal.

Government policies to drive ODS phaseout did not seem to be necessary. However, we identified the government role as:

- first and foremost, signing the Protocol to secure a continuing supply of ODSs into Zimbabwe after 1 January 1993, as all the suppliers are in signatory countries;
- reviewing foreign exchange allocations to foster the use of substitutes; and
- overseeing or coordinating arrangements to ensure a continuing CFC-12 supply for recharge purposes.
Given this situation, we did not undertake any cost modeling for Zimbabwe. However, we identified that the principal economic costs to Zimbabwe were likely to be:

- the additional costs of imported substitute substances and components; and
- potentially, costs associated with the forced early replacement of refrigeration equipment if it fails in service after the time at which there is no CFC-12 available for recharge.

Lessons Learned

Market-Driven Phaseout

There is a strong market influence on phaseout, especially in countries that import their ODSs or components for use with ODSs from developed countries. The market influence, often mirroring developed country phaseout dates, can leave the Article 5 country governments with few, if any, choices. The government role can be limited in these cases; policies such as taxes and regulations may not be needed to drive change. However, training and awareness activities driven by government may continue to be important, especially in some specialized applications where direct substitution is not the only option and supplier information may be insufficient or biased.

Country Programs need to reflect the more limited government role in these cases and may therefore be much simpler than expected.

ODS producer countries are more insulated from the influence of market forces from developed country producers, although the influence still persists where there are joint ventures or technology agreements with developed country producers. A Country Program based on the country incremental cost concept may still be relevant in these situations, where government policies need to be selected to drive phaseout.

Experience suggests that ODS producer and nonproducer countries need to be treated differently, and the strong influence of market forces fully taken into account in phaseout planning.

Country Incremental Cost Concept

The country incremental cost concept nets off savings against costs of phaseout. Typically, the projects that result in overall savings to an enterprise (such as changing the propellants in aerosols) occur first, because it is in the company's financial interests. Increasingly, such phaseout has already taken place before a Country Program is prepared. Therefore, future country incremental costs overstate total costs, as the savings have already been realized and are not included.

Country incremental costs are highly uncertain, because:

- They are based on long-range projections that will always be subject to considerable uncertainty; and
- Unit incremental costs can only be estimated.

The country incremental cost concept

- is useful for testing alternative possible phaseout timings and determining least-cost strategies for a country overall. However, where market forces are causing phaseout, the government may not need such detailed projections to drive policies, since it is not making choices;
- does not contribute to selection of suitable policy measures, although it may guide the timing of their introduction;
- may be useful for sequencing investments; and
- does not identify project costs for the purposes of assistance from the Multilateral Fund.

Confidentiality and Transparency

Some industrial companies in Article 5 countries are initiating phaseout to maintain or improve their competitive position. These companies rightly feel that their phaseout
plans, including timetable and costs, are commercially confidential in a competitive market. A national phaseout plan needs to respect this confidentiality.

In these reports, we have made every effort to ensure that economic cost calculations are transparent by including details of all cost and other assumptions, and describing the rationale behind the modeling. This was not a problem in India, where phaseout was at a very early stage and estimates were drawn from internationally available data. However, there are potential conflicts where companies have specific plans that they do not wish to be released into the public domain.

**Project Costs**

In practice, projects seem to be put forward for funding from the Montreal Fund independent of influence on the country incremental costs. The estimates of country incremental costs become redundant, and detailed modeling does not seem to be appropriate in such cases, especially since country incremental costs are not equal to the sum of all identified project costs. Also, we have not observed, in the preparation of country programs, conscious reconciliation of what should be funded to least-cost strategies.

Even at the project level, true incremental costs can be difficult to identify. In practical terms, it is most realistic to limit applications for funding to capital costs, and exclude ongoing costs. This seems to be the practice. Any project funding in a competitive economy is effectively a subsidy to the companies receiving the assistance and may distort the market.

In many small countries, projects tend to be small in terms of the total investment required. Responsive means of providing assistance in such cases are needed, with the minimum of administrative overhead. It may be more efficient for implementing agencies to deal directly with companies in disbursing assistance rather than through governments.

**Dominance of Early Replacement Costs**

The country incremental costs of ODS phaseout are dominated by the costs of early replacement of appliances when CFCs are no longer available for recharging. This cost is sensitive to the size of the population of CFC-based refrigerators and air conditioners in use when CFC supply ceases. The size of the population will generally be lower as soon as substitute appliances are introduced into the market. This argues for phaseout as soon as possible. The supply of CFCs for recharge can be prolonged, for example, by recovering and recycling CFCs, or by sourcing drop-in substitutes. The costs of this need to be balanced against the potential early replacement costs. Governments may be best placed to initiate action to create mechanisms to ensure a continuing supply of recharge material compatible with CFC-12 appliances.

**Project Priorities**

Projects submitted for assistance from the Multilateral Fund may be those whose incremental costs are easiest to identify rather than strategically important leadership projects, or those that will help the early replacement in the consumer sector. This suggests that some way of prioritizing is needed for the most effective use of international funds for phaseout.

**Conclusions**

The conditions set out for the Multilateral Fund of the Montreal Protocol for providing assistance for ODS phaseout to developing countries have proved difficult to apply in practice. Country incremental costs are not a very helpful measure. They are extremely difficult to estimate and do not pinpoint the areas in the economy that are most critical for effecting phaseout, nor where the costs will fall.

No distinction is made in the terms of reference of the Multilateral Fund between the different situations in ODS producer and
nonproducer countries. The type of assistance that is required by chemical producers, with complex plants and capacity utilization implications, is quite different from that needed in equipment manufacturing sectors.

Experience shows that the additional costs per unit of consumer product are a very small proportion of the total cost of the product and the consumer can bear the increase. Projects that catalyze activity may be most important.

Annex 2–1: Unit Cost Assumptions

The following is an extract from the Phase II report prepared by Touche Ross in 1990 for the Government of India on “Reducing the Consumption of Ozone-Depleting Substances in India.” It describes unit cost assumptions and is included with this chapter to illustrate efforts to make the calculations transparent.

The Costs of Substitution: Introduction

As described in the section above entitled “Methodology Used to Calculate Country Incremental Costs,” the costing methodology used takes account of costs on a cash flow basis. For the producer sector, the full capital and operating cost cash flows are calculated first to meet continuing unconstrained demand for ODSs (“base case”) and then to meet the same level of demand with substitutes. The difference gives the incremental cost of compliance to India. In the user and consumer sectors, the incremental costs (conversion of existing facilities and additional operating costs) are identified directly. This section sets out the unit costs for each sector.

Costs are expressed in rupees and pounds sterling. An exchange rate of Rs 28=£1 is used and, in every conversion, the resulting amounts are rounded. In presenting the rupee amounts, we have used the Indian convention of expressing amounts as follows:

- Rs 1 crore = Rs 10 million; and
- Rs 1 lakh = Rs 100,000.

The Producer Sector

In estimating the costs in the producer sector, we have modeled the capital and operating cash flows for ODS plants, substitute plants or substitute imports, and for significant feedstock industries. In this section we also show the assumed capacity increments and estimated unit costs for additional plants. Where a feedstock industry is costed separately, the cost of the raw material it supplies to the ODS-substitute plants is excluded from the operating costs of these subsequent plants to avoid double counting. For both HFC-134a and HCFC-123, we have assumed that when production capacity is constructed in India, it will comprise 5,000 tons per annum units. This is very small in comparison with the scale of plants which are being designed and built in developed countries. Therefore, it may prove to be difficult to acquire designs and specifications for small units. If small units are built, they may not enjoy the economies of scale available to producers in developed countries. The transition from existing substances to substitutes may therefore require the import of substitutes for a period of time.

All costs are expressed in 1990 prices. Capital costs include plants and machinery, land and buildings, utilities, and commissioning. As is normal practice in India, land prices take into account infrastructure costs. For new processes, technology transfer costs are identified separately. Fixed operating costs include labor, overhead, rates and insurance, and maintenance, but not depreciation, which is a noncash item, nor return on capital, which is allowed for when the cash flows are subsequently discounted to 1990.

CFC-11/12 and HCFC-22 Manufacture

In meeting base case demand, new CFC-11/12 and HCFC-22 plants will be required. We have assumed that it would be similar to the recently installed swing plants with capacity increments of 5,000 tons, although this is relatively small by international industry
standards and may fail to generate available economies of scale. The costs included for such plants reflect the cost structure in the Indian industry today and are set out in Table 2-7.

With phaseout of ODSs, two of the five CFC-11/12 production plants can progressively decrease CFC-11/12 production and switch to full HCFC-22 production; these are the newest plants, and are swing plants. One of the two old CFC-11/12 only plants is very small and will become redundant. The other two plants can be converted to full HCFC-22 production by adjusting the operating conditions. Additional HCFC-22 capacity will be installed as required, with capacity increments and costs the same as the modern swing plants given in Table 2-7.

**Chloromethanes**

Additional chloromethane capacity would be needed to meet the base case projections. Such a new plant is assumed to be similar to the most recent existing plant, using the chlorination of methane process. It will have the capacity to produce a total of 6,000 tons per annum of chloroform and carbon tetrachloride. Cost estimates are based on information collected in the United Kingdom and are set out in Table 2-8.

With phaseout of ODSs, chloromethane capacity will continue to be required to supply the chloroform feedstock for HCFC-22 production. Fewer new plants will be required than in the base case, but no plant closures will be necessary. The demand for carbon tetrachloride will decline both as a feedstock for CFC-11/12 and as it is phased out for use in cleaning and as a solvent.

This will pose a problem for chloromethane producers, as it is not possible to eliminate carbon tetrachloride production and still continue to produce chloroform. This is true even though the proportion of carbon tetrachloride in the product mix can be reduced from the current 15 percent to about 8 percent or less with minimal additional capital investment. The small amount of existing carbon tetrachloride production from a rayon plant is assumed to cease during the phaseout period.

We have assumed that carbon tetrachloride produced as a by-product from chloroform production will be incinerated at high temperatures (in excess of 1,100 degrees Celsius) in a purpose-built furnace, with all the requisite effluent treatment facilities, including wet gas scrubbing. We have researched cost estimates in the United Kingdom, where highly effective modern incinerators are already operated commercially, and the costs assumed are set out in Table 2-9.

**HFC-134a**

The principal substitute for CFC-12 as a refrigerant is assumed to be HFC-134a. We have assumed that demand for HFC-134a will be met initially by imports and subsequently from domestic production once demand is sufficient to justify a local plant. Cash flow projections therefore include the cost of imports until these are supplanted by a local product. The estimated long-run sales price of HFC-134a is taken to be five times the current CFC-12 sales price (both net of any import or other duties imposed by the government of India), as is anticipated by companies currently developing HFC-134a.

The capital investment and operating costs of local plants are included as incurred. The feedstocks required for HFC-134a production are still commercially secret, but could be ethylene and HF acid, both of which are readily available in India. Capacity increments of 5,000 tons have been assumed, as this seems appropriate to the scale of demand in India. However, this may not achieve the full benefit from economies of scale.

Again, there is a wide range of views as to what is likely to be the minimum economic size of a plant, ranging from 5,000 or 10,000 tons up to 50,000 tons. At such an early stage in the development process for HFC-134a, only order of magnitude estimates of costs are available. The capital costs are expected to be
roughly double the costs of CFC plants in the United Kingdom, allowing for some progress down the learning curve before a plant is set up in India in 2005. It is implicit in the analysis that the technology will be made available to India. The terms for such a transfer are unknown as yet, but could take the form of a one-time payment or a royalty payment. We have included a one-time payment of 25 percent of the total capital cost for illustrative purposes. See Table 2–11.

**HCFC-123**

We have assumed that HCFC-123 (a substitute for some CFC-11 applications) will be imported initially and then manufactured locally once demand is sufficient to justify an indigenous plant. Cash flow projections therefore include the cost of imports until these are supplanted by local production. The estimated sales price of HFC-134a is taken to be 2.5 times the current CFC-11 sales price (both net of any import or other duties imposed by the government of India), as is anticipated by companies currently developing HCFC-123.

The capital investment and operating costs of local plants are included as incurred. The feedstocks for HCFC-123 are ethylene, chlorine, and HF acid, all available locally in India. Capacity increments of 5,000 tons have been assumed, as seems appropriate to the scale of demand in India. However, as with HFC-134a, this may not fully benefit from economies of scale.

Again, there is a wide range of views as to what is likely to be the minimum economic size of plant, ranging from 5,000 or 10,000 tons up to 50,000 tons. At such an early stage in the development process for HCFC-123, only order of magnitude estimates of costs are available.

The capital costs are expected to be roughly double the costs of CFC plants in the United Kingdom, allowing for progress down the learning curve before a plant is set up in India in 2005. It is implicit in the analysis that the technology will be made available to India. We have included a one-time payment of 25 percent of the total capital cost for illustrative purposes. See Table 2–11.

**Hydrofluoric Acid and Fluorspar**

More hydrofluoric (HF) acid plants would be required to meet base case demand. It is assumed that this will be similar to existing plants. Cost estimates are based on the cost structure in the Indian industry today and are set out in Table 2–12.

With phaseout, HF will continue to be a feedstock for HCFC-22, and will also be required for the production of HFC-134a and HCFC-123, which require more HF per product than the CFCs they will replace. Overall, the tonnage of HF required will be a little less than that for base case demand, since the substitute production volumes are projected to be less than those of CFCs.

Fluorspar will also be required in slightly reduced quantities compared with the base case. Although there are plans to source fluorspar indigenously, we do not at this stage have details of the likely scale and price of domestic production. Cash flows therefore assume an uninterrupted supply of imported fluorspar at today’s landed prices.

**Methyl Chloroform**

New methyl chloroform plants will be needed to meet base case demand. It is assumed that these will be part of vinyl chloride complexes, like the existing plant. Costs have been estimated on this basis, based on U.K. experience.

Under the Protocol, methyl chloroform production will have to be phased out completely. Most of the vinyl chloride complex will, however, be unaffected with the bulk of its output, continuing to be polymerized into polyvinylchloride (PVC). See Table 2–13.

**CFC-113**

All CFC-113 demand is currently met from imports, costed at the landed price, excluding
all import and other duties collected by the
government of India. As has been true from
early 1991, demand will be supplied from
local production.

In addition to the two new CFC-113 produc-
tion facilities about to come on stream, further
plants will be required to meet base case
demand. It is assumed that this will be a stand-
alone plant, and not an add-on to CFC-11/12
capacity. Cost estimates are based on both
U.K. and Indian industry experience. The
1,000 ton capacity increments are small by
international standards, but match the pattern
of demand build-up projected for India. See
Table 2–14. The CFC-113 plants will become
redundant and will close as use of these ODSs ceases and they
will close down.

Halons

All halons used in India today are imported.
We have costed them at the landed price,
excluding all import and other duties collected
by the government of India. As from the
beginning of 1992, demand will be supplied
from local production.

In addition to the new halon production
facilities about to come on stream, further
plants will be required to meet base case
demand. Cost estimates are based on Indian
industry experience and use the same 1,000
ton capacity increments as the plants that is
currently planned. See Table 2–15. The halon
plants will become redundant and will close as
use of these ODSs ceases.

Not-in-Kind and Other Substitutes

Some substitutes are costed in the model by
the inclusion of the substitute purchase price
(net of all Indian taxes) rather than by the
capital and operating costs of a manufacturing
plant. They appear in the producer sector
figures (Figure 2–3) for consistency. The
following substitutes are treated in this way:
• LPG replacing CFCs as aerosol propellants;
• surfactants replacing CFC-113 and methyl
  chloroform in electronics cleaning;
• trichloroethylene replacing methyl chloro-
  form and carbon tetrachloride in metal
  cleaning;
• carbon dioxide and dry chemical powders
  replacing halons;
  organic solvents replacing carbon tetrachlo-
  ride when used as a solvent.

Our cost estimates for these substitutes and
the tons of substitute required per ton of ODS
replaced are given in Table 2–16.

In the user sector (manufacture of products
using or containing ODSs) only incremental
costs are identified. These include capital
costs to modify or convert existing facilities,
incremental capital (over and above that
required before substitution) to build new
facilities, or incremental operating costs.
These are discussed below. All costs are
quoted in 1990 prices.

Domestic refrigeration

Costs of switching to water blowing (using
a water/CFC-11 mixture) for the cabinet insu-
lating foam are assumed to be negligible,
based on U.K. experience to date. Beyond
this, two types of change are required in exist-
ing domestic refrigerator manufacturing facili-
ties to produce HFC-134a/HCFC-123 refriger-
ators:
• minor changes to the integrated foam blow-
ing facilities to work with a wa-
ter/HCFC-123 mixture;
• some modifications to the production lines
  (principally retooling) to accommodate
  redesigned compressors, evaporators and
  condensers that will optimize power con-
  sumption with HFC-134a refrigerant.

Discussions with refrigerator manufacturers
in Europe suggest that, for a typical manufac-
turing unit in India capable of producing
500,000 refrigerators per annum, the conver-
sion costs will be in the order of Rs 1.3 crore
(£0.5 million). In addition, a technology trans-
fer fee may be involved, for which we have
included Rs 1.5 crore (£0.5 million) for each 500,000 refrigerator unit.

We do not expect there to be any incremental capital costs associated with new capacity. That is, new capacity will cost the same to build whether it is designed to produce CFC or HCFC-134a/HCFC-123 refrigerators.

An increase in operating costs in foam blowing (excluding the extra cost of substitute HCFC-123, which is included in the producer sector cash flows) may result from the use of different polyols and more process control. However, any such increase is expected to be very small.

European refrigerator manufacturers are not anticipating any incremental costs of manufacturing HFC-134a compressors, evaporators, or condensers (excluding the extra cost of substituting HFC-134a as refrigerant, which has been included in our costing model in the producer sector cash flows).

**Other refrigeration**

Water and bottle coolers, ice candy machines, deep freezers, and cold stores will all require redesigned compressors, evaporators, and condensers to operate with HFC-134a. The manufacturing facilities tend to be smaller for these systems. The cost of retooling compressor lines is estimated to be Rs 1 crore (£0.4 million) per 100,000 units of annual production capacity for all such lines, other than those for ice candy machine compressors, for which we have estimated the cost to be Rs 10 lakhs (£35,700) per 5,000 units of annual production capacity. The assembly operations will be unaffected.

There are not expected to be any incremental capital costs associated with new capacity, nor any incremental operating costs for compressor manufacture or for assembly of the finished goods.

**Air conditioning**

Most room air conditioners are already made with HCFC-22 compressors. The few CFC-12 room air conditioner compressor manufacturers should not incur any significant incremental costs in converting to HCFC-22 units. There will be no conversion costs or change in assembly costs in either the organized or unorganized sectors, since the HCFC-22 units are essentially similar to the CFC-12 units they replace.

Most reciprocating central air conditioners are currently built using HCFC-22 compressors; no changes will be required. The remainder of production which still has CFC-12 compressors will require redesigned compressors, and therefore the production lines may need some retooling. We have assumed that this will cost in the order of Rs 50 lakhs (£0.2 million) per 1,000 compressor unit. There are not likely to be any incremental operating costs, over and above the extra cost of the substitute refrigerant.

Some centrifugal central air conditioner compressors manufactured today are fully compatible with HCFC-123 and will require no further modifications. For the remainder, some conversion costs will be incurred in retooling the production line. These are likely to be the same for reciprocating compressor lines, although the manufacturing unit size is smaller (only about 1,000 each per annum). There are not likely to be any incremental operating costs, over and above the extra cost of the substitute refrigerant.

Car air conditioners will also require some redesign to operate with HFC-134a, and therefore there will be conversion costs incurred by the manufacturers to accommodate this in their facilities. Indications are that these will be roughly Rs 40 lakhs (£143,000) per 50,000 production line. There are not likely to be any incremental operating costs, over and above the extra cost of the substitute refrigerant.

**Foam blowing**

Other than the changed costs of the blowing agents themselves, which are costed in the producer sector, conversion costs to modify
the blowing nozzles and flow lines will be negligible.

**Aerosols**

We have assumed that aerosol cans will begin using LPG as a propellant, except for inhalants, which will use HFC-134a when it becomes available, and that bottles will begin using mechanical pumps.

LPG to be used as propellants in aerosols may be purchased in and used from cylinders, or bought in bulk quantities and stored in a sphere or bullet. In the former case, the cost per kilogram of the LPG is significantly higher than a bulk purchase, while in the latter a sphere or bullet must be purchased. The decision will hinge around the volumes involved. We have assumed bulk purchases and the use of storage bullets.

LPG also introduces fire risks to the aerosol fillers. Therefore, safety precautions (including a ventilation system and a gas detection system) will have to be introduced at each filling line; relocation to more suitable premises may also be advisable. Costs for each of these elements, based on experience in the United Kingdom, are estimated to be in the order of Rs 10 lakhs (£35,700) per filling line. The investment will not be economic for very small filling units; we have assumed that those filling fewer than one million cans per annum are more likely to switch to the mechanical pump alternative. A similar incremental investment is assumed for new capacity.

There do not appear to be any incremental operating costs when filling aerosol cans using LPG as the propellant. The conversion of bottle aerosols to mechanical pumps does not require any significant changes to the filling stations. However, the pump valves cost 50 percent more (an additional Rs 1 or 3.5p each) compared to aerosol valves. We have assumed that these will continue to be imported.

Early indications are that there will be no costs associated with switching filling stations to HFC-134a propellant for inhaled aerosols. There may be some product reformulation required, since the CFC-11 currently acts as a solvent, but this is likely to be a one-time development cost, not incurred in India.

**Electronics vapor degreasing**

The changeover from CFC-113 and methyl chloroform to aqueous cleaning systems will generally require slightly increased batch sizes, heaters to warm the water baths and for drying, and the installation of effluent disposal facilities. Based on survey work in the United Kingdom, the capital costs involved are estimated to be around Rs 3 lakhs (£11,000) for a small batch operation (equivalent to an existing unit with an annual consumption of 0.6 tons of CFC-113 or 1 of methyl chloroform). Offsetting this, operating costs (excluding the cost of the surfactants, which are costed in the producer sector) will decrease by about Rs 24,000 (£850) per ton of ODS solvent replaced. Incremental capital costs for new facilities are around Rs 2 lakhs (£7,000) for small batch operations.

**Metal vapor degreasing**

Research in the United Kingdom shows that when methyl chloroform is substituted with trichloroethylene, there is no loss of cleaning effectiveness, change in processing time, changes to process facilities, or incremental operating costs.

**Metal dip cleaning**

Similarly, the use of trichloroethylene in place of carbon tetrachloride incurs no penalties. There is no loss of effectiveness and cleaning times will be very similar.

**Incremental Cost Assumptions for the Consumer Sector**

Only owners of refrigeration and air conditioning equipment incur incremental costs in the consumer sector, as we have defined it. These are costs that have not already been included in the producer and user sector and fall into two broad categories:
OZONE LAYER PROTECTION: COUNTRY INCREMENTAL COSTS

- incremental running costs, which would be incurred by all owners of non-ODS equipment;
- forced replacement costs, which would be incurred only by those owners whose CFC-based equipment fails in service but cannot be recharged once CFCs are no longer available.

**Running costs**

The latest evidence from development in the use of HFC-134a and HCFC-123 as refrigerants indicates that there will be no energy penalty with their use. Although HFC-134a is thermodynamically less energy efficient than the existing CFC-12, the combination of redesigned compressors and new, less viscous lubricants is considered by informed sources likely to result in energy savings. We have conservatively assumed that, overall, the substitution is energy neutral and that there will be no cost or savings for the consumer, and there are indications that there could be a net energy benefit.

**Forced replacements**

Costs to some consumers may arise from the forced replacement of domestic refrigerators, air conditioner compressors and ice candy machines, and other refrigeration compressors when no CFCs are available for recharging. This could be a particular problem in India where consumers continue to use equipment for much longer than in developed countries, prolonging the useful life by repair and recharging.

We have calculated the number of units that are likely to be forced to be replaced prematurely, when CFC availability ceases, based on an estimate of the number of refrigerators that would have been recharged in any year were CFCs still available. In the forecast population of refrigerators, the age of each refrigerator at this time is known. Therefore, we know when this refrigerator would normally have reached the end of its useful life and have been re- placed. The cost to the consumer of forced replacement is therefore represented by the timing difference between the actual early replacement and the normal replacement. The cost of a new refrigerator is included in the cash flow at the time of early replacement, and an equal and offsetting credit is given at the projected time of normal replacement.

This additional demand for replacement refrigerators will increase the required supply of refrigerators, refrigerant HFC-134a, and foam blowing agent HCFC-123 and will therefore impact the producer and user sectors. For simplicity of presentation, however, we have not separately priced these effects but have included instead the full cost of a replacement refrigerator in the consumer sector cash flows. Similarly, the costs of early replacement of compressors in air conditioners and other refrigeration units are attributed in full to the consumer sector.

Because of the scale of these early replacement costs, we have evaluated how they can be reduced by the use of recovery and recycling, or by stockpiling, which can extend the period of time for which CFCs are available for recharging. The possible structure and cost of a recycling industry to meet the demand for recharging substances is described below.

**Recycling**

A recycling industry, subdivided into relatively self-contained parts, may emerge in India in response to economic opportunities in the market place as follows.

- **Mobile air conditioners.** Collection of used CFC-12 will take place at a service point when the vehicle is taken for compressor repair and recharge. The used CFC-12 can be reprocessed on site and reused for recharging other mobile air conditioners. The amount of CFC-12 reclaimed will not be sufficient to supply all recharge demand from mobile units, since leakage occurs during normal use. Also, there tend to be losses from mobile air conditioners, and these emissions will not be available for
recovery. Each service point will require a reclaim unit and two full-time, trained operators.

- **Central air conditioners.** Large volumes of CFC-12 are involved in reciprocating units, and of CFC-11 in centrifugal systems. A reclaim machine will be taken to the plants to extract used CFC and to clean it up, allowing recharge to take place on-site. Some additional CFC may be required for topping up. When reciprocating systems reach the end of their normal life, the CFC-12 can be extracted and added into a bank of recycled material for use in other applications, such as domestic refrigerators.

- **Refrigeration, including domestic refrigerators.** When a service engineer goes to repair and recharge a domestic refrigerator, he will take with him a simple portable collection device to collect the tiny volume of used CFC-12 from the refrigeration system before he starts. He will take this back to a distribution center. Here the collected CFC-12 will be placed in batches with other used CFC-12 and reprocessed on the spot, since most of the impurities in the CFCs collected from domestic refrigerators will be acids, moisture, carbon particles, and metal swarf that can be removed by filtering. Badly contaminated CFC will be collected and returned to a CFC producer for reprocessing.

In this latter case we have worked on the basis that collection is only likely to occur in the ten major urban conurbations in India. We have assumed that there will be a number of distribution centers in each of these cities, each with a reclaim unit and two trained operators. The additional cost of collection from the individual refrigerator and delivery to the distribution center is likely to be very small, since the engineer will visit to diagnose the problem, whether recharging is required or not.

The same type of reclaim unit can be used in each sector and costs about Rs 126,000 (£4,500) each. Running costs of the machines are negligible, although two operators may be required for each. Portable collection devices cost about Rs 280 (£10) each.

Our estimate of the total costs of establishing and operating a significant recycling industry in India are set out in Table 2–17. All costs are in 1990 prices.
Table 2-1: Uses of ODSs in India and Possible Substitutes, 1990

<table>
<thead>
<tr>
<th>Sector</th>
<th>Current use</th>
<th>Substitute assumed</th>
<th>Assumed earliest availability in India</th>
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</thead>
<tbody>
<tr>
<td>Refrigeration</td>
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<tr>
<td>Domestic refrigerant</td>
<td>CFC 12</td>
<td>HFC 134a</td>
<td>1998</td>
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<tr>
<td>Industrial refrigerant</td>
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<td>Ammonia</td>
<td>Now</td>
</tr>
<tr>
<td>Water coolers, bottle and walk-in coolers, ice candy machines, cold storage unit refrigerants</td>
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<td>HFC 134a</td>
<td>1998</td>
</tr>
<tr>
<td>Fridges insulating foam</td>
<td>CFC 11</td>
<td>HCFC 123</td>
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<td>Phenolic</td>
<td>CFC 11, 113</td>
<td>HCFC 123</td>
<td>1998</td>
</tr>
<tr>
<td>Poly</td>
<td>CFC 12</td>
<td>HFC 134a</td>
<td>1998</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>CFC 12</td>
<td>HCFC 22</td>
<td>Now</td>
</tr>
<tr>
<td>Aerosols</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhaled pharmaceuticals</td>
<td>CFC 11, 12</td>
<td>HFC 134a</td>
<td>2005</td>
</tr>
<tr>
<td>Bottle aerosols</td>
<td>CFC 11, 12</td>
<td>Mechanical pumps</td>
<td>Now</td>
</tr>
<tr>
<td>Can aerosols</td>
<td>CFC 11, 12</td>
<td>LPG</td>
<td>Now</td>
</tr>
<tr>
<td>Cleaning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapor degreasing electronics</td>
<td>CFC 113</td>
<td>Aqueous</td>
<td>1995</td>
</tr>
<tr>
<td>computer hard disc memory</td>
<td>CFC 113</td>
<td>None known</td>
<td></td>
</tr>
<tr>
<td>electronics</td>
<td>Methyl chlorofom</td>
<td>Aqueous</td>
<td>1995</td>
</tr>
<tr>
<td>metal cleaning</td>
<td>Methyl chlorofom</td>
<td>Trichloroethylene</td>
<td>Now</td>
</tr>
<tr>
<td>Metal dip cleaning</td>
<td>Carbon tetrachloride</td>
<td>Trichloroethylene</td>
<td>Now</td>
</tr>
<tr>
<td>Firefighting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable units</td>
<td>Halon 1211</td>
<td>None known</td>
<td></td>
</tr>
<tr>
<td>Fixed flooding units</td>
<td>Halon 1301</td>
<td>None known</td>
<td></td>
</tr>
<tr>
<td>Process solvents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pesticides, pharmaceutical, industrial, paint manufacture</td>
<td>Carbon tetrachloride</td>
<td>Other organic solvents</td>
<td>Now</td>
</tr>
</tbody>
</table>
2. Incremental Cost Methodologies for ODS Phaseout: India, Turkey, Jordan, and Zimbabwe

### Table 2-2: Producer Sector Annual Incremental Cash Flows (high-demand, accelerated phaseout), Group I (CFCs)

<table>
<thead>
<tr>
<th>Total economic cost (present value, 1990)</th>
<th>Rs crore</th>
<th>£ million</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8%</td>
<td>12%</td>
</tr>
<tr>
<td>Producer sector</td>
<td>360</td>
<td>170</td>
</tr>
<tr>
<td>User sector</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Consumer sector (no recharging after 2010)</td>
<td>440</td>
<td>250</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>920</strong></td>
<td><strong>500</strong></td>
</tr>
</tbody>
</table>

### Table 2-3: India: User Sector Annual Incremental Cash Flows (high-demand) for Group I (CFCs)

<table>
<thead>
<tr>
<th>Recycling strategy</th>
<th>Rs crore</th>
<th>£ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>No recharging after 2010</td>
<td>920</td>
<td>500</td>
</tr>
<tr>
<td>Limited recharging</td>
<td>870</td>
<td>460</td>
</tr>
<tr>
<td>Significant recharging</td>
<td>630</td>
<td>330</td>
</tr>
<tr>
<td>Full recharging</td>
<td>490</td>
<td>254</td>
</tr>
</tbody>
</table>

High-demand scenario used.

### Table 2-4: India: Consumer Sector Annual Incremental Cash Flows (high-demand) for Group I (CFCs)

<table>
<thead>
<tr>
<th>Scenario/alternative</th>
<th>Rs crore</th>
<th>£ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-demand/accelerated phaseout</td>
<td>920</td>
<td>500</td>
</tr>
<tr>
<td>High-demand/allowable phaseout</td>
<td>2,110</td>
<td>1,065</td>
</tr>
<tr>
<td>Low-demand/accelerated phaseout</td>
<td>735</td>
<td>400</td>
</tr>
<tr>
<td>Low-demand/allowable phase-out</td>
<td>1,860</td>
<td>935</td>
</tr>
</tbody>
</table>

"No recharging after 2010" strategy assumed.
Table 2-5: Turkey: Breakdown of Net Present Values for Each Sector (high-demand) for Group I (CFCs)

<table>
<thead>
<tr>
<th>Economic cost, present value (1990)</th>
<th>Optimum phaseout US$ million</th>
<th>Allowable phaseout US$ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incremental capital costs</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Incremental operating costs</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>Forced early replacement costs (no recycling)</td>
<td>56</td>
<td>200</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>127</strong></td>
<td><strong>232</strong></td>
</tr>
</tbody>
</table>

Table 2-6: Turkey: Phaseout Costs

<table>
<thead>
<tr>
<th>Economic cost, present value (1990)</th>
<th>Optimum phaseout US$ million</th>
<th>Allowable phaseout US$ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early replacement costs with:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• no recycling</td>
<td>56</td>
<td>200</td>
</tr>
<tr>
<td>• limited recycling</td>
<td>34</td>
<td>117</td>
</tr>
<tr>
<td>• substantial recycling</td>
<td>10</td>
<td>71</td>
</tr>
</tbody>
</table>

Table 2-7: Unit Costs of CFC-11/12 and HCFC-22 Swing Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>5,000 tons</th>
<th>6,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 11 crore</td>
<td>£4 million</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 2 crore</td>
<td>£0.75 million</td>
</tr>
<tr>
<td>Variable operating costs per ton*</td>
<td>Rs 3,600</td>
<td>£130</td>
</tr>
</tbody>
</table>

* Excluding raw materials (HF, chloroform, and carbon tetrachloride) for which costs are included in the cost estimates for the feedstock industry. One ton of CFC-11 requires 0.17 tons HF and 1.24 tons of carbon tetrachloride. One ton of CFC-12 requires 0.38 tons HF and 1.43 tons of CTC. One ton of HCFC-22 requires 0.62 tons of HF and 1.54 tons of chloroform.

Table 2-8: Unit Costs of Chloromethane Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>6,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 28 crore</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 2 crore</td>
</tr>
<tr>
<td>Variable operating costs per ton</td>
<td>Rs 9,900</td>
</tr>
</tbody>
</table>
### Table 2-9: Unit Costs of Chlorinated Hydrocarbons Furnace

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>5,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 28 crore</td>
</tr>
<tr>
<td>Technology transfer</td>
<td>25 percent of capital costs payable in foreign currency</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 27 crore</td>
</tr>
<tr>
<td>Variable operating costs per ton*</td>
<td>Rs 1.5 lakh</td>
</tr>
</tbody>
</table>

* Excluding HF raw material for which costs are included in our cost estimates for the feedstock industry. We have assumed that one ton of HFC-134a will require 0.66 ton of HF.

### Table 2-10: Unit Costs of HFC-134a Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>5,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 42 crore</td>
</tr>
<tr>
<td>Technology transfer</td>
<td>25 percent of capital costs payable in foreign currency</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 10 crore</td>
</tr>
<tr>
<td>Variable operating costs per ton*</td>
<td>Rs 40,000</td>
</tr>
</tbody>
</table>

* Excluding HF raw material for which costs are included in our cost estimates for the feedstock industry. We have assumed that one of HCFC-123 will require 0.66 tons HF, and that each ton of HF requires 2.2 tons of fluorspar as feedstock.

### Table 2-11: Unit Costs of HCFC-123 Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>5,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 42 crore</td>
</tr>
<tr>
<td>Technology transfer</td>
<td>25 percent of capital costs in foreign currency</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 10 crore</td>
</tr>
<tr>
<td>Variable operating costs per ton*</td>
<td>Rs 40,000</td>
</tr>
</tbody>
</table>

* Excluding HF raw material for which costs are included in our cost estimates for the feedstock industry. We have assumed that one ton of HCFC-123 will require 0.66 tons HF, and that each ton of HF requires 2.2 tons of fluorspar as feedstock.
Table 2-12: Unit Costs of Hydrofluoric Acid Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>5,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 9 crore £3.2 million</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 4 crore £1.5 million</td>
</tr>
<tr>
<td>Variable operating costs per ton</td>
<td>Rs 27,600 £985</td>
</tr>
</tbody>
</table>

Table 2-13: Unit Costs of Methyl Chloroform Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>3,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 6 crore £2.1 million</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 0.7 crore £.25 million</td>
</tr>
<tr>
<td>Variable operating costs per ton</td>
<td>Rs 18,400 £660</td>
</tr>
</tbody>
</table>

Table 2-14: Unit Costs of cFc-113 Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>1,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 5 crore £1.75 million</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 1 crore £0.35 million</td>
</tr>
<tr>
<td>Variable operating costs per ton*</td>
<td>Rs 17,300 £610</td>
</tr>
</tbody>
</table>

* Excluding hydrofluoric acid raw material for which costs are included in the cost estimates for the feedstock industry. One ton of CFC 113 requires 0.36 tons of HF acid.

Table 2-15: Unit Costs of Halon Plants

<table>
<thead>
<tr>
<th>Capacity increments</th>
<th>1,000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Rs 25 crore £9 million</td>
</tr>
<tr>
<td>Fixed operating costs per annum</td>
<td>Rs 2 crore £0.7 million</td>
</tr>
<tr>
<td>Variable operating costs per ton</td>
<td>Rs 8,800 £310</td>
</tr>
</tbody>
</table>
Table 2-16: Incremental Cost Assumptions for the User Sector

<table>
<thead>
<tr>
<th>Substitute</th>
<th>Rs/ton of substitute</th>
<th>£/ton of substitute</th>
<th>Tons of substitute/ton of ODS replaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>16,800</td>
<td>600</td>
<td>1.00 for 11/12</td>
</tr>
<tr>
<td>Surfactants</td>
<td>84,000</td>
<td>3,000</td>
<td>1.56 for 113</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.00 for MC</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>17,500</td>
<td>625</td>
<td>1.38 for MC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.00 for CTC</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>38,250</td>
<td>1,370</td>
<td>3.00 for halon</td>
</tr>
<tr>
<td>Dry chemical powders</td>
<td>50,000</td>
<td>1,785</td>
<td>Not known</td>
</tr>
<tr>
<td>Organic solvents</td>
<td>13,800</td>
<td>490</td>
<td>1.00 for CTC</td>
</tr>
</tbody>
</table>

Table 2-17: Costs of Recycling Industry

<table>
<thead>
<tr>
<th>Type</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td></td>
</tr>
<tr>
<td>215 reclaim units</td>
<td>Rs 2.8 crore</td>
</tr>
<tr>
<td>100,000 portable collection units</td>
<td>Rs 2.8 crore</td>
</tr>
<tr>
<td>Operating</td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td></td>
</tr>
<tr>
<td>Portable collection units renewal</td>
<td>Rs 3.4 crore</td>
</tr>
<tr>
<td>Costs to buy in contaminated CFC 12 (20 percent of virgin CFC price)</td>
<td>Rs 10,320/ton £370/ton</td>
</tr>
<tr>
<td></td>
<td>£1.2 million</td>
</tr>
<tr>
<td></td>
<td>£1 million</td>
</tr>
</tbody>
</table>
Figure 2–1: Example of Phaseout for Domestic Refrigerators (high-demand, accelerated phaseout)

![Graph showing the phaseout of CFCs for domestic refrigerators.](image)

Figure 2–2: Elements of the Model

![Diagram illustrating the model elements.](image)
Figure 2–3: Producer Sector Annual Incremental Cash Flows (high-demand, accelerated phaseout) for Group I (CFCs)

Figure 2–4: User Sector Annual Incremental Cash Flows (high-demand, accelerated phaseout) for Group I (CFCs)
**Figure 2-5:** Consumer Sector Annual Incremental Cash Flows (high-demand, accelerated phaseout) for Group I (CFCs).

**Figure 2-6:** Breakdown of Net Present Values for Each Sector (high-demand, accelerated phaseout) for Group I (CFCs).
ACCURATE ESTIMATES OF COUNTRY INCREMENTAL COSTS for phasing out ozone-depleting substances (ODSs) are critical in the development and evaluation of alternate national policies and ODS phaseout strategies for developing countries. The policies and strategies selected in the estimating process form the basis for a Country Program to phase out ODSs. This Country Program becomes a commitment by government upon which financial grants are made by the Multilateral Fund under the Montreal Protocol to assist the phaseout. Egypt was one of the first countries in which such cost data were evaluated with the assistance of the World Bank (July–August 1991). Subsequently, the Country Program was prepared, reviewed, and submitted by the government of Egypt to the Executive Committee of the Multilateral Fund. It was subsequently approved in October 1992.
This chapter details how the incremental costs for Egypt were estimated and used in the process of preparing its Country Program.

Calculating Country Incremental Cost

The methodology for calculating country incremental costs drew on experience by the author in forecasting the impact of the Montreal Protocol on the international markets for chlorofluorocarbons (CFCs) and on early World Bank documents which outlined the guidelines and important considerations for estimating incremental costs (King and Munasinghe 1991). In the case of Egypt, it is important to distinguish between financial costs to enterprises, incremental costs which may be eligible for grant financing through the Multilateral Fund, and country incremental costs, which are used to evaluate country program alternatives. Financial costs are determined at the enterprise level and include profitability elements. Multilateral Fund grant financing is based on the “Indicative List of Categories of Incremental Costs” included in the appendices to the Montreal Protocol and the policies of the Executive Committee of the Multilateral Fund. Country incremental costs include estimated Multilateral Fund grant financing plus the economic costs to a country resulting from early obsolescence of equipment and technologies based on the continued use of ODSs. Specifically excluded from country incremental costs are customs, tariffs, and duties on the imported goods needed to accomplish the phaseout.

Steps Used for Estimation

The overall process for estimating costs for the Egypt Country Program required the preparation of a spreadsheet ODS consumption forecast which could be modified as necessary to reflect various Montreal Protocol (MP) compliance and country strategies. With this forecast in hand, the needs for replacement materials, equipment, and technologies were estimated, and the direct incremental costs of the phaseout were compiled. The forecast was then used to estimate inventories of ODSs using equipment (such as refrigerators) which would be subject to early obsolescence for each case studied. The consumption forecast was the key element in the analysis. It was developed by adjusting the unconstrained demand for ODSs for all significant elements, forcing conversion to non-ODSs for each strategy evaluated.

Projection of Demand

Unconstrained demand is the baseline for strategy development and is defined as the demand forecast for chlorofluorocarbons (CFCs) and other ODSs as if the ozone issue had not evolved into the Montreal Protocol and local business conditions remained steady through 2010. The baseline provided discrete data against which to forecast the impact of the Protocol-related constraints, conservation or substitution, recovery or recycling program consequences, and other conditions which might increase or decrease the actual demand for CFCs or its substitutes.

Actual demand is defined as:

\[
\text{Actual} = \text{UC} - \text{Conserve} - \text{NIK} + \text{New Uses}
\]

where:

- Actual = Actual ODS Demand (without Protocol constraints)
- UC = Unconstrained ODS Demand
- Conserve = Material savings via recovery or recycle, others
- NIK = Not-in-kind substitutes for ODS
- New Uses = New applications requiring ODS substitutes

Note: All units must be in common ODS units or equivalents so they can be converted to actual quantities via appropriate factors related to physical properties or actual experience.

Actual consumption is the actual demand as constrained by the conditions imposed by the Protocol and multiplied by the percentage of forecast consumption not replaced by substitute products (for instance, the hydrofluorocarbon HFC-134a substituting for CFC-12).
3. Incremental Cost Methodologies for Phasing Out ODSs: Egypt

The demand for ozone-depleting substances (ODSs), chlorofluorocarbons (CFCs) in particular, has traditionally been related to basic social and economic conditions which impact the quality of life. In general, the state of the economy has a direct bearing on gross national product (GNP), which in turn relates to the consumption per capita of ODS. As GNP increases, disposable income expended on items other than food and housing will also increase, and consumers will tend to purchase increasing numbers of items related to their standard of living, such as refrigerators, air conditioners, and miscellaneous household luxury items. Marketing activities by multinational producers of CFCs have recognized this relationship and commonly based growth assumptions for CFCs on GNP growth. Globally, a logarithmic relationship has also been developed to relate CFC consumption to GNP. A characteristic of most countries has been that consumption of CFCs exceeds GNP growth by at least two percentage points. The highest growth is observed in countries moving from poverty to economies in which there is some discretionary income.

Egypt's economy has varied widely in the past 10 years. In the decade from 1974–1985 Egypt's economy grew at 8 percent per year. Despite this growth, a widening gap between foreign exchange needs and earnings led to a large foreign debt situation (greater than 100 percent of GNP), and ultimately to debt rescheduling in 1987. In response to this situation, the government initiated a series of policy changes which reduced price controls, initiated reforms in public industries, and encouraged foreign investment. The periodic lack of foreign exchange distorted regular imports of raw materials (such as CFCs). In turn, this led to distortion of production when foreign exchange was short and to stockpiling of unused materials when foreign exchange was available. Overall, the available historical statistics for CFC use in Egypt are difficult to interpret with confidence.

A large domestic market, a diversified industrial base, ideal agroclimatic conditions, a favorable location and a large, skilled labor force give Egypt strong potential to achieve noninflationary growth and a viable balance of payments. Future growth depends primarily on the implementation of meaningful economic reforms without jeopardizing social and political stability. If accomplished, the demand for domestic goods such as home refrigerators and furniture is forecast to grow again at 5 to 10 percent per year; such growth will directly impact the demand for ODSs and alternatives. In the Egypt case study, a conservative assumption was made of a growth rate increasing to 3 percent per year by 1996. The unconstrained demand for CFC products was assumed to increase at a rate of 2.7 percent per annum faster than the GNP per capita growth rate while also increasing directly with the population (currently 2.6 percent per annum growth).

Sectoral differences also affect the forecast growth rate, particularly when emerging ODS consuming industries, such as electronics, are introduced into a country. In Egypt, this was not a factor and the 2.7 percent growth factor was used in all sectors. Spreadsheet methodology, however, can readily adjust to reflect sectoral differences.

Table 3–1 illustrates growth assumptions used to project growth of unconstrained demand for CFCs and other ODSs from actual ODS consumption data.

**Specifying Montreal Protocol Constraints**

The Montreal Protocol imposes direct constraints on domestic consumption of CFCs and other ODSs. In recent years, these constraints have been modified significantly. Spreadsheet interpretation of these constraints requires the following data:

- the base year for estimation of constraints;
- the percentage of the base year consumption allowable;
• ozone-depleting potential (ODP) weighting factors for each controlled substance.

The spreadsheet objective was to calculate the allowable ODS demand so that it could be compared with forecast ODS demand to determine if forecast ODS demand had to be constrained as a result of the Montreal Protocol. While developed countries have specific base years upon which to key their phaseout programs (such as 1986 for CFCs), Article 5 Paragraph 1 developing countries have a 10-year grace period for phaseout. Under the conditions of the Protocol for Article 5 Paragraph 1 countries, base years will be no earlier than 1996. Consequently, the ODS quantities upon which to base future Protocol restrictions in Article 5 Paragraph 1 countries cannot be determined until 1997. This could impose a rather interesting constraint on countries that move aggressively to substitute alternatives for ODSs, as in doing so they may reduce the quantity of ODSs otherwise allowable under the Protocol.

Defining Technical Options and Assumptions

Technical options for implementation of the ODS phaseout have been thoroughly evaluated and published in the reports of the Technical Options Committee for the Montreal Protocol. On a global basis, these preferred technologies are similar for each ODS end use. The costs of each replacement technology and the timing of its introduction are critical factors impacting incremental costs.

Refrigeration and Air Conditioning

Six-hundred-and-eighty tons of CFCs were used as cooling fluids in Egypt during 1990 (Arif 1991). Usage was as follows:

• 20 percent to fill new refrigerators during manufacture.
• 65 percent to service refrigerators and related equipment.
• 15 percent to fill and service large units (such as chillers).

The primary replacement for CFC-12 in most applications was assumed to be HFC-134a, the alternative of choice by the majority of global refrigerator manufacturers. Replacement of CFC-11 in commercial large refrigeration units and chillers was assumed to be via retrofit with the hydrochlorofluorocarbon HCFC-123. New chillers were assumed to be designed to use HFC-134a. It was also assumed that HFC-134a and HCFC-123 availability would not constrain their application as alternatives beyond 1994.

The low cost of CFCs has discouraged conservation practices during servicing of refrigeration equipment. While it was assumed that improved servicing practices will develop as CFC prices increase in the future, CFC-12 service requirements were assumed to remain constant at an average of 50 grams per year CFC-12 per active refrigerator. A more basic assumption was that refrigerators in Egypt required a full replacement charge of CFC-12 once every five years. Recovery or recycling activities related to the refrigeration sector were forecast to directly reduce demand for CFCs, depending upon the strategy under analysis with the spreadsheet cost model.

Foams

Demand for CFCs in the foam sector derives from the ideal characteristics provided by CFCs as blowing agents for insulating foams in appliances, housing, and miscellaneous automotive applications and for flexible foams used for cushioning in mattresses and furniture. The effectiveness of insulating foams relates to the thermal conductivity of the blowing agent and the cell size of the finished foam. To date, no alternative has demonstrated comparable performance to the CFC blowing agents. Replacing up to 50 percent of the CFC-11 requirement with water has produced satisfactory insulation in a large portion of the refrigerators made in Europe. In the future, the short-term replacements are as-
3. Incremental Cost Methodologies for Phasing Out ODSs: Egypt

Assumed to be HCFCs (for instance, HCFC-141b) and hydrocarbons (for instance, cyclopentane). In the long term, application of non-ODS technology is considered likely.

For flexible foams, CFCs are currently being replaced with methylene chloride. By 1994 in Egypt, it is assumed that all cushioning needs will be replaced with substitutes that are not in kind or with methylene chloride blown foams.

**Solvents**

The demand for ODS solvents in Egypt is low in comparison to the demand for CFCs. A simple assumption is that all ODS solvents would be phased out via new cleaning or no-clean processes or through redesign of components requiring cleaning.

**Halons**

As with solvents, the domestic demand for halons in Egypt is small. Again, it is assumed that a phaseout will be feasible within the constraints of the Protocol. It is assumed that critical needs will be met from stockpiles of halon. The stockpile would be formed from halon recovered from existing installed equipment, retrofit with another extinguishant such as carbon dioxide (CO$_2$) or water.

**Outlining Alternative Strategies**

There are an infinite number of alternative strategies and scenarios which could be considered as likely for an ODS phaseout. ODS users serve a wide variety of applications. Some ODS users can benefit from immediate replacement of CFCs with less costly substitutes, while others would be severely impacted by an unduly rapid CFC phaseout. Country economic conditions directly impact ODS demand, technology development is uncertain, and Protocol constraints are likely to be tightened. In developing the strategy framework for Egypt, only the most likely high, baseline, and low economic growth rates were considered. Also considered under the Protocol were CFC phaseout rates from accelerated to allowable.

For the Egypt case study, nine cases were analyzed under the Protocol constraints in existence in 1992. Three phaseout timing alternatives were analyzed at three different economic growth scenarios.

The phaseout timing alternatives were:

1. **Allowable phaseout.** The transition to non-ODS substitutes is not encouraged in Egypt until forced under the terms of the Montreal Protocol (that is, complete phaseout by 2006).

2. **Accelerated phaseout.** The transition to ODS substitutes is accomplished at a rate consistent with the availability of technology and is fully accomplished by 1998.

3. **Optimum phaseout.** The rate transition to ODS substitutes results in the minimum country incremental cost. The details of this case were developed by iteration of the basic cost model. However, it was eventually determined that the timing for the optimum alternative lagged behind that of the accelerated alternative by approximately one to three years.

The following growth scenarios were used:

- **High**—global economic factors favor a GDP per capita growth in Egypt of better than 4 percent per year.

- **Reference**—most likely economic situation. The growth rate of gross national product (GNP) per capita is given in Table 3–1.

- **Low**—zero economic growth. The growth rate of GNP per capita is given in Table 3–1.

The growth assumptions were used primarily to develop ranges for country costs calculated under the different phaseout timing alternatives, thereby providing an estimate of sensitivity for each alternative to economic factors.
Recognizing Incremental Costs

The "Indicative List of Incremental Costs" included in Appendix VIII of the Protocol document was the primary reference for determining eligible incremental costs. In general, such costs are borne at the enterprise level as a direct result of Protocol phaseout requirements. Only those activities underway in 1989, when the Protocol went into force, were considered to be eligible for funding by the Protocol Multilateral Fund. The forecasts of unconstrained and actual ODS demand established useful benchmarks and provided indicators for areas in which incremental costs were likely to be incurred. Only those cost items judged to be significant were included in the final analysis.

Net incremental operational costs which are expected to qualify for grant financing through the Multilateral Fund were also included in the analysis. Such costs are net of savings and are generally related to the following items:

- cost of non-ODS raw materials;
- labor and supervision; and
- plant efficiency.

Significant projects which were considered to qualify for funding through the Protocol Multilateral fund and which were incorporated in the Egypt case study analysis were:

- retrofit of chillers and large refrigeration units;
- retooling of domestic refrigerator manufacture;
- redesign and retooling of water cooler manufacture;
- facilities to make HFC-134a compatible compressors;
- plant improvements for safe use of methylene chloride;
- high pressure foam machines for rigid foams;
- technical assistance and retraining;
- public awareness programs to reduce ODS use;
- institutional capacity building;
- improved monitoring of ODS imports;
- safe replacement of CFCs with liquefied petroleum gas (LPG) in aerosols;
- recovery or recycling equipment and programs;
- reclamation of recovered CFCs; and
- establishment of a halon bank.

Estimating Obsolescence Costs

Costs associated with premature replacement of equipment designed for use of ODS represents a significant cost burden which must be borne by ODS equipment owners. It also represents a direct cost burden to the economy of a country and is therefore considered to be an incremental country cost in the Egypt case study. Whereas the incremental capital and operating costs for the transition to non-ODS for Egypt are estimated to be about $50 million, the early obsolescence costs could approach $200 million, depending on the phaseout strategy followed by Egypt. The major item subject to early obsolescence is the household refrigerator. If it is assumed that Egypt continues to import or manufacture CFC refrigerators until forced to stop under the terms of the Montreal Protocol, essentially all refrigerators in Egypt would become obsolete and would require replacement within five years (that is, whenever they fail).

Figures 3-1 and 3-2 compare refrigerator populations for two strategies and clearly illustrate the effects of an early phaseout on the refrigerators subject to early obsolescence in 2010.

Estimation of obsolescence costs for Egypt's refrigerator fleet required estimates of the following:

- total number of refrigerators in service in the base year;
- annual production of CFC refrigerators;
3. Incremental Cost Methodologies for Phasing Out ODSs: Egypt

- annual production of non-ODS refrigerators; and
- average useful life of refrigerators.

Using spreadsheet methodology, the numbers and average ages of the fleets of CFC and non-ODS refrigerators were calculated for each year through 2010 under each phaseout strategy. It was then assumed that all such CFC refrigerators would become obsolete in 2010 and the increment cost for obsolescence could be calculated based on the average CFC refrigerator age. It was also assumed that such refrigerators had depreciated on a straight-line basis over 20 years.

**Model Description**

**General**

The model used to simulate costs for the Egypt case study was developed as a single spreadsheet. While it might have been feasible to use the same modeling concept with multiple spreadsheets, laptop memory and spreadsheet recalculation speed appeared to impose severe limitations. The simplicity of a single spreadsheet offered more options for iteration of a wide variety of strategies prior to full definition of the final cases included in the country study. It was also possible to quickly eliminate insignificant considerations by simple what-if analyses.

**Structure of the Model**

- Key assumptions for the strategy under study are GNP and population growth, rate of transition to alternative substances or processes, total phaseout investment and operational costs, and miscellaneous constants. The impact of recovery or recycling operations on CFC supplies and on investment requirements are also estimated.
- A forecast of ODS demand is then prepared using these assumptions. Estimates of total ODS demand and ODP contribution are made to compare with Protocol constraints.
- The current constraints imposed by the Protocol are known. The amount of ODS allowable under the Protocol for each substance is calculated for comparison with the ODS demand forecast. The allowable consumption is then calculated to estimate the ODS consumption forecast (for example, if the allowable consumption exceeds the calculated demand, the consumption is taken to be equal to demand; otherwise, consumption is taken to be the allowable level).
- Assumptions are made concerning the alternative strategies and scenarios.

**Calculation Flow**

Forecast demand is projected from a historical base (pre-1991) of data using growth scenarios and other key assumptions appropriate to the case being analyzed. The population of various types of refrigerators and the need for recovery or recycling machines to service installed equipment is estimated. Demand is adjusted to reflect the ODS involved. Next, forecast demand is compared to that allowable under the Protocol and the forecast is constrained, where necessary, to estimate ODS consumption. Capital and operational cost estimates were prepared off-line to reflect the magnitude and timing of the interventions needed to accommodate the forecast of ODS consumption. Finally, all costs are accumulated year by year, and the totals are discounted at 10 percent to the base year to estimate the net present value of the cost to Egypt for the phaseout strategy under analysis.

**Summary of Country Incremental Costs**

**Cost to Egypt**

The methodology facilitated tabulation of each cost component year by year. Three categories of incremental costs were developed for each case studied—capital, operational, and early obsolescence. A set of three
potential country growth rate scenarios was analyzed for each phaseout alternative (see Table 3-1). The high and low growth rate cases were then used to establish a probable range for incremental country cost for each strategy (see Table 3-2).

**Sensitivities**

The spreadsheet technique provides a convenient process for many types of “what-if” sensitivity analyses. Most analyses are strongly influenced by one or more key assumptions, and the degrees of freedom are large. In the Egypt study, as in other similar country studies, however, the effect of refrigerator obsolescence overwhelmed most other contributors to country phaseout costs. Therefore, assumptions impacting obsolescence required careful scrutiny before inclusion in the final model. Growth scenarios, as illustrated in the above-mentioned figure, had only minor impact on total phaseout costs and had no significant impact on the ordering of the alternative strategies. Consequently, the growth scenarios were used mainly to develop range estimates.

**Recommending Policies**

**Overall Strategy**

Based on the analysis of costs, the optimum overall strategy for ODS phaseout in Egypt was one which followed the phaseout in developed countries by one to two years but where cost-effective phaseouts were accomplished immediately (for instance, in the case of aerosol conversion to LPG propellant). There are, however, practical limitations on how fast such phaseouts can be accomplished. Limitations relate to the availability of technology and licenses, the lead time for construction of new facilities, as well as the availability of foreign exchange and financial resources provided through the Multilateral Fund. In addition, flexibility must be maintained throughout the phaseout to meet unforeseen developments.

**Policy Instruments Used**

The following policy instruments were proposed for the Egypt Country Program:

- A panel of industry and government leaders, referred to as the “Ozone Panel,” to provide a consultative role in the formulation and promulgation of specific policies to be incorporated into the National Ozone Policy. The recommended policies include voluntary agreements with industry to establish specific end-use bans consistent with the overall objectives of the ODS phaseout and to recommend timing of ministerial decrees to back up the agreements.

- A licensing system for ODS users which encourages environmentally responsible ODS handling practices and restricts distribution to users qualified through approved training programs.

- A formal ODS import monitoring system as required to meet Protocol conditions.

- Selective price increases through import taxes to minimize the financial cost for substituting alternative materials or processes for the ODSs used in key industries.

**Impact on Country Incremental Costs**

Recommended policies in the Egypt Country Program were primarily designed to facilitate an effective phaseout of ODS and will only impact country costs by delaying the phaseout if not adopted promptly and effectively. Monitoring ODS users and licensing of ODS handlers are examples where action is needed to assure that country phaseout goals are not contravened.

**Lessons on Methodology**

**Recommendations for Future Models**

This case study, and other similar studies, revealed that the most cost-effective strategy involves phaseout of ODS on a schedule which is significantly more accelerated than that
required under the Protocol. The basic question is, therefore, how best to accomplish this accelerated phaseout given the existing infrastructure and available financial resources. The development of models has a role in identifying the country ODS consumption patterns and future needs and the elements of potential costs. The need for optimization does not appear to exist, as the most practical cost-effective accelerated phaseout is the optimum one. Models are also of value as a mechanism to mobilize local involvement in the decisionmaking through identifying data needs, structuring “what-if” strategies, and developing ownership over the final results.

Other lessons apply to the methodology and suggest that for the best results, the model should be logical, easy to apply in the field, and easy to learn. Internally, macros should be used to develop all results to assure consistency and to avoid mistakes.

Spreadsheet models often reflect the personality of the model-builder and can contain hidden information or assumptions. There is also a common tendency to overstate the accuracy of such models even though they contain hundreds of interactive assumptions. A good way to overcome such potential problems is to identify the key variables in an iterative process and then to analyze why they are important and, if necessary, to make appropriate adjustments to the model structure. In the final analysis, the spreadsheet should only guide the study of the problem and support the conclusions and recommendation.

Areas for Improving Cost Calculations

Unit Prices for ODS and Alternatives

Basic assumptions of unit prices for materials imported into developing countries have major impacts on the estimated operational costs for an ODS phaseout. A methodology is needed for estimating future prices for ODSs and replacement materials. One way to do this would be to enlist the support of multinational suppliers or distributors to develop a tabulation of prices of key materials free-on-board key global ports (such as Rotterdam, Marseilles, Houston, San Francisco, Tokyo, and Singapore). Freight costs would then be estimated independent of product type for use in specific country studies and projects for consideration by the Multilateral Fund.

Unit Abatement Costs

The methodology for developing benchmark unit abatement costs needs modification to reflect capacity effects. It would be desirable to have unit abatement costs which can be compared directly between similar projects and between countries so that modeling of capital cost estimates can take full advantage of experiences on projects with technological similarities but at different capacities. A suggested procedure would be to adjust the incremental capital cost in a unit abatement cost baseline for a similar operation by the 0.6 power of the baseline capacity divided by the actual capacity for the project under evaluation.

Example:

Data

Actual capacity of plant = 350,000 appliance units per year
Unit abatement cost for project to convert XYZ plant to non-CFC foams = $27.32/kg ODS saved
“Standard” plant capacity = 1,000,000 appliance units per year
Baseline unit abatement cost for similar foam project in a “standard” plant = $13.75/kg ODS saved

Calculation

Estimated unit abatement cost for XYZ project = \((\frac{1,000,000}{350,000})^{0.6}\) x 13.75 = $25.81/kg ODS saved
**Project Cost Effectiveness**

The project costs and ODS savings for the XYZ project are comparable ($27.32 vs. $25.81) to those for a "Standard" project even though the unit abatement cost is almost two times higher than the baseline unit abatement cost ($13.75).

A constraint would be that the adjustment should only be made on the basis of discrete operating units, such as manufacturing lines. If the XYZ project was to convert two similar manufacturing lines, the calculation would be as follows:

Estimated unit abatement cost for XYZ project = (1,000,000/175,000)$^{0.6} \times 13.75 = \$39.12/kg ODS saved

The conclusion would then be that for some undefined reason, either the XYZ project was possibly underestimated, the scope was not directly comparable to the "standard" project, or country differences yielded significant economies to the XYZ project.

**Bibliography**


Table 3-1: Growth Assumptions for Reference Demand

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Table 3-2: Accelerated, Optimum, and Allowable Phaseout

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Evaluating the Incremental Costs of Complying with the Montreal Protocol: Discussion of a Framework Developed for Thailand

Vikram Widge, Mark Radka, and Thomas Dillon

Background

THIS CHAPTER IS BASED ON WORK PERFORMED in conducting the country study on the phaseout of ozone-depleting substances (ODSs) in Thailand. It presents an analysis of ODS consumption in Thailand and recommended certain national policies and actions to meet the global ODS phaseout.

The study was conducted for the Department of Industrial Works of Thailand's Ministry of Industry by a three-part team consisting of ICF Incorporated, SIAMTEC International, Ltd., and the Thailand Development Research Institute Foundation, and was completed in September 1992.
Thailand’s consumption of ODSs is not large by world standards, but until recently it had been growing rapidly. On an ozone-depleting potential (ODP)-weighted basis, imports in 1991 were 10,044 weighted tons, indicating a per capita consumption of 0.16 kg per person for chlorofluorocarbons (CFCs) and halons and 0.02 kg per person for 1,1,1-trichloroethane (methyl chloroform, or MCF) and carbon tetrachloride (CTC). Major use sectors include solvent cleaning in the electronics and metals industries, domestic and commercial refrigeration (both original manufacture and servicing), vehicle and building air conditioning, production of rigid polyurethane insulating foam, and fire protection.

Calculating Country Incremental Costs

Introduction to the Methodology

Incremental costs for the phaseout of ODSs were calculated using a simulation model called COSCOM (the Country Study Cost Model) that was developed for the Thailand Country Study.\(^1\) We chose to use a simulation model because simulation provides a tool by which to model systems that are not necessarily amenable to a mathematical representation and, therefore, to standard optimization techniques like linear programming. Simulation was appropriate for this analysis because the optimization of the phaseout plans and costs had to be performed over multiple end uses with diverse characteristics.

The incremental cost of phasing out ODSs in Thailand is the difference between costs incurred under a chosen phaseout strategy and costs corresponding to the series of actions that would have occurred in the absence of the Montreal Protocol (the “baseline”). Incremental costs can be either imposed or voluntary. Imposed costs include increases in chemical prices brought about by Protocol-induced supply shortages; because Thailand does not produce ODS itself, these costs are faced whether or not Thailand complies with the Protocol. Voluntary costs include the cost of new equipment needed to produce goods without using ODSs; these costs are incurred only if Thailand complies with the Protocol.

In ICF Incorporated’s original version of COSCOM, the chemical cost component of control costs was not adjusted to account for the projected rise in the price of ODSs or the fall in alternative chemical prices. Instead, we used constant ODS and substitute prices, partly because price projections were tenuous, at best, at the time the study was conducted. ODS prices are rising because the phaseout is making the chemicals scarce, not because the resource or social costs of production are changing. Although scarcity will force consumers to pay more for ODS-based products, extra costs paid by consumers are transfer payments and not true social costs in a global sense. Money is being transferred from consumers to producers or importers, providing them with supranormal profits, but no additional resources are being expended in producing ODSs.\(^2\) Incremental costs are the costs incurred over the baseline; in the baseline, there is no phaseout, and ODS prices do not rise.

Thai decisionmakers, however, weigh the present and projected future prices of ODS and non-ODS technologies when making conversion decisions. We believe that the most accurate way to calculate incremental costs is to determine the sequence of investments that would occur under different

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1. Although some of the substitutes of CFCs, halons, and 1,1,1-trichloroethane are also ozone depleters, in this chapter we use ODS to refer only to the chemicals being phased out per the London Amendments to the Montreal Protocol.

2. An ODS tax can be designed to redistribute transfer payments from ODS producers and importers to the government. In essence, this tax will transfer to the government any supranormal profits resulting from price increases that are caused by production restrictions.
phaseout strategies using unit abatement costs that have variable ODS and substitute prices, and compute the costs relative to a non-Protocol baseline. This approach was made explicit in later versions of our model, and was accounted for in a rough way in the reference strategy used in the Thai study.

The principal inputs to COSCOM were (1) projections of unconstrained ODS demand, (2) phaseout schedules with interim targets set by the Montreal Protocol, and (3) the costs and characteristics control options and substitute technologies. Together these inputs determined the initial scenario, the set of exogenous factors that affected the analysis but over which Thai decisionmakers were expected to have little control. The principal outputs were the sequence of actions required to meet phaseout targets and the incremental cost of these actions. The costs were computed following guidelines put forth by the World Bank for the Executive Committee of the Multilateral Fund. The following sections describe in greater detail the model's inputs, the alternative phaseout strategies modeled, and the results of the analysis.

Unconstrained Demand

Projections of unconstrained demand for CFCs, halons, and MCF in the air conditioning, refrigeration, solvent cleaning, aerosol, foam, and fire protection sectors were the starting point for the analysis. Projections for each sector were based on 1991 ODP-weighted ODS consumption data and on growth rates derived from economic data from Thai industries. Demand projections were truncated in 2015, the end year for the analysis.

For most domestic sectors, ODS consumption was projected to grow at the same rate as projections of gross domestic product (GDP) made by the Bank of Thailand (5.7 to 8.6 percent per year). Mobile air conditioners (MACs) and domestic refrigerators were notable exceptions. For these sectors, pooled cross section and time-series statistical regression analysis was used to estimate growth rates for ODS demand. This added complexity was warranted because: (1) the premature retirement or retrofitting of these items—a critical component of overall costs—is very sensitive to projections of total stock in the final years of the phaseout; (2) MACs and domestic refrigerators are likely to account for a significant portion of the growth in total ODS use; and (3) reducing ODS use in MACs and domestic refrigerators will account for a substantial portion of the costs of the phaseout.

For export sectors, two sets of growth rates were used to project consumption. Growth in exports of electronics was assumed to be 10 percent per year for the first three years of the projection (based on historical trends), falling to 5 percent per year thereafter. Growth in other exports sectors was assumed to be 5 percent per year through 1995, falling to 3 percent per year thereafter. Growth was expected to stabilize at the lower rates in a few years as Thai export industries reach their potential in world markets.

In the demand forecasts for the refrigeration and air conditioning sector, manufacturing demand was separated from servicing demand. These were tracked separately in the simulation because real-world controls affect them differently. For example, as increasing numbers of newly installed MACs are charged with HFC-134a, the demand for CFC-12 at installation will dwindle quickly in the MACs sector. The demand for CFC-12 at service, however, depends on the stock of existing MACs and will decline gradually, disappearing only after the last vehicles with CFC-12 MAC systems are retrofitted or retired. For this reason, it was important to maintain the distinction between manufacturing and charge demand, versus servicing demand in the model.

Phaseout Schedules

Also figuring in the analysis was the Montreal Protocol-imposed phaseout schedule, which expresses interim and final
consumption ceilings as percentage reductions from the consumption levels in a base year. The Thailand analysis used the pre-Copenhagen Montreal Protocol control schedule for CFCs, halons, and MCF. Because COSCOM was not designed to evaluate the impact of a hydrochlorofluorocarbon (HCFC) phaseout, no HCFC phaseout schedule was defined.

Phaseout plans for those strategies modeled were required to meet the 2010 to 2015 phase-out, as well as interim caps and other constraints, such as the ban on exports to developed countries of products containing ODSs imposed during the 10-year grace period for meeting Protocol targets.

**Control Options**

The last set of model inputs was the controls available to reduce ODS consumption in each sector. Controls were based on the authors’ appraisal of the alternatives and control technologies likely to be available in each sector during the period of the analysis. Controls used in the study were of four types:

- **Substitution controls.** When substitution controls are implemented, new equipment is manufactured with alternative chemicals instead of ODSs (for instance, new refrigerators made with HFC-134a instead of CFC-12; foam blown with HCFC-141b instead of CFC-11).

- **Recovery controls.** Recovery controls reduce ODS use through recovery or recycling of ODSs at service or disposal. Recovery controls only apply to equipment with a continuing demand for ODSs at service. Recovery controls reduce ODS use, but do not eliminate it.

- **Retrofit controls.** Retrofit controls replace ODSs with alternative chemicals in existing equipment. (that is, CFC-11 chiller converted to use HCFC-123). Like recovery controls, retrofit controls only apply to equipment with a servicing demand for ODSs.

- **Early retirement controls.** Early retirement controls cause existing equipment to be retired prematurely and replaced with new equipment using alternative chemicals. Early retirement controls only apply to equipment with a servicing demand. Early retirements typically occur in end uses where a retrofit is technically impossible or costs more than the value of the equipment.

Different types of controls were allowed to interact in a number of ways. For example, it was assumed that recycling always begins in an end use at least as early as the beginning of conversion to alternative chemicals. As a result, implementation of substitution controls triggers recycling if recycling was not already occurring in the end use. Recycling has the effect of decreasing the demand for virgin ODSs and obviating the need for other controls. Conversely, early retirement and retrofit controls decrease the remaining stock of equipment being serviced, and diminishes the reductions achievable through recycling.

The following market characteristics were specified for each control in the model:

- **Date of earliest availability:** the year in which the alternative was expected to become commercially available. In no strategy modeled could a control be implemented before its date of earliest availability.

- **Eventual market penetration:** the percentage of the unconstrained ODS consumption in the sector that the alternative was expected to displace once it reached its full market potential. The sum of the maximum market penetrations for all of the substitution controls in a sector was set equal to 100 percent so that a phaseout could be achieved.

- **Years to reach maximum market penetration:** the number of years it would take for a control, once it was introduced, to reach its maximum possible market penetration. This parameter reflected
fact that the transition to a substitute is never instantaneous.

- **Per kilogram cost to industry**: the incremental cost per kilogram of avoided ODS use that industry would incur by implementing the control. This included projected changes in capital, operating, and chemical costs.

- **Per kilogram cost to consumers**: the incremental cost per kilogram of avoided ODS use that consumers would incur. This included changes in the energy efficiency of new equipment, changes in the costs of maintenance and service, and a portion of the retooling costs in some sectors.

- **Premature retirement and retrofit costs**: the incremental cost per kilogram of avoided ODS use expected to be incurred as a result of retrofits or early retirements. This was either the cost of the retrofit or the cost of having to pay for new equipment prior to the normal replacement schedule on a per kilogram of ODS avoided basis.

Technical data on control options were obtained from ICF Incorporated's technical experts, United Nations Environment Programme technology assessments, surveys of manufacturers, and trade literature. In total, the model contained information on 41 alternatives in seven ODS-using sectors. Although this was fewer than the number of alternatives actually or potentially available, particularly in sectors like solvent cleaning, many alternatives share enough cost characteristics that the modeled alternatives served as proxies for related alternatives with no appreciable loss of accuracy in a country-level analysis.

**Phaseout Strategies Examined**

Given the input data described in the preceding sections, COSCOM was used to calculate total incremental costs for four phaseout strategies: accelerated, allowable, forward-looking, and reference.

- **Accelerated**: The accelerated strategy assumed that all substitution and recycling controls were implemented as soon as they became commercially available, without regard to cost. If the remaining ODS demand for servicing existing refrigeration and air conditioning equipment was high enough that phaseout targets were violated, retrofits and early retirements were implemented, from least expensive to most expensive, until compliance is reached each year. This strategy would result in the fastest ODS phaseout.

- **Allowable**: The allowable strategy assumed that Thailand would take the minimum action required to meet yearly phaseout targets. In each year in the simulation, controls were implemented to meet immediate phaseout targets with the minimum marginal cost but without regard to possible future costs. In contrast to the accelerated strategy, no action was taken that was not directly forced by the constraints of the Montreal Protocol. Controls were implemented in order of increasing expense and were delayed for as long as possible, being implemented only when needed to meet the phaseout schedule. By delaying implementation of substitution controls, expensive retrofitting and early retirement were required after the phaseout date.

- **Forward-looking**: The forward-looking strategy was a variation of the allowable strategy, in which the future costs of actions were taken into account by the model in selecting the controls. As in the allowable strategy, most controls were delayed for as long as possible while meeting the constraints imposed by the Protocol. The forward-looking strategy, however, recognized that decisions in the refrigeration and air conditioning sector would consider the trade-off between delayed implementation of substitution controls and increased early retirements. Because the acceleration of substitution
Cont. Jls would reduce the stock of ODS-using equipment requiring servicing after the phaseout date, the need for retrofits and early retirements was reduced. This strategy, therefore, lowered the present value of total phaseout costs as compared to the allowable strategy.

- **Reference.** ICF Incorporated modeled this strategy to follow closely the phaseout actions recommended to the Thai government, most of which were later adopted in the National Phaseout Policy. Like the national policy, this strategy assumed that implementation of some alternative technologies would occur more rapidly than the allowed or forward-looking strategies because of global trade and environmental pressures. In part, this device allowed us to circumvent the issue of variable chemical prices in the unit abatement costs. A user-defined strategy was also deemed necessary because several criteria could be important to a risk averse decisionmaker forming national phaseout policy, yet could be difficult to quantify in a modeling framework. These include:
  
  - human health and environmental benefits resulting from an earlier phaseout;
  - competitive advantages from manufacturing facilities that use state-of-the-art technologies;
  - the value to producers of exports to markets where consumers prefer products containing ODS substitutes (especially if ODS-containing products must be labeled);
  - international goodwill fostered by Thailand’s taking an environmentally proactive position; and
  - the potential for earlier phaseout dates mandated by the parties to the Protocol.

The reference strategy was based on the results of the other strategies, and represented a compromise between the accelerated strategy and the allowable or forward-looking strategies. The reference strategy called for an aggressive phaseout but exempted servicing use for refrigeration and air conditioning equipment. Enough ODS use was allowed for servicing after the phaseout for new equipment to prevent the expensive retrofits and early retirements that would otherwise be required.

**Calculation of Unit Abatement Costs**

The unit abatement cost of each alternative technology modeled, that is, the cost per kilogram of ODS reduction achieved, included incremental capital costs, variable costs, and nonrecurring costs. Costs were incremental because they were defined relative to the baseline (that is, incremental to the cost of continuing to use ODSs). As a result, the aggregate costs estimated in the analysis were the net social costs of the phaseout.

Because Thailand has no ODS producers, incremental phaseout costs can be incurred only by (1) manufacturers who produce ODS-containing equipment or who use ODS in the manufacturing process and (2) consumers of products made with or using ODSs. Hence, costs in the model were divided into industry costs and consumer costs.

Because industry can be expected to pass some of its increased costs to consumers in the form of higher prices, we sought to avoid double counting costs in the simulation. Costs were evaluated at the point where they were first incurred. We believed this to be appropriate because various factors could limit the scope of price increases by manufacturers in the near term. Where it was anticipated that some pass-through would occur, the burden of incremental costs was split between manufacturers and consumers to avoid double counting.

Examples of specific industry costs modeled were:

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3. Depending on the alternative and the sector, costs can either be positive or negative, where negative costs indicate economic benefits of phasing out ODS use.
• Capital costs, primarily the incremental costs of new or modified facilities and equipment. An example in the model was the cost of new technologies, such as an aqueous cleaning machine assumed to replace a CFC-113 vapor degreaser or a new off-site recycling plant.

• Variable costs or operating costs, such as raw materials, labor, and energy expenses. Examples of specific variable costs modeled were increased chemical costs, increased labor charges associated with improved charging and maintenance practices, and increased electricity and water consumption associated with the use of alternatives.

• Nonrecurring costs or fixed costs incurred on a one-time basis. Examples used in the model included personnel retraining costs and research and development for adapting new technology.

Examples of costs borne exclusively by consumers included:

• Incremental operating costs such as increased electricity costs associated with operating an HFC-134a refrigerator.

• Forced retrofits or early retirement costs such as those arising from shortages in the supply of ODSs. These would force consumers to bear the costs of retrofitting or retiring their mobile air conditioners and refrigerators earlier than necessary.

The costs associated with each control in the model were not consistent over time. Some nonrecurring costs, such as capital costs, R&D, and training, were expected to be incurred once for all units on a plant basis, while other nonrecurring costs would typically occur only once on a unit basis, such as the cost of a compressor for an HFC-134a refrigerator. Incremental operating costs (energy, labor, chemical costs, and so on) would be incurred over time. These disparate cost profiles for individual controls were made comparable on a per-kilogram basis in COSCOM by “levelizing” the cost components. Levelizing the costs—that is, creating a smooth annualized stream from the present value of the costs over time—was necessary to avoid double discounting when total phaseout costs were calculated.

Calculation of unit abatement costs also accounted for the fact that not all end uses would have the same profile of chemical use. Some end uses modeled would be expected to have only a one-time demand for an ODS (for example, HFC-134a used to charge refrigerators manufactured for export), some end uses would have an annual demand (CFC-113 use in an electronics cleaning facility), and some end uses would have uneven demand over time, which implies it was either not constant on an annual basis or that would occur only periodically. Examples of the latter include refrigerators and MACs that in the simulation were “charged” with HFC-134a initially and then serviced every few years, depending on their respective servicing frequencies.

Unit abatement costs were calculated assuming a discount rate of 12 percent.

**Estimating Premature Retirement and Consumer Costs**

In a country such as Thailand, if the constraints imposed by the Montreal Protocol do not allow sufficient quantities of ODS to be imported to meet the total servicing demand for refrigeration and air conditioning equipment in a given year, the excess demand must be eliminated by retiring or retrofitting a certain fraction of the equipment stock. In the model, enough retrofits and retirements were implemented when necessary so that ODS demand equaled ODS supply. Retrofit and retirement controls reduce future demand as well because they reduce the stock of equipment that will need service in the future. The incremental costs associated with retrofits and premature retirement were calculated based on the actual stock predicted to be retired or retrofitted.
The calculated reductions achievable through retrofits and premature retirements and the costs associated with these activities depended on projections about the size of the equipment stock and the number of units requiring service. COSCOM estimated these factors using the servicing frequency for the end use and the distribution of the stock by age or vintage. The vintaging information was also used to adjust the stock distribution when premature retirements or retrofits were undertaken. The servicing frequency was made a variable that could be adjusted for sensitivity analyses.

Retrofits and early retirements were assumed to occur only when equipment required service. As a result, retrofits and retirements in the model that occurred after the phaseout date were made to take place over a period of time based on the servicing frequency assumed in the end use. Some studies we have seen assume that all remaining equipment will be retired or retrofitted as soon as ODSs are no longer available (that is, in 2010). This can result in a substantial overestimation of costs because (1) equipment without further need of service can be normally retired and (2) retrofit and retirement costs incurred after the phaseout year will be discounted more than those incurred in the phaseout year. More realistically, equipment should be retired or retrofitted in a simulation (and in the real world) only when it requires servicing. The only way in which all CFC-using equipment would be retired during a single year is if it all required annual service. This is not the case for refrigerators, which are serviced infrequently, and which are usually the most expensive item to retire prematurely per kilogram of ODS use avoided. Retiring all refrigerators as soon as ODSs are no longer available results in a substantial overestimation of the costs of premature retirement. The same is true in the case of retrofitting MACs.

Technical Options and Economic Assumptions

Technical options and economic assumptions about the alternative technologies used in the model are summarized in Table 4–4. These were obtained from a variety of sources, including trade literature, government agencies, intergovernmental organizations, chemical suppliers, ODS users, trade associations, independent consultants, and academics. The data collection was as exhaustive as possible within the existing cost constraints.

Results and Recommendations

This section summarizes the results of the study as well as ICF Incorporated’s recommendations for the phaseout of ODSs in Thailand.

Summary Incremental Costs—1991 to 2010

As noted above, incremental costs are the costs above those that would be incurred in the absence of the Montreal Protocol provisions. Costs for each strategy discussed below are the present value of incremental costs predicted to be incurred between 1991 and 2010. Estimates do not include the costs associated with promotion of the ODS phaseout, training, and institutional changes. Costs for the four strategies modeled are summarized in Figure 4–1 and described below.

Accelerated Strategy

The incremental cost of complying with the Montreal Protocol under the accelerated strategy was estimated to be $471 million. Over 94 percent of the costs were attributable to phasing out domestic ODS use. About 90 percent of the costs would occur in the air conditioning and refrigeration sectors, primarily because of their high per-kilogram control costs. Because conversion to
alternatives was predicted to occur early in this strategy, substitution costs were incurred over the entire range of the analysis. Costs from retrofits and premature retirements, however, were minimal. Retrofit costs accounted for only 6 percent of all domestic costs. The accelerated strategy would result in about 618,000 tons of avoided ODS use at an average cost of $763 per ton.

Allowable Strategy

The incremental cost of complying with the Montreal Protocol under the allowable strategy was estimated to be $431 million, $40 million less than under the accelerated strategy. Many of the costs would be incurred far into the future, which reduced their present value when they were discounted. About 96 percent of the cost was attributable to phasing out domestic ODS use. Air conditioning accounted for 49 percent of total domestic costs and refrigeration for another 47 percent. The costs for these sectors was high primarily because of retrofits and premature retirements predicted to occur during the period 2005–2015. Although the total cost of the allowable strategy was similar to the total cost of the accelerated strategy, a much higher percentage of the cost came from retrofits and early retirements. In the allowable strategy, 76 percent of the costs came from retrofits and early retirements arising from the late implementation of substitution controls. Although the magnitude was similar, the distinction is important for equity reasons because retrofit and retirement costs would primarily fall on consumers. The allowable strategy would result in about 542,000 tons of avoided ODS use at an average cost of $796 per ton.

Forward-Looking Strategy

The incremental cost of complying with the Montreal Protocol under the forward-looking strategy was estimated to be $282 million. This was $189 million less than under the accelerated strategy and $149 million less than under the allowable strategy. Although the strategy was similar to the allowable strategy, the optimization of refrigeration and air conditioning controls limited retrofits and early retirements to 17 percent of domestic phaseout costs. The forward-looking strategy would result in about 550,000 metric tons of ODS use avoided at an average cost of $512 per ton. This was the least expensive strategy modeled for Thailand, both in terms of the total costs as well as the cost per kilogram.

Reference Strategy

The incremental cost of complying with the Montreal Protocol under the reference strategy was estimated to be $418 million. About 94 percent of the cost was attributable to phasing out domestic ODS use. Particularly important were the refrigeration and air conditioning sectors, which had high per-kilogram control costs and account for a significant percentage of total ODS consumption in Thailand. Under this strategy, phaseout of all ODS use would occur by January 1, 1997, with the exception of CFC use for servicing air conditioning and refrigeration equipment existing at that time. CFC use for servicing equipment would continue until 2010 if the reference strategy were followed. The reference strategy would result in about 605,000 metric tons of avoided ODS use at an average cost of $690 per ton.

Sensitivity Analyses

The estimated cost of the ODS phaseout was sensitive to a number of assumptions including projections of unconstrained ODS demand, technical assumptions underlying the costs of ODS control options, chemical prices, discount rate, and constraints imposed by the Montreal Protocol. We changed the phaseout scenario by varying some of these in different model runs.

Unconstrained ODS Demand Projections

Projections of unconstrained ODS demand were initially made under low and high
economic growth rate assumptions for Thailand. Given the narrow separation between the two projections provided by the Bank of Thailand, we concluded that the cost estimates were not particularly sensitive to projections of unconstrained demand and only the low growth projections were used.

**Technical Assumptions Underlying ODS Control Options**

No sensitivity analysis was performed for the technical assumptions underlying ODS control options because the assumptions used were based on actual data available from Thailand or documented from investment projects undertaken in other developing countries.

**Chemical Price Projections**

Changes in the prices of ODSs and substitute chemicals attributable to the global phaseout will have substantial impacts on the costs faced by industry and consumers. As noted above, we originally modeled the Thai situation using constant real chemical and substitute prices. A more sophisticated approach would have been to develop the reference phaseout strategy using unit abatement costs based on chemical price projections. The incremental costs of the strategy would be calculated using unit abatement costs reflecting base year ODS prices. This methodology allows for the development of a realistic phaseout scenario without omitting the imposed costs of the Protocol.

Although using a price projection can change the timing of controls to a certain extent, the impact on total incremental costs is generally modest for two reasons. First, significant changes in costs are usually associated with changes in the number of retrofits and premature retirements. However, rising chemical prices are not likely to change these numbers significantly, since substitution controls in serviced end uses generally occur as soon as possible, even with constant chemical prices. Second, incremental costs, as we have construed them, are based on base-year chemical prices, even if the controls are chosen using price projections.

**Discount Rate**

The choice of a discount rate has an important impact on incremental costs because the present value of costs for any specified strategy will increase as the discount rate is lowered. All things being equal (ceteris parabus), incremental costs can be substantially higher if a lower discount rate is used. The 12 percent real discount rate used in the base case was essentially the private rate of return in Thailand at the time of the study. ICF Incorporated examined the results using an alternative discount rate based on the public rate of return. In June 1991 the medium term rate for government-issued bonds in Thailand was 11 percent, and the inflation rate was 6 percent, yielding a 5 percent real rate of return for public investments. This was the discount rate used for purposes of sensitivity analysis. A summary of results based on this rate is presented in Table 4-2.

As expected, the reference and accelerated strategies showed an increased cost but no change in the total amount of ODS used vis-à-vis the results calculated using a 12 percent discount rate. The same was true for the allowable strategy. This outcome arose because the lower discount rate did not change the ordering of the controls in the case of Thailand, and therefore, the same sequence of controls was predicted as when using a 12 percent discount rate. The forward-looking strategy, however, showed an increase of about 5,000 tons of ODS avoided, indicating a change in the order in which controls were implemented. As shown in Table 4-2, a substantial decrease in the percentage share of predicted premature retirement and retrofit costs also occurred with a lower discount rate; this indicates that these costs, although they
would be incurred 15 to 20 years in the future, became more important.

**Constraints Imposed by the Montreal Protocol**

Because the Copenhagen meeting of the parties was imminent at the time the study was concluded, ICF Incorporated analyzed the sensitivity of costs to changes in the constraints imposed by the Montreal Protocol. With no prior knowledge of changes in interim targets, we examined the sensitivity of total incremental costs to different phaseout dates, keeping all applicable interim targets the same as for the 2010 phaseout. The costs for each approach were recalculated assuming different phaseout dates, that is, dates by which all import and use of ODS, including ODS required to service existing air conditioning and refrigeration equipment, was no longer possible.

This analysis was conducted in case the phaseout dates were revised in Copenhagen, in which case the new dates would be binding on Thailand. The same constraint would apply if Thailand unilaterally adopted a schedule that called for a faster phaseout.

If the date of the ODS phaseout were earlier than 2010, the costs incurred under the forward-looking, allowable, and accelerated strategies would increase. Even though an accelerated strategy would achieve a phaseout of all ODSs by 1996, except for ODSs required to service existing equipment, a phaseout date of 1997 that did not permit use of ODSs even for servicing uses after that date would result in substantially higher costs because retrofitting or prematurely retiring existing equipment would start in that year. Premature retirement and retrofit considerations would become important sooner; and the conversion to alternatives, instead of being pushed off until later in the decade, would have to begin earlier. Because the phaseout date, by which no use of ODS is allowed (not even for servicing existing equipment), was made a variable in the model, it was easy to compare the costs for different strategies, assuming different ultimate phaseout dates.

Figure 4-1 shows the costs associated with the three strategies for phaseout dates ranging from 1997 to 2010. The costs for a 2010 phaseout were the same as those presented earlier. The top panel in the figure shows the sensitivity of costs to the phaseout date, assuming a 12 percent discount rate, and the bottom panel shows the sensitivity, assuming a 5 percent discount rate. A lower discount rate not only results in substantially higher costs overall, but also results in the allowable strategy always being more expensive than even the accelerated phaseout strategy.

**Recommended Plan of Action for Thailand**

The study team investigated a number of ways that Thailand could meet its phaseout obligations, and recommended that the country commit to a rapid ODS phaseout as part of its national industrial policy. Our suggestion was that the government move to eliminate the use of ODSs in new equipment by 1997 while allowing consumption of small quantities of CFCs for servicing certain long-lived refrigeration and air conditioning equipment up until the final phaseout date allowed by the Protocol.

As discussed above, our rationale for recommending this overall strategy was that a rapid phaseout would benefit Thailand in ways that were not captured by the economic modeling techniques used. Implicit in our recommendations were the probable cost increases in ODSs and cost decreases of alternatives. Furthermore, human health and environmental benefits, competitive advantages, protection of markets, and international goodwill are real benefits, if difficult to quantify, that we believe should be factored into the analysis.

Our recommendations were grouped into four categories: institutional and policy measures, regulatory measures, financial
measures, and sectoral measures. Table 4–3 summarizes these measures.

Institutional and Policy Measures

We recommended that the Cabinet should commit Thailand to a rapid phaseout, relative to that allowed a developing country by the Protocol. This recommendation reflected our concern that earlier phaseout actions in Thailand suffered from the sense that the issue was not a government priority. The Study Team also recommended that the Office of the Board of Investment make formal its policy of not extending Board of Investment (BOI) promotional privileges to ODS-consuming industries, and that within the Department of Industrial Works, a special unit be set up to deal exclusively with the ODS phaseout, primarily determining government policies, monitoring consumption, and making sure that Thailand meets its commitments as a party to the Protocol. Other recommendations were that the Industrial Finance Corporation of Thailand, with its experience in providing financial and technical assistance to Thai industries, be given authority to manage and disburse funds received from multilateral and bilateral sources, and that the Department of Industrial Works and the Customs Department jointly undertake a review of ODS data collection procedures.

Regulatory Measures

The Study Team suggested that the Department of Industrial Works set up subsector working groups consisting of representatives from industry, government agencies, and academic institutions that would advise the government on its ODS phaseout policies. We believed that Thai industry, in particular the Federation of Thai Industries, could play a major role in the switch to alternatives. Within the Industrial Finance Corporation of Thailand, we recommended that a resource center or clearinghouse be set up with access to databases containing information on ODS alternatives, costs of conversion, and so on. As a regulatory measure, the research team recommended that the government strongly consider product or process bans for those uses where substitutes or ODS are clearly available, as it had done with moderate success with the ODSs in the aerosols sector.

Financial Measures

ODS substitutes are generally still more expensive than the chemicals they replace; this was certainly true at the time of the study. To make substitutes more attractive and to encourage recycling of ODSs, ICF Incorporated recommended that the government increase the duty on ODSs and waive or reduce duties on chemical alternatives, possibly in a measured way to prevent a sudden increase in prices.

Sectoral Measures

Refrigeration and air conditioning

Delaying the phaseout in this sector could impose very large costs on Thailand, as equipment would need to be retrofitted or retired prematurely after the phaseout date. Our main recommendation in this sector was that the government require manufacturers of household refrigerators and MAC systems to convert to the refrigerant HFC-134a as soon as possible. ICF Incorporated also recommended that the government expand its existing recycling program for MACs and institute one for commercial refrigeration and air conditioning systems, as well as ban the import of building chillers that could operate only on CFC refrigerants.

Solvent cleaning

ICF Incorporated’s recommendations in this sector were that Thai industry install solvent recycling equipment and adopt housekeeping measures that reduce solvent consumption in the short term. We also suggested that the government persuade multinational
corporations to eliminate ODS solvent use in Thailand at the same rate that they do so in Japan, the United States, and Western Europe. The research team also suggested that the government discourage or ban the use of certain HCFCs as replacements for CFC-113 in solvent cleaning applications.

**Foam blowing**

In the foams sector, ICF Incorporated suggested that Thailand’s Department of Industrial Works ban the use of ODSs as foam blowing agents in certain applications and work with industry to make the conversion to alternatives, such as methylene chloride and pentane. We suggested that the Department closely monitor developments regarding alternatives for CFC-11 blowing agents in insulating foams, and ban the use of CFC-11 when an adequate alternative is found.

**Aerosols**

Although most use of ODSs in aerosols is prohibited, anecdotal evidence pointed to continued use in some nonmedical applications. ICF Incorporated recommended that the Department of Industrial Works work with manufacturers and chemical suppliers to determine the exact consumption in this sector and take measures to ensure a speedy conversion to alternative formulations.

**Fire Protection**

Halon use in Thailand is not large, but these chemicals have high ozone depletion potentials. ICF Incorporated recommended that the government ban the manufacture and sale of hand-held portable halon 1211 fire extinguishers, require recycling of halon 1211, and ban tests of halon 1301 total flooding systems.

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**Drawing Lessons from the Methodology**

**Lessons about Methodology to Benefit Future Studies**

As mentioned above, one way to improve the methodology used in this study would be to base the model decisions on price projections for ODSs and ODS alternatives. This would allow the model to approximate an optimal strategy more closely. Another improvement might be to add the option of incorporating projected price increases in the baseline. If run with base year prices, the model would produce estimates of the total social costs of the Protocol. If run with projected price increases, the model would produce estimates of the voluntary costs of complying with the Protocol. This is the same as using a post-Protocol baseline, and the voluntary costs are the same as the total social costs minus the imposed costs of the Protocol.

In our experience it has been difficult to find ODS price projections that are much better than guesses. One possible solution would be to have the model generate its own price projection based on the unit abatement costs of the controls required to meet the interim targets each year. However, there are a number of difficulties in this approach. First, ODS prices cannot be considered in a closed system. Prices will be influenced by global market forces and by unforeseeable technological factors such as the development of a drop in substitutes or inexpensive retrofits. Second, prices projected in this manner are sensitive to assumptions about the cost and availability of controls. Third, projecting prices would require complicating the analysis with modeling of ODS stockpiling. Finally, this approach does not take account of elasticities in ODS demand, which may limit the range of possible price increases.

The strategies defined by the World Bank are appropriate and should continue to be evaluated. Although different studies present the descriptions of these scenarios in different
forms, in essence, three scenarios are usually described. These are the accelerated strategy, which is intended to show the fastest possible phaseout without regard to any institutional or capital constraints; the allowable strategy that shows the drawbacks of doing the least possible in any year while meeting the Protocol's requirements; and the optimized strategy that presents, as the name suggests, the minimum costs that a country will likely have to incur. Although the optimized strategy captures most of the problems associated with delaying actions to eliminate ODS use—chief among them is the avoidance of premature retirements and retrofits—there are certain considerations not captured by such a strategy, such as environmental and trade benefits. In addition, an earlier phaseout for use in new equipment could be mandated by the parties, with use for servicing permitted until the original 2010 phaseout date. In either case, there exists the need to add a preferred strategy, much like the reference strategy developed by ICF Incorporated for Thailand and other countries like Poland, the Philippines, and Taiwan.

Areas of Policy Research and Data Collection

As noted above, ODS and alternative price trends figure prominently in determining a country's optimal phaseout strategy. We were hampered somewhat in the study by the unavailability of reliable price projections. Additional research on global supply and demand and projected prices for ODS and chemical alternatives, particularly HCFCs and HFCs, is warranted by the important effect they will have on phaseout paths and costs.

Data collection was a problem in some areas of the study. Identifying sources of data was not difficult, but it proved particularly troublesome to persuade companies to part with closely held information, particularly as the study was being conducted for a government ministry. As expected, data collected from different sources was often inconsistent or contradictory.

The best, most consistent information was obtained from ODS importers and distributors, who identified the consumption of each ODS by end use in the Thai economy. Data was harder to obtain from enterprises that used ODSs, particularly smaller users. In areas where the Thai government had already adopted regulatory measures limiting ODS use, such as in aerosol applications, sound data was extremely hard to obtain.

Regarding unit abatement costs, nonappliance insulating and noninsulating foams and halons presented a challenge, as there was less information available on conversion costs. In the Thailand study, fortunately, these end uses were not critical. Additional data collection is also justified in the area of determining servicing requirements and lifetimes of refrigeration and air conditioning equipment in developing countries, where age profiles, servicing practices, use patterns, and operating conditions often differ greatly from those in the developed countries. This is particularly important as the costs of premature retirement are a large component of incremental phaseout costs for most strategies.

Usefulness of Country Incremental Cost Methodology

The main strength of the methodology used for analyzing the country incremental costs is that it lays out a sequence of actions that illustrates some general principles useful in designing policies to achieve an ODS phaseout. The model illustrates, for example, the importance of avoiding retrofits and premature retirements through early conversion to alternatives in new refrigeration and air conditioning equipment and through allowances for a servicing tail. The model also illustrates the importance of comparing control measures on the basis of unit abatement costs throughout the entire life of
equipment rather than at just one point in time. In addition, the methodology is useful because it calculates social costs of complying with the Montreal Protocol, which may serve as a lower bound estimate of reimbursement necessary from the Multilateral Fund. The incremental cost estimate is a lower bound because the model does not account for costs associated with conducting the various analyses, feasibility studies, and institutional strengthening activities that will be required. It should be noted that the methodology is not useful for determining the level of reimbursement appropriate for specific projects. It should also be noted that decisions about strategies to pursue should be based not only on total incremental costs, but also on quantity of ODS use avoided; average cost per unit of ODS eliminated; impact on consumers; differential impact on sectors; logistical and institutional considerations; and equity concerns.

Making Calculations of Incremental Costs More Transparent

The model developed by ICF Incorporated is a spreadsheet framework consisting of several linked worksheets. Although this approach makes it difficult to model various features such as vintaging, premature retirements and retrofits, and implementation of recycling and recovery controls (including the interaction with other controls), the user benefits from the transparency that comes with such a platform. The inputs, calculation of unit abatement costs for individual controls, reductions in ODS achieved annually, premature retirements and retrofits undertaken, sequencing of controls and investments, and incremental costs associated with phasing out ODSs are all transparent in the model used by ICF Incorporated. Even the macro algorithms used to calculate the different strategies are available for the user to review and customize.
Table 4-1: Summary of Model Results for Various Phaseout Strategies

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Phased out date</th>
<th>Total costs (mm $)</th>
<th>Total ODS use avoided (tons)</th>
<th>Average cost of ODS use avoided ($/ton)</th>
<th>% of total costs</th>
<th>% of total costs</th>
<th>% of total costs</th>
<th>% of total costs</th>
<th>% of total costs</th>
<th>% of total costs</th>
<th>% of total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>1997</td>
<td>418</td>
<td>605,000</td>
<td>690</td>
<td>393</td>
<td>94%</td>
<td>25</td>
<td>6%</td>
<td>22</td>
<td>5%</td>
<td>283</td>
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<tr>
<td>Forward looking</td>
<td>2010c</td>
<td>2005</td>
<td>282</td>
<td>550,000</td>
<td>512</td>
<td>94%</td>
<td>17</td>
<td>6%</td>
<td>72</td>
<td>27%</td>
<td>181</td>
</tr>
<tr>
<td>Allowable</td>
<td>2010</td>
<td>2005</td>
<td>431</td>
<td>542,000</td>
<td>796</td>
<td>96%</td>
<td>17</td>
<td>4%</td>
<td>314</td>
<td>76%</td>
<td>167</td>
</tr>
<tr>
<td>Accelerated</td>
<td>1996</td>
<td>1996</td>
<td>471</td>
<td>618,000</td>
<td>763</td>
<td>94%</td>
<td>28</td>
<td>6%</td>
<td>18</td>
<td>4%</td>
<td>314</td>
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</table>

a Phaseout date indicated is for all ODS use except for use in servicing existing equipment. All ODS use ceases in 2010.
b Total ODS avoided is shown to the nearest thousand metric tons.
c CFC use, except for servicing existing equipment, ceases in 2008.

Note: (1) All costs are present values discounted at 12 percent.
(2) Numbers may not add due to rounding.
Table 4-2: Summary of Model Results for Various Phaseout Strategies (Using a 5% Discount Rate)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Phaseout date&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Total ODS use avoided&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Total ODS use avoided&lt;sup&gt;b&lt;/sup&gt; (tons)</th>
<th>Average cost of ODS use avoided&lt;sup&gt;b&lt;/sup&gt; ($/ton)</th>
<th>Domestic costs % of total costs</th>
<th>Export sector costs % of total costs</th>
<th>Premature retirement and retrofit costs % of total costs</th>
<th>Industry costs % of total costs</th>
<th>Consumer costs % of total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>1997</td>
<td>720</td>
<td>1,189</td>
<td>680</td>
<td>94%</td>
<td>6%</td>
<td>51</td>
<td>7%</td>
<td>466</td>
</tr>
<tr>
<td>Forward looking</td>
<td>2010&lt;sup&gt;c&lt;/sup&gt;</td>
<td>573</td>
<td>655,000</td>
<td>971</td>
<td>94%</td>
<td>31</td>
<td>84</td>
<td>17%</td>
<td>323</td>
</tr>
<tr>
<td>Allowable</td>
<td>2010</td>
<td>974</td>
<td>542,000</td>
<td>1,796</td>
<td>97%</td>
<td>31</td>
<td>718</td>
<td>76%</td>
<td>393</td>
</tr>
<tr>
<td>Accelerated</td>
<td>1996</td>
<td>777</td>
<td>618,000</td>
<td>1,257</td>
<td>94%</td>
<td>43</td>
<td>43</td>
<td>6%</td>
<td>493</td>
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</table>

<sup>a</sup> Phaseout date indicated is for all ODS use except for use in servicing existing equipment. All ODS use ceases in 2010.

<sup>b</sup> Total ODS avoided is shown to the nearest thousand metric tons.

<sup>c</sup> CFC use, except for servicing existing equipment, ceases in 2008.

Note: (1) All costs are present values discounted at 5 percent.
(2) Numbers may not add due to rounding.
### Table 4–3: Recommended Action Plan

<table>
<thead>
<tr>
<th>Year</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>Make a Cabinet-level commitment to a rapid ODS phaseout part of Thailand’s industrial policy. Stop extending Board of Investment promotional privileges to new ODS-consuming industries. Set up a special unit in Department of Industrial Works (DIW) devoted to ODS phaseout activities. Give IFCT responsibility for managing and disbursing funds received for phaseout related projects. Impose a progressively higher excise tax on imported ODS.</td>
</tr>
<tr>
<td>1993</td>
<td>Undertake a public awareness/industry outreach campaign about the ODS phaseout. Set up subsector working groups to advise the government on ODS policy. Set up in IFCT an ODS resource center with access to the latest information on alternatives. Improve DIW and Customs Department data collection methods and computerize import records. Ban tests of halon 1301 total flooding systems in which the halon is released. Remove duties on ODS recycling equipment, alternative technologies, and chemical substitutes. Undertake a pilot project promoting recycling of refrigerants from commercial refrigeration systems. Ban the import of chillers that can only use CFC-11 or CFC-12. Continue testing the HCFC-22/HCFC-124/HFC-152a ternary blend in mobile air conditioning systems. Encourage industry to adopt measures that reduce solvent consumption. Adopt measures to limit the use of HCFC-123 and HCFC-141b as solvents. Use the DIW/MITI/EPA program to compel Thai companies to eliminate solvent use. Institute a CFC-12 recycling program for mobile air conditioners. Require remaining aerosol manufacturers to adopt non-ODS technology.</td>
</tr>
<tr>
<td>1994</td>
<td>Ban the manufacture, sale, and import of hand-held portable halon 1211 fire extinguishers. Require recycling of halon 1211 when units are serviced. Require household refrigerator manufacturers to convert to HFC-134a systems. Require automobile assemblers to convert to mobile air conditioners that use HFC-134a. If necessary, implement a quota system that will keep imports below targets. Ban the use of CFC-12 in polystyrene foam production.</td>
</tr>
<tr>
<td>1995</td>
<td>Ban the use of ODSs as a foam blowing agent in packaging foam and flexible polyurethane foam. Ban the use of CFC-11 in flexible polyurethane foams.</td>
</tr>
<tr>
<td>1997</td>
<td>Ban the use of CFC-11 in rigid insulating foams.</td>
</tr>
</tbody>
</table>
Table 4-4: Characteristics of Control Technologies Use in the Analysis

<table>
<thead>
<tr>
<th>Sector</th>
<th>Application</th>
<th>Control technology</th>
<th>Earliest estimated availability*</th>
<th>Years to reach maximum penetration</th>
<th>Maximum market penetration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigeration</td>
<td>Home appliances</td>
<td>HFC-134a</td>
<td>1993</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>HFC-22</td>
<td>1993</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HFC-134a</td>
<td>1993</td>
<td>3</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recovery</td>
<td>1993</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>Mobile air conditioning</td>
<td>HFC-134a</td>
<td>1993</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recycling</td>
<td>1993</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retrofits (HFC-134a)</td>
<td>1994</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Building chillers</td>
<td>HFC-123</td>
<td>1993</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HFC-134a</td>
<td>1993</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recovery</td>
<td>1993</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retrofits (HFC-123)</td>
<td>1993</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retrofits (HFC-134a)</td>
<td>1993</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>CFC-113 solvent cleaning</td>
<td>Electronics/precision cleaning</td>
<td>No-clean</td>
<td>1993</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>1993</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semi-aqueous</td>
<td>1993</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HFC-225</td>
<td>1995</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recovery</td>
<td>1995</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Metal cleaning</td>
<td>Aqueous</td>
<td>1993</td>
<td>4</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi-aqueous</td>
<td>1993</td>
<td>4</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recovery</td>
<td>1993</td>
<td>2</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>1,1,1-Trichloroethane solvent cleaning</td>
<td>Electronics/precision cleaning</td>
<td>No-clean</td>
<td>1993</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>1993</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semi-aqueous</td>
<td>1993</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HFC-225</td>
<td>1995</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recovery</td>
<td>1995</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Metal cleaning</td>
<td>Aqueous</td>
<td>1993</td>
<td>4</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi-aqueous</td>
<td>1993</td>
<td>4</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recovery</td>
<td>1993</td>
<td>2</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Aerosols</td>
<td>Cosmetics/cleaners</td>
<td>Hydrocarbons</td>
<td>1993</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Foams</td>
<td>Appliances</td>
<td>HFC blend</td>
<td>1994</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>1994</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Flexible</td>
<td>Methylene chloride</td>
<td>1993</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Rigid</td>
<td>HFC blend</td>
<td>1994</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Polyurethane packaging</td>
<td>HFC blend</td>
<td>1993</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>other</td>
<td>1993</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>Fire protection</td>
<td>Portable</td>
<td>Chemical replacements</td>
<td>1995</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>(halon 1211)</td>
<td>Alternatives</td>
<td>1993</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Total flooding</td>
<td>Chemical replacements</td>
<td>1995</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>(halon 1301)</td>
<td>Alternatives</td>
<td>1993</td>
<td>2</td>
<td>80</td>
</tr>
</tbody>
</table>
Figure 4-1a: Phaseout Costs vs. Phaseout Year

Figure 4-1b: Phaseout Costs vs. Phaseout Year
Evaluation of Incremental Cost Methodologies for Phasing Out Ozone-Depleting Substances: Case Studies of Tunisia and Czechoslovakia

Ulla Blatt Bendtsen

Background

The World Bank and the Global Environment Facility are evaluating the economic and policy issues of Country Programs for implementing the Montreal Protocol in developing countries and countries in economic transition, such as Central and Eastern Europe (CEE) and the Commonwealth of Independent States (CIS). Incremental cost estimates and policy recommendations are features of the ozone-depleting substances (ODSs) Country Programs that form the basis for financial transfers from the Multilateral Fund for the Implementation of the Montreal Protocol and the Global Environment Facility (in the case of economies in transition).
Although this evaluation specifically addresses the problem of calculating the incremental costs of phasing out the use of ODSs, it is part of a broader effort by the World Bank to address economic and policy issues arising in global and regional environmental contexts.

This chapter will form part of an integrated report on costs and policies related to elimination of ODSs. The report comprises analytical papers on theoretical and conceptual issues related to international funding of ODS phaseout projects and methods for estimating country incremental costs as well as country case studies which focus on methodologies used in practice to analyze cost-effective phaseout strategies.

This chapter comprises the country case study on Tunisia and Czechoslovakia. The objective of the chapter is to evaluate the method used for calculating incremental costs of ODS phaseout in these countries and to discuss the recommended national policies.

This chapter describes the methodology used by Cowi consult to analyze cost-effective ODS phaseout strategies in a number of countries, including developing countries, countries in economic transition, and the European Community. This chapter focuses on the methodological and conceptual issues, illustrated primarily by the experiences of the Tunisian Country Program preparation. Case study material from Czechoslovakia is only referred to when this illustrates a special issue or problem, for instance in relation to the early phaseout date (1996) required in CEE and CIS countries. The chapter is based on work already completed (see Table 5–1 for a list of ODS references). No new data gathering, research, or analysis has been made.

The steps used to estimate the country incremental costs of ODS phaseout in Tunisia and Czechoslovakia are summarized below.

- Step 1: assessment of present and past ODS consumption by specific applications.
- Step 3: technical assessment of the most appropriate substitution techniques for each ODS application.
- Step 4: estimation of the incremental user costs of each replacement technique.
- Step 5: estimation of the incremental consumer costs of premature obsolescence of refrigeration equipment.
- Step 6: specification of the constraints imposed by the Montreal Protocol as well as potential technical and institutional constraints.
- Step 7: specification of alternative ODS phaseout strategies.
- Step 8: calculation (minimization) of the incremental costs of each phaseout scenario relative to the without Protocol situation.
- Step 9: cash flow analysis.
- Step 10: sensitivity analyses.

Steps 1 through 7 comprise the required input data to the chlorofluorocarbon (CFC) cost model which was developed by Cowi consult with the purpose of estimating a country’s minimum incremental costs by phasing out the use of ODS subject to the requirements of the Montreal Protocol or any alternative phaseout schedule. The model, a linear programming model, is described below under the section entitled Model for Calculating Incremental Costs of ODS Phaseout. Steps 8 through 10 are the model calculations. A brief review of each step is provided below.

**Steps in Estimating Country Incremental Costs**

*Step 1: Assessment of present and past ODS consumption by specific ODS application*

The consumption of ODS is divided into six major user sectors (in the model denoted: \(H_n\) for \(n = 1, \ldots, 6\):
5. Evaluation of Incremental Cost Methodologies for ODS Phaseout Case Studies

- **H₁**: refrigeration, air conditioning and heat pumps;
- **H₂**: rigid foam;
- **H₃**: flexible foam;
- **H₄**: aerosols, sterilants, and other uses;
- **H₅**: solvents; and
- **H₆**: fire extinguishants.

For each major application area, a set of subapplications is defined, depending on the specific consumption pattern of the country. These are denoted \( H_nS_i \) for \( n = 1, \ldots, 6 \) and \( i = 1, \ldots, 6 \) and comprise, in the case of Tunisia:

**\( H_1S_i \) (i = 1,...,6):**
- domestic refrigeration for the home market;
- domestic refrigeration for the export market;
- servicing of domestic refrigerators;
- commercial refrigeration;
- industrial refrigeration; and
- mobile air conditioning.

**\( H_2S_i \) (i = 1,...,4):**
- polyurethane (PU) foam for domestic refrigerators for the home market;
- PU foam for domestic refrigerators for export;
- other PU insulation foam; and
- extruded polystyrene packaging foam.

In the Tunisia Country Report no subapplications were defined for the major user sectors: flexible foam, aerosols, solvents, and fire extinguishants (\( H_3-H_6 \)). For Czechoslovakia, the solvents sector was divided in four subapplications: electronics, dry cleaning, metal degreasing, and other applications.

The reason for distinguishing between domestic refrigeration for the home market and for export is that the 10-year delay provision in the Protocol only applies to the use of ODSs for basic domestic needs. Thus, the use of ODSs in export products must be regulated according to the same phaseout schedule as in developed countries.

Estimates of ODS consumption were made for the period 1986–1991 based on import statistics, previously conducted surveys, and interviews conducted during field missions with the major ODS importers, distributors, and users.

**Step 2: Projection of unconstrained demand, 1991–2010**

The projection of unconstrained demand assumes that the Montreal Protocol did not exist, that is, that ODS are not regulated (in Tunisia or elsewhere), and unconstrained quantities of controlled substances continue to be available from existing sources at current prices. The base for projecting unconstrained demand is the 1991 consumption adjusted for possible reductions in ODS use that have already taken place. In Tunisia, for example, part of the aerosol sector had already shifted to alternative propellants, such as liquid petroleum gas (LPG). In the model, \( \text{Do}(H,S) \) denotes the demand for ODS in year \( 0 \) (1991) within the main application \( H \) and subapplication \( S \). Demand is measured in ozone-depleting potential (ODP) weighted tons.

Projections are then made on the basis of factors which are expected to influence the demand for products that contain or are made with ODS, for instance:
- population growth rate;
- income growth rate;
- sector plans (near-term expectations of industry leaders);
- present state of market saturation for consumer goods, for instance, refrigerators, aerosol products, and mattresses; and
- the quality of consumer products (service needs and standards).
A view is also made to the past development in ODS consumption. Table 5-2 below summarizes the basic assumptions made for Tunisia concerning the growth rate of individual ODS applications during the period 1991–2010. The future demand (in year t) is determined on the basis of D0(H,S) and the expected growth rate V(H,S):

\[ D(H,S,t) = D0(H,S) \times (1 + V(H,S))^t, \quad t = 1, \ldots, T; \quad 1 = 1992; \quad T = 2010. \]

The model allows the user to specify varying growth rates over the period of analysis; for example, ODS demand in many developing countries may be expected to grow at a faster rate in the beginning of the period than towards the end of the period.

**Step 3: Technical assessment of the most appropriate substitution techniques for each ODS application**

For each specific ODS application (H,S), feasible alternative technologies (or control options) are specified. Only the most plausible alternatives to each subapplication are included. Examples of alternative technologies are:

- **Product substitutes**, that is, replacement of an ODS-consuming product by a non- (or less) CFC-producing product such as roll-on deodorants, paper, and cardboard packaging;
- **Process substitutes**, for instance, recovery and recycling and mechanical pumps; and
- **Chemical substitutes**, that is, use of a non- or less ozone-depleting chemical than the controlled substance or change in the proportions by which CFC and other chemicals enter into a traditional mixture, for example, hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), liquid petroleum gas (LPG), or 50 percent CFC reduced foam (reduced with water).

The control options are denoted by Cj in the CFCcost model. For example, control options in the commercial refrigeration sector may be

- \( H_1S_4C_1 \): better maintenance and servicing procedures (a process substitute);
- \( H_1S_4C_2 \): HFC-134a (a chemical substitute); and
- \( H_1S_4C_3 \): HCFC-22 (a transitional chemical substitute).

The model assumes that the control options are independent of each other so that reductions attainable from each control can be added. For each control option, the following input is specified:

- assumed earliest start date (denoted by `BEGIN[H,S,C]`), which reflects the year in which a control is expected to be commercially available in Tunisia or Czechoslovakia;
- market penetration time (denoted by `PEN[H,S,C]`), which is an estimate of how long it will take for a control to fully penetrate the market to reach the maximum reduction potential;
- reduction potential (denoted by `PRO[H,S,C]`), that is, the maximum percentage reduction in ODS use within a subapplication that can be expected when the control has fully penetrated the market; and
- unit incremental substitution costs (see Step 4 below).

There is an interrelationship between unit substitution costs on the one hand and earliest start date and market penetration time on the other. It may be feasible to implement a control earlier and/or with shorter penetration time than stated in the model, but that would generally imply higher substitution costs.
Step 4: Estimation of the incremental user costs of each replacement technique

Incremental costs may arise in four different sectors:

- ODS producer (Czechoslovakia);
- ODS user industries;
- at the level of final consumers (see Step 5); and
- in the government sector.

The general principle is to identify costs where they first arise, with one exception: we assume that the costs arising in the producer sector (incremental costs of building or modifying a CFC plant to make a chemical substitute) are passed on to the users in the form of higher prices on ODS substitutes. This exception from the general principle is made in order to avoid double counting, and in order to include incremental costs of raw materials in the cost calculations for countries that rely on ODS imports.

The incremental costs to the country are calculated as economic costs rather than financial costs; that is, transfer payments between the public and the private sector are not included. Therefore, unless special local conditions call for adjustments in the cost levels (for instance, in the case of labor costs), we have used world market prices on inputs (for example, on materials and machinery). Freight and other related costs are only assessed in cases where ODS imports are replaced by locally-produced substitutes (as in the case of LPG for aerosols in Tunisia, where the incremental cost is estimated as the difference between the local ODS price—excluding taxes and the local price of LPG—implicitly taking account of the freight costs). Otherwise, we assume that freight costs will be the same in the with and without scenarios.

Also, it should be noted that all incremental costs are calculated on the basis of existing economic and industrial policies in the country (Tunisia). Thus, the model does not include the potential economic savings which could be gained by closing down small-scale, inefficient production in connection with the transition to ODS substitution technologies.

The incremental user costs include:

- capital cost of new production facilities or conversion of existing facilities and of new equipment, such as recovery and recycling machines;
- cost of patents and designs and incremental cost of royalties;
- operational costs, including raw materials, labor, energy, and waste disposal;
- costs of retraining personnel, including research and development to adapt technology to local circumstances; and
- cost of technical assistance and engineering support.

The unit incremental substitution costs, measured in US$ per kilogram of ODS use avoided, are calculated as follows:

\[
\text{COST} = \text{CC} \times a + \text{NOC}_{\text{QODS}}
\]

where:

- COST : unit substitution cost
- CC : incremental capital and other one-time costs such as training, technical assistance, and so on
- a : annualization factor, defined as
  \[
  a = \frac{r}{1 - \left[1/(1+r)^t\right]}
  \]
- r : real discount rate
- NOC : net incremental operating costs
- QODS : quantity of ODS saved per year if the control option is implemented.

The government itself will incur economic costs in complying with the Montreal Protocol, for instance, for implementing the necessary laws and regulations, monitoring the use of ODS, and disseminating information. All of these government costs are regarded as incremental, but they are not included in the model calculations because they do not affect the choice of phaseout strategy.
Step 5: Estimation of the incremental consumer costs of premature obsolescence of refrigeration equipment

The model calculates the costs incurred directly by the final consumers resulting from forced early replacement of refrigerators, which cannot be recharged because of nonavailability of ODS. (It is assumed that CFC-12 is available for servicing up to the year 2010 but that none will be available thereafter. The option of recycling is discussed and analyzed as part of the sensitivity analyses.)

It is assumed that the new refrigerant will be as energy efficient as the CFC-based ones.

Possible forced early replacement costs of other commercial and industrial refrigeration and air conditioning equipment and fire fighting installations are not included in the model, partly because it is assumed that most of these can be retrofitted, and partly because not enough data is available.

The costs to consumers resulting from higher purchasing prices of non-ODS-based products are not included as consumer costs, as this would involve double counting. In order to calculate the incremental consumer costs, the following data are needed:

- the present stock and age profile of refrigerators;
- the annual production of refrigerators;
- the rate of servicing (recharging) of refrigerators; and
- the present price, excluding taxes, of a new refrigerator (average).

Step 6: Specification of the constraints imposed by the Montreal Protocol as well as potential technical and institutional constraints

The Montreal Protocol imposes different phaseout requirements for different groups of ODSs (CFCs, halons, methyl chloroform [MCF], carbon tetrachloride [CTC]), and substitution between groups of ODSs is not credited for compliance purposes. Thus, in principle, it is necessary to calculate the incremental costs and optimum phaseout schedules for each group separately. In other words, one would need four models in this case. However, this distinction has not been made in the Tunisia Country Report because halons, MCF, and CTC only represent 2 percent of the total ODP weighted ODS consumption. In other words, it is assumed that all ODSs are regulated by the same phaseout requirements as CFCs.

According to the London Amendments, these phaseout requirements include:

- a freeze by 1999 compared to base year consumption;
- a 50 percent reduction by 2005;
- an 85 percent reduction by 2007; and
- a 100 percent reduction by 2010.

According to the Protocol, the base against which ODS reduction requirements are measured is defined as the average consumption in 1995, 1996, and 1997 or 0.3 kg per capita if this were lower. In Tunisia, the projected unconstrained demand for ODS in the years 1995–1997 is well below the 0.3 kg limit, so the first mentioned base definition applies. In the model, the constraints imposed by the Montreal Protocol are denoted by MON(t) and the base year ODS consumption by BASIC.

The technical and institutional constraints are given by the start date, market penetration times, and reduction potentials of each control option.

Step 7: Specification of alternative ODS phaseout strategies

Three alternative phaseout scenarios were analyzed for Tunisia:

- Allowable phaseout—a scenario that postpones ODS phaseout until the latest possible date while keeping the country within the limits of the Montreal Protocol.
- Phaseout at minimum incremental costs (least-cost scenario).
• *Accelerated phaseout*—phaseout at a pace set by the availability of technology, (option of lowest ODS emissions).

The first and second scenarios are characterized by full utilization of the 10-year delay provision in the Protocol (except for domestic refrigerators in the second scenario). Under the last scenario, the transition to ODS substitutes is accomplished over the period 1992–1999, except for servicing of refrigeration equipment, which is allowed up to year 2010. The reduction schedule for the third scenario is based on a model calculation of the maximum feasible reduction in percent of initial ODS demand. For Tunisia, the scenario runs thus:

**Base year 1991**

* Freeze by 1993;  
* 50 percent by 1995;  
* 85 percent by 1997;  
* 90 percent by 1999;  
* 95 percent by 2005; and  
* 100 percent by 2010.

**Step 8: Calculation (minimization) of the incremental costs of each phaseout scenario relative to the without protocol situation**

The total incremental costs are calculated (minimized) subject to the constraints of each phaseout scenario. The model operations are described in the section *Description of Model for Calculating Incremental Costs of ODS Phaseout* and result in the calculation of the following output:

* the present value of total incremental cost of ODS substitution during the period 1991–2010; the cost is expressed in 1991 U.S. dollars;  
* the total accumulated ODS use (1991–2010) in the with and without situation;  
* the optimum choice of control options, that is, the most cost-effective timing and choice of available substitution technologies;  
* the cost-effective total substitution costs for the individual application areas (user costs);  
* the costs to the consumers of premature retiring of refrigerators.

**Step 9: Cash flow analysis**

Following the estimation of the most cost-effective choice of control options and timing of phaseout in the individual user sectors, a cash flow is calculated for each scenario. Costs are again divided into the following categories for each subapplication:

* incremental capital and other one-time costs;  
* net incremental operating costs; and  
* incremental consumer costs of premature retiring of refrigerators.

The timing of investments is determined according to the optimum phaseout schedule resulting from Step 8.

**Step 10: Sensitivity analyses**

The calculation of incremental costs of alternative phaseout scenarios is supplemented by analyses of sensitivity with respect to:

* assumed ODS prices and ODS availability;  
* assumed servicing rates for domestic refrigerators; and  
* assumed growth rates in unconstrained demand.

It should be noted that analysis of the sensitivity of the results to changed ODS prices is the same as analysis of changed substitution costs: higher ODS prices mean lower incremental unit substitution costs. The sensitivity analyses are presented in a section below.
Technical and Economic Assumptions

The technical and economic assumptions made in the Country Program for Tunisia are summarized in Tables 5-2 and 5-3. A real discount rate of 10 percent is used in all model calculations to annualize capital costs over the lifetime of the investment and discount future cash flows to comparable present values.

Special Conceptual Features and Problems

For each step, 1 to 7 above, this section discusses any special conceptual features, difficulties in obtaining relevant data, or problems of interpretation in the country.

Step 1: Difficulties in obtaining import and consumption data

Difficulties were experienced both in obtaining data for the total consumption (= production + import - export) of individual substances (CFCs, halons, CTC, MCF and HFCs) and information about the distribution on specific applications.

In Tunisia, import statistics are not easily accessible or catalogued with monitoring of ODS use in mind; also, the statistics might be incomplete, and they do not identify ODS by type. Interviews with the key chemical importers and distributors only provide part of the picture because several of the larger users have their own direct import of ODS. Data collection, therefore, focused on interviews with the user industries.

In Czechoslovakia, user surveys covering 90 percent of consumption have been carried out since 1989. There is one state-owned producer and until recently only one importer, so the total consumption is fairly easy to obtain. However, as new private companies emerge and customs control is liberalized, the monitoring system will have to be extended.

The assessment of the distribution of ODS use on specific applications is a difficult or at least time-consuming task in all countries. In some user sectors, there are numerous minor applications and many small users. This is particularly the case in the solvents sector—uses of MCF and CTC in Czechoslovakia, for example, are not well established—but also in part of the refrigeration sector, such as in the servicing of domestic appliances, as well as in commercial and transport refrigeration (for instance, refrigerated fishing vessels and other vessels with refrigeration equipment on board).

Step 2: The problem of defining the without scenario

The projection of unconstrained demand assumes that no countries had imposed the Protocol, including its restrictions on trade. This implies that losses connected to trade with developed countries that have ratified the Protocol are regarded as incremental and therefore could be compensated by the Multilateral Fund or the Global Environment Facility (GEF), although trade losses are normally not compensated.

Furthermore, any future increases in the real prices of ODS are regarded as incremental costs, since we assume continued availability at current prices. Future increases in the real prices of ODS could result from factors other than the Protocol; the current ODS price could already be influenced by the Protocol as in Europe now because of an oversupply of CFC. Therefore, in order to avoid overcompensation, it is important that the incremental costs of alternative substances like HFCs and the transitional HCFCs are calculated on the basis of equilibrium prices, that is, prices that are expected to prevail once the ODS replacement has been made.

Unconstrained demand is projected up to the year 2010 both for Tunisia and Czechoslovakia. The calculation of incremental user costs thus assumes that costs are compensable over this time horizon both from the Multilateral Fund and from the GEF.

Another problem arises already when determining the base year ODS consumption. First of all, it must be adjusted for already
substituted ODS as a result of the Montreal Protocol, that is, after 1987. Secondly, it should be adjusted for temporary plant closings, as has been observed in Czechoslovakia and other Central and Eastern European countries since the breakdown of the former centrally-planned economies. This is necessary in order to make sure that countries that have already taken steps to comply with the Protocol are not disadvantaged vis-à-vis countries where no actions have been taken yet.

It is assumed that higher- or lower-priced alternatives to ODS do not affect the demand for ODS-based products. This is justified if incremental costs are compensated and not passed on to the consumers, but if markets are not competitive, this will seldom be the case in practice. On the other hand, too little is known about the elasticities of demand for ODS-based products to take account of this information in the demand projections.

Because very little information is generally available concerning the factors that influence the demand for ODS-based products, it is not possible to make scientific projections of unconstrained demand—certainly not up to the year 2010. Therefore, the projections made for both Tunisia and Czechoslovakia should be interpreted as scenarios rather than as actual forecasts.

Step 3: uncertainty concerning technical alternatives

The search for suitable alternatives to ODS has been and still is extensive; a wide range of feasible alternatives exists for each ODS application. These alternatives may or, as in most cases, may not have exactly the same properties as the well-known and tested ODS. One alternative may be the most likely today but become unlikely tomorrow when the results of new tests become available. Development has been very fast in this field. Furthermore, one firm or country may choose one alternative, whereas this may not be acceptable to another firm or country. This situation makes it difficult to choose the most plausible combination of control options. Uncertainty also exists as to the earliest start date, market penetration times, and reduction potentials, which may vary from one country to another depending on institutional capacity, economic policy, and the general economic structure. Therefore, a lot of best guesses, or qualified guesses, have to be made based on available data and experience from other countries.

Step 4: problems of estimating incremental substitution costs

Rapid technical change will also have a large but unknown effect on the costs of supplying these techniques as well as on the induced costs to the consumers. If, for instance, success is made in finding an acceptable drop-in substitute for CFC-12 in domestic refrigerators, consumers will not suffer any forced early replacement costs, and the cost-effective phaseout strategy may be completely altered. Another example is the uncertainty related to the assessment of the substitution costs in the commercial refrigeration sector, where each case has to be evaluated individually. It may be possible to retrofit one installation but not another without significant extra energy costs or modification costs.

The social costs of potential changes in the quality of the product as a result of substitution are not included in the incremental cost calculations.

The principle of identifying costs where they first arise (except in the ODS producer sector) is problematic if the country does not manufacture its own ODS-based equipment (refrigerators, for example) but relies on import, often of second hand, equipment. For instance, in the case of Ghana, we included the extra costs of the ODS-free refrigerators in the country’s incremental consumer costs. This problem also arises in connection with the assessment of import of intermediary or final products containing ODS, for instance,
halon import in portable fire extinguishers from the former German Democratic Republic to the Czech and Slovak Federal Republic (CSFR) or Bulgaria's premixed foam import from Italy. The ODS content should be registered as consumption in Germany and Italy, but both Czechoslovakia and Bulgaria have the problem of retrofitting, retiring, or converting production facilities to alternative technologies. Therefore, incremental costs would be underestimated if these uses were not included.

By using world market prices on major inputs such as raw materials, energy, and machinery, we implicitly assume that the economy is open. This is a reasonable long-term assumption. Although market imperfections certainly exist, especially in the short term in the former Council for Mutual Economic Assistance (CMEA) countries, it would not be justifiable to spend resources trying to adjust the costs accordingly. Those costs will certainly change over time, and incremental user costs are already surrounded by enough uncertainty.

The incremental cost estimates obtained from the industries should be critically reviewed, as their prices tend to be on the high side. Perhaps they are relevant as short-term costs, but most often these are too high compared to long-term equilibrium prices. Furthermore, care should be taken to adjust financial costs where these differ from economic costs. In terms of compensation from the Multilateral Fund and the GEF, this adjustment raises a problem, because in practice, compensation is likely to be for financial costs, since it is to these costs that the user industries and consumers respond. The Fund, in particular, focuses on grant financing of specific phaseout projects at the industry level. To maximize the benefits from the Fund, there is a need for a more flexible financial mechanism (loan and revolving fund type). The aerosol sector is an example: net incremental costs are negative, but there are heavy up-front investment costs which cannot be met because of capital constraints.

One of the largest uncertainties in the calculation of unit substitution costs arises when trying to estimate the amount of ODS that can be saved from investing in the alternative technology. The capacity utilization of the equipment often determines whether the technique is cost-effective or not. For example, a recycling machine used in a large repair shop with centralized repairs may be compared to the same machine used by a small service shop for on-site repairs. Thus, depending on assumptions about capacity utilization, unit costs may vary considerably from country to country, even though capital and operating costs are almost the same.

Step 5: problems of estimating costs of forced early replacement

The estimates of forced early replacement costs are extremely sensitive to the assumptions made about the future availability of drop-in substitutes as well as available ODS from recycling and reclaiming. It is important, therefore, that these key assumptions be included in the sensitivity analyses.

Only forced early replacement costs of domestic refrigerators are included. If other ODS-based equipment that requires ODS for servicing were included, data problems would be insurmountable. This is true not only because the stock of other ODS-based equipment is not known beforehand, but because the price and size of this equipment has extreme variations. There is a dearth of knowledge about how many of these installations can be retrofitted, and how many require significant modifications or complete replacement.

The calculation of forced early replacement costs of domestic refrigerators is more complicated in countries where no production of refrigerators takes place and a substantial share of the refrigerators are secondhand. The used refrigerators are much cheaper than the new ones but consume much more energy. It
is not known whether the secondhand refrigerators will be replaced by new or used ODS-free refrigerators when CFC is no longer available. These considerations have to be incorporated into the calculation of consumer incremental costs in countries that rely heavily on secondhand imports. There are also significant distributional problems in countries where the price of electricity is subsidized.

**Step 6: different phaseout requirements for different ODSs**

This problem was discussed earlier. In cases where ODSs other than CFCs constitute a significant share of total ODS consumption, one model or incremental cost calculation should be made for each significant group of substances.

**Step 7: alternative ODS phaseout strategies**

For CEE countries and those CIS countries that will not obtain the status of developing countries, the actual difference in alternative phaseout scenarios has all but completely disappeared due to the November 1992 tightening of the Montreal Protocol in Copenhagen. With January 1, 1996, as the required phaseout date for CFCs, MCF, and CTC and January 1, 1994, for halons, there are few options but to shift to non-ODS technologies as soon as technically and institutionally feasible. Therefore, the general framework for Country Program preparation (analyses of alternative phaseout scenarios) may be questioned in the case of these countries. This point is discussed in further detail in the section *Drawing Lessons in Methodology*.

**Model for Calculating Incremental Costs of ODS Phaseout**

The CFC cost model identifies the cost-minimizing combination and timing of phaseout actions subject to the requirements of the Montreal Protocol and the technical and institutional constraints. It is a cost-effectiveness model rather than a cost-benefit model: it identifies the most cost-effective way of reaching a given environmental target (the Montreal Protocol or alternative reduction requirements), but is not able to determine whether the reduction requirements themselves are optimal from a cost-benefit point of view. The benefits are calculated in terms of ODS use avoided by implementing the cost-effective phaseout strategy, but the benefits are not valuated in monetary terms.

The model is a computer-based linear programming model using the General Algebraic Modelling System (GAMS). It can be executed on a PC with at least a 386 processor and a minimum of two megabytes of RAM.

The basic optimization problem is formulated as follows (corresponds to the least-cost scenario):
\[
\min Z = \sum_{(h,s,c,t)} \left[ \frac{1}{1+r} \right] \cdot X(h,s,c,t) \cdot D(h,s,t) \cdot \frac{\text{COST}(h,s,c)}{1000} \cdot \sum_v \text{OLD}(v,2010) \cdot \text{SCRAPCOST}(v)
\]

s.t. (1) \[ X(h,s,c,t) \leq \text{REDUC}(h,s,c,t) \] \(H,S,C,t\)
(2) \[ X(h,s,c,t) = \text{REDUC}(h,s,c,t) \text{ if } \text{COST}(h,s,c) \leq 0 \] \(H,S,C,t\)
(3) \[ \sum_c X(h,s,c,t) \leq 1 \] \(H,S,t\)
(4) \[ \sum_{i,s} \text{DO}(h,s) \cdot (1 - \text{MON}(t)) \geq \left( 1 - \sum_{h,s,c} \text{SHARE}(h,s) \cdot X(h,s,c,t) \right) \cdot \sum_{i,s} \text{D}(h,s,t) \] \(t\)
(5) \[ \text{NEW}(1,t) + \text{OLD}(1,t) \leq \text{REF} \cdot \text{D(\text{refrigeration,domestic},t)} \] \(t\)
(6) \[ \text{NEW}(v+1,t+1) = \text{NEW}(v,t) \] \(v,t\)
\[ \text{OLD}(v+1,t+1) = \text{OLD}(v,t) \] \(v,t\)
(7) \[ \text{NEW}(1,t) = \text{REF} \cdot X(\text{refrigeration,domestic},t) \cdot \text{D(\text{refrigeration,domestic},t)} \] \(t\)
(8) \[ \text{SERVICE}(t) = \sum_v \text{OLD}(v,t) \cdot \text{SERV}(v) \cdot \text{CFCSERV} \] \(t\)
(9) \[ \sum_c X(\text{refrigeration,servicing},c,t) \cdot \text{D(\text{refrigeration,servicing},t}) \leq \text{SERVICE}(t) \] \(t\)

where

- \(X\) is the decision variable and indicates the reduction achieved for each control option—in percent of the projected ODS demand for the corresponding subapplication;
- \(r\) is the discount rate used to discount the costs to the base year; and
- \(\text{SCRAPCOST}(v)\) is defined as

\[
\sum_{i=v-1}^{21-v} \left[ \frac{\text{NEWPRICE} \cdot \text{SCRAPSHARE}(i)}{(1+r)^{i-v}} \right] = \frac{\text{NEWPRICE}}{(1+r)^{21-v}}
\]

where

- \(v\) : refrigerator vintage, \(v = 1,\ldots,20\)
- \(\text{NEWPRICE}\) : price of a new CFC-free refrigerator
- \(\text{SCRAPSHARE}\) : share of refrigerators that have to be retired in each vintage because no CFC is available for servicing
5. Evaluation of Incremental Cost Methodologies for ODS Phasedout Case Studies

The parameter REDUC indicates for every control option the technically feasible reduction potential in percent of the projected ODS demand for the corresponding subapplication. When the control has fully penetrated the market, REDUC is equal to PRO(H,S,c). The reduction potential for the preceding years is approximated by using linear interpolation.

SHARE(H,S) indicates for every subapplication the share of total ODS demand. If the growth rates, used to project the future unregulated demand, differ across applications, the SHARE parameter will not remain constant. In that case, SHARE must be a function of t as well as of H and S.

MON(t) indicates for every year the reduction requirements imposed. MON is expressed in percent of the total ODS demand in the base year.

NEW(v, t) and OLD(v, t) are the number of HFC-134a and CFC-12 based refrigerators, respectively, for each refrigerator vintage and every year.

REF is the number of refrigerators which can be produced from 1 ton of CFC-12;

SERVICE(t) is the demand for CFC for servicing of domestic refrigerators in each year.

SERV(v) is the recharge requirement for each refrigerator vintage (measured in percent of a vintage).

CFC\_SERV is the average amount of CFC-12 used each time one refrigerator is serviced (for purging, leak testing, recharging, and so on).

The problem is to choose the control options in such a way that the total discounted incremental economic cost \( Z \) is minimized, while at the same time fulfilling the reduction requirements. \( Z \) is expressed in millions of U.S. dollars. The objective function \( X*D*\text{COST}*1000 \) indicates for every subapplication the eliminated CFC use in kilograms (\( D \) is expressed in ODP tons) multiplied by the unit substitution cost. By totaling all subapplications, the total user substitution cost is calculated. To this must be added the costs to the consumers of premature retiring of refrigerators, \( \text{OLD*SCRAPCOST} \) for every refrigerator vintage from 1 to 20 (the assumed lifetime of a refrigerator).

The constraints (1), (2), and (3) define the technically feasible solutions for every control option. From constraint (1) it is evident that the control options are assumed to be independent (the reduction potential for one control does not depend upon the level of other control options chosen). Constraint (2) ensures that ODS reduction is maximized once costs are minimized, that is, that control options with zero substitution costs are implemented as soon as technically feasible. Constraint (3) ensures that the reduction obtained for each subapplication does not exceed 100 percent.

Constraint (4) reflects the reduction requirements. The left-hand side gives the number of ODP tons of ODS use remaining after the cost-minimizing substitution has taken place, and the right-hand side indicates how many ODP tons of ODS use are allowed to remain when the reduction requirements must be fulfilled.

Constraints (5) to (9) are all related to the calculation of the forced early replacement costs of refrigerators.

Analysis of the allowable phaseout scenario is based on the same model input as the least-cost scenario; account is not taken of the forced early replacement costs when determining the optimum choice and timing of phaseout actions. In other words, the consumer costs are not included in the cost minimization problem but are added to total costs afterwards.

Finally, the accelerated phaseout is based on the same optimization routine as the least-cost (that is, forced early replacement costs are
included), but the input phaseout requirements MON(t) are changed to reflect the maximum feasible reduction given by the technical and institutional constraints.

**Summary of Country Incremental Costs**

The model calculations result in optimum ODS consumption profiles over the period 1991–2010 in each of the three phaseout strategies shown in Figure 5–1.

In the first strategy, the production of -134a refrigerators for the local market is postponed until 2009, just in time for a complete phaseout in 2010. In scenario two, production of CFC-free refrigerators is initiated as early as possible, that is, by 1996, in order to minimize total incremental costs to the Tunisian economy.

Although the consumption profiles in the first two scenarios are very similar, the difference in total incremental costs is significant due to the fact that the total costs in the allowable strategy are dominated by the costs associated with forced early replacement of domestic refrigerators, as shown in Table 5–4. Minimum net incremental phaseout costs are estimated at about $25 million discounted to 1991 values compared to approximately $100 million in the allowable phaseout scenario.

It is assumed that economically viable phaseout actions (net incremental costs are zero or negative) will be implemented regardless of Protocol restrictions. This is the reason the consumption profiles do not follow the Protocol limits in the beginning.

The extra costs to Tunisia of implementing the accelerated phaseout (strategy 3) compared to the minimum cost strategy are estimated at less than $5 million. Conversely, the extra environmental benefits in terms of ODS consumption avoided are considerable: 12,000 ODP tons. Thus, the marginal reduction cost of implementing the accelerated phaseout instead of the minimum cost phaseout is only $0.3/kg of avoided ODS emissions.

Net present value capital, operating, and forced early replacement costs for each scenario are shown in Table 5–5. The incremental annual cash flows in fixed prices from 1991 to 2015 are illustrated in Figures 5–2 and 5–3 for the allowable and accelerated phaseout scenarios.

The capital costs of ODS phaseout only constitute a small share of total phaseout costs. Incremental operating cost is the dominant cost element in Scenario 2 and 3 in Table 5–5 due to the expected higher prices of intermediate components and HFC and transitional HCFC raw materials. The costs to the consumers of forced early replacement of refrigerators is the dominant cost element in the allowable phaseout scenario.

**Sensitivity of the Cost Estimates**

Based on analyses of the sensitivity of the model results to changes in the critical assumptions (ODS prices, ODS availability, servicing rates for refrigerators and unconstrained ODS demand growth rates), the following can be concluded:

- A doubling of the present ODS prices will make most of the technical substitution options economically attractive, whereby the accelerated phaseout scenario will be identical to the least-cost scenario;

- If CFCs are no longer available for Tunisia to import after the year 2000 and no drop-in substitutes become available, total incremental costs will increase significantly from about $30 million to $100 million, even if the accelerated phaseout schedule is followed and the production of CFC-based refrigerators is stopped by 1996. In this case, a comprehensive recovery, recycling and reclaiming scheme for Tunisia is economically feasible. Recycled CFCs would serve as a supply source reducing the need to retire refrigerators before the end of their lifetime.

- In Czechoslovakia, where new CFC will be banned from January 1, 1996, forced early
replacement costs have been estimated at more than $150 million in present value terms. These costs can only be avoided if CFC is hoarded in the coming years, CFC can be supplied from recycling, or a drop-in substitute becomes available.

- The results are not sensitive to changed assumptions about the rate of servicing of domestic refrigerators. Even if failure rates are much lower than experienced in Tunisia today, the conclusion that an accelerated phaseout of CFCs in production of new refrigerators is the most cost-effective does not change.

- A 50 percent increase (decrease) in assumed growth rates of unconstrained demand increases (decreases) total incremental phaseout costs by 25–30 percent.

The sensitivity of the discount rate was not analyzed in the Tunisia and Czechoslovakia Country Program Reports. However, earlier analyses of ODS phaseout strategies in the Philippines indicate that the discount rate has a significant effect on the absolute net present value of incremental costs. It does not, however, affect the optimum choice of phaseout strategy.

**Recommended Policies**

**Overall ODS Phaseout Strategy and Policy Instruments**

We recommend that the Tunisian government adopt an ODS phaseout schedule that corresponds to the accelerated phaseout scenario. This phaseout schedule proposes a freeze in consumption compared to 1991 levels by 1993, a 50 percent reduction by 1995, 85 percent reduction by 1997, 90 percent reduction by 1999, and 100 percent reduction by 2010. This schedule is well ahead of Protocol limits and reflects the government’s objectives to minimize Tunisia’s consumption of ODS while at the same time minimizing the cost to Tunisian industries and consumers of the Montreal Protocol. Furthermore, an accelerated phaseout is in accordance with the projects proposed for financing from the Multilateral Fund and in agreement with the aim of the Fund to provide incentives for early action. The reasons this phaseout strategy is recommended as opposed to the least-cost phaseout schedule are the following:

- First, although the phaseout schedule is not the cheapest, it is only slightly more expensive than the least-cost scenario, whereas the additional environmental benefits are significant.

- Second, if CFC prices rise, as can be expected from 1995 or earlier when ODS production will be banned in the European Community, substitution costs will in many cases become negative, implying that an early phaseout is economically advantageous.

Furthermore, some of the major users in Tunisia have already taken actions to eliminate their use of ODS, or have formulated plans to do so despite incurring extra costs. This is either because expatriate business owners or partners are under pressure from consumer groups abroad, or because ODS-based export products must be replaced by 1996 (the phaseout date in developed countries). As a result, it may be cost-effective to switch the whole production in one step, even though only part of the production is exported.

The total incremental costs of the recommended phaseout schedule is estimated at $29 million (net present value). The benefit is a reduction in total unconstrained ODS consumption of almost 85 percent over the period 1991–2010. The planned consumption of ODSs until complete phaseout is shown in Figure 5–4 by end user sector.

In addition to the overall phaseout strategy, an Action Plan covering an initial period of three years (1993–1995) to implement the strategy is recommended. The plan comprises
the introduction of government initiatives to effectively regulate and monitor the use of ODS, and a series of proposed projects in the ODS end user sectors, all of which are seen as prerequisites for implementation of the phaseout schedule.

A summary of recommended government actions or policy instruments is shown in Table 5–6. These comprise:

- **Creation of an Ozone Committee for implementation of the Action Plan.** The overall objectives of the committee should be to initiate and facilitate the implementation of the Action Plan. It is envisaged that the committee will be supported by an ODS working group with representatives from each of the major industry sectors using ODS. A full time coordinator of the committee is proposed.

- **Setting up a monitoring system for ODS use by substance and end user sector.** An import license will enable the government to effectively control the supply of ODS. Furthermore, ODS users should be obliged to report annually their purchase and consumption of ODS so that considerate policy actions and adjustments of the Action Plan can be made if necessary.

- **Regulatory measures which include sector-specific bans on the use of ODS; a special ODS tax on imports of all controlled substances to encourage initial substitution of ODS in easily substitutable applications such as aerosols and foams; tax exemptions for imports of ODS-conserving technology; and standards for recycled CFC and flexible foam densities.**

- **Introduction of an accreditation system for refrigeration technicians with the purpose of supporting and enforcing ODS conservation methods during service of refrigeration equipment.**

- **Information dissemination with the purpose of increasing consumer awareness of the ozone problem and informing the ODS user industry about the most recent Protocol regulations, new developments on the markets for ODS substitutes, and the results of the proposed demonstration projects.**

From an economic efficiency point of view, it is generally recommended to control ODS supplies rather than ODS use, and leave it to the market to allocate scarce ODS supplies among the users. However, under such a system there will also be a tendency to utilize the maximum allowable ODS consumption; where market distortions exist or full information is not available, this system will disfavor the small user industries. It is, therefore, strongly recommended to supplement supply control by user specific bans and control. Doing so would also prevent users from replacing ODS by alternative technologies that may have adverse human health effects.

The applicability of the above regulatory instruments in Central and Eastern Europe has been studied in a recent report on regional considerations for the phasing out of ODS in CEE countries (Commission of the European Communities and the World Bank 1993). Here, the policy instruments recommended for Czechoslovakia and other CEE countries include the following:

- A tax on the production and import of ODS is recommended. First, an ODS tax may provide an important incentive to recycle ODS in order to avoid high costs of forced early retirement of ODS-based equipment. Furthermore, the fiscal effect of the tax is particularly important in transitional economies where other revenue raising instruments, such as corporate and income taxes, are not yet well developed and where public companies still play a dominant role. It is emphasized, however, that the general incentive effect of a tax is probably limited due to inflation, soft budget constraints, and uncertainty. A tax or other economic instrument should not stand alone but should be used in combination with administrative regulation, such as import licenses and sector specific bans. This is
particularly important in transitional economies due to the predominant market imperfections. The distribution of government action costs on individual items is arbitrary, as the Ozone Committee secretary will be involved in all activities.

- Tradable permits are not recommended as part of the ODS regulation in CEE countries, mainly due to the difficulties in determining the initial allocation of permits in a situation where old industrial and trade structures are changing rapidly and due to the risk of creating large quasi-rents in the case of auctioning.

- Economic support (for instance, for research and development projects or investment in ODS free technology) is recommended in order to assist ODS industries in CEE countries in complying with the tight phaseout schedule of the Copenhagen Amendments. Furthermore, there is a need for establishing a financial mechanism for ODS reduction.

- Both sector-specific bans and production and import licenses are recommended—sector specific bans in order to allow the most essential uses (refrigeration and some solvents and rigid foam applications) to be maintained until the latest possible date, and production and import licenses in order to facilitate monitoring and control.

- In addition to an appropriate mix of administrative measures and economic instruments, a comprehensive ODS phaseout strategy requires the following supportive measures:
  - introduction of emission control measures to conserve the large stock of ODS in refrigeration and cooling equipment which can be reused to extend the economic life of these equipment;
  - development of monitoring and enforcement measures to support regulatory measures;
  - modification of certain product standards and norms in support of the introduction of non-ODS alternatives in some applications; and
  - extensive efforts in awareness-building in the form of information dissemination and product labeling.

The type of ODS phaseout projects proposed for Tunisia for funding from the Multilateral Fund are shown in the project summary figure in Table 5–6. The type of projects recommended for each user sector are almost generic, whereas the size of the projects (total costs and benefits), organization, and detailed design are country specific.

**Drawing Lessons on Methodology**

**Pros and Cons of the CFC Cost Optimization Model and the Need for Model and Scenario Modifications**

The main strength of the CFC cost optimization model is that it automatically selects the scenario with the lowest incremental costs subject to the Montreal Protocol requirements and the specified technical and institutional constraints. Trial and error methods of finding the least-cost scenario are not necessary. The results of the model have pointed out that the accelerated phaseout schedule is not the least-cost schedule, except in the case of domestic refrigeration and possibly some other sectors that may endure premature retiring costs. Only if we assume that ODS prices rise during the phaseout period will the accelerated phaseout schedule be identical to the least-cost. Apart from the environmental argument, rising ODS prices are the main reason for recommending the accelerated phaseout.

Presently, the price issue is analyzed as part of the sensitivity analyses; it would increase the validity of the model if price changes over
the period of analysis were incorporated directly. This would be fairly easy to do from a modeling viewpoint. The problem lies on the data side.

Another element which needs to be included more directly in the model analyses is the supply side, which is extremely relevant in connection with the calculation of forced early replacement costs and subsequent recommendations made for phaseout projects. Alternative strategies or options exist with regard to the future supply of ODS: recycling and reclaiming, stockpiling ODS for future servicing needs, continued ODS supply to developing countries from chemical producers up to the year 2010, and discovery of drop-in substitutes. These options need to be analyzed in further detail, not only at a country level, but also on an overall strategy level.

The CFC cost model was originally developed to analyze alternative phaseout strategies at a time when the Montreal Protocol only demanded a 50 percent reduction by 1998 (2008 for developing countries). At the time of the London Amendments, there was still great scope for optimization of alternative strategies. Following the Copenhagen Amendments, however, this is no longer the case for countries in transition who must meet the strict 1996 phaseout date and intermediate reduction requirement of 75 percent by 1994. Analyses show that in these countries there are few options but to implement phaseout actions in all user sectors as soon as technically and institutionally feasible. The actual difference in alternative phaseout scenarios has all but completely disappeared.

Today, it would be more relevant to elaborate cash flow analyses for these countries that can be directly used for sequencing investments and estimating levels of reimbursement necessary from the GEF. This also means that project preparation should be given higher priority in the initial planning phase. The question of heavy up-front investment costs is critical in these countries because of the present capital constraint (financial market imperfections), and should therefore play a key role when choosing between the few available phaseout options and deciding on project priorities.

Of course, analyses of alternative phaseout scenarios still make sense in the case of developing countries because of the 10-year delay provision. However, strategies, policy instruments, and the type of projects being proposed tend to become generic, as described below.

General Policy Research and Data

The costs of ODS substitute technologies tend to become generic if world market prices are used, as can be argued for open economies. Therefore, a worldwide applicable cost catalogue should be developed which can be modified according to special local conditions (where these modifications can be justified).

At present, incremental cost estimates made for different countries at varying points in time by different consultants cannot be directly compared. The different Country Programs reflect the development over time in phaseout options and costs as well as individual experts' different views as to the most plausible and recommendable choice of alternative technology, which is often based on practices and experiences in neighboring regions. The substitutes recommended for Tunisia and Czechoslovakia reflect the technical solutions that have been adopted in the European Community and especially in the Nordic countries. As an example, we recommend CO₂ or water blowing as a substitute for CFC-11 in the flexible foam sector, whereas others have recommended methylene chloride.

It should be emphasized that Country Programs on ODS phaseout have already been completed for many countries. The next step is project preparation, feasibility studies, and appraisal. Therefore, it is important that a cost catalogue focus on detailed project costs. This
catalogue can then be used as a guideline both to calculating country incremental costs and as a basis for project preparation and feasibility studies when adjusted properly to accommodate local conditions and needs. A cost catalogue should not be used for making desk studies, since local, supplementary data collection and industry contact are very important parts of the Country Program. Often, the collection of cost data is the first coordinated and comprehensive action taken to mobilize, inform, and motivate the local user industries on matters related to the Montreal Protocol.

Another area where more research is needed is the projection of future ODS prices as well as prices of substitute chemicals. This is the key factor determining the optimum phaseout strategy in developing countries. Although this area is extremely difficult to say much about, the basis for guessing could be improved, for example, through contacts to all the major ODS producers in the World (to find out what their production plans are and what the supply costs of alternative chemicals are).

Although priority should be given to eliminating large ODS quantities as soon as possible, more research is or will be needed in the many small applications of ODS—especially MCF, CTC, and CFC solvents applications and the options and costs for replacing them. Finding alternatives to methyl bromide has also now become a new priority for which research and data gathering is needed.

Usefulness of the Model in Relation to the Multilateral Fund and the GEF

Basically, the CFC cost model is an extremely powerful tool when it comes to testing alternative ODS phaseout strategies and policies, including strategies to phaseout the transitional HCFCs. The model or model type can also be used to solve similar problems, such as cost-effective reductions of greenhouse gas emissions, SO₂ emissions, nutrient pollution of water bodies, and many other environmental problems.

On the other hand, the model is not well suited for sequencing investments or for estimating levels of reimbursement necessary from the Multilateral Fund or the GEF. For these purposes, a cash flow model developed in spreadsheet form would be more useful; the two could easily supplement each other.

Making Calculations More Transparent

The model calculations are, admittedly, not very transparent. More transparency can be obtained by better explaining the parameters, variables, and equations in the model, by organizing the model in a more understandable way, and by eliminating calculations that are not used later on. However, it should also be stressed that the model (regardless of whether or not it is made more transparent) is not suitable for use by persons unfamiliar with the General Algebraic Modelling System (GAMS) and economic modeling and linear programming techniques.

Bibliography

Table 5-1: List of ODS References

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<thead>
<tr>
<th>Project description</th>
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<tbody>
<tr>
<td>Information project on alternatives to CFC-113 and methyl chloroform in the metal degreasing industry.</td>
<td>Denmark. 1991. The Environmental Protection Agency, Denmark.</td>
</tr>
</tbody>
</table>
### Project description

| Alternatives to CFC-113 in the dry cleaning sector. | The Nordic countries.  
The Nordic Council of Ministers. |
|---------------------------------------------------|------------------------------------------------------------------|
| Technical and economic consequences of reducing CFCs. | The Nordic countries.  
The Council of Nordic Industrial Federations and the Nordic Council of Ministers. |
| Trade aspects of regulating CFC use. | The Nordic countries.  
The Nordic Council of Ministers. |
## Table 5-2: Summary of Growth and Other Assumptions Made for Tunisia

<table>
<thead>
<tr>
<th>Area/user sector</th>
<th>Application</th>
<th>Growth and other assumptions</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.2 million&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2.3% average annual growth &lt;sup&gt;2&lt;/sup&gt;</td>
<td>1991</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.1% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td>1.6 million</td>
<td></td>
<td>1997–2010</td>
</tr>
<tr>
<td><strong>Real GDP</strong></td>
<td></td>
<td>5% average annual growth &lt;sup&gt;3&lt;/sup&gt;</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td></td>
<td>GDP/capita: US$ 1,560</td>
<td></td>
<td>1991</td>
</tr>
<tr>
<td><strong>Refrigeration and air conditioning</strong></td>
<td>Refrigerators for the local market</td>
<td>10% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td>Domestic refrigeration</td>
<td>Refrigerators for export</td>
<td>5% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td></td>
<td>Servicing (average refrigerator failure)</td>
<td>10% fail</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5% fail</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;–9&lt;sup&gt;th&lt;/sup&gt; year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90% fail</td>
<td>10&lt;sup&gt;th&lt;/sup&gt; year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% fail</td>
<td>11&lt;sup&gt;th&lt;/sup&gt; year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8% fail</td>
<td>12&lt;sup&gt;th&lt;/sup&gt;–20&lt;sup&gt;th&lt;/sup&gt; yr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average lifetime</td>
<td>20 years</td>
</tr>
<tr>
<td></td>
<td>Production of refrigeration equipment,</td>
<td>5% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td>installation and servicing</td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average lifetime (comm.)</td>
<td>7 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average lifetime (ind.)</td>
<td>20 years</td>
</tr>
<tr>
<td><strong>Commercial and industrial refrigeration and air conditioning</strong></td>
<td>Servicing</td>
<td>3% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td>Mobile air conditioning</td>
<td></td>
<td>Average lifetime</td>
<td>10 years</td>
</tr>
<tr>
<td><strong>Foam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigid</td>
<td>PU insulation in domestic refrigerators for local market</td>
<td>10% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td>Rigid</td>
<td>PU insulation in domestic refrigerators for export</td>
<td>5% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td>Flexible</td>
<td>Other PU foam and packaging foam</td>
<td>5% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td>Aerosols &lt;sup&gt;4&lt;/sup&gt;</td>
<td>Mattresses and cushions</td>
<td>7% average annual growth</td>
<td>1991–2010</td>
</tr>
<tr>
<td></td>
<td>All applications</td>
<td>4% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td>Solvents</td>
<td>Various minor applications</td>
<td>5% average annual growth</td>
<td>1991–1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3% average annual growth</td>
<td>1997–2010</td>
</tr>
<tr>
<td>TOTAL CFCs</td>
<td></td>
<td>1,130</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Source: Institut National de Statistique.

<sup>2</sup> Source: The World Bank.

<sup>3</sup> Source: The World Bank.

<sup>4</sup> The average lifetime of a compressor is 7–10 years, and the price of a new refrigerator is US$500.

<sup>5</sup> Unconstrained consumption of CFCs in aerosols differs from the actual consumption in 1991 because part of the aerosol industry has already shifted to alternative propellants, such as liquified petroleum gas (LPG).
Table 5-3: Assumed Substitutes for CFCs in Tunisia

<table>
<thead>
<tr>
<th>User sector</th>
<th>Current use</th>
<th>Substitutes assumed</th>
<th>Assumed earliest start date in Tunisia</th>
<th>Unit substitution cost (US$/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic refrigeration (production)</td>
<td>CFC-12</td>
<td>HFC-134a</td>
<td>1995</td>
<td>40</td>
</tr>
<tr>
<td>Servicing of domestic refrigerators</td>
<td>CFC-12</td>
<td>Nitrogen and recycling at large service shops HFC-134a</td>
<td>1993</td>
<td>1</td>
</tr>
<tr>
<td>Commercial refrigeration</td>
<td>CFC-12</td>
<td>Better maintenance and service procedures HFC-22 HFC-134a</td>
<td>1995</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>CFC-115 (in R-502)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial refrigeration</td>
<td>CFC-12</td>
<td>Better maintenance and service procedures Ammonia HFC-22 HFC-134a</td>
<td>1993</td>
<td>5</td>
</tr>
<tr>
<td>Mobile air conditioning</td>
<td>CFC-12</td>
<td>Better maintenance and service procedures HFC-134a</td>
<td>1994</td>
<td>2</td>
</tr>
<tr>
<td>Polyurethane (PU) foam</td>
<td>CFC-11</td>
<td>50% CO₂/water</td>
<td>1993</td>
<td>1</td>
</tr>
<tr>
<td>Polystyrene packaging</td>
<td>CFC-12</td>
<td>Product substitute HFC-142b/22</td>
<td>1995</td>
<td>3</td>
</tr>
<tr>
<td>Flexible foam</td>
<td>CFC-11</td>
<td>CO₂/water</td>
<td>1993</td>
<td>0.5</td>
</tr>
<tr>
<td>Aerosols</td>
<td>CFC-11/12</td>
<td>LPG and other alternative propellants</td>
<td>1991</td>
<td>0</td>
</tr>
<tr>
<td>Solvents</td>
<td>CFC-113</td>
<td>Aqueous cleaning</td>
<td>1995</td>
<td>4</td>
</tr>
<tr>
<td>Fire extinguishants</td>
<td>Halon-1301</td>
<td>INERGEN, FE-25 or other alternative</td>
<td>1997</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 5-4: Costs and Benefits of Alternative Phaseout Scenarios in Tunisia

<table>
<thead>
<tr>
<th>Scenario</th>
<th>ODS use eliminated over the period 1991-2010</th>
<th>Incremental operating costs (million US$ 1991 present value)</th>
<th>Incremental capital or project costs (million US$ 1991 present value)</th>
<th>Early replacement costs (million US$ 1991 present value)</th>
<th>Total incremental costs (million US$ 1991 present value)</th>
<th>Discounted cost per kg ODS eliminated (US$/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Allowable phaseout</td>
<td>22,500 (54%)</td>
<td>15-20</td>
<td>1</td>
<td>95-100</td>
<td>110-120</td>
<td>5.1</td>
</tr>
<tr>
<td>2. Minimum cost phaseout</td>
<td>23,200 (56%)</td>
<td>20-25</td>
<td>2</td>
<td>1</td>
<td>20-25</td>
<td>1.1</td>
</tr>
<tr>
<td>3. Accelerated phaseout</td>
<td>35,000 (85%)</td>
<td>25-30</td>
<td>2</td>
<td>1</td>
<td>25-30</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*Total unconstrained ODS demand over the period 1991-2010 is estimated at 41,300 ozone-depleting potential (ODP) tons.

Table 5-5: Capital, Operating, and Forced Early Replacement Costs for Each Scenario for Tunisia

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Incremental costs</th>
<th>Total replacement costs (US$/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1 Allowable phaseout</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Scenario 2 Minimum cost phaseout</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>Scenario 3 Accelerated phaseout</td>
<td>98</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5-6: Summary of Recommended Government Actions in Tunisia

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Description of action</th>
<th>Sector (if any)</th>
<th>Intended effect/purpose</th>
<th>Estimated costs* US$ 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993-1995</td>
<td>1. Creation of an Ozone Committee for implementation of the Action Plan</td>
<td>All</td>
<td>Prerequisite for effective implementation of ODS phaseout in Tunisia</td>
<td>210,000</td>
</tr>
<tr>
<td>1993</td>
<td>2. Monitoring system for ODS use by substance and end user sector</td>
<td>All</td>
<td>Monitoring and control and basis for efficient and considerate policy action</td>
<td>60,000</td>
</tr>
<tr>
<td>1993</td>
<td>3. Introduction of regulatory measures</td>
<td>All</td>
<td>Control, incentive, and revenue generation</td>
<td>60,000</td>
</tr>
<tr>
<td>1993-1995</td>
<td>4. Introduction of an accreditation system for refrigeration technicians</td>
<td>Refrigeration sector</td>
<td>Incentive for conserving ODS during service of refrigeration equipment</td>
<td>60,000</td>
</tr>
<tr>
<td>1993-1995</td>
<td>5. Information dissemination</td>
<td>User industries and the general public</td>
<td>Awareness, ODS use reduction and conservation</td>
<td>30,000</td>
</tr>
</tbody>
</table>

*The distribution of government action costs on individual items is arbitrary, since the Ozone Committee secretary will be involved in all activities.
Figure 5-2: Annual Incremental Costs: Allowable Phasemout in Tunisia
Figure 5–3: Annual Incremental Costs: Accelerated Phaseout in Tunisia

![Graph showing annual incremental costs for accelerated phaseout in Tunisia]

Figure 5–4: Recommended Phaseout Schedule in Tunisia by End User Sector

![Graph showing recommended phaseout schedule for different end user sectors in Tunisia]