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COST ASSESSMENTS OF MITIGATION OPTIONS IN THE ENERGY SECTOR

Conceptual and methodological issues

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Abstract

This report discusses some major conceptual and methodological issues concerning cost assessments of mitigation options in the energy sector of non-Annex I countries, based on an evaluation of a previous joint ECN-AED-SEI study on the potential and cost of such options (Van der Linden et al, 1999). In addition to reviewing and updating the cost curves and other major findings of this bottom-up study, the present report provides (i) a conceptual framework for analysing the costs of mitigation options, (ii) a discussion of the major methodological issues involved in constructing and applying abatement cost curves by means of a bottom-up approach, and (iii) a comparison of different methodological approaches - i.e. 'bottom-up', 'top-down' and 'intermediate'- to assess the cost effects of the Kyoto Protocol.

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SUMMARY

Background and main objectives

In 1999, the unit Policy Studies of the Energy research Centre of the Netherlands (ECN) published the report *'Potential and Cost of Clean Development Mechanism Options in the Energy Sector'*. This study was carried out jointly by ECN Policy Studies and two other institutes, i.e. the Alternative Energy Development, Inc. (AED, Silver Springs, USA), and the Stockholm Environment Institute (SEI, Boston, USA). The main purpose of the joint ECN-AED-SEI study was to assess the potential and cost of CDM options in the energy sector of non-Annex I countries. In order to achieve this purpose, these options were inventoried by means of project and country abatement studies in non-Annex I countries. The main result of this exercise was a bottom-up construction of a CDM cost curve for all non-Annex I countries. This curve was used in a supply-demand analysis of a CDM-related market of emission credits in order to determine the international clearing price of these credits and, subsequently, to estimate the cost effects of the Kyoto Protocol.

The objectives of the present study are (i) to review and, where possible, update or adjust the major results of the ECN-AED-SEI study, (ii) to provide a conceptual framework for mitigation cost assessments, especially for CDM options, (iii) to review the bottom-up methodology of constructing and applying abatement cost curves as employed in the ECN-AED-SEI study, and, where possible, make suggestions for improvements in this methodology, and (iv) to compare the results of different methodological approaches - 'bottom-up', 'top-down', 'intermediate' - of estimating the cost effects of the Kyoto Protocol.

Major findings and conclusions

- A major distinction in assessing the costs of a mitigation option is between *economic* versus *financial* costs on the one hand and *private* versus *social* costs on the other hand.
- In addition to direct engineering costs, mitigation options such as CDM projects may incur a variety of other costs such as implementation costs, the costs of risks and uncertainties, ancillary costs and benefits, and macroeconomic costs.
- In mitigation studies, cost effectiveness is the most widely used criterion in order to evaluate, compare, rank or aggregate GHG abatement options. This criterion is simply defined as the cost of a mitigation option divided by its emission reductions. However, an adequate comparison, ranking or aggregation of mitigation option assessments by means of the cost-effectiveness criterion requires that at least the following three conditions have to be met: (i) the same definition of costs has to be applied throughout all options considered, (ii) the same unit of measurement has to be used to express the cost effectiveness of all mitigation options analysed, and (iii) the same, comparable methodology has to be applied to measure the cost effectiveness of all mitigation options assessed. The analysis in the present report shows that these conditions have not been met with regard to the cost-effectiveness assessments of the mitigation options generated by a sample of 24 non-Annex I country abatement studies that have been employed by the ECN-AED-SEI team to construct a CDM-related abatement cost curve for all non-Annex I countries.
- Cost definitions in country abatement studies are either not clear or not uniform across these studies, whereas an additional conceptual limitation of the ECN-AED-SEI study is that its major cost definitions are not common in mainstream economics or mitigation cost assessments.

- Although country abatement studies have used some common analytical elements, there are significant differences between these studies with regard to (i) the cost definitions used, (ii) the definition and underlying assumptions of the baseline scenario, (iii) the identification and coverage of the mitigation options, (iv) the energy sector models used, (v) the availability, reliability and consistency of the data, (vi) the choice of the discount rate and other accounting methods used, and (vii) the unit of measurement to express the cost-effectiveness assessments of mitigation options. Moreover, an adequate comparison between the cost-effectiveness assessments of the country abatement studies is not always possible due to a lack of information provided on the data and methodology used. Therefore, a comparison, ranking or aggregation of the mitigation options concerned by means of the cost-effectiveness criterion in order to construct an abatement cost curve has only a limited meaning.
- *Abatement cost curves reflect the strengths and weaknesses of the methodologies and data used to construct them.* This general statement applies particularly to the bottom-up CDM cost curve designed by the ECN-AED-SEI research team. Its major strength is that this curve is based on detailed information on specific mitigation options in non-Annex I countries, which has been generated by national study teams that are familiar with the local conditions of these countries. Its major weakness, on the other hand, is that the data used to construct this curve suffer from a lack of consistency and comparability as well as from a significant degree of uncertainty due to a variety of data problems, methodological limitations and other analytical shortcomings of the country abatement studies providing these data. Another major weakness of the bottom-up CDM cost curve is that it covers only direct engineering costs of eligible mitigation options, and that it neglects other cost categories such as the implementation costs of CDM options, the potential ancillary costs and benefits of these options, and the costs of risks and uncertainties inherent to CDM projects in less developed countries. Moreover, the *sector* approach of constructing and applying such a cost curve does not account for the macroeconomic costs and other interacting, feedback effects at the macro level resulting from the mitigation options covered.
- Alternative approaches to the ECN-AED-SEI bottom-up methodology of constructing and applying cost curves are the so-called ‘top-down’ and ‘intermediate’ approaches’. Each approach has its own set of advantages and disadvantages in assessing the costs of mitigation options. A comparison of differences among national, regional and global abatement studies in estimates of the cost effects of the Kyoto Protocol reveals that these differences can only be partly related to the distinction between top-down, bottom-up and intermediate approaches. More specifically, differences in mitigation costs assessments can be ascribed to three categories of explanatory factors: (i) the way in which welfare and abatement costs are defined and measured, (ii) the scope and methodology of the mitigation cost assessments, and (iii) the assumptions underlying the mitigation cost assessments.

Recommendations

- Country abatement studies should provide explicit and detailed information on the cost definitions, data, methodologies and assumptions used.
- Country abatement studies should use the same cost definitions and cover the same cost categories.
- Country abatement studies should preferably conduct a *social* assessment of mitigation options in both *financial* and *economic* terms.
- Country abatement studies should use the same unit of measurement to express the cost-effectiveness of mitigation options, notably apply the same target year(s) for the assessment of mitigation potentials and costs.

- Country abatement studies should further streamline and uniform their methodology and assumptions used as far as possible, given the actual differences between the countries concerned. This implies that these studies should at least use (i) the same analytical structure, (ii) the same system boundary (iii) the same 'most likely' definition of the baseline scenario, (iv) the same baseline assumptions with regard to parameters that apply more or less equally to all countries, such as the projected development of the international energy prices, (v) the same, full coverage of the mitigation options identified, and preferably (vi) the same or, at least, comparable energy sector models and other accounting methods to calculate the cost effectiveness of mitigation options. Finally, as far as differences in baseline assumptions, accounting methods, models and data used are justified or unavoidable, they should be explicitly accounted for.
- The ECN-AED-SEI database should be improved by including other cost categories besides direct engineering costs, notably by conducting additional research on the importance of implementation costs of CDM options, the risks and uncertainties of these options, and their ancillary costs and benefits.
- The ECN-AED-SEI sector approach of constructing and applying bottom-up cost curves should be supplemented by a macroeconomic analysis to account for the full socio-economic impact of mitigation options, including their interacting effects at the (inter-) national, regional and global levels.
- All major limitations with regard to the construction and application of an abatement cost curve should be explicitly accounted for in the studies concerned. Moreover, these studies should include a set of sensitivity analyses to provide an adequate indication of the reliability and possible range of outcomes of the major research findings.
- The supply-demand analysis of the CDM market of emission credits should be improved by additional research on the institutional, political and legal aspects of this future market, including the risks and uncertainties inherent to the start and further development of such a market.
- Different methodological approaches and tools should complement each other by conducting mitigation cost assessments at different levels of analysis. At the macro level, the identification and assessment of broad mitigation policy packages can be best performed by a top-down approach using macroeconomic models. At the sector level, specific mitigation options and technologies can be best identified and assessed by a bottom-up approach applying technology-rich sector models. Finally, at the micro level, a mitigation project can be best evaluated by a cost-benefit analysis, preferably supplemented by a multi-criteria analysis in order to take account of the wider socio-political aspects in the selection and decision-making process of mitigation options.

1. INTRODUCTION

1.1 Background

In 1999, the Energy research Centre of the Netherlands (ECN) published the report '*Potential and Cost of Clean Development Mechanism Options in the Energy Sector*' (Van der Linden et al, 1999). This study contained the major findings of a research project that - on behalf of the Netherlands Development Co-operation (DGIS) - was carried out jointly by three institutes:

- The unit Policy Studies of ECN, Petten, the Netherlands.
- The Alternative Energy Development (AED), Inc., Silver Springs, USA.
- The Stockholm Environment Institute (SEI), Boston, USA.

The main purpose of the joint ECN-AED-SEI study was to assess the potential and cost of Clean Development Mechanism (CDM) options in the energy sector of non-Annex I countries.[1] In order to achieve this purpose, these options were inventoried by means of project and country abatement studies in non-Annex I countries. The main result of this exercise was a bottom-up construction of a CDM cost curve for all non-Annex I countries. This curve was used in a supply-demand analysis of a CDM-related market of emission credits in order to determine the international clearing price of these credits and, hence, to indicate the cost effects of relying on the CDM rather than other, notably domestic measures to meet the Kyoto commitments of Annex I countries.

During the ECN-AED-SEI research project, questions arose with regard to some major conceptual and methodological issues involved. Due to a lack of resources, however, the research team was not able to address these issues adequately within the framework of the project. After the final study report had been drafted, it was sent for comments to the Institute for Environmental Studies (IVM) of the Free University in Amsterdam. Late 1999, some staff members of IVM commented on the ECN-AED-SEI study, particularly on some conceptual and methodological issues needing further research (Verbruggen et al, 1999). In response, both institutes - i.e. ECN and IVM - decided to start a joint research programme to address these issues. The present report is the result of the first research project conducted by ECN and IVM in the period April-December 2000.

1.2 Objectives of the study

The objectives of this study are:

- To review and, where possible, update or adjust the major results of the ECN-AED-SEI study on the potential and cost of CDM options in the energy sector of non-Annex I countries.
- To provide a conceptual framework for mitigation cost assessments, specifically for CDM options in the energy sector of non-Annex I countries.
- To review the bottom-up methodology of constructing and applying abatement cost curves as employed in the ECN-AED-SEI study, and - where possible - make suggestions for improvements in this methodology.

[1] The Clean Development Mechanism (CDM) is one of the three flexible instruments or 'Kyoto Mechanisms' that offers Annex I countries the opportunity to meet part of their national commitments to reduce GHG emissions by means of mitigation options in non-Annex I countries. Hence, such options are called CDM options. For more details on the role of CDM and the other Kyoto Mechanisms - i.e. Emissions Trading and Joint Implementation - in meeting GHG mitigation commitments of Annex I countries, see Sijm et al (2000).

- To compare the results of different methodological approaches - ‘bottom-up’, ‘top-down’, ‘intermediate’ - of estimating the cost effects of the Kyoto Protocol.

1.3 Outline of the report

The structure of the present report is as follows. Chapter 2 discusses first of all the methodological approach and the major results of the ECN-AED-SEI study on CDM options in the energy sector. Subsequently, it provides an upgrade and an adjustment of cost curves generated by this study. Finally, Chapter 2 is concluded by some specific conceptual and methodological research questions raised by the ECN-AED-SEI study, which - together with the general objectives mentioned above - will be addressed in the remaining chapters of this report.

Chapter 3 presents a conceptual framework for assessing the cost of GHG mitigation options. Firstly, it defines and outlines the major cost concepts used in cost evaluations of abatement activities. Secondly, it discusses the term cost effectiveness and some other selection criteria in the decision-making process regarding mitigation options. Finally, it comments on the use and definition of cost concepts in both the ECN-AED-SEI study and its underlying project and country abatement studies.

Chapter 4 reviews the ‘bottom-up’ methodology employed by the ECN-AED-SEI study to construct and apply a cost curve for all non-Annex I countries. More specifically, this chapter (i) discusses the major methodological issues affecting the comparability of country abatement studies with regard to their assessments of the potential and costs of mitigation options identified by these studies and, hence, the usability of these assessments for the construction of a bottom-up abatement cost curve, (ii) reviews some additional, specific analytical issues concerning the construction and application of the ECN-AED-SEI cost curve for all non-Annex I countries, and (iii) compares the results of different methodological approaches - ‘bottom-up’, ‘top-down’, ‘intermediate’ - to estimate the cost effects of the Kyoto Protocol.

Finally, Chapter 5 presents a summary of the major findings, conclusions and recommendations of this report.

2. THE ECN-AED-SEI STUDY ON POTENTIAL AND COST OF CDM OPTIONS IN THE ENERGY SECTOR: REVIEW AND UPDATE

2.1 Methodological approach and major results

As noted in the previous chapter, the main purpose of the ECN-AED-SEI study was to assess the potential and cost of CDM options in the energy sector of non-Annex I countries. In order to achieve this purpose, these options were inventoried by means of two principal data sources, i.e. (i) national/sectoral abatement costing studies, and (ii) information obtained from projects carried out within the framework of either the programme of Activities Implemented Jointly (AIJ) and/or the Global Environmental Facility (GEF).

2.1.1 Inventory of CDM options based on abatement costing studies

As part of the ECN-AED-SEI research project, information on 253 eligible CDM options in the energy sector was collected from GHG abatement costing studies in 24 non-Annex I countries.[2] Of the countries covered, 13 were situated in Asia, 7 in Africa, and 4 in Latin America. In 1995, these 24 non-Annex I countries accounted for more than two-thirds of total GHG emissions in all non-Annex I countries (see Annex A).

For all 253 eligible CDM options, emission reduction potentials and costs in 2010 were assessed and entered into a database. By ranking and combining this information - starting from the least-cost option up to the most expensive opportunity - a bottom-up CO_2 abatement cost curve was constructed for the sample of 24 non-Annex I countries in 2010 (representing the annual average of the first budget period, 2008-2012). The left part of Figure 2.1 depicts this cost curve for options in the unit cost range of -50 to +50 US$/tonne CO_2 equivalent.[3]

The total abatement potential in the 24 study countries in the year 2010 at a price of 50 US$/tonne CO_2 equivalents or lower is estimated at roughly 1.5 Gt CO_2 equivalents. Roughly 38 percent of this potential is projected to be achievable at negative or zero incremental costs (the so-called no-regret options). Of the total identified abatement potential, 80 percent is accounted for by options in only 4 non-Annex I countries (China, India, Egypt and Mexico). However, some major countries such as Brazil or South Africa were not included in the sample of non-Annex I countries studied. Considering the distribution of mitigation options over different types of technologies, the major share of the total identified abatement potential is accounted for by energy efficiency measures at the demand side of the energy sector (41 percent), followed by power supply innovations concerning either energy efficiency improvements (25 percent), fuel switch opportunities (15 percent) or renewable energy options (Van der Linden et al, 1999).

In order to achieve a GHG abatement cost curve for all non-Annex I countries, the ECN-AED-SEI research team applied a simple extrapolation method. As mentioned above, the sample of

[2] These abatement studies have been conducted as part of the following donor programmes: (i) the Asia Least-cost Greenhouse Abatement Strategy (ALGAS) sponsored by the ADB and UNDP/GEF, (ii) the UNEP Greenhouse Gas Abatement Costing Studies, (iii), the United States Country Studies Programme (USCSP), and (iv) the Netherlands Climate Change Studies Assistance Programme. For details, see Van der Linden et al (1999) and references cited there. See also Annex A and references of this report.

[3] Out of 253 eligible options included in the database, the unit abatement costs of 22 options were below -50 US$ per tonne, whereas for 15 options these costs exceeded +50 US$ per tonne. Hence the cost curve presented includes 216 abatement options.

24 non-Annex I countries accounted for more than two-thirds of total non-Annex I emissions in 1995. So, by scaling up the identified abatement potential of the 24 sample countries by a factor of approximately 1.5, an extrapolated estimate was obtained of the GHG mitigation cost curve for all non-Annex I countries in the year 2010 (based on the premise that the share of the 24 sample countries in total non-Annex I emissions in 1995 corresponds to their share in total non-Annex I abatement potentials in 2010). The result of this extrapolation method is presented in the right part of Figure 2.1. It shows that, at unit costs up to 50 US$/t CO_2 equivalents, the total annual abatement potential of all non-Annex I countries in 2010 is estimated at approximately 2.25 Gt CO_2 equivalents.[4] Most of this potential is assessed to be achievable at quite low costs. Up to 1.6 Gt/yr appears feasible at costs of 6 US$/t or lower. Hence, the main conclusion of the ECN-AED-SEI research project was that "an enormous abatement potential in non-Annex I countries can be potentially harnessed at very low incremental costs" (Van der Linden et al, 1999).

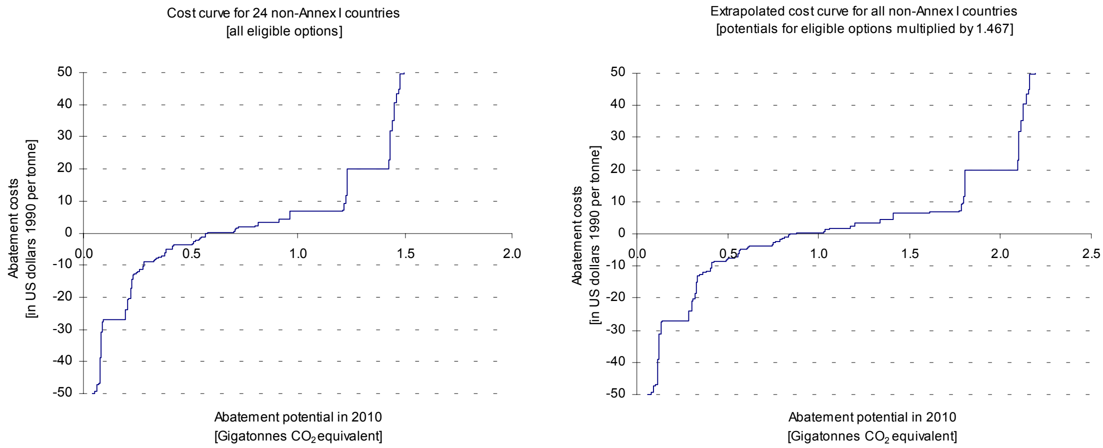

Figure 2.1 *Abatement cost curves for non-Annex I countries*

The main conclusion mentioned above was qualified by noting the following limitations to the analysis:

- The abatement costing studies are far from comprehensive, as they do not exhaustively consider all options in the energy sector of the countries concerned.
- Different assumptions and approaches across abatement costing studies make it difficult to reconcile and combine results.
- The studies do not reveal all information needed to construct cost curves from all available options.
- Estimates of abatement potential and incremental costs depend very sensitively on assumptions about the baseline scenarios.
- Definition of costs was not consistent across studies.
- CDM transaction costs were often excluded.

Nevertheless, the main findings were maintained and repeated in the conclusions, summary and abstract of the final report, whereas the extrapolated cost curve for all non-Annex I countries was used in a supply-demand analysis of an international market of emission credits in order to obtain a rough indication of the market clearing price per tonne of GHG abatement by relying on the CDM (see Section 2.1.3 below).

[4] The possibility to bank credits produced by projects implemented in the period 2000 - 2008 has not been included in the analysis.

2.1.2 Inventory of CDM options based on AIJ/GEF project information

In order to validate the abatement cost curve derived from the country abatement costing studies at the energy sector level, the ECN-AED-SEI research team also collected information on mitigation options at the project level. In total, some 60 AIJ/GEF projects were reviewed. In addition to information on abatement potentials per project, data were gathered concerning mitigation costs in terms of both net incremental costs and AIJ/GEF contributions per unit of GHG abated. It should be noted that the data concerned are mostly ex ante assessments of abatement potentials and costs retrieved from feasibility studies. Another major qualification is that abatement potentials are expressed in total carbon savings over the total project lifetime rather than per annum. Hence, in order to compare these savings with the abatement potentials of Figure 2.1, they have to be divided by the project lifetime, implying that the estimated CO_2 reductions are, on average, at least 10 to 15 times too high compared to those of Figure 2.1.

With regard to net incremental costs, the resulting abatement cost curve is presented in the left part of Figure 2.2. According to Van der Linden et al (1999), this curve comprises the same cost information as the curves of Figure 2.1, and it is 'based on the same methodology as the cost curves derived from the abatement costing studies'. Keeping the above-mentioned qualification on the comparability of abatement potentials in mind, the project cost curve of Figure 2.2 (left) confirms the shape of the country cost curves of Figure 2.1, although it is flatter (i.e. the number of options with high negative costs are less than in the curves of Figure 2.1, whereas the costs rise less fast at the end of these curves). According to the project cost curve, 99 percent of the identified abatement potential costs less than 10 US$/t CO_2 equivalents. The share of no-regret options is approximately 60 percent, which is substantially higher than the 38 percent of the abatement potential identified in Figure 2.1.

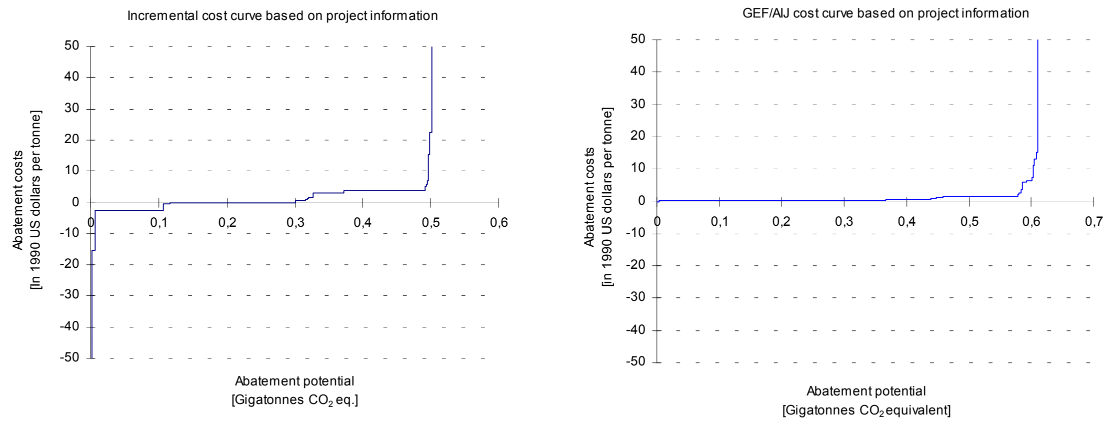

Figure 2.2 *Abatement cost curves of non-Annex I countries based on project information*

The right part of Figure 2.2 presents the cost curve based on unit abatement costs in terms of AIJ/GEF contributions to the projects concerned. According to Van der Linden et al (1999), these contributions "are an indication of the actual costs required to acquire credits from CDM projects". They conclude that the AIJ/GEF curve shows high resemblance with the shape of the project incremental cost curve and, hence, that similar findings - and qualifications - apply to this curve.

However, a sound comparison between the project-based information and the database from the country abatement costing studies appeared not to be possible as only 6 cases could be identified whereby both the technology and the country concerned corresponded in both the AIJ/GEF project database (covering about 60 options) and the database set up by means of the country abatement costing studies (including more than 250 mitigation options). Hence, no meaningful conclusions could be drawn from this small sample of 6 cases.

2.1.3 Supply-demand analysis

The ECN-AED-SEI research team used the abatement cost curve of all non-Annex I countries to determine the international clearing price of CDM-related emission credits and, thus, to indicate the cost effects of the Kyoto Protocol.[5] According to Van der Linden et al (1999), this cost curve can be regarded as the supply curve of CDM-based emission credits, officially referred to as 'Certified Emission Reductions' (CERs). Within the framework of a simple market simulation model covering full global trading in emission credits, this supply curve can be combined with the Annex I demand curve for emission credits as developed in earlier studies (Van Harmelen et al, 1997; Koutstaal et al, 1998). While acknowledging the strict limitations and sweeping assumptions involved, Van der Linden et al (1999) report the following results of this supply-demand analysis:

1. If Emissions Trading (ET) would be confined to CO_2 trade between the western Annex I countries, the resulting equilibrium price of credits would be 57 US$/tonne.
2. If both ET and Joint Implementation (JI) within the Annex I region would be allowed, the equilibrium price of CO_2 emission credits would range from 18 to 29 US$/tonne, depending on whether no-regret options are included or excluded.
3. If all Kyoto Mechanisms - including both ET, JI and CDM - would be allowed, the international market clearing price of emission credits would be either 4 or 15 US$/tonne, depending on whether no-regret options are included or excluded in both Annex I and non-Annex I regions.

So, using CDM leads to a significant fall in the price of internationally traded emission credits and, hence, to substantial cost savings for Annex I countries to meet their Kyoto commitments. The latter finding is confirmed by a later study (Sijm et al, 2000), which used the extrapolated non-Annex I cost curve derived by Van der Linden et al (1999) in order to assess the cost effects of the Kyoto Protocol. In a situation of full global emission trading, CDM-related emission credits will account for about half of the reduction commitments of all Annex I countries (see Table 2.1). As a result, total Annex I abatement costs in 2010 will fall from 91 billion US$ before trade (i.e. no use of the Kyoto Mechanisms) to 23 billion US$ after trade - i.e. full, unrestricted use of all Kyoto Mechanisms - if no-regret options are excluded, and even to 5.8 billion US$ if these negative cost options are included. For non-Annex I countries, the costs of generating CDM credits are estimated at 5.9 billion US$, while the revenues of selling CDM credits are 15.4 billion US$, resulting in net profits of 9.5 billion US$ if no-regret options are excluded. If these options are included, however, these figures are 0.8, 5.2 and 4.4 billion US$, respectively. Hence, the use of the CDM and other Kyoto Mechanisms results in major cost savings for the Annex I countries and, on balance, major net profits for the non-Annex I countries.[6]

[5] The Kyoto Protocol has been agreed at the third international Conference of the Parties to the UNFCCC (CoP-3, Kyoto, December 1997). As part of this Protocol, the economically more developed countries - the so-called 'Annex I countries' - have agreed to reduce their GHG emissions in the first budget period (2008-2012) by approximately 5.2 percent compared to their 1990 emission levels. In addition, it has been agreed that a part of the national reduction commitments can be achieved abroad by means of the flexible instruments or 'Kyoto Mechanisms', i.e. International Emissions Trading (IET), Joint Implementation (JI) and the Clean Development Mechanism (CDM). The latter mechanism offers Annex I countries the opportunity to meet part of their reduction commitments by means of abatement projects in economically less developed countries, the so-called 'non-Annex I countries'.

[6] These figures - expressed in US$ prices of 1990 - relate to the case where only CO_2 is considered. In addition, Sijm et al (2000) analysed the cost effects of the Kyoto Protocol if the other GHGs are covered as well.

Table 2.1 *Selected trade and cost effects of the Kyoto Protocol in 2010 (CO_2 only, in 1990 US$ prices)*

	Unit	Excluding no-regret options	Including no-regret options
Price of emission credits	[US$/t$CO_2$]	14.9	4.2
Total Annex I commitments	[mtCO_2]	2470	2470
Total CDM credits traded	[mtCO_2]	1035	1239
Annex I abatement costs:			
• Before trade	[bUS$]	90.8	90.8
• After trade	[bUS$]	22.9	5.8
Non-Annex I CDM benefits:[a]			
• Gross revenues of CDM	[bUS$]	15.5	5.2
• Total abatement costs	[bUS$]	5.9	0.8
• Net benefits	[bUS$]	9.5	4.4

[a] Non-Annex I data have not been recorded in Sijm et al (2000), but have been derived straight from the model used. These data can also be obtained by (i) drawing a vertical line in the right part of Figure 2.1 (at a price level of 14.9 and 4.2 US$, respectively), (ii) calculating the size of the areas between this line and the X-axis as well as between the cost curve and the X-axis, and (iii) calculating the difference between the size of these two areas in order to achieve the total non-Annex I benefits of generating and selling CDM credits.

Source: Sijm et al (2000).

To conclude, an abatement cost curve covering all non-Annex I countries is an important tool in an analysis to assess the international market equilibrium price for emission credits, the amount or share of CDM-related emission credits in meeting Annex I reduction commitments, as well as the total cost savings of meeting these commitments by relying on the CDM and other Kyoto Mechanisms.

2.2 Updates and adjustments of CDM-related cost curves

As part of the present research project, attempts have made to update/adjust the CDM-related cost curves discussed in the previous section. The major results of these attempts are discussed below.

2.2.1 Cost curves updated by additional country abatement studies

Over the past two years, the UNFCCC has published a large sample of national communications of non-Annex I countries (UNFCCC, 2000a). In general, however, these studies do not contain relevant information on abatement options in the energy sector that could be added to the data-base derived from country abatement costing studies. A major exception is the recent study of Lebanon (UNFCCC, 2000b). Moreover, besides the studies already included in the database, additional UNEP studies are available with regard to Brazil and Ecuador (UNEP, 1994 and 1999).[7] Adding these three countries to the database concerned raises the number of non-Annex I countries covered to 27, and the number of eligible CDM options by 19, i.e. from 253 to 272.

Except South Africa, all major GHG emitting non-Annex I countries are now included in the database, covering about 72 percent of all GHGs emitted by non-Annex I countries in 1995 (see

[7] Although the results of the Brazil study were already published in 1994, for unclear reasons they were not included in the database of the ECN-AED-SEI research project. Unfortunately, a more recent abatement costing study of Brazil is not available. Brazil is one of the countries covered by the United States Country Studies Programme (USCSP), but a cost mitigation study of Brazil is no part of this programme. Meyers et al (2000) have recently published a 'Preliminary Assessment of Potential CDM Early Start Projects in Brazil', but these projects cover only a small sample of the potential abatement options in the energy sector of Brazil.

Annex A).[8] The resulting cost curve derived from the updated database is shown in Figure 2.3. The left part of this figure shows the abatement cost curve for both the original sample of 24 non-Annex I countries and the updated sample of 27 countries. As expected, adding 3 countries moves the cost curve to the right as the identified abatement potential is enlarged (in total, by about 150,000 tonnes of CO_2 equivalents).

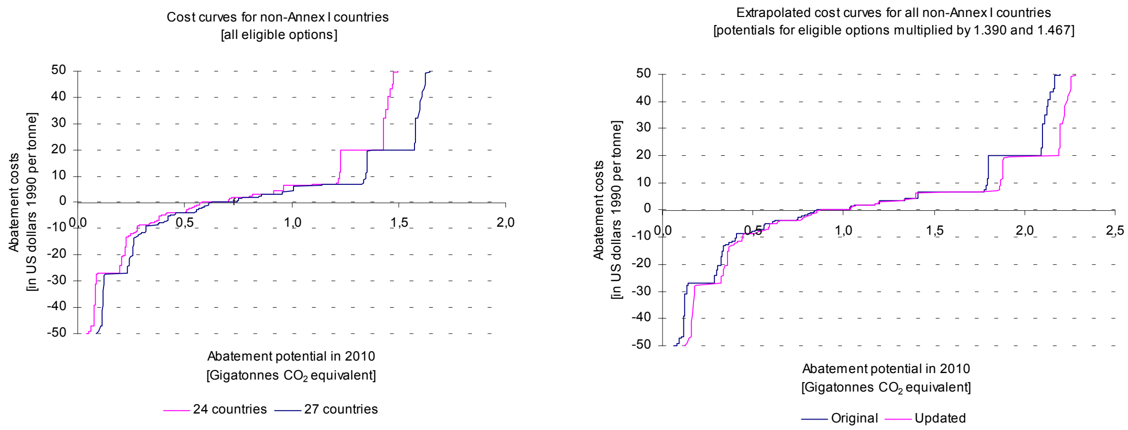

Figure 2.3 *Original and updated abatement cost curves for non-Annex I countries*

The right part of Figure 2.3 presents the extrapolated cost curves for all non-Annex I countries based on both the original and updated database (using the same methodology and assumptions outlined in Section 2.1.1). If the extrapolation would have been implemented perfectly in both cases, the resulting cost curves should have been exactly the same. Although - as shown - this condition is not fully met, the differences between the two extrapolated curves are generally small.[9] This indicates that the (original) extrapolation method has a high degree of robustness in constructing an abatement cost curve for all non-Annex I countries.[10]

2.2.2 Adjusted cost curve based on AIJ/GEF project information

The cost curves presented in Figure 2.2 - based on AIJ/GEF project information - tend to overestimate the quantity of CERs produced per project and to underestimate the cost per CER. This arises due to the lifetime of most projects extending beyond the thirteen-year framework of the CDM (i.e. the first budget period, 2008-2012, preceded by the years 2000-2007 in which CERs can be banked as suggested by the Kyoto Protocol). Emissions reduced after 2012 are at present not valid as CERs because they can not be used in meeting Annex I reduction commitments. CDM investments, therefore, only produce CERs of value before the end of the first budget period.[11]

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[8] A national cost mitigation study of South Africa is part of the USCSP but has not yet been published. Some (preliminary) sub-sectoral cost mitigation studies are already available, but they cover only a part of the energy sector (Howells, 1999; Lloyd et al, 2000). As soon as the national mitigation cost study of South Africa - and other countries studied as part of the USCSP, UNFCCC, etc. - becomes available, the results can be entered into the database in order to enhance the robustness of the non-Annex I cost curve.

[9] The total abatement potential below 50 US$/t is about 90,000 tonnes - or about 4 percent - higher in case of the updated cost curve compared to the original cost curve.

[10] Note, however, that even the updated database does not cover a large sample of (small) non-Annex I countries responsible for about 28 percent of all GHGs emitted by non-Annex I countries in 1995 and, thus, for a similar (assumed) share of the non-Annex I abatement potential in 2010 (Annex A).

[11] This is not the case if a second budget period is agreed that follows soon after the first.

In order to reflect the defined timeframe of the CDM, the method to assess the project abatement potentials and unit costs has been adjusted as follows:

- Estimate total CERs per project before the end of the first budget period. It is assumed that all projects begin in 2000. For projects with a lifetime greater than 13 years the total emissions reduction is taken as the average annual emission reduction multiplied by 13.[12]
- Calculate unit abatement costs as the AIJ/GEF contribution to the project divided by total emissions reductions achieved before the end of the first budget period.[13]

The result of this exercise is depicted in Figure 2.4.[14] It is based on information from 41 energy project reports from which the required data could be obtained. Figure 2.4 illustrates that the two curves are essentially the same shape. Both show that a large proportion of abatement potential is achieved at very low cost, i.e. 99 and 97 percent of the identified reductions can be obtained at below 1 US$/t, respectively. This is due to the inclusion of a small number of projects that reduce a very large quantity of GHG emissions with a relatively small AIJ/GEF contribution. Two of these large-scale projects are in China. After these few low cost-high reduction options there is a set of smaller scale options which produce emissions reductions at between 1 and 10 US$ per tonne. Finally, there are a few high-cost/low-reduction options.

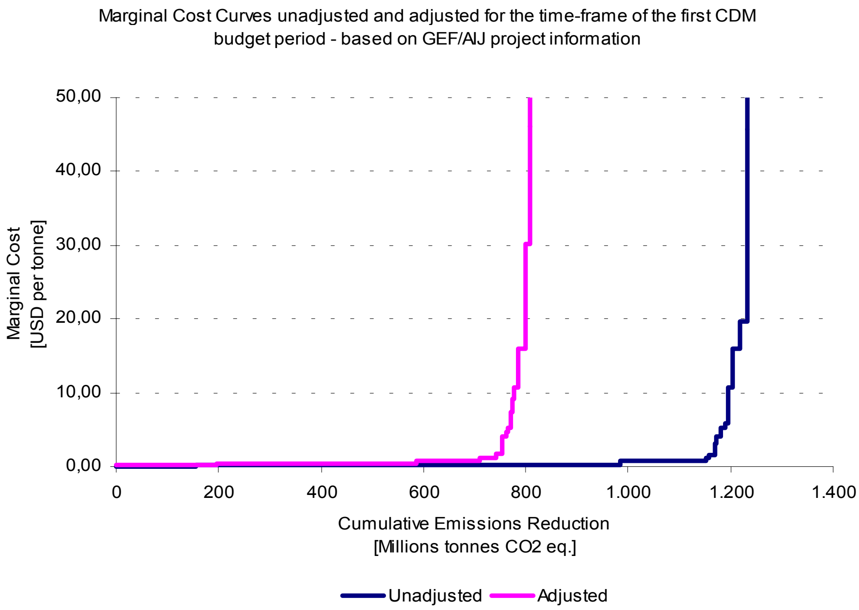

Figure 2.4 *Unadjusted and adjusted non-Annex I abatement cost curves based on project information*

The difference between the two curves reflects the lower quantity of emissions reduction that is achieved due to the restricted timeframe of the CDM, and also the higher cost per unit of emissions reduced due to the cost of each option being spread over a lower output. It will be clear that this difference will be larger if projects start later than the year 2000, and that it will be smaller once a second budget period is agreed following soon after the first.[15]

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[12] Using average annual emission reductions implies that equal reductions are made each year. This is not necessarily the case and it is possible for annual reductions to increase or decrease over the lifetime of the project.

[13] The AIJ/GEF contributions are mostly calculated as incremental project cost although with varying methodologies and cost definitions (see Chapters 3 and 4).

[14] The unadjusted cost curve is comparable to the right part of Figure 2.2.

[15] The time frame issue regarding the cost assessment of CDM options is further discussed and illustrated by Brander (2000). See also Van der Linden et al (1999) and Section 4.4.2 of this report.

2.3 Some conceptual and methodological questions

The methodological approach and major results outlined above with regard to the bottom-up construction and application of abatement cost curves raises some conceptual and methodological research questions, notably:

- What are the major cost concepts used in monetary assessments of mitigation options? How are these cost concepts defined and applied in the general literature on evaluating the costs and benefits of (abatement) projects and policies? Which cost concepts and definitions have been used in the ECN-AED-SEI study on assessing CDM options (including its underlying project and country abatement studies), have these concepts and definitions been employed in a clear and consistent matter, and how do they fit with those of the general literature on cost assessments?
- What are the major methodological assumptions and techniques employed in the abatement studies used by the ECN-AED-SEI research team to construct an abatement cost curve for all non-Annex I countries? What are the implications of these assumptions and techniques for the mutual comparability of these studies and, hence, for the construction and soundness of this cost curve? What are the major methodological assumptions and limitations of applying the cost curve concerned in a supply-demand analysis of a CDM-related market of emission credits? What are the major strengths and weaknesses of constructing and applying cost curves according to the so-called ‘bottom-up’ approach compared to an alternative methodology, the so-called ‘top-down’ approach?

In addition to the general objectives of this study outlined in Section 1.2, these specific questions will be addressed in the following chapters. In particular, Chapter 3 will treat the former set of conceptual questions, whereas Chapter 4 will deal with the latter set of methodological questions.

3. COST ASSESSMENTS OF MITIGATION OPTIONS: CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter presents a conceptual framework for assessing the costs of GHG mitigation options.[16] Actions taken to abate GHG emissions will generally divert resources from other alternative uses. Ideally, a mitigation cost assessment should consider all changes in resources demanded and supplied by a given abatement option in relation to a specific non-policy case (the so-called reference or baseline case). This implies that both the benefits and the cost of a mitigation option versus a baseline situation should be included in the assessment and that, as far as possible, all relevant (net) costs should be covered. In some cases, the sum of all costs and benefits associated with an abatement option might be negative, meaning that society benefits from undertaking this option. It should be stressed, however, that costs - even if they are, on balance, negative - are only one piece of information in the decision-making process of addressing climate change (Halsnaes et al, 1998).

The structure of this chapter runs as follows. First of all, Sections 3.2 up to 3.4 will define and outline the major cost concepts used in the assessment of mitigation actions. Subsequently, the term *cost effectiveness* and some other selection criteria in the decision-making process regarding abatement actions will be discussed in Section 3.5. Finally, Section 3.6 will comment on the use and definition of cost concepts in both the ECC-AED-SEI study and its underlying project and country mitigation studies.

3.2 Economic, financial, private and social costs

A major distinction in assessing the costs of a mitigation option - or any other activity - is between economic versus financial costs on the one hand and private versus social costs on the other hand. Although these cost concepts are closely related - and largely overlapping - it is important to define and use them in a clear, correct and consistent matter. As indicated in Table 3.1, the distinction between economic and financial costs on the one hand and private versus social costs on the other hand is in fact based on two different dimensions of assessing mitigation costs.

The horizontal dimension of Table 3.1 refers to the difference between economic and financial costs. This dimension/difference concerns the monetary valuation of mitigation costs. An assessment of a mitigation option in terms of *financial costs* is based on actual payments and market prices of the resources involved. For a variety of reasons, however, these actual prices and payments may not reflect the true scarcity values or *opportunity costs* of the resources used and generated by the mitigation option.[17] These reasons may concern taxes, subsidies, trade and exchange rate controls, other policy-induced market distortions, and market imperfections such as lack of competition or imperfect information. A monetary analysis of a mitigation option based

[16] In the context of climate change, mitigation or abatement costs are distinguished from adaptation costs. *Mitigation* or *abatement costs* refer to net costs of actions to limit or sequester GHG emissions. On the other hand, *adaptation costs* relate to net costs of changing investment, production and/or consumption patterns due to increasing concentrations of GHGs and the resulting risks/effects of climate changes. Although mitigation and adaptation costs are usually considered separately, they are actually closely interrelated. For details and further reading on the linkages between adaptation and mitigation costs, see Markandya and Halsnaes (2000).

[17] The term *opportunity costs* refers to the value of the next best thing - i.e. the opportunity forgone - that could have been produced with the same resources used for the mitigation option. For instance, in a forestry project, the opportunity costs of the land involved is the highest valued output - e.g. recreational use or agricultural output - that would have been received from that land had it not been used for forestry (Markandya et al, 1998).

on the true scarcity values of the resources involved is called an *economic* cost assessment. It implies that, if market prices are distorted - i.e. they do not reflect true scarcity values - corrections have to be made. These corrected prices, which should be equal to the opportunity costs of the resources involved, are called *shadow prices* (see Box 3.1).[18]

The other, vertical dimension of Table 3.1 refers to the difference between private and social costs.[19] This dimension/difference concerns the categories of costs taken into account in the decision-making process, depending on the perspective from which costs are considered. Categories of costs that influence an individual's decision-making are called *private costs*. The terms 'individual' and 'private' in the last sentence, however, may be a bit misleading as they relate not only to private/individual entities such as producers, traders, end users, interest groups and commercial enterprises, but also to (quasi-) public agencies or even to the government budget or treasury as a whole.[20]

Table 3.1 *Mitigation cost assessment: main dimensions and cost concepts*

Dimension		*Cost valuation*	
		Financial	Economic
Cost perspective	Private	1	2
	Social	3	4

Social costs, on the other hand, are usually defined as all relevant costs of an activity considered from either a national or global perspective.[21] The major distinction between social and private costs are the so-called 'external costs' (see below). Hence, these external costs should be explicitly accounted for in a social cost assessment, which can be conducted in both financial and economic terms.[22]

External costs refer to the costs or impacts arising from any human activity that are inflicted upon one or more members of a society, but that are not accounted for in the decision-making process of the agent or entity causing these impacts (mainly because the costs involved are not adequately 'internalised' through price mechanisms, markets or other institutions such as well-defined property rights or tax systems). The impacts concerned - called *external effects* or *externalities* - can be positive or negative, implying that the costs involved can also be positive or negative. An example of an externality is global warming in the sense that the costs imposed by increased concentrations of GHGs are usually not taken into account in decisions or activities causing their emissions. Another example is the negative health impact associated with particulate and other emissions from diesel fuel use. Such an impact might be reduced by a project that replaces diesel generators with gas-fuelled or photovoltaic systems (see Box 3.2).[23]

[18] The difference between cost-benefit analyses in terms of financial versus economic costs is extensively discussed and illustrated in classical handbooks on project appraisal in developing countries such as Gittinger (1972) or Little and Mirrlees (1982).

[19] The conceptual difference between private and social cost is related to but different from the methodological issue of determining so-called system boundaries in cost analyses (see Chapter 4).

[20] For instance, a government may apply a project assessment in terms of private costs in order to analyse the financial viability of a project or its impact on the treasury through government investments, subsidies, taxes, etc.

[21] In principle, social costs can also be considered from the perspective of a region or group of countries such as the EU, or even from a sub-national perspective such as the province or town level.

[22] Note that certain (transfer) payments are regarded as costs from a private perspective but not from a social point of view. Hence, such payments should not be included in a social cost assessment.

[23] External costs are, by definition, hard or even impossible to determine by means of market prices. There are, however, a number of well-established techniques for valuing external costs such as 'hedonic pricing', 'contingent valuation' or 'benefit transfer'. For details, see Navrud (1994), CSERGE (1999), ExternE (1999), and Markandya and Halsnaes (2000).

Box 3.1 *Shadow prices*

Several sophisticated approaches have been developed to determine shadow prices for different categories of resources such as land, labour, capital, foreign exchange, etc.[#1] A more practical, simple approach is to use conversion factors, i.e. ratios of shadow prices to domestic market prices. These factors can often be obtained from existing databases of the World Bank or other donor organisations, which have ample experience in appraising projects in developing countries.[#2]

In order to illustrate the use of shadow prices by means of conversion factors, the Table 3.A provides a simple example of a project appraisal in financial versus economic terms.[#3] The project concerned incurs costs over 3 years under the categories of unskilled labour and foreign capital. The corresponding conversion factors of these resources are 0.8 and 1.5, respectively, implying that unskilled labour is less scarce than its market price would suggest, whereas foreign capital is scarcer than considered in financial terms. The table below shows the impact of shadow pricing on project costs. In economic terms, total costs have not only risen by 10 percent, but the relative changes in resource costs are also important as they influence the design of the project, for instance by substituting unskilled labour for foreign capital (Markandya, 1998).

Cost adjustments by means of shadow price conversion factors

Year	Unskilled labour		Foreign capital		Total costs	
	Financial	Economic	Financial	Economic	Financial	Economic
1	100	80	70	105	170	185
2	80	64	60	90	140	154
3	60	48	50	75	110	123
Total	240	192	180	270	420	462

[1] See, particularly, Gittinger (1972) or Little and Mirrlees (1982). See also Halsnaes et al (1999), suggesting some simple price correction rules.

[2] The framework of shadow prices and conversion factors has also been used by means of applying so-called income weights in order to address the fact that policy-makers place different valuations on costs and benefits accruing to different sections of society. See Little and Mirrlees (1982), Markandya (1998), and Markandya et al (1998).

[3] Other practical illustrations of shadow pricing can be found in Gittinger (1972), Markandya (1998), and Brander (2000).

To conclude, by combining the two dimensions outlined above, at least four categories of cost assessments can be distinguished (Table 3.1):
1. private-financial
2. private-economic
3. social-financial
4. social-economic.

As noted, a social cost analysis - in financial or economic terms - may be conducted from either a national or global perspective. Hence, categories 3 and 4 can, in principle be further divided in sub-categories of cost analyses (national/global). Ideally, mitigation cost assessments should be conducted in social-economic terms, including all relevant cost of a society expressed in true scarcity values (i.e. shadow prices). In practice, however, most mitigation studies cover only a (small) part of all relevant costs, often expressed in uncorrected or partially corrected market prices (see Section 3.6).

Box 3.2 *External Costs*

Project: AIJ, Bolivia, San Ramon Rural Electrification

This project involves a switch from diesel fuel to gas in electricity generation in a rural area of Bolivia, primarily aimed at reducing GHG emissions. In addition, emissions of SO_2 and NO_x per unit of electricity produced are also considerably lower for gas- than diesel-fuelled generators, as illustrated in the table below.

External effects of fuel switch project in rural Bolivia.

	CO_2	SO_2	NO_x
Diesel [kg/MWh]	995	0.43	7
Gas [kg/MWh]	565	0	0.6
Estimated emission reduction [tonnes]	26700	72	980
External cost [US$/tonne]		145	630
Local external benefit [US$]		10440	617400

In the project analysis, the external benefits - in terms of reduced damage costs from SO_2 and NO_x - are considered to be entirely local. The local benefits of emissions reductions have not been valued directly but shadow prices for the value of reduced external costs of each gas have been used (IPCC reference manual, 1995). These shadow prices have been adjusted to local equivalent values using a Purchasing Power Parity index (CIA World Factbook, 2000).

3.3 Direct, indirect and full costs

3.3.1 Introduction

Cost assessments in conventional, bottom-up studies are usually restricted to analysing the so-called direct engineering costs of a mitigation option, i.e. the resource costs of up-front capital investments, maintenance, fuel and other operation costs. In addition, however, an abatement project or innovation may incur a variety of other, indirect costs such as:[24]

- implementation costs
- costs of risks and uncertainties
- ancillary costs and benefits
- macroeconomic costs.

These cost categories will be discussed below. Together, the direct and indirect costs of a mitigation option are defined as its *full costs.*

3.3.2 Implementation costs

All mitigation options involve some costs of policy or project design, planning, baseline study, monitoring, evaluation, verification of emission credits, etc. However, besides these so-called *administration costs* (or *transaction costs* defined strictly), the implementation of mitigation options - notably in less developed countries - is usually faced by a variety of constraining factors such as lack of human or physical capacities, ill-defined and/or not well-enforced property

[24] Following Markandya (1998), a broad definition of indirect costs will be used in this report (in contrast to some authors who restrict the concept of indirect costs to macroeconomic costs only).

rights and contracts, lack of information, imperfect markets, or other institutional failures. Due to these institutional failures and barriers, the transaction costs of a mitigation option - defined broadly - may be very significant or even prohibitively high.[25] Hence, the implementation of a mitigation option may be supported by specific measures aimed at removing or reducing these barriers and the costs involved. Following Halsnaes et al (1999), these additional measures are called *barrier removal measures,* the associated costs *barrier removal costs*, whereas the sum of the barrier removal costs and the administration/transaction costs of a mitigation option are defined as its *implementation costs.* Examples of implementation barriers and policy measures to reduce these barriers and the costs involved are presented in Table 3.2.[26]

In general, barrier removal policies are aimed at improving the performance of institutions - markets, property rights systems, private organisations, public agencies, etc. - in order to reduce transaction costs and, hence to enhance economic efficiency. As noted, however, barrier removal policies themselves are not free of costs. On the contrary, the costs of these policies may be very high depending on the institutional development of a country, the mitigation option concerned, the specific barriers to be removed and, hence, the specific barrier removal policies to be taken.

Depending on the mitigation option concerned, the design of barrier removal policies and the estimation of the costs involved may sometimes be quite complicated. For instance, it is generally more complicated to design and estimate the costs of implementation programmes aimed at changing the behaviour of many individual actors - such as a Demand Side Management (DSM) or end-use energy efficiency programme - than those with centralised project planning, e.g. a fuel-switch programme of a large-scale power supply plant (Markandya, 1998).

Barrier removal policies can also be distinguished according to their level of intervention such as the project, sector or macroeconomic level (Halsnaes et al, 1999). Another, related distinction is between ‘specific’ and ‘general’ implementation policies. A specific policy effort is usually directly related to a certain project or sector option, whereas its impact is largely limited to this option. Examples concern specific programmes for information, training, institution strengthening, and the introduction of technical standards. Such policies and the costs involved can relatively easily be integrated in project or sector mitigation assessments. General implementation policies, on the other hand, are less directly related to a certain option, whereas both their positive and negative effects reach usually far beyond a specific mitigation project or sector strategy. Examples include measures to reform key market prices, taxes, subsidies or exchanges rates, as well as general efforts to develop and strengthen administrative capacities, markets and other institutions. As the costs and benefits of such general policy measures reach usually far beyond a specific option, they are usually much harder to integrate in project or sector mitigation assessments. Therefore, an adequate cost-benefit analysis of these general measures requires an economy-wide assessment involving the use of intersectoral, macroeconomic models (see Markandya, 1998; Markandya and Halsnaes, 2000; and Section 3.3.5 below).

To conclude, the implementation costs of a mitigation option are defined as the sum of its administration, transaction and barrier removal costs. To some degree, there will be a trade-off between administration/transaction costs on the one hand and barrier removal costs on the other, in the sense that the former category will be reduced if higher amounts are spent on the latter. Hence, an optimal allocation between both cost categories has to be found in order to minimise total implementation costs. However, even if minimised, total implementation costs may still be substantial and, therefore, they have to be considered in a mitigation cost assessment. Moreover,

[25] The exclusion of transaction (and other) costs from conventional, bottom-up mitigation studies may at least in part explain the so-called ‘no-regret paradox’, i.e. the existence of ‘negative-cost’ mitigation options that are not implemented of their own accord, for instance through private market forces. The issue of no-regret options will be further discussed in Chapter 4.

[26] Additional, more specific examples of implementation barriers and policies or costs involved can be found in a number of project/country mitigation studies in developing countries (USCSP, 1999; Brander, 2000).

these costs may vary considerably among mitigation options and, hence, including these costs may significantly change the ranking (and selection) of these options compared to the ranking according to a conventional, bottom-up cost curve excluding these costs.

Table 3.2 *Barrier removal policies*

Barriers	Barrier removal policies
Market barriers	
• Lack or poor performance of capital and other markets	• Creating or improving markets for credits, savings, insurance and other (financial) transactions
• Lack of competition	• Deregulation, privatisation, stimulating (international) competition through price reforms or exchange rate devaluation
• Lack of market integration	• Investments to improve infrastructure and information systems
• Price distortions or lack of price incentives	• Reforming prices, taxes and/or subsidies
Inflexibility and other barriers of established technical systems	
• Irreversibility of infrastructure and capital investments	• Capital turnover subsidies; improved timing, planning and/or flexibility of investment programs
• Inertia in technology innovation and learning	• Demonstration projects; subsidies to research & development programmes, learning processes, etc.
Human capacity barriers	
• Lack of skilled labour and professionals, notably of managerial and administrative capacities	• Education and training programmes; wage and salary reforms
Other institutional barriers/failures	
• Ill-defined or poorly enforced property rights, contracts, etc.	• Establishing and strengthening legal institutions, land tenure and other property rights systems
• High risks and uncertainties	• Improving information, insurance and risk analysis systems; promoting project diversification and other risk management strategies
• Poor decision-making, implementation and managerial accountability in public sector	• Improving public performance through decentralisation, transparency, clear performance objectives and rules, well-designed budgets, improved remuneration systems and other incentives
• Lack of involvement of local beneficiaries in policy design and implementation	• Improving local consultation and participation through grass-root organisations

Source: Sathaye and Bouille (2000), Halsnaes et al (1999), and USCSP (1999)

3.3.3 Costs of risks and uncertainties

Risks affect the expected value of CDM investments. The costs of risk bearing faced by CDM investors need to be explicitly considered in project assessments. Developing countries are characterised by a high degree of uncertainty over most of the variables related to appraising CDM projects. The costs associated with this uncertainty need, as far as possible, to be quantified in order to make comparisons between CDM options with different levels of risk. Types of risk relevant to CDM options include baseline risk, country risk, and project risk.

Uncertainty over both the emissions and cost baseline will affect the expected value of a particular investment. If emissions baselines are dynamic (i.e. allowed to vary over the course of the project), the quantity of additional emissions reductions cannot be known with certainty at the planning stage of the project. This uncertainty may be overcome by fixing the baseline at the start of the project. In this case, there is a trade-off between the accuracy of the cost effectiveness measurement of the project and the level of uncertainty faced by the investor. One proposed solution is to reduce the uncertainty faced by investors by setting an ex ante baseline but scaling the number of Certified Emission Reductions (CERs) available from the project according to the level of baseline uncertainty (Meyers, 1999).

Project risk concerns the uncertainty related to the success of the project itself. Projects may be unsuccessful for a large number of reasons, such as unforeseen technical or development problems. Projects could also be unsuccessful due to uncertain developments in the market for the final product of the investment (usually electricity in the case of CDM-type projects in the energy sector), or in relevant factor markets.

Country risk includes the natural, political and economic risks associated with investing in a particular country. The stability of a country can have a significant impact on the expected value of an investment. Natural risk refers to the potential for natural disasters such as floods, earthquakes and hurricanes that may damage the functioning of the project. Political risk refers to uncertain property rights regarding the CDM project or the investing company. Political risk may arise due to weakness of legal processes such as non-enforcement of contracts, or to non-fulfilment of promised actions of the host government. Economic risks include uncertainty over exchange rates and interest rates (Janssen, 1999).

It is necessary to analyse and quantify the risks associated with CDM investments in order to make comparisons and choices between them, and to gain an accurate expectation of the emissions reductions that will be produced. The application of risk analysis techniques, i.e. expressing benefits and costs of a project as certainty equivalents to allow standard discounting and comparison, has a huge information requirement. A less demanding approach is to attach a probability of failure to a project as a whole. Project failure can be defined through a logical framework approach, which sets out a number of criteria for project success that can be checked ex post. It is important for ex ante project appraisals to recognise the fact that a significant proportion of projects fail, and to avoid the 'appraisal optimism' that is observed for many GEF projects. Observation of the portfolios of international development agencies suggests that the rate of project failure is roughly 25% (Weiss, 1996). The failure rate of projects in the energy sector, based on World Bank experience in the period 1987-1990, is around 16%. Such figures - differentiated by region and/or type of project - could provide guidelines for including risks in CDM cost assessments. Another opportunity is the involvement of specialist risk analysis firms (e.g. Standard and Poors, Political Risk Services) in the identification, indexation and prediction of potential risks of CDM investments along the lines of existing services for usual foreign direct investments.

There are several strategies available for the management of CDM project risks, the costs of which should be included in the mitigation cost assessment. Risk management strategies include insurance, project diversification, and the specific structuring of CDM investments to reduce risk. *Insurance* is the transfer of a particular risk to a third party that is able to pool the risk with other uncorrelated risks. There is clearly a role for insurance companies such as Lloyds of London or the American International Group to become involved in CDM options, and also potentially for the Multilateral Investment Guarantee Agency (MIGA), which is an affiliate of the World Bank. *Project diversification* involves the reduction of total asset value risk by spreading investments across a number of projects with uncorrelated performance. Project diversification provides a strong argument for the creation of mutual funds to manage investments in emissions reductions. *Project structuring* could involve the creation of local stakeholders in the project to reduce political risks. For CDM options, this could include both the creation of local benefits and the sharing of CERs produced by the project.

Some costs of these risk management strategies - notably insurance - can be easily integrated in conventional mitigation cost assessments, for instance as part of the administration, transaction or barrier removal costs discussed above. These strategies, however, do not fully reduce or cover all CDM-related risks and, hence these risks and the costs involved have to be explicitly mentioned and, where feasible, quantified in mitigation cost assessments by means of risk analysis techniques.[27]

3.3.4 Ancillary costs and benefits

The literature uses a number of terms to depict the benefits that may arise in conjunction with GHG mitigation policies. These include ‘ancillary benefits’, ‘associated benefits’, ‘co-benefits’, ‘collateral benefits’ and ‘side benefits’. Although these terms have all slightly different connotations, they all reflect the fact that most activities to mitigate GHG emissions also have other benefits related to objectives such as health, development, equity, environmental protection or sustainability. Occasionally, these benefits are referred to as ‘ancillary costs’ - or just ‘ancillary impacts’, etc. - to express the fact that in some cases the benefits may be negative. All these terms are closely related to the concepts of ‘externalities’ and ‘external costs/benefits’ discussed in Section 3.2. In fact, the term ‘ancillary impacts’ may have a broader coverage than ‘externalities’ as some ancillary impacts would not necessarily count as external effects from the standpoint of economic efficiency, depending on whether markets or other institutions fail to account for these impacts in the decision-making process of individual agents or entities (Markandya and Halsnaes, 2000; Hourcade and Shukla, 2000).[28]

There are a variety of effects that may result from mitigation policies that are secondary to the primary aim of reducing GHG emissions. Existing studies have identified mortality and morbidity benefits associated with collateral reductions in particulates, nitrogen dioxides and sulphur dioxides from power plants and mobile sources as a major source of ancillary benefits (Idem). Reduced private auto use and substitution to mass transit will reduce air pollution and congestion. Other ancillary benefits concern improvements in visibility and ecosystem health, and reduced damages of crops and materials. On the other hand, there may be ancillary costs or negative side effects of mitigating GHG emissions such as a greater reliance on nuclear power with its attendant externalities, an increase in indoor air pollution associated with a switch from electricity to household energy sources (e.g. wood or lignite), or additional costs in terms of fewer amenities, time forgone due to substitution from private to public transport or other changes in people’s customs and behaviour.[29]

Existing studies provide assessments of net ancillary benefits ranging from a small fraction of GHG mitigation costs to more than offsetting them.[30] Besides differences in methodologies applied, this variation in cost estimates results from differences in geographical areas, sectors, ancillary effects and/or mitigation options considered.[31] Hence, including ancillary impacts in mitigation studies may significantly change the cost assessment of individual CDM options and,

[27] Most of the GEF and AIJ project reports deal in some way with project risk although the analysis tends not to give a quantitative view of risk in terms of a probability of project success or expected value of the investment. See Brander (2000) for an example of addressing risks in an AIJ hydroelectric project in Costa Rica.

[28] For instance, health impacts and other side effects such as loss of time or amenities involved with mitigation options may be considered in individual decision-making and, hence, can not be classified as external effects.

[29] See Markandya and Halsnaes (2000) for additional examples of ancillary costs and benefits.

[30] See particularly chapters 8 and 9 of the forthcoming Third Assessment Report of the IPCC (Hourcade and Shukla, 2001; and Barker and Srivastava, 2000) and references cited there. See also Kram (1998) and Markandya (1998).

[31] As noted, methodologies for valuing external/ancillary effects are discussed in Navrud (1994), CSERGE (1999), ExternE (1999), and Markandya and Halsnaes (2000).

hence, the ranking and selection of these options in the decision-making process of mitigation actors.

3.3.5 Macroeconomic costs

Certain mitigation projects may have significant macroeconomic effects, i.e. impacts on GDP, income distribution, employment or trade. Examples concern CDM options that involve major changes in using energy or other resources (land, labour, capital), as well as other mitigation projects requiring 'general' implementation policies to succeed (see Section 3.3.3). Through changes in prices and quantities, such options may bring about a variety of dynamic, feedback effects at the (inter-) sectoral or national level. These effects may be particularly strong if a set of mitigation options is implemented more or less simultaneously during a certain time interval. In such cases, the macroeconomic impacts have to be included in a mitigation cost assessment. Such an exercise, however, requires complex macroeconomic modelling and a large amount of reliable, aggregated data that may be hard to generate in less developed countries.

A viable alternative to complex macroeconomic modelling is to make a broad, more descriptive assessment of important economic trends of a developing country that implements mitigation options. Through combining economic development trends with assumptions on energy use and GHG emissions, at least a qualitative assessment of different development scenarios can be undertaken. Halsnaes et al (1999) have recently developed such a coherent framework for analysing macroeconomic and emission trends in developing countries, called 'Simplified Macroeconomic Assessment of GHG limitation (SMAG).[32]

3.4 Average, incremental, marginal and total costs

In mitigation studies, the terms average, incremental, marginal and total costs are frequently used. *Marginal* abatement costs are defined as the extra cost of reducing an additional unit of GHG emissions. *Total* abatement costs are the sum of all marginal costs of achieving a certain amount of emission reductions, whereas *average* abatement costs are simply the total mitigation costs divided by the total amount of emission reductions.

The term *incremental costs* is mentioned in both the Framework Convention on Climate Change (FCCC) and the Kyoto Protocol. It is particularly used by the Global Environment Facility (GEF) as part of its function of providing financial support for abatement projects and other environmental activities in developing countries. In the context of a mitigation project, incremental costs are defined as the additional costs of the project compared to the costs of the (baseline) activity that can be assumed to be substituted by the project concerned.

Actually, the FCCC speaks of *agreed full incremental costs* (Article 4.3). The adjective 'full' implies that all relevant costs of an activity should be considered, notably its implementation and ancillary costs. The word 'agreed' refers to the fact that it is usually very difficult and potentially controversial to determine the full incremental costs of a mitigation project. Hence, parties involved have to agree on a realistic basis for the assessment of these costs.[33]

Table 3.3 provides a stylised example of assessing the incremental costs of a mitigation project. The direct costs of the project are estimated at 101 million US$ compared to 104 million US$ for the baseline situation. So, the direct incremental costs of the project are -3 million US$. In this respect, the project may be regarded as a 'no-regret' option. However, both the implemen-

[32] See also Markandya (1998) for some other, simple suggestions and illustrations of including macroeconomic impacts in mitigation cost assessments in developing countries. See also Hourcade et al (1998).
[33] The concept incremental costs and the major methodological issues involved are discussed and illustrated in GEF-publications such as Ahuja (1993), King (1993), Mintzer (1993) and GEF (1996). See also Markandya et al (1998), Christensen et al (1998), Halnaes et al (1999), and Brander (2000).

tation costs and the external costs - i.e., in this case, local benefits - have not yet been considered in this evaluation. Including these items results in an assessment of full incremental costs of 10 million US$. As the project contributes to an additional emission reduction of 20 million tonnes of CO_2 equivalents, this implies that the average incremental costs are 0.5 US$ per tonne CO_2 equivalents.

Table 3.3 *Example of assessing incremental costs of mitigation project*

	Unit	Mitigation project	Baseline situation	Incremental effect
Direct costs	Million US$	101	104	-3
Implementation costs	Million US$	14	0	14
Ancillary, local benefits	Million US$	-5	-4	-1
Total/full costs	Million US$	110	100	10
GHG reduction	Million tonnes CO_2 eq.	22	2	20
Unit abatement cost	US$/t$CO_2$ eq.	5	50	0.5

3.5 Cost effectiveness and other selection criteria

3.5.1 Defining and comparing cost effectiveness

In mitigation studies, cost effectiveness is the most widely used criterion in order to evaluate and compare GHG abatement options. In principle, the definition and calculation of this criterion is simple: the costs of a mitigation option divided by its emission reductions, or in equation form:

$$\text{Costeff} = \frac{C}{E} \qquad \text{(Eq. 1)}$$

Where C is the balance of incremental costs and benefits of a mitigation option and E its incremental amount of emission reductions. Both C and E, however, are flows of costs and emission reductions that occur at different points in time. Because of 'impatience' or time preferences of economic agents as well as the 'marginal productivity' or opportunity costs of capital, the present value of costs and benefits differ depending on the time when they occur. In order to compare and aggregate a flow of costs and benefits, it has to be transformed by a discounting method resulting in its net present value, defined as:

$$NPV_c = \sum_{t=0}^{T} \frac{C_t}{(1+i)^t} \qquad \text{(Eq. 2)}$$

Where NPV_c is the aggregated net present value of a flow of costs and benefits, T represents the time interval of the option concerned, C_t is the net costs at time t, and i is the interest or discount rate.

The flow of emission reductions (E) is usually not discounted in mitigation cost assessments.[34] Hence, the total amount of a flow of emission reductions can be calculated by:

$$NPV_e = \sum_{t=0}^{T} E_t \qquad \text{(Eq. 3)}$$

[34] This and other issues related to the method of discounting are discussed in Section 4.2.7.

Where NPV_e is the aggregated net present value of a flow of emission reductions, and E_t is the amount of emission reduction at time t.

Another, comparable approach to calculate the cost effectiveness of a mitigation option is the so-called levelized cost method, resulting in a flow of constant net annual costs over the lifetime of a mitigation option (UNEP, 1994, Halsnaes et al, 1998 and 1999). The levelized cost of an option (C_L) can be calculated with the formula:

$$C_L = NPV_c \frac{i}{1-(1+i)^{-t}} \qquad \text{(Eq. 4)}$$

However, in order to obtain an estimate of the cost effectiveness of a mitigation option according to the levelized cost method (C_L/E_L) that is similar to the NPV method (NPV_c/NPV_e), the flow of emission reductions has to be levelized as well:

$$E_L = NPV_e \frac{i}{1-(1+i)^{-t}} \qquad \text{(Eq. 5)}$$

Table 3.4 provides a simple example of calculating the cost effectiveness of a mitigation option according to the NPV and levelized cost methods. At a discount rate of 8 percent (i = 0.08) and a time interval of 10 years (t = 10), the cost effectiveness is similar according to both methods, i.e. 1.5 US$ per tonne CO_2.

Table 3.4 *Example of calculating the cost effectiveness of a mitigation option by two alternative methods*

Year	Costs undiscounted [US$]	Costs discounted at 8% [US$]	Emission reductions undiscounted, [tonnes CO_2]	Cost effectiveness [US$/t$CO_2$]
1	200	185.2	10	
2	100	85.7	15	
3	80	63.5	20	
4	-80	-58.8	25	
5	70	47.6	30	
6	100	63.0	30	
7	40	23.3	30	
8	-30	-16.2	35	
9	20	10.0	35	
10	10	4.6	35	
Net present value	510	408	265	1.5
Levelized cost method		60.8	39.4	1.5

In addition to evaluating and comparing different mitigation options, the cost-effectiveness criterion is also used to rank and aggregate these options as illustrated by the bottom-up approach of constructing abatement cost curves (see previous and next chapters). However, an adequate comparison, ranking or aggregation of mitigation options by means of this criterion requires that at least the following three conditions are met:

1. The same definition of costs has to be applied throughout all mitigation options considered. Hence, as outlined in the previous sections, analyses of these options should cover the same cost categories assessed in equal terms, for instance including direct costs and implementation costs, both valued in social-economic terms.

2. The same unit of measurement has to be used to express the cost effectiveness of all mitigation options considered. This implies, first of all, that the costs of these options - i.e. the numerator of equation 1 - has to be expressed in the same currency of the same year, e.g. in US dollars of 1990. If not, they have to be converted by means of an official price deflator and/or exchange rate. Secondly, the emission reductions - i.e. the denominator of equation 1 - have to be expressed in the same unit of GHGs abated for the same period, e.g. in tonnes of CO_2 equivalents for the year 2010 (reflecting the Kyoto budget period 2008-2012). If not, they have to be converted by using the same methodology.[35] The final result is that the cost effectiveness of all mitigation options considered is expressed in the same unit, i.e. in (1990) US$ per tonne (2010) CO_2 equivalents.
3. The same, comparable methodology has to be applied to measure the cost effectiveness of all mitigation options considered. This implies that the numerator and denominator of equation 1 have to be assessed by similar, transparent approaches, including key underlying assumptions, calculation techniques, models used, etc.

Although these conditions may seem quite obvious at first sight, for a variety of reasons they are not always met, as will be illustrated below in Sections 3.6 and 4.2. First of all, however, some brief attention will be paid to other selection criteria besides cost effectiveness.

3.5.2 Other selection criteria

Cost effectiveness is used as a principal criterion in the decision-making process of identifying and selecting the least-cost options for achieving a certain GHG mitigation objective. This criterion, however, has a limited meaning as it is based only on monetary costs and benefits, whereas it neglects other (more) important aspects in the selection process of mitigation options. Examples of such non-monetary aspects concern equity, employment, long-term development or other policy objectives of a country; the institutional capacity, the social acceptability or other implementation issues regarding specific mitigation options; the impact of abatement projects on the incidence of morbidity and mortality, the irreversibility of environmental or ecological changes, the high (political) risks and other, non-quantifiable uncertainties of specific mitigation options, etc. Although these aspects are usually very hard or controversial to measure in terms of monetary costs and benefits, they can in some cases be quantified in physical terms while in other cases they can only be expressed in qualitative terms. If relevant, these non-monetary aspects have to be considered explicitly as major selection criteria - besides cost effectiveness - in the decision analysis of mitigation options.[36]

3.6 Cost definitions in the ECN-AED-SEI study

As stated above, an adequate comparison, ranking or aggregation of mitigation options by means of the cost-effectiveness criterion requires that at least the same definition of costs has to applied throughout all mitigation options considered. This section will discuss whether this condition has been met by the ECN-AED-SEI study on assessing the costs of CDM options in the energy sector.[37] As this study is based on the use of two separate data sources - i.e. AIJ/GEF project reports and country abatement assessments - some brief remarks will firstly be made on the use of cost definitions in these reports and assessments.

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[35] Non-CO_2 GHGs can be converted to CO_2 equivalents by means of so-called Global Warming Potentials (GWPs) defined by the IPCC for a time horizon of 100 years (Houghton et al, 1996). Emissions reductions calculated for different time periods can be converted by using the same inter- or extrapolation method (see Chapter 4).

[36] Several decision-making frameworks or techniques have been developed to consider mitigation options under a variety of (non-monetary) selection criteria such as multi-attribute or multi-criteria analysis, decision analysis under irreversibility, risk or uncertainty, or the so-called Analytical Hierarchy Process (AHP, i.e. a decision analysis tool that allows the explicit application of both quantitative and qualitative policy criteria). For details, see Munasinghe et al (1996), Markandya (1998), Halsnaes et al (1999), and ALGAS (1998, both Country and Summary Reports).

[37] The other two conditions mentioned in Section 3.5.1 will be addressed in Chapter 4.

In general, AIJ/GEF project evaluations are based on a financial analysis of net incremental costs, including both the direct engineering costs and the specific implementation costs of a project. Although other cost categories - such as costs of project risks, ancillary benefits, general implementation costs or macroeconomic costs - are often considered in AIJ/GEF project reports, they are often not quantified in monetary terms and, hence, not included in the estimation of project costs. However, the definition and, so, the inclusion or exclusion of costs may vary significantly between individual project reports, which reduces an adequate comparison of the estimated cost effectiveness of the mitigation options concerned. This applies particularly to estimates of cost effectiveness based on AIJ/GEF contributions as the latter are more the result of (political) negotiations between donor and recipient parties - including all idiosyncrasies involved - than a clear, strict and consistent definition of 'actual costs'.[38]

In national abatement studies, the definition and other information on costs is generally less specific and detailed than in AIJ/GEF project reports. It seems that these studies are usually based on assessments in terms of net incremental costs - just as in AIJ/GEF project reports - but that they cover only direct engineering cost and, hence, exclude (specific) implementation costs and all other, indirect cost categories. In most cases, however, it is not clear which cost items are included or excluded in the analysis. Moreover, whereas some abatement studies have been conducted in financial terms, others suggest that costs have been assessed in economic terms. In these latter cases, however, it is often not clear whether market prices have been adjusted at all and, if yes, which prices have been indeed corrected for market distortions, and how these corrections have been made. Probably, only some prices have been adjusted for taxes or subsidies, while other market distortions have been neglected. In general, it seems that country abatement studies have used a hybrid set of different cost definitions, although it is not possible to adequately test or correct this finding because of a lack of information provided.[39]

As noted, the ECN-AED-SEI study has used the above-mentioned project and country abatement reports to construct cost curves based on a comparison, ranking and aggregation of information on cost-effectiveness of mitigation options derived from these data sources. Therefore, although it has employed these data sources separately, it nevertheless suffers from the limitations outlined above with regard to the use of different cost definitions when compiling, comparing and aggregating these data sources. Partly as a result of these limitations and partly due to using cost concepts in the ECN-AED-SEI study that are not always adequately defined, it is not always clear what kinds of costs are included in the different cost curves generated by this study. Moreover, as far as cost definitions are explicitly considered, they are neither particularly precise nor common in mainstream economics or mitigation cost assessments. These observations can be substantiated by, first of all, quoting at length the specific section on cost definitions in the ECN-AED-SEI study and, subsequently, commenting on it. The section concerned runs as follows:[40]

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[38] In this respect, it is notable to reiterate the phrase in the ECN-AED-SEI study stating that "AIJ/GEF contributions are an indication of the actual costs required to acquire credits from CDM projects" and that "cost borne by GEF… might be a better indicator of investor costs under CDM than the overall economic costs…[which]…suggests that the use of abatement costs curves based on economic costs may substantially understate the likely investor cost of CERs generated" (Van der Linden et al, 1999, p. 25 and 18, respectively). Although these phrases are far from clear (e.g. what is meant by the different cost concepts: 'actual', 'investor', 'overall economic'), they assume implicitly that the institutional setting for the (future) determination of costs/prices for CDM emission credits will be comparable to the (past/present) practice of setting AIJ/GEF contributions per tonne CO_2 abated in AIJ/GEF projects (which is questionable). Moreover, if AIJ/GEF contributions are indeed "a better indicator of investor costs under CDM than the overall economic costs", one would expect that an extrapolated cost curve for all non-Annex I countries would primarily be based on the former - i.e. AIJ/GEF contributions - rather than the latter (i.e. 'overall economic costs', as employed in the ECN-AED-SEI study).

[39] Moreover, several country studies noted that cost assessments were 'preliminary', 'highly uncertain' or 'merely qualitative'.

[40] See Van der Linden et al (1999), pp. 17-18. Some minor editorial corrections have been made in order to suit with the spelling and table numbering of the present report.

"Cost and benefits of distinct activities can be regarded from three major perspectives: the private perspective, the perspective of the national economy, and the perspective of society. Monetary costs and benefits accruing to individual persons or entities are called *financial costs and benefits*. Cost from the perspective of the national economy, including national external effects, are often referred to as *economic costs and benefits*. When assessing the value of the effects of distinct activities from the broadest societal perspective, including also transborder external effects impacting on other countries, costs and benefits are often referred to as *social costs and benefits*.

In the abatement costing studies, cost of reduction options are assessed from the perspective of the national economy and compared with the baseline scenario. The appropriate basis therefore is the net (costs minus benefits) economic costs compared to the baseline; this is referred to as the *net incremental costs.*

An explanation of how the net incremental costs of a project are determined is given in Table 3.5. The example concerns the Ilumex High Efficiency Lighting AIJ/GEF Project in Mexico. The objective of this project is to replace approximately 200,000 incandescent light bulbs with Compact Fluorescent Light bulbs (CFLs) in the Mexican cities Monterrey and Guadalajara. The AIJ component is US$ 3 million from the Government of Norway and is complemented by US$ 10 million from the GEF [and US$ 10 million from the Federal Electricity Commission, i.e. the local project implementator].

Table 3.5 *Incremental costs of 'Ilumex High Efficiency Lighting Project' in Mexico*

Cost category	Costs in millions [1994 US$]
Incremental cost for AIJ/GEF	
Project costs	13.0
Incremental costs for utility	
Project costs	10.0
Lost income of unsold electricity	28.5
Incremental costs for consumer	
Buying CFLs	12.9
Total incremental costs	64.4
Incremental benefits for utility	
Revenues from avoided capacity expansion and electricity generation	98.4
Sales of CFLs	12.3
Incremental benefits for consumer	
Energy savings and avoided purchase of incandescent bulbs	29.7
Total incremental benefits	140.4
Net Incremental Costs (costs minus benefits)	-76.0

The total estimated GHG savings are 727 ktonne CO_2 equivalents, resulting in net incremental costs of US$ (1994) -105 per tonne CO_2 equivalents. Total AIJ/GEF contribution amounts to US$ 13 million, or US$ (1994) 18 per tonne CO_2 equivalents.

"[…] The Ilumex project provides a useful example of how financial and economic perspectives can differ. From an economic perspective, the project appears to yield emission reductions at US$ -105 per tonne CO_2 equivalents, while at the financial perspective of GEF the costs are +18 US$/tonne. Even though the project is a so-called 'no-regret' project, it was unlikely to have happened in absence of GEF assistance. Therefore, such a programme, if initiated under CDM, would likely be considered additional and eligible for crediting, and the cost borne by GEF (+18 US$/tonne) might be a better indicator of investor costs under CDM than the overall economic cost (-105 US$/tonne) of such a CFL programme. This interpretation suggests that the use of abatement costs curves based on economic costs may substantially understate the likely investor cost and price of CERs generated".

Some observations can be added to the section quoted above. First of all, as stated, the definitions of costs and benefits in the first paragraph quoted are not common in mainstream economics or mitigation cost assessments.[41] The key issue is that these definitions are not based on an adequate distinction of the two major dimensions in cost assessments, i.e. the difference between financial versus economic costs on the one hand and private versus social costs on the other (as explained in Section 3.2). As a result, the Ilumex project does not provide 'a useful example of how financial and economic perspectives can differ'. In fact, as indicated by the project report (UNFCCC, 2000c), the example does not offer any economic analysis at all as it is primarily based on financial costs and benefits accruing to a number of private, individual agents (i.e. the electricity utility, its customers and its AIJ/GEF donors). Or, to put it slightly different, the example is largely based on (uncorrected) market prices, although the prices of key items such as electricity and the CFL bulbs used to be heavily subsidised for the project target group of low income households (UNFCCC, 2000c; Halsnaes et al, 1999). Moreover, different (market) discount rates were used for the utility and its customers rather than one uniform (social) discount rate. Finally, as noted by Verbruggen et al (1999), one may even wonder if the Ilumex example provides a complete financial analysis as financial impacts on the government - through changes in taxes, etc. - appear not to be included.

[41] See, for instance, Sills (1968), Gwinnet et al (1991), Markandya (1998), Halsnaes et al (1998), Markandya et al (1998), or Markandya and Halsnaes (2000). It should be acknowledged, however, that in the extensive literature on cost-benefit analysis or project appraisals a wide variety of cost definitions is used that are not always clear, precise, consistent or uniform. See, for instance, Gittinger (1972), Little and Mirrlees (1982), UNIDO (1978), Irvin (1978), Kuyvenhoven and Mennes (1985), or ADB (1997).

4. METHODOLOGICAL ISSUES REGARDING THE DESIGN AND USE OF A BOTTOM-UP ABATEMENT COST CURVE

4.1 Introduction

As outlined in Chapter 2, the ECN-AED-SEI study on CDM options in the energy sector resulted in the construction of a bottom-up cost curve for all non-Annex I countries, based on data of mitigation potentials and costs derived from country abatement studies. This curve was subsequently applied in a supply-demand analysis of a CDM-related market of emission credits in order to determine the price of these credits and, hence, to indicate the cost effects of the Kyoto Protocol. This chapter reviews the major methodological issues involved in the design and use of such a bottom-up cost curve, including a comparison of the ECN bottom-up approach of estimating the cost effects of the Kyoto Protocol to similar estimates generated by other (i.e. top-down and intermediate) approaches.

More specifically, the contents of this chapter runs as follows. First of all, Section 4.2 reviews the major methodological issues affecting the comparability of country abatement studies with regard to their assessments of the cost-effectiveness of mitigation options and, hence, the usability of these assessments for the construction of an aggregated, bottom-up abatement cost curve.[42] Major issues to be considered include (i) the determination of system boundaries, (ii) the definition of baseline scenarios, (iii) the identification and coverage of mitigation options, (iv) the use of energy sector models, (v) the availability, reliability and consistency of data, and (vi) the choice of the discount rate. Subsequently, Section 4.3 addresses some additional analytical questions with regard to the construction of the ECN-AED-SEI bottom-up cost curve for all non-Annex I countries, whereas Section 4.4 deals with some specific methodological issues of applying this curve in a supply-demand analysis of a CDM-related market of emission credits. Finally, Section 4.5 compares the results of the ECN bottom-up approach of assessing the cost effects of the Kyoto Protocol to similar assessments generated by means of other methodologies such as the 'top-down' and 'intermediate' approaches.

4.2 Issues affecting the comparability of cost-effectiveness assessments

4.2.1 Analytical structure

In general terms, all country abatement studies used by the ECN-AED-SEI research team have employed a common analytical structure. With regard to the mitigation assessment of the energy sector, this structure included the following steps:[43]

- Construction of a baseline scenario, including energy demand and supply projections.
- Identification of mitigation options.
- Assessment of mitigation potential and cost of options identified.
- Construction of an abatement cost curve and a mitigation scenario that integrates multiple mitigation options.
- Assessment of broader social, environmental and political impacts of mitigation options.

[42] Although the discussion in this chapter is focussed on methodological issues with regard to the design and use of bottom-up abatement cost curves based on mitigation studies at the energy sector level, most issues are also relevant to (the comparability of) abatement studies at the project and/or other sector levels.

[43] This analytical structure and the major elements involved are discussed in several guidebooks and survey studies such as UNEP (1992 and 1994), Sathaye and Meyers (1995), ALGAS (1998), Halsnaes et al (1998 and 1999), and USCSP (1999).

As part of the present study, notably the first four steps are of particular interest. The major methodological issues involved in these steps will be considered in the sections below.

4.2.2 The determination of system boundaries

The issue of determining the system boundary of a mitigation assessment is important to achieve a consistent calculation of abatement potentials and costs across different GHG reduction options and mitigation studies. The system boundary is the limit to which both direct and indirect impacts of a mitigation option are analysed. Depending on the characteristics of the option concerned, the significance and range of these impacts may vary from reducing GHG emissions, switching resources from alternative uses, and producing ancillary costs and benefits, to influencing the prices of inputs and affecting macroeconomic variables.

System boundaries can be distinguished at the project, sector and macroeconomic level, defined as follows:[44]

- *Project.* A mitigation assessment at the project or micro level considers an individual abatement project as if it were an isolated, stand-alone case based on the assumptions that (i) it has no significant impact beyond the activity itself, and (ii) its mitigation potential and costs are independent of other abatement options. Impacts at the project level are usually assessed by methodological tools such as cost-benefit analysis, cost-effectiveness analysis or multi-criteria analysis.
- *Sector.* An assessment at the sector level considers a number of mitigation options implemented in one specific sector. Such an assessment should include technical interdependencies between projects in that sector as well as impacts on production inputs and final products of that sector. Intersectoral and macroeconomic impacts, however, are assumed to be small and can, therefore, be considered exogenous to the analysis. Methodological instruments for sectoral assessments include various partial equilibrium models and technical, sectoral optimalization or simulation models.
- *Macro.* An analysis at the macroeconomic level - either national, regional or global - considers the full socio-economic impacts of mitigation options and strategies in one or more sectors of one or more countries, including the intersectoral/macroeconomic interaction of these impacts. The options and strategies concerned may include a wide variety of investment projects and policies such as taxes, subsidies or technology innovation programmes. Impacts at the macroeconomic level are usually analysed by methodological frameworks such as general equilibrium models or integrated assessment models.

All mitigation options derived from the country studies and used by the ECN-AED-SEI research team have been assessed at the energy sector level. Although this common characteristic enhances the mutual comparability of the cost-effectiveness of these options, this comparability is reduced by the fact that the abatement studies concerned have employed different sector models (see Section 4.2.5 below).

4.2.3 The definition of the baseline scenario

The definition of the baseline or reference scenario is one of the most critical issues in assessing the cost effectiveness of abatement activities as it affects the estimation of both the potential and

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[44] See, particularly, Markandya and Halsnaes (2000), as well as Halsnaes et al (1998 and 1999). A framework to ensure consistency between these different levels - project, sector and macro - is discussed by Markandya et al (1998). See also Brander (2000) for a practical illustration of the importance of determining system boundaries.

the costs of mitigation options.[45] In general, the literature on climate change distinguishes three main definitions or typologies of baseline scenario concepts:[46]

1. The *'business-as-usual'* baseline, which assumes a continuation of current trends, including eventual major inefficiencies due to capital constraints, lack of information or other institutional barriers.
2. The *'economic-efficient'* baseline, which assumes that all profitable efficiency improvements will be implemented during the time frame considered.
3. The *'most-likely'* baseline, which represents a compromise between (1) and (2), including assumptions on the extent to which existing barriers to efficiency improvements may be overcome.[47]

In case 2, it is assumed that all resources will be employed efficiently in an economic sense and, hence, that all possible abatement activities with negative costs - the so-called 'no-regret options' - are included in the baseline. In cases 1 and 3, on the other hand, such options may exist if it is further assumed that it is possible to identify policies that are able to remove market failures and other institutional barriers without incurring larger implementation costs than the benefits incurred (UNEP, 1994, Halsnaes et al, 1998).[48]

More specifically, the definition of the baseline scenario at the national or energy sector level depends on a wide set of assumptions, affecting both GHG emissions and abatement costs. These assumptions concern particularly:[49]

- population growth,
- economic growth,
- price and income elasticities of energy demand and supply,
- future energy prices,
- autonomous, structural changes in technology and energy efficiency.

The latter factor - i.e. non-price induced changes in energy efficiency - is usually accounted for by modellers through a technical coefficient called the 'Autonomous Energy Efficiency Improvement' (AEEI). This coefficient reflects the rate of structural change in the energy intensity of economic activities - i.e. the energy/GDP ratio - holding relative energy prices constant. As a small change in the AEEI will have a significant impact on energy consumption over time, many observers view the assumptions made regarding the AEEI as crucial in defining the baseline and, therefore, in assessing the potential and costs of mitigation options. However, empiri-

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[45] The concept *baseline scenario* itself can be defined as a set of assumptions affecting future GHG emissions at either the project, sector or macro level in case no additional abatement activities are undertaken. It must be emphasised that the baseline scenario should include abatement measures already implemented or planned and, hence, that the assessment of mitigation options considers only abatement activities *additional* to any that are or will be occurring anyway.

[46] In addition, as remarked in the previous note, baseline scenarios can be defined according to the system boundary or level of analysis (project, sector, and macro). A complicated issue concerns the consistency of defining baseline scenarios at these three different levels. Another tough, controversial issue is related to defining baseline cases for JI and CDM projects. Over the past four years, the literature dealing with these issues has expanded enormously (see, for example, Willems (2000) and Markandya and Halsnaes (2000) and references cited there, as well as a special, recently opened website - www.uccee.org. - providing references dealing with baseline issues). In the present report, the discussion will be restricted to the main factors affecting the baseline scenario at the energy sector level as employed in the country abatement studies used by the ECN-AED-SEI research team.

[47] See UNEP (1994). In addition, the literature on climate change reports other, similar sets of baseline scenario concepts (see Halsnaes et al, 1998).

[48] See also Section 3.3.2 on implementation costs, as well as Box 4.1 in Section 4.2.4 considering the controversial issue of no-regret options.

[49] These assumptions are extensively discussed in guidebooks and survey studies such as UNEP (1992 and 1994), Hourcade et al (1996a), ALGAS (1998), Halsnaes et al (1999) as well as in the individual country abatement studies employed by the ECN-AED-SEI research team.

cal estimates of the AEEI - notably for the long-term future for a large variety of individual developing countries - are scarce, highly uncertain and, hence, highly controversial.[50]

The importance of the assumptions mentioned above for defining the baseline scenario of GHG emissions in the energy sector can be illustrated by means of the following version of the so-called 'Kaya identity':

$$GHG = (GHG/Energy) \times (Energy/GDP) \times (GDP/Population) \times Population \qquad \text{(Eq. 6)}$$

This identity establishes a relationship between, on the one side, the level and/or growth rate of the GHG emissions of the energy sector and, on the other side, the level and/or growth rate of (i) the GHG emission intensity of energy consumption (as influenced by relative prices and income/price elasticities of different energy sources), (ii) the energy intensity of GDP (as discussed above), (iii) per capita GDP (reflecting income level and/or economic growth), and (iv) population. The identity indicates that, over time, even small differences or changes in baseline assumptions - e.g. 'optimistic' versus 'pessimistic' assumptions - may have a significant (multiplicative) effect on the level and growth rate of baseline GHG emissions through its underlying constituent components. Baseline assumptions regarding future developments of these components are, however, - to a greater or lesser extent - subjective, uncertain and/or controversial (notably, as mentioned above, with regard to the AEEI). This applies particularly for less developed countries where reliable data for underpinning the baseline assumptions are less readily available, and where the spectrum for future developments and structural changes seems to be wider than in industrialised countries with more developed infrastructure and energy systems.

The implications of the above-mentioned observations are twofold. Firstly, abatement studies - particularly of non-Annex I countries - have to explicitly mention and account for the assumptions and data indicators used for defining the baseline scenario. Secondly, these studies should preferably include multiple baseline scenarios - giving a range of GHG emission projections - in order to provide an indication of the uncertainties surrounding these projections and the resulting mitigation assessments.

Definition of baseline scenarios in country abatement studies
The definition of the baseline scenarios of the energy sector in the country abatement studies employed by the ECN-AED-SEI research team shows wide variations. For instance, in the studies conducted under the umbrella of UNEP (1992, 1994 and 1999), the baseline scenario of Venezuela assumes that all profitable efficiency improvements in the energy system are taken up automatically ('energy efficiency' case), whereas in the Egypt study all these improvements are assumed to be excluded from the ('business-as-usual') baseline scenario.

A similar range of baseline definitions can be found in the country abatement studies carried out as part of the Asian Least-cost GHG Abatement Strategy (ALGAS, 1998). In the China study, for example, the ('optimistic') baseline scenario assumes a high degree of adoption of improved energy efficiency and abatement technologies at both the demand and supply side of the energy system. The ('pessimistic') baseline scenario of the Vietnam study, on the other hand, assumes no progress at all in reducing end-use energy intensities. The ('most likely') baseline scenario of India - and other ALGAS country studies - represents a middle ground, including some abatement technologies that are considered to be used in the future.

The country abatement studies show similar variations with regard to other key baseline assumptions, especially on growth of GDP. Assumptions on economic growth are usually based on official projections or targets derived from medium- or long-term development plans, on projections from economic experts or on own judgements of country study teams. Although a

[50] Assumptions and implications regarding the AEEI are discussed by Hourcade et al (1996a), Kram (1998), Weyant (1998), Sathaye and Makundi (1998), and Markandya and Halsnaes (2000).

major part of the variations in baseline assumptions on technological changes and GDP growth can be accounted for by 'real' expected differences among the countries concerned, another part can be ascribed to the 'optimism' or 'pessimism' of the study teams involved.

In the UNEP and ALGAS country studies, however, baseline assumptions even varied with regard to those variables that will change more of less the same for all countries (e.g. the future development of international energy prices). Moreover, although almost all country abatement studies have mentioned explicitly the major assumptions underlying their baseline scenarios, the explanation and accountability of these assumptions varies largely between these studies. Finally, while some major country abatement studies address some uncertainties concerning the baseline assumptions, none of these studies - except India - has developed multiple scenarios in order to provide an indication of the uncertainties surrounding the baseline definition.

Table 4.1 *Total identified abatement potential and no-regret options in the energy sector of selected non-Annex I countries for the year 2010*

	Baseline GHG emission [million tonnes CO_2 eq.]	Total abatement potential [million tonnes CO_2 eq.]	Total no-regret options [in million tonnes CO_2 eq.]	Total abatement potential as % of baseline emissions	No-regret options as % of baseline emissions	No-regret options as % of total abatement potential
China	4318.5	645.0	258.0	14.9	6.0	40.0
India	1415.1	410.0	0.0	29.0	0.0	0.0
Egypt	188.0	105.4	94.0	56.1	50.0	89.2
Korea, South	595.4	57.3	46.0	9.6	7.7	80.3
Philippines	131.3	14.8	13.0	11.3	9.9	87.9
Argentina	234.0	24.8	3.7	10.6	1.6	14.9
Indonesia	551.1	18.9	7.0	3.4	1.3	37.0
Pakistan	255.7	55.2	36.0	21.6	14.1	65.2
Vietnam	133.3	13.0	12.8	9.8	9.6	98.5
Venezuela	103.0	8.2	0.0	7.9	0.0	0.0
Zimbabwe	33.0	6.8	4.6	20.6	13.9	67.7
Bangladesh	45.6	5.1	5.1	11.3	11.1	98.4
Mongolia	35.3	3.7	2.5	10.6	7.1	67.0
Senegal	41.0	0.2	0.0	0.4	0.0	0.0
Total[b]		1528.0	586.0			38.4

[a] Estimates of GHG baseline emissions and mitigation options have been interpolated or extrapolated when country abatement studies report figures other than for the year 2010.
[b] Total identified in abatement studies of 24 non-Annex countries.
Source: Country abatement studies (UNEP, 1994 and 1999, ALGAS, 1998) and Van der Linden et al (1999).

4.2.4 The identification and coverage of mitigation options

In almost all country abatement studies employed by the ECN-AED-SEI research team, the identification of mitigation options in the energy sector has been far from comprehensive, whereas the coverage of the options identified has varied widely among these studies.[51] Most of these studies have been implemented as capacity building exercises, without attempting to obtain an exhaustive assessment of the abatement potential or even of *most* mitigation options in the energy sector of the countries concerned. Some studies considered only one or two energy sub-sectors, or highlighted a few examples within a sub-sector without analysing the energy sector as a whole. While a few country studies identified as many as 40 options, others evaluated only 5 or less. For example, the Argentina study did not cover any demand-side options for residential or commercial buildings; the Mexico study analysed only co-generation options; the Venezuela study did not assess any electricity supply options; whereas the Kazakhstan study included only options for the electricity supply sector (Van der Linden et al, 1999).

[51] The options identified are extensively analysed in the individual country abatement studies as well as in the survey or summary studies concerned (ALGAS, 1998; UNEP, 1999; and USCSP, 1999). See also Van der Linden et al (1999) and Section 2.1 of the present report.

Table 4.1 provides an indication of the coverage of the mitigation options identified for the year 2010 with regard to a selected sample of non-Annex I countries studied by the ECN-AED-SEI team. As a percentage of estimated baseline GHG emissions of the energy sector in 2010, the share of abatement options identified varies from 0.4 percent in Senegal to more than 56 percent in Egypt. These rates, however, have to be interpreted prudently, as they do not only depend on the coverage of the mitigation options but also on the baseline definition for the year 2010. This applies particularly for the identification and coverage of the no-regret options. Mainly due to the baseline assumptions discussed in Section 4.2.3 above, the Egypt study has identified 50 percent of its baseline emissions in 2010 as no-regret options, whereas this share is 0 percent in the Venezuela study (Table 4.1). As a share of the total abatement potential in the year 2010, the no-regret options amount even to almost 100 percent in Bangladesh compared to some 15 percent in Argentina.

Box 4.1 *Reconsidering no-regret options*

No-regret options are by definition GHG emission reduction options that have negative net incremental costs. Since the mid-1990s, estimates of the potential size of such options have resulted in a lasting controversy between believers and non-believers in the existence of such 'free lunches' (see, for instance, Hourcade et al, 1996a; Kram, 1998; Markandya and Halsnaes, 2000; Hourcade and Shukla, 2000 and, particularly, Sutherland, 2000). This unresolved, sensitive issue is actually closely related to the discussion on the incidence of energy-economic inefficiencies in defining baseline scenarios (see Section 4.2.3). Whereas adherents of the so-called 'bottom-up' or 'energy-technology' approach have indicated the existence of a significant potential of no-regret options, supporters of mainstream economics or the so-called 'top-down' approach have highly questioned or even denied the existence of such options (see also Section 4.5).

In fact, the incidence of no-regret options implies that (i) market imperfections or other institutional failures do exist, and (ii) additional policies can be identified and can be implemented effectively to address these institutional failures without incurring implementation costs larger than the benefits gained (Hourcade et al 1996a, and Section 3.3.2 of the present report).

As noted in the main text, the study of Van der Linden et al (1999) has identified a potential of no-regret options in the energy sector of 24 non-Annex I countries estimated at almost 590 million tonnes CO_2 equivalents (Table 4.1). This estimate, however, may be questioned as it is based on a specific definition of mitigation costs. In fact, this definition includes only direct engineering costs - either in financial or economic terms, depending on the country abatement study concerned - and excludes all other, indirect costs and benefits discussed in Section 3.3, notably:

- Implementation costs, particularly the costs of barrier removal policies.
- Costs of risks and uncertainties.
- Ancillary costs and benefits, including real preferences of consumers.
- Macroeconomic costs.

Other factors that may affect the existence and real magnitude of no-regret options concern:

- The discount rate and the prices of capital and other resources used may not reflect true private/social scarcity values (see Sections 3.2 and 4.2.6).
- The so-called 'rebound effect', which implies that deployment of cost-effective measures reduces the price of the energy service delivered, thereby inducing an increases demand for that service (Kram, 1998; Hourcade and Shukla, 2000).

As a result, the real potential of no-regret options may deviate substantially from the above-mentioned estimate by Van der Linden et al (1999). Most likely, this estimate is too high, although additional research is needed to substantiate this hypothesis. It should be noted, however, that the qualifications made above with regard to the potential and costs of no-regret options can similarly be applied to all other, so-called 'regret' options identified by Van der Linden et al (1999).

Overall, the total amount of no-regret options in the 24 non-Annex I countries covered by Van der Linden et al (1990) is estimated at almost 590 million tonnes CO_2 equivalent in 2010, or more than 38 percent of the total abatement potential identified for these countries in 2010 (Table 4.1). These assessments of no-regret options, however, have to be treated with some mistrust, as they do not only depend on the definition of the baseline scenarios but also on some other methodological issues and the definition of the cost concepts concerned (see Box 4.1 for a reconsideration of no-regret options).

4.2.5 The use of energy sector models

In order to assess the potential and costs of mitigation options, the country abatement studies have used a variety of bottom-up, energy-technology sector models such as MARKAL, EFOM-ENV, LEAP or ENPEP.[52] These models can be categorised as either optimalization models (MARKAL, EFOM), energy accounting or simulation models (LEAP), or iterative equilibrium models (ENPEP), each with its own characteristics, opportunities and limitations. However, differences in parameter values among models within a certain category may be more significant than the differences in model structure across categories. Moreover, there are many differences between the theory underlying a particular category of models and the actual models used.

Another major problem in evaluating the differences among the energy sector models used by the country abatement studies - and, hence, in judging the implications involved for their assessments of mitigation potentials and costs - is that most studies have hardly specified the major characteristics of the models used. This applies particularly to the question whether these models have accounted for the interdependencies or interactions between the identified mitigation options. For certain options, these interdependencies may be particularly strong, e.g. changing the fuel mix of electricity supply versus implementing actions to save electricity demand in end-use sectors. As a result, the total amount of GHG emission reductions will be significantly lower than the sum of the abatement potentials of each option analysed separately (whereas the estimates of the cost-effectiveness of interacting options will be correspondingly higher). However, as noted, most country abatement studies did not adequately specify whether and how they accounted for such interdependencies.[53]

4.2.6 The availability, reliability and consistency of data

Assessing the potential and costs of mitigation options by means of bottom-up energy sector models requires a large amount of data - notably with regard to energy demand and supply, technology performance and costs, emission factors, as well as macro- and socio-economic indicators - in order to construct a GHG inventory for the base year (e.g. 1990) and to make emission projections and cost estimates for both the baseline and mitigation scenario. Some of the major problems concerning the availability, reliability and consistency of the data generated by the country abatement studies and used by the ECN-AED-SEI- research team includes (UNEP, 1994 and 1999, Sathaye and Meyers, 1995, ALGAS, 1998, and USCSP, 1999):

[52] The characteristics and differences between these and other energy sector models used are outlined in UNEP (1992 and 1994), Sathaye and Meyers (1995), ALGAS (1998) and USCSP (1999).

[53] In fact, there are at least three major approaches to account for interdependencies of mitigation options identified and, hence, to construct cost curves (UNEP, 1992 and 1994, Markandya and Meyer, 1995). These approaches include: (i) *the partial solution*, in which each technology is evaluated separately and all potential interdependencies with other options are neglected, (ii) *the retrospective systems approach*, in which the interdependencies of a mitigation option are considered with regard to less expensive (i.e. lower ranked, already assessed) mitigation options but not with regard to more expensive (i.e. higher ranked, not yet assessed) abatement options, and (iii) *the integrated system approach*, in which all interdependencies of all mitigation options considered (and covered by the cost curve) are assessed in an integrated way, regardless the ranking of these options. The latter, integrated approach - as employed by optimisation models such as MARKAL - is obviously the most preferable, but has the disadvantage that it is often hard to distinguish the abatement potentials and cost of each mitigation separately. The integrated system approach of MARKAL has been applied in the abatement studies of China and Indonesia, whereas it is not clear which specific approach has been used in the other country studies. Moreover, it should be marked that - notably in optimisation models such as MARKAL - the assessment of the cost effectiveness and, hence, the ranking of mitigation options depends on the level of abatement and time interval considered.

- The country studies generally applied the *IPCC Guidelines for National Greenhouse Gas Inventories*. The default values of emission factors recommended by these guidelines, however, are mostly derived from measurements in developed countries and do not represent the conditions in developing countries (as confirmed by field measurements undertaken by the ALGAS project).
- The IPCC recommendations to use a 'bottom-up' approach in estimating GHG inventories and to compare it with a 'top-down' approach resulted sometimes in significant differences between these approaches.
- Current and projected cost and performance data for certain mitigation technologies are often not locally available and, hence, technology data from other countries or general technology databases have to be used.
- The accuracy of locally available data used for mitigation assessments varies among the countries concerned. For some countries, e.g. Tanzania, the reliability of the data may even be highly questioned.

These problems do not only reduce the reliability of the estimates of the potentials and costs of the mitigation options included in the ECN-AED-SEI database but also the comparability of these estimates as the availability, accuracy and consistency of the data used varies among the countries - or even the mitigation options - concerned.

4.2.7 The choice of the discount rate and other measurement issues

As explained in Section 3.5.1, the method of discounting is used in mitigation assessments to calculate the net present value and, subsequently, the cost effectiveness of an abatement option. Discounting, however, has aroused a lasting debate, mainly with regard to two issues.[54] Firstly, whereas the discounting of monetary costs and benefits of a mitigation option is widely accepted, there has been some discussion on the discounting of GHG emission reductions. Although there seems to be some justification for discounting emission reductions at a very low rate, the actual level of this rate has been hard to determine and has remained a matter of disagreement.[55] As a result, emission reductions have usually not been discounted.

Another, second issue of debate concerns the height of the rate to discount future costs and benefits of a mitigation option. Two different approaches can be distinguished (Sathaye and Makundi, 1998). The *descriptive* approach proposes the use of (relatively high) market interest rates in the evaluation of abatement options, whereas the *prescriptive* or *ethical* approach recommends the use of a (relatively low) social discount rate.[56] The first approach is usually applied in private-financial assessments of mitigation options, with different real market interest rates - including a risk premium - for different parties of investors and end-users involved. The second approach is generally recommended for social-economic mitigation assessments. In contrast to market-based interest rates, however, the social discount rate is often much harder to determine, notably for long-term projects in less developed countries. Hence, there is some policy discretion in setting this rate for long-term mitigation options in non-Annex I countries.

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[54] See Sathaye and Makundi (1998), Tol and Downing (2000), Markandya and Halsnaes (2000), and Brander (2000).

[55] The justification for discounting GHG emission reductions is that future reductions are worth less than present reductions in terms of mitigating the greenhouse effect and the resulting costs of damage and adaptation. Although this argument may be particularly significant for the total set of mitigation options at the global level - notably in the long run - it seems to be less relevant for individual, short-term abatement options at the national, sector of project level. Moreover, if emission reductions are to be discounted, it should be at a rate that reflects the higher climate change damage caused by a higher stock of GHGs over time. Projections of negative impacts of climate change are characterised by high uncertainty, and as a result the selection of an appropriate discount rate is extremely difficult (Brander, 2000).

[56] The prescriptive approach is based on the argument that, due to market imperfections, the market interest rate does not adequately reflect the marginal productivity of capital and/or the marginal rate of substitution between current and future consumption and, hence, it is not a correct measure of the social opportunity cost of capital.

The calculation of the cost effectiveness of abatement options, however, is rather sensitive to the choice of the discount rate, as illustrated in Table 4.2.

Table 4.2 *Cost effectiveness of mitigation options using different discount rates*

Option	Cost effectiveness [US$/t$CO_2$eq.]				Ranking of options according to least-cost effectiveness			
	3%	7%	10%	15%	3%	7%	10%	15%
A	-25.11	-8.67	7.90	42.87	1	1	1	1
B	-21.78	-1.61	19.30	64.78	2	2	2	2
C	-16.60	17.03	56.30	155.15	3	3	4	4
D	-3.18	36.02	75.50	159.60	4	5	5	5
E	2.70	48.79	95.20	193.70	5	6	6	6
F	7.63	16.01	45.00	86.89	6	4	3	3
G	17.42	78.91	140.50	271.14	7	7	7	7
H	143.80	180.30	211.20	267.94	8	8	8	8

Source: Argentina country abatement study (UNEP, 1999).

Table 4.2 shows that, if the discount rate is higher (i) the cost effectiveness of mitigation options deteriorates, i.e. the costs per tonne GHG abated becomes higher, (ii) the number of no-regret options decreases, and (iii) the ranking of least-cost mitigation options may change significantly. For instance, due to changing the discount rate from 3 to 15 percent, the cost effectiveness of option F deteriorates from 7.6 to 86.9 US$/t$CO_2$eq., while its ranking improves from position 6 to 3. Because of this impact of the social discount rate on cost-effectiveness assessments, country abatement studies should account for the choice of this rate and include a sensitivity analysis on this issue in order to indicate the importance of choosing this variable in mitigation cost assessments.

The country abatement studies employed by the ECN-AED-SEI research team have generally used different (social) discount rates to calculate the cost effectiveness of the mitigation options identified. Although these differences in discount rates may be justified by national differences in consumers' time preferences or producers' opportunity costs of capital, they reduce the comparability of cost-effectiveness assessments among these studies as the accountability or information provided on the discounting methodology is often lacking (including the question whether GHG emission reductions have been discounted or not). Moreover, whereas some studies have presented sensitivity analyses using two or more discount rates - often without indicating, however, which rate is the 'most appropriate' - others have employed only one rate, often without accounting for the choices made (ALGAS, 1998, UNEP, 1999, Van der Linden et al, 1999).

Other measurement issues

In addition to the choice of the discount rate and other accounting methods discussed in previous sections, the calculation of the cost effectiveness of a mitigation option depends on some other measurement issues such as the assumptions made with regard to the technical/economic lifetime of an abatement project, the target year or time interval to calculate the potential and costs of mitigation options, or the method to account for the depreciation of capital investments and other annual (fluctuating) costs of operation and maintenance.

In general, the country abatement studies employed by the ECN-AED-SEI research team provide hardly any information on how they have addressed these issues. Whereas some of these studies, however, have calculated the average annual potentials and costs of a mitigation option over a certain period (e.g. 1995-2020), others have assessed the incremental mitigation costs and potentials for a specific year (e.g. 2010, 2020 or 2030). Such differences in accounting methods among studies further reduce the comparability of the estimated cost effectiveness of the mitigation options concerned.[57]

A final, related issue concerns the unit of measurement to express the cost effectiveness of a mitigation option. All country abatement studies covered by the ECN-AED-SEI database have expressed the amount of emission reductions in tonnes of CO_2 equivalents (most likely by using the Global Warming Potentials recommended by the IPCC). Moreover, although abatement cost have occasionally been expressed in different currencies and/or different reference years, these differences can relatively easily be addressed by applying appropriate exchange rates and/or price indices.[58] As noted above, however, the major problem is that several country abatement studies have assessed abatement potentials and costs for different specific years or time intervals. Although one may try to tackle this problem by applying simple intra- or extrapolation methods, the only correct solution would be to make a new, additional model run for those cost-effectiveness assessments diverging from a certain target year, e.g. 2010 (which is hardly a viable option to 'outsiders' using the assessments of the abatement studies concerned).

4.2.8 The comparability of country abatement studies: conclusions

In Section 3.5.1, it was postulated that an adequate comparison, ranking and aggregation of mitigation option assessments by means of the cost-effectiveness criterion requires that at least the following three conditions have to be met:

(i) the same definition of costs has to be applied throughout all options considered,
(ii) the same unit of measurement has to be used to express the cost effectiveness of all mitigation options analysed, and
(iii) the same, comparable methodology has to be applied to measure the cost effectiveness of all mitigation options assessed.

The analysis in Sections 3.6 and 4.2 above has shown that none of these conditions is met with regard to the cost-effectiveness assessments of the mitigation options derived from the sample of 24 country abatement studies and employed by the ECN-AED-SEI team to construct a CDM-related abatement cost curve for non-Annex I countries. Although these studies have used some common analytical elements (e.g. covering only direct engineering costs, a common analytical structure, and a common system boundary), there are major, significant differences between these studies with regard to (i) the cost definitions used (notably defining costs in financial versus economic terms), (ii) the definition and underlying assumptions of the baseline scenario, (iii) the identification and coverage of the mitigation options, (iv) the energy sector models used, (v) the availability, reliability and consistency of the data, (vi) the choice of the discount rate and other accounting methods used, and (vii) the unit of measurement to express the cost-effectiveness assessments of mitigation options, notably the target year to evaluate the potential and costs of these options. Moreover, an adequate comparison between the cost-effectiveness assessments of the country abatement studies is not always possible due to a lack of information provided on the data and methodology used. Therefore, a comparison, ranking and aggregation of the mitigation options concerned by means of the cost-effectiveness criterion in order to construct an abatement cost curve has only a limited meaning.

This conclusion seems to be supported by the survey or summary studies of the three major programmes of the 1990s that have sponsored the implementation of abatement studies in non-Annex I countries. These programmes include: (i) the Asia Least-cost Greenhouse Abatement Strategy (ALGAS) sponsored by the Asian Development Bank (ADB) and UNDP/GEF, (ii) the

[57] A recent study has shown that such differences in accounting methods - including discounting - may result in estimates of cost effectiveness for the *same* mitigation option that vary from slightly negative ('no-regret') to largely positive, with absolute differences ranging from 16 to 508 Dutch Guilders for a certain mitigation option in the Netherlands, and even from -1 to 298 Dutch Guilders for another option (Ybema et al, 2000).

[58] It should be noted, however, that several studies have not indicated the year in which prices and costs have been expressed.

UNEP Greenhouse Gas Abatement Costing Studies Programme, and (iii), the United States Country Studies Programme (USCSP). On the one hand, each programme has tried to uniform the analytical approach of its country study teams by organising workshops throughout the 1990s and publishing manuals and guidelines for mitigation cost assessments.[59] On the other hand, however, each programme has enabled or even encouraged individual country study teams to select a methodological approach that best suits their informational needs, available data and analytical capacities. As a result, the country abatement studies show major differences in methodologies and research findings, not only between these three programmes but also within each program.

In this respect, it is worth quoting some statements made in survey reports of the three programmes mentioned above with regard to the comparability of the mitigation assessments of the country abatement studies they have sponsored. In the mid-1990s, an interim-summary report of the UNEP country abatement study programme was still quite prudent in its statement: "Technical and economic data for the individual abatement options identified for each country were thus left to be selected by the national teams. This approach clearly complicates any inter-country comparison of efficiencies and direct costs of individual abatement technologies." (UNEP, 1994, p. 85). In the late 1990s, the ALGAS summary report was already more outspoken: "Given the differences among the studies in their approach to developing and defining Baseline and Abatement Scenarios and in the breadth of technologies that were considered, there is little to be gained by comparing the magnitude of GHGs emissions reductions seen in the various Abatement Scenarios. The percentage reduction is largely a function of the decision made by the individual teams regarding what would be included in Baseline and Abatement Scenarios." (ALGAS, 1998, p. 74). Finally, a 1999 survey report of the USCSP concluded: "The design and underlying assumptions of the various models vary greatly, and therefore do not facilitate a comparison of mitigation potential and costs across countries[…] It should be emphasised that the data on emissions and costs reported in this section were calculated by each country using different methods, and therefore these data should not be compared across countries." (USCSP, 1999, p. 11-12). It will be clear that, rather than comparing country abatement studies within a partly uniform approach of a specific programme, it is even more complicated and less meaningful to compare country abatement studies sponsored by different programmes lacking mutual attunement.[60]

4.2.9 Suggestions for improving the inter-country comparability of abatement studies

In order to enhance the comparability of country abatement studies, the following recommendations are suggested:

- Country abatement studies should provide explicit and detailed information on the cost definitions, data, methodologies and assumptions used.
- Country abatement studies should use the same cost definitions and cover the same cost categories.

[59] See, for instance, Sathaye and Meyers (1995) or Halsnaes et al (1999).

[60] In this context, it is also worth quoting a recent ECN study on the analysis and comparison of different methods to assess the cost effectiveness of mitigation options. Translated in English, the study remarks: "Of course, an adequate marginal cost curve can only be constructed if the costs of [mitigation] options are calculated by means of the same system boundaries, cost method and underlying assumptions. A marginal cost curve that is designed according to one specific method can only be transformed in a marginal cost curve conformably to another method if all assumptions of the underlying options are known." In Dutch, the original quote runs as follows: "Vanzelfsprekend kan enkel een deugdelijke marginale kostencurve geconstrueerd worden wanneer de kosten van opties met dezelfde systeemgrenzen, kostenmethode en uitgangspunten zijn berekend. Een marginale kostencurve die volgens één methode is opgesteld kan slechts worden omgezet in een marginale kostencurve conform een andere methode, indien alle uitgangspunten van de achterliggende opties bekend zijn". (Ybema et al, 2000, p. 13). It should be remarked that additional conditions for the construction of an 'adequate cost curve' are the use of the same cost definition and the same unit of measurement to express the cost effectiveness of all mitigation options considered.

- Country abatement studies should preferably conduct a *social* assessment of mitigation options in both *financial* and *economic* terms.
- Country abatement studies should use the same unit of measurement to express the cost-effectiveness of mitigation options, notably apply the same target year(s) for the assessment of mitigation potentials and costs.
- Country abatement studies should further streamline and uniform their methodology and assumptions used as far as possible and justified, given the actual differences between the countries concerned. This implies that these studies should at least use (i) the same analytical structure, (ii) the same system boundary (iii) the same 'most likely' definition of the baseline scenario, (iv) the same baseline assumptions with regard to parameters that apply more or less equally to all countries, such as the projected development of the international energy prices, (v) the same, full coverage of the mitigation options identified, and preferably (vi) the same or, at least, comparable energy sector models and other accounting methods to calculate the cost effectiveness of mitigation options. Finally, as far as differences in baseline assumptions, accounting methods, models and data used are justified or unavoidable, they should be explicitly accounted for.

4.3 Designing and using a bottom-up abatement cost curve

4.3.1 The construction of the ECN-AED-SEI cost curve for all non-Annex I countries

Despite the limitations analysed above, the ECN-AED-SEI research team has used the data on abatement potentials and costs of 253 eligible CDM options in the energy sector derived from mitigation studies in 24 non-Annex I countries in order to construct a bottom-up, CDM-related abatement cost curve for all non-Annex I countries (see Section 2.1.1). In order to reach this purpose, however, at least two methodological issues had to be tackled.

Firstly, as a minimum condition, the unit of measurement with regard to the assessment of abatement costs and potentials had to be uniform for all options considered. Whereas some country abatement studies explicitly expressed costs in prices of the same year (i.e. in US$ of 1990, the standard or base year applied by the ECN-AED-SEI team), other studies employed other years or did not mention any year at all. Moreover, while some studies assessed abatement potentials for the year 2010 (the reference or target year applied by the ECN-AED-SEI team), others estimated these potentials for other years - e.g. 2020 or 2030 - or for a certain time interval (e.g. 1995-2020). The price-year issue was relatively easily solved by either assuming (implicitly) that country abatement studies had used 1990 as the base year or by converting estimates of abatement costs to the base year by means of a relevant price index. The abatement-year issue, on the other hand, was solved by either simply averaging the estimated annual abatement potential over a certain time interval for the year 2010, or by means of a simple, arbitrary interpolation method. Notably the latter approach is problematic because the only correct solution would be to make a new, additional model run for those cost-effectiveness assessments diverging from the reference year 2010 (but, as noted above, this solution is hardly a viable option to 'outsiders' using the assessments of the country abatement studies concerned).

The second methodological issue to be tackled by the ECN-AED-SEI team concerns the extrapolation of the mitigation assessments with regard to the eligible CDM options in the energy sector of 24 non-Annex I countries to the whole group of all non-Annex I countries. As explained in Section 2.1.1, this issue was solved by scaling up the identified abatement potential of the 24 sample countries by a factor of approximately 1.5, i.e. the inverse of the proportion - about two thirds - of these countries in total GHG emissions of all non-Annex I countries in 1995 (based on the assumption that the share of the 24 sample countries in total non-Annex I emissions in 1995 corresponds to their share in total non-Annex I abatement potentials in 2010). Although this assumption may be questioned, three other observations seem to be more relevant. Firstly, a major issue is whether the 24 sample countries are representative of the other non-Annex I countries as many of the latter may either (continue to) oppose CDM projects for a variety of socio-political reasons, or be unable to provide the institutional set-up to promote such projects because of civil crises, armed conflicts or other kinds of political instability (Verbruggen et al, 1999). Secondly, as outlined in Section 4.2.4, the identification of mitigation options in the energy sector of the 24 sample countries has been far from comprehensive. Hence, the extrapolated cost curve for all non-Annex I countries suffers from a similar lack of covering all possible CDM projects in the energy sector.[61] Finally, the cost curve for both the sample and total group of non-Annex I countries is based on estimated abatement potentials in the energy sector only and, hence, excludes other important sectors for identifying potential CDM options such as in the sectors of agriculture, forestry or waste management.

4.3.2 The application of the ECN-AED-SEI cost curve for all non-Annex I countries

As set out in Section 2.1.3, the ECN-AED-SEI cost curve for all non-Annex I countries has been applied in a supply-demand analysis of a CDM-related market of emission credits in order to determine the international clearing price of these credits and, subsequently, the cost effects of the Kyoto Protocol. According to Van der Linden et al (1999), this cost curve can be regarded as the supply curve of CDM-based emission credits. Within the framework of a simple market simulation model covering full global trading in emission credits, this supply curve can be combined with the Annex I demand curve for emission credits as developed in earlier studies (Van Harmelen et al, 1997; Koutstaal et al, 1998). By means of these supply and demand curves, the international clearing price of emission credits can be determined, which can be further used to assess the cost effects of the Kyoto Protocol.

Besides the observations made in previous sections, some additional analytical limitations of the above-mentioned supply-demand analysis can be noted, including:[62]

- The analysis is based on the assumption of a *perfect market* for trading emission credits, i.e. a fully integrated market with no trade restrictions, no transaction costs, no strategic behaviour of market parties, no risks and uncertainties, etc. In practice, however, both transaction costs, risks and uncertainties of generating and transferring emission credits may be very substantial, major countries - such as Russia, the US, Japan, China or India - may act politically or show oligopolistic behaviour, and markets of emission credits may be characterised by sequential, bilateral, secret and ‘out-of-equilibrium’ trading.
- The analysis takes the CDM demand curve as given. However, as this bottom-up curve results from projections of abatement commitments, potentials and costs in Annex I countries - including transition economies in Central and Eastern Europe - it suffers from a variety of data problems, methodological shortcomings and other analytical limitations comparable to those of the CDM supply curve (Harmelen et al, 1997, Koutstaal et al, 1998, and Sijm et al, 2000).[63]
- The analysis is predominantly based on CO_2 emissions and excludes ‘sinks’ and non-CO_2 GHGs identified by the Kyoto Protocol.

[61] On the other hand, the cost curves for the sample and total group of non-Annex I countries include mitigation options that - for a variety of reasons - may be not viable or acceptable to the countries concerned).

[62] Van der Linden et al (1999) and Sijm et al (2000); see also Verbruggen et al (1999) and Van der Linden et al (2000).

[63] An additional problem concerns the assumptions regarding the so-called ‘hot air’ issue in Annex I countries of Central and Eastern Europe (Sijm et al, 2000).

- The analysis does not account for the time frame of CDM options - including the opportunity of 'banking' - as stipulated by the Kyoto Protocol. Banking is the possibility to save CDM credits during the years 2000-2007 in order to meet Annex I reduction commitments during the first budget period of the Protocol (2008-2012). If this opportunity will be actually applied, it will reduce the market price of all emission credits.[64] On the other hand, the lifetime of many CDM projects will extend beyond the year 2012. The cost assessments underlying the supply-demand analysis, however, are based on the full lifetime of the options, assuming that emission potentials and costs beyond the first budget period will be accounted for by reduction commitments in subsequent periods.[65]
- The analysis does not account for a variety of institutional issues - notably with regard to the guidelines, rules and modalities of the Kyoto Mechanisms - that are either not clarified by the Kyoto Protocol or at present not yet solved by policy negotiations within the Framework Convention on Climate Change (FCCC). Besides the definition of the baseline scenario, these issues concern particularly (i) the condition of '*additionality*', i.e. the condition that emission reductions should be 'additional to any that would otherwise occur' (Kyoto Protocol, Art. 6; also known as the issue whether real 'no-regret' options are eligible as CDM options), (ii) the condition of '*supplementarity*', i.e. the condition that foreign transactions to acquire emission credits should be supplementary to domestic emission reductions (also known as the issue whether - and to what extent - '*ceilings*' should be imposed on the use of the Kyoto Mechanisms), (iii) the condition of '*sustainable development'* and other criteria with regard to the in- or exclusion of mitigation projects as eligible CDM options, (iv) the opportunity of *'credit sharing'* between host and investing countries involved in CDM (and JI) projects, and (v) the intended levy on CDM projects in order to create an *'adaptation fund'* for covering the administrative expenses and assistance to non-Annex I countries that are particularly vulnerable to the adverse effect of climate change. Depending on how these institutional issues will be solved by ongoing policy negotiations, they will affect the available amount and price of emission credits.

Some or perhaps most of the above-mentioned analytical limitations may be relieved by future improvements in the availability and reliability of data as well as by additional research and more sophisticated bottom-up (energy) sector modelling. But even then, two major analytical issues remain. The first issue concerns the question whether the same cost curve can be used to express or determine the (social) economic costs of mitigation options on the one hand, and to express and determine the (international) market price of emission credits on the other hand. Under some stringent conditions, this question might be answered affirmatively, but normally for each purpose a different cost curve should be designed, with each curve based on its own (different) cost definition and covering its own (different) cost categories.

The second issue concerns the question whether a bottom-up *sector* approach - even when improved, updated or more sophisticated than applied by the ECN-AED-SEI study team - is able to provide an adequate analysis of climate change policy topics at the (inter-) national or global level, notably such topics as the assessment of abatement costs at the (inter-) national level or the determination of the (inter-) national market clearing price of emission credits. At present, the approach of the ECN-AED-SEI team covers only direct engineering costs and neglects all other, indirect cost categories (see Chapter 3). Although the performance of this approach might be enhanced by including some indirect cost categories such as implementation costs or ancillary benefits, in its present form it is unable to account adequately for abatement costs at the macroeconomic level. These macroeconomic costs (as well as the other indirect costs) might be substantial or even more important than the direct engineering cost, although only additional research can address this supposition adequately. However, regardless which cost category might

[64] It is highly questionable, however, whether banking of CDM credits starting from the year 2000 will ultimately be realised given the fact that (i) the rules and modalities of CDM are still part of ongoing policy negotiations, and (ii) it might take some additional years before the Kyoto Protocol will be ratified by sufficient Parties to the UNFCCC and, hence, enters into force.

[65] See also Section 2.2.2 and references mentioned there.

be most important, the key issue is setting the right system boundary and analysing the corresponding level of abatement costs by means of the most appropriate methodological tool (see Section 4.2.2). At the project level, the most appropriate instruments to conduct a mitigation assessment are a cost-benefit analysis, a cost-effectiveness analysis or a multi-criteria analysis. These instruments, however are inadequate to account for the interdependencies among mitigation options and other, interacting effects at the (energy) sector level. In general, (bottom-up) sector models are the most appropriate methodological tools to assess mitigation options at the sector level, including the above-mentioned interacting effects. On the other hand, these sector models are not able to account adequately for the macroeconomic, interacting effects of mitigation options at the intersectoral or (inter-) national level. The latter effects can best be analysed by a general equilibrium model or any other integrated macroeconomic approach. Hence, a sector-based assessment of mitigation costs has to be supplemented by such a macroeconomic approach in order to account adequately for the full socio-economic costs of mitigation options.

4.3.3 Conclusions and recommendations

Abatement cost curves reflect the strengths and weaknesses of the methodologies and data used to construct them. This general statement applies particularly to the bottom-up CDM cost curve designed by the ECN-AED-SEI research team. Its major strength is that this curve is based on detailed information on specific mitigation options in non-Annex I countries, which has been generated by national study teams that are familiar with the local conditions of these countries.[66] Its major weakness, on the other hand, is that the data used to construct this curve suffer from a lack of consistency and comparability as well as from a significant degree of uncertainty due to a variety of data problems, methodological limitations and other analytical shortcomings of the country abatement studies providing these data.

Another major weakness of the bottom-up CDM cost curve is that it covers only direct engineering costs of eligible mitigation options, and that it neglects other cost categories such as the implementation costs of CDM options, the potential ancillary costs and benefits of these options, and the costs of risks and uncertainties inherent to CDM projects in less developed countries. Moreover, the *sector* approach of constructing and applying such a cost curve does not account for the macroeconomic costs and other interacting, feedback effects at the macro level resulting from the mitigation options covered.

Overall, the weaknesses of the ECN-AED-SEI-constructed CDM cost curve seem to be so substantial that it can be questioned as an appropriate tool to analyse the cost effects of the Kyoto Protocol, notably at the macroeconomic level. It is sometimes suggested that, at the present state of climate change policy research, the construction and application of such a CDM curve can be justified as a capacity building exercise mainly for internal use, waiting for future improvements in data availability and research modelling. This argument is basically correct, but it still requires a full awareness and understanding of the major analytical limitations of such an exercise as well as a full explicit account and explanation of these limitations and their potential implications for the major research findings and policy recommendations. This means that one should be very reluctant to use the research findings of such an exercise for external purposes - notably policy advice - and that the latter can only be justified if a full explicit account and explanation of the major analytical limitations and uncertainties inherent to the research findings is given, including a set of sensitivity analyses to provide an adequate indication of the reliability and possible range of outcomes of the major research findings.

[66] It should be noted, however, that up to now this potential strength has only been partly exploited. Another qualification is that this detailed information is hardly useful or even necessary for conducting climate change policy research at the macroeconomic level.

Recommendations
Besides the recommendations for improving the comparability of country abatement studies - see Section 4.2.9 - some additional recommendations for improving the construction and application of a bottom-up cost curve for all non-Annex I countries include:

- The ECN-AED-SEI database should be improved by including other cost categories besides direct engineering costs, notably by conducting additional research on the importance of implementation costs of CDM options, the risks and uncertainties of these options, and their ancillary costs and benefits.
- The ECN-AED-SEI sector approach of constructing and applying bottom-up cost curves should be supplemented by a macroeconomic analysis to account for the full socio-economic impact of mitigation options, including their interacting effects at the (inter-) national, regional and global levels.
- All major limitations with regard to the construction and application of an abatement cost curve should be explicitly accounted for in the studies concerned. Moreover, these studies should include a set of sensitivity analyses to provide an adequate indication of the reliability and possible range of outcomes of the major research findings.
- The supply-demand analysis of the CDM market of emission credits should be improved by additional research on the institutional, political and legal aspects of this future market, including the risks and uncertainties inherent to the start and further development of such a market.[67]

4.4 Some alternative approaches

4.4.1 Introduction

The previous sections have discussed some methodological issues with regard to the construction and application of the ECN-AED-SEI abatement cost curve for all non-Annex I countries, based on the so-called 'bottom-up' approach. In general, this approach is characterised by a rather detailed, technology-rich analysis of the energy sector by means of engineering-economic models such as MARKAL, EFOM or LEAP. Such an approach provides usually an adequate analysis of the potential and direct engineering cost of mitigation options, including their interdependencies and other interacting effects at the energy sector level. In principle, however, this approach does not adequately account for interactions and other feedback effects of mitigation options at the macro level, although these effects might occasionally be quite substantial.

Historically, the bottom-up approach has been opposed by an alternative methodology called the 'top-down' approach. The latter is usually characterised by an analysis that is primarily conducted at the macro level by means of socio-economic models such as computable general equilibrium models or neo-Keynesian macroeconomic models. These models analyse the economy - including the energy sector - in aggregated terms, without much detail on mitigation technologies at the sector level. Such models are particularly suitable for analysing macroeconomic effects of mitigation options, including the interactions and other feedback effects at the intersectoral, (inter-) national, regional or global level.

In addition to the above-mentioned differences with regard to the analytical level of aggregation (or system boundary), the top-down and bottom-up approaches used to be characterised by other, specific differences in model specification and underlying assumptions.[68] Over the past decade, however, the distinction between these approaches has become rather blurred as a vari-

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[67] See Sijm et al (2000) for some specific suggestions for further research on the role of the Kyoto Mechanisms in GHG mitigation, as well as Verbruggen et al (1999) for additional research suggestions regarding the performance and institutional aspects of a CDM market of emission credits.

[68] A full, detailed discussion of these differences and other characteristics of the top-down versus bottom-up approaches in energy modelling is included in Hourcade et al (1996a).

ety of mixed methodologies and hybrid models have been developed by combining elements of both approaches (Hourcade et al, 1996a, Weyant and Hill, 1999, Markandya and Halsnaes, 2000, and Hourcade and Shukla, 2000).

In the sub-sections below, two examples of alternative approaches to the ECN-AED-SEI methodology of constructing and applying abatement cost curves will be briefly discussed. These examples concern particularly the top-down approach as practised by Ellerman et al (1998), and a mixed or 'intermediate' approach as employed by Criqui et al (1999). The discussion will first of all focus on the methodology of these approaches to construct and apply a marginal abatement cost curve. Subsequently, the main results of these approaches with regard to estimating the cost effects of the Kyoto Protocol will be compared with similar estimates based on the ECN bottom-up approach as applied by Sijm et al (2000), followed by a discussion of the main factors explaining differences in cost estimates between these approaches and other mitigation studies assessing the cost impacts of the Kyoto Protocol. Finally, this section will be ended by some concluding remarks.

4.4.2 The top-down approach of Ellerman et al

The study of Ellerman et al (1998), based on a top-down approach, analyses the cost effects of the Kyoto Protocol by applying abatement cost curves generated by the Emissions Prediction and Policy Assessment (EPPA) model developed at the Massachusetts Institute of Technology (MIT, Cambridge, USA). This is a multi-sectoral, computable general equilibrium model of global economic activity, energy use and carbon emissions, covering 6 Annex I and 6 non-Annex I regions in the world. In order to construct the abatement cost curves for these regions, the EPPA model is run under different constraints corresponding to different levels of carbon abatement such as 10, 20 or 30 percent of baseline emissions in the year 2010. For each level of carbon abatement (q), the corresponding regional shadow prices (p) of carbon are an output of the model. By joining the points (q and p) together and fitting a line - or a mathematical equation - to these points, a marginal cost curve can be designed - and econometrically estimated - for each region.[69] By integration, i.e. assessing the area between the curve and the X-axis, the total costs for a certain amount of emission reduction can be calculated for each autarkic region. Depending on the abatement cost curve and the amount of reduction commitments of each region, the (aggregated, international) supply and demand curves of emission credits can be derived by varying the market price of emission credits. The intersection of these supply and demand curves determines the international clearing price of emission credits. Finally, by means of this price, the cost effects of trading emission credits can be assessed for each region.

The major advantages of this methodological approach to construct and apply an abatement cost curve are that it is based on a broader cost concept (including macroeconomic costs), and that it is relatively simple and consistent throughout all regions. The major disadvantages are that it lacks a detailed analysis of mitigation technologies, and that it suffers from a set of stringent assumptions and other analytical limitations.[70]

[69] The same marginal abatement cost curves as derived by MIT-EPPA have been used by Zhang (1999). The latter study, however, also considers non-CO_2 GHGs and employs emission projections obtained from national communications, which are much lower than the MIT-EPPA projections.

[70] Besides the assumption of complete economic rationality, these limitations are to a large extent similar to those of the ECN-AED-SEI approach discussed in Section 4.3.2 (i.e. only CO_2, no sinks, no banking of emission credits, etc.).

4.4.3 The intermediate approach of Criqui et al

Similar to Ellerman et al (1998), the study of Criqui et al (1999) also analyses the cost effects of the Kyoto Protocol, but this study derives its abatement cost curves from the POLES model developed by the *Institut d'Economie et de Politique de l'Energie* (IEPE, Grenoble, France). POLES is a world energy system model, divided in 26 regions, which is based on an intermediate approach. It has some common features with the top-down models in that prices play a key role in the adjustment of most variables in the model, while it also resembles the bottom-up models because of the degree of details shown in the treatment of technologies.

Although the methodology to construct and apply abatement cost curves is largely similar to the EPPA approach outlined above, there is a major difference. Whereas the EPPA model designs abatement cost curves by first setting a certain level of abatement (q) and subsequently calculating the corresponding carbon price (p) for each region, the POLES model constructs abatement cost curves by first introducing a shadow carbon tax (p) and subsequently assessing the corresponding abatement level (q). Starting from a baseline projection in which the shadow carbon tax is zero, it is then possible to calculate - through a successive set of recursive simulations - the abatement levels associated with different tax levels.

Compared to the top-down approach of the EPPA model, the major advantage of the intermediate approach of the POLES model is that it is more detailed in analysing energy technologies. Its major disadvantage, however, is that the abatement costs calculated by the POLES model are sectoral costs, which - unlike the EPPA model - do not take account of the full range of impacts of mitigation policies.

4.4.4 Comparing the results of alternative approaches of mitigation cost assessments

Table 4.3. presents a comparison of the main results of the MIT, IEPE and ECN studies with regard to the cost effects of the Kyoto Protocol in the year 2010. Such a comparison should consider first of all the estimates of total Annex I reduction commitments as projections of baseline emissions for the year 2010 and, hence, projections of Annex I reduction commitments may vary significantly among mitigation cost studies. Table 4.3 shows that estimates of total Annex I abatement commitments range from 2470 million tonnes CO_2 by ECN to 4810 mt CO_2 by MIT. In case of full global trading, the international clearing price of emission credits is estimated at 6 US$ by IEPE, 8 US$ by MIT, and 15 US$ by ECN if no-regret options are excluded and 4 US$ if these options are included. In such a case, CDM accounts for a major share of total Annex I reduction commitments, varying from 40 percent in the ECN study (excluding no-regrets) to 60 percent in the IEPE study. Before trade, i.e. relying only on autarkic mitigation measures, total abatement costs for the year 2010 are estimated at 145 billion US$ by MIT, 56 billion US$ by IEPE, and 91 billion US$ by ECN. After trade, i.e. allowing the full use of the Kyoto Mechanisms, these cost estimates fall drastically to 13, 5.8 and 13 billion, respectively (and even to 1.4 billion US$ in the ECN study if no-regret options are included). These variations in cost estimates, however, change significantly if differences in estimated reduction commitments are taken into account. Before trade, the average abatement costs range from 27 US$ per tonne CO_2 (IEPE) to 37 US$/t$CO_2$ (ECN), whereas after trade these costs vary from 0.6 US$/t$CO_2$ (ECN, including no-regrets) to 5.4 US$/t$CO_2$ (ECN, excluding no-regrets), with both MIT and IEPE in an intermediate position (2.8 US$/t$CO_2$).

Table 4.3 *Main results of selected studies and different approaches regarding the cost effects of the Kyoto Protocol for the year 2010 (in million tonnes CO_2 and 1990 US$ prices)*

	Unit	MIT[a] (top-down)	IEPE[b] (intermediate)	ECN[c] (bottom-up, excluding no regrets)	ECN (bottom-up, including no regrets)
Total Annex I commitments	[mtCO_2]	4811	2068	2470	2470
Price emission credits	[US$]	8	6	15	4
Trade in CDM credits	[mtCO_2]	2651	1258	1035	1239
Total costs before trade	[bUS$]	145	56	91	91
Total costs after trade	[bUS$]	13	5.8	13	1.4
Average cost before trade	[US$/t$CO_2$]	30.2	27.1	37.0	37.0
Average costs after trade	[US$/t$CO_2$]	2.8	2.8	5.4	0.6

[a] Massachusetts Institute of Technology, Cambridge, USA (see Ellerman et al, 1998).
[b] Institut d'Economie et de Politique de l'Energie, Grenoble, France (see Criqui et al, 1999).
[c] Netherlands Energy Research Foundation, Petten/Amsterdam, the Netherlands (see Sijm et al, 2000).

4.4.5 Explaining the differences in mitigation cost estimates

In addition to the studies mentioned above, there is a large sample of other studies that have assessed the cost effects of mitigation strategies - notably of the Kyoto Protocol - at the global, regional and/or national level.[71] Estimates of total abatement costs vary widely, ranging from almost zero - or even negative - up to 2 percent of GDP (in 2010, either at the global, regional or country level). These differences in mitigation cost assessments can be ascribed to three categories of explanatory factors:[72]

1. *The way in which welfare and abatement costs are defined and measured*, particularly (i) the distinction between financial and economic costs, and (ii) the inclusion or exclusion of implementation costs, ancillary costs and benefits, macroeconomic costs, etc.
2. *The scope and methodology of the mitigation cost assessments,* notably (i) the level of analysis (global, regional, national), (ii) the coverage of GHG emitting sectors (energy, agriculture, waste management), (iii) the inclusion or exclusion of sinks and non-CO_2 GHGs, (iv) the approach followed (top-down, bottom-up, intermediate), (v) the desired level and timing of abatement (notably of those mitigation cost studies extending beyond the first budget period of the Kyoto Protocol), etc.
3. *The assumptions underlying the mitigation cost assessments,* especially (i) the assumptions underlying the baseline and mitigation scenarios (demographic changes; the rate and structure of economic growth, technological changes and infrastructural investments; the availability and relative price changes of energy sources; the incidence of market imperfections, other institutional failures and resulting no-regret options; the costs and availability of existing and new mitigation technologies at both the demand and supply side of the energy and other sectors, etc.), (ii) the choice of the discount rate, (iii) the choice of policy instruments such as implementing mitigation projects, promoting the development and adoption of GHG-reducing technologies, allocating emission permits, or imposing energy/carbon taxes (including assumptions on whether and how revenues from auctioned permits and energy/carbon taxes will be used or recycled, e.g. to reduce other, distortionary forms of taxation), and (iv) the use of the Kyoto Mechanisms, including assumptions regarding institutional conditions restricting the use of these mechanisms and their interactions with domestic policy measures.

[71] See particularly chapter 8 of the forthcoming IPCC Third Assessment Report (Hourcade and Shukla, 2000), as well as a special issue of the Energy Journal on the costs of the Kyoto Protocol (Weyant and Hill, 1999).
[72] In addition to the previous sections of the present report, these explanatory factors have been considered by Hourcade et al (1996a and 1996b), Hourcade and Shukla (2000), as well as IPCC (2001).

4.4.6 Concluding remarks

As noted above, differences in mitigation cost assessments can be ascribed to a variety of explanatory factors, which are only partly - or even hardly - related to the distinction between top-down versus bottom-up approaches. Often, these factors - and, hence, the resulting cost estimates - may vary even wider within each of these approaches than between them. Moreover, over the past decade, the distinction between the top-down and bottom-up methodologies has become rather blurred due to the development of intermediate approaches and mixed, hybrid models that include elements of both the top-down and bottom-up methodologies. Nevertheless, within the field of energy studies and mitigation assessments, there is still an ongoing debate regarding the appropriateness of cost evaluations generated by top-down (macroeconomic) approaches versus bottom-up (sector and project level) approaches.

It is important, however, to qualify the debate concerning the top-down versus bottom-up approaches by emphasising the relative strengths of each approach and, hence, the need to complement each other by conducting mitigation cost assessments at different levels of analysis.[73] At the macro level, the assessment should be based on (inter-) national mitigation targets, followed by an identification of broad, different policy packages of abatement options for all GHG-emitting sectors and an evaluation of the implications of these options to meet the mitigation targets. Such an assessment can be best performed by a top-down, macroeconomic approach as the relative strength of this approach lies particularly in its ability to evaluate broad, different policy packages of mitigation options and their long-run, interacting effects on the overall economy.

Subsequently, at the sector level, the assessment should be based on sectoral mitigation targets, followed by an identification of sectoral options of abatement technologies - consistent with the broader, macroeconomic policy packages - and an evaluation of the cost implications of these technological options. This kind of assessment can be best conducted by a bottom-up approach as the relative strength of this approach lies especially it its disaggregated analysis of technology options, including the interdependencies and other interacting effects of these options at the sector level.

Finally, at the micro or project level, the assessment should include an even more detailed, disaggregated analysis of all relevant effects of each technology option identified by the above-mentioned bottom-up sector approach. Such a project appraisal can best be carried out by means of a cost-benefit analysis, preferably supplemented by a multi-criteria analysis in order to take account of the wider socio-political aspects in the selection and decision-making process of mitigation options.

[73] This mutual completion can be achieve by (i) informally linking the top-down and bottom-up models so that the models are operated independently, but the results from one model are reflected in the other in an iterative way until adequate convergence is reached, or (ii) formally linking a simple bottom-up model with a top-down model. See Hourcade et al, 1998 and references cited there, as well as Christensen et al (1998). See also Section 4.2.2 of the present report dealing with the issue of system boundaries, as well as Markandya et al (1998) for a discussion of 'the ideal method' of estimating GHG mitigation and adaptation cost in a consistent way between different levels of analysis.

5. SUMMARY OF MAJOR FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Background and main objectives

In 1999, the unit Policy Studies of the Energy research Centre of the Netherlands (ECN) published the report *'Potential and Cost of Clean Development Mechanism Options in the Energy Sector'*. This study was carried out jointly by ECN Policy Studies and two other institutes, i.e. the Alternative Energy Development, Inc. (AED, Silver Springs, USA), and the Stockholm Environment Institute (SEI, Boston, USA). The main purpose of the joint ECN-AED-SEI study was to assess the potential and cost of CDM options in the energy sector of non-Annex I countries. In order to achieve this purpose, these options were inventoried by means of project and country abatement studies in non-Annex I countries. The main result of this exercise was a bottom-up construction of a CDM cost curve for all non-Annex I countries. This curve was used in a supply-demand analysis of a CDM-related market of emission credits in order to determine the international clearing price of these credits and, subsequently, to estimate the cost effects of the Kyoto Protocol.

The objectives of the present study are (i) to review and, where possible, update or adjust the major results of the ECN-AED-SEI study, (ii) to provide a conceptual framework for mitigation cost assessments, especially for CDM options, (iii) to review the bottom-up methodology of constructing and applying abatement cost curves as employed in the ECN-AED-SEI study, and - where possible - make suggestions for improvements in this methodology, and (iv) to compare the results of different methodological approaches - 'bottom-up', 'top-down', 'intermediate' - of estimating the cost effects of the Kyoto Protocol.

Major findings and conclusions

- A major distinction in assessing the costs of a mitigation option is between *economic* versus *financial* costs on the one hand and *private* versus *social* costs on the other hand.
- In addition to direct engineering costs, mitigation options such as CDM projects may incur a variety of other costs such as implementation costs, the costs of risks and uncertainties, ancillary costs and benefits, and macroeconomic costs.
- In mitigation studies, cost effectiveness is the most widely used criterion in order to evaluate, compare, rank or aggregate GHG abatement options. This criterion is simply defined as the cost of a mitigation option divided by its emission reductions. However, an adequate comparison, ranking or aggregation of mitigation option assessments by means of the cost-effectiveness criterion requires that at least the following three conditions have to be met: (i) the same definition of costs has to be applied throughout all options considered, (ii) the same unit of measurement has to be used to express the cost effectiveness of all mitigation options analysed, and (iii) the same, comparable methodology has to be applied to measure the cost effectiveness of all mitigation options assessed. The analysis in the present report shows that these conditions have not been met with regard to the cost-effectiveness assessments of the mitigation options generated by a sample of 24 non-Annex I country abatement studies that have been employed by the ECN-AED-SEI team to construct a CDM-related abatement cost curve for all non-Annex I countries.
- Cost definitions in country abatement studies are either not clear or not uniform across these studies, whereas an additional conceptual limitation of the ECN-AED-SEI study is that its major cost definitions are not common in mainstream economics or mitigation cost assessments.

- Although country abatement studies have used some common analytical elements, there are significant differences between these studies with regard to (i) the cost definitions used, (ii) the definition and underlying assumptions of the baseline scenario, (iii) the identification and coverage of the mitigation options, (iv) the energy sector models used, (v) the availability, reliability and consistency of the data, (vi) the choice of the discount rate and other accounting methods used, and (vii) the unit of measurement to express the cost-effectiveness assessments of mitigation options. Moreover, an adequate comparison between the cost-effectiveness assessments of the country abatement studies is not always possible due to a lack of information provided on the data and methodology used. Therefore, a comparison, ranking or aggregation of the mitigation options concerned by means of the cost-effectiveness criterion in order to construct an abatement cost curve has only limited meaning.
- *Abatement cost curves reflect the strengths and weaknesses of the methodologies and data used to construct them.* This general statement applies particularly to the bottom-up CDM cost curve designed by the ECN-AED-SEI research team. Its major strength is that this curve is based on detailed information on specific mitigation options in non-Annex I countries, which has been generated by national study teams that are familiar with the local conditions of these countries. Its major weakness, on the other hand, is that the data used to construct this curve suffer from a lack of consistency and comparability as well as from a significant degree of uncertainty due to a variety of data problems, methodological limitations and other analytical shortcomings of the country abatement studies providing these data. Another major weakness of the bottom-up CDM cost curve is that it covers only direct engineering costs of eligible mitigation options, and that it neglects other cost categories such as the implementation costs of CDM options, the potential ancillary costs and benefits of these options, and the costs of risks and uncertainties inherent to CDM projects in less developed countries. Moreover, the *sector* approach of constructing and applying such a cost curve does not account for the macroeconomic costs and other interacting, feedback effects at the macro level resulting from the mitigation options covered.
- Alternative approaches to the ECN-AED-SEI bottom-up methodology of constructing and applying cost curves are the so-called 'top-down' and 'intermediate' approaches'. Each approach has its own set of advantages and disadvantages in assessing the costs of mitigation options. A comparison of differences among national, regional and global abatement studies in estimates of the cost effects of the Kyoto Protocol reveals that these differences can only be partly related to the distinction between top-down, bottom-up and intermediate approaches. More specifically differences in mitigation costs assessments can be ascribed to three categories of explanatory factors: (i) the way in which welfare and abatement costs are defined and measured, (ii) the scope and methodology of the mitigation cost assessments, and (iii) the assumptions underlying the mitigation cost assessments.

Recommendations

- Country abatement studies should provide explicit and detailed information on the cost definitions, data, methodologies and assumptions used.
- Country abatement studies should use the same cost definitions and cover the same cost categories.
- Country abatement studies should preferably conduct a *social* assessment of mitigation options in both *financial* and *economic* terms.
- Country abatement studies should use the same unit of measurement to express the cost-effectiveness of mitigation options, notably apply the same target year(s) for the assessment of mitigation potentials and costs.

- Country abatement studies should further streamline and uniform their methodology and assumptions used as far as possible and justified, given the actual differences between the countries concerned. This implies that these studies should at least use (i) the same analytical structure, (ii) the same system boundary (iii) the same 'most likely' definition of the baseline scenario, (iv) the same baseline assumptions with regard to parameters that apply more or less equally to all countries, such as the projected development of the international energy prices, (v) the same, full coverage of the mitigation options identified, and preferably (vi) the same or, at least, comparable energy sector models and other accounting methods to calculate the cost effectiveness of mitigation options. Finally, as far as differences in baseline assumptions, accounting methods, models and data used are justified or unavoidable, they should be explicitly accounted for.
- The ECN-AED-SEI database should be improved by including other cost categories besides direct engineering costs, notably by conducting additional research on the importance of implementation costs of CDM options, the risks and uncertainties of these options, and their ancillary costs and benefits.
- The ECN-AED-SEI sector approach of constructing and applying bottom-up cost curves should be supplemented by a macroeconomic analysis to account for the full socio-economic impact of mitigation options, including their interacting effects at the (inter-) national, regional and global levels.
- All major limitations with regard to the construction and application of an abatement cost curve should be explicitly accounted for in the studies concerned. Moreover, these studies should include a set of sensitivity analyses to provide an adequate indication of the reliability and possible range of outcomes of the major research findings.
- The supply-demand analysis of the CDM market of emission credits should be improved by additional research on the institutional, political and legal aspects of this future market, including the risks and uncertainties inherent to the start and further development of such a market.
- Different methodological approaches and tools should complement each other by conducting mitigation cost assessments at different levels of analysis. At the macro level, the identification and assessment of broad mitigation policy packages can be best performed by a top-down approach using macroeconomic models. At the sector level, specific mitigation options and technologies can be best identified and assessed by a bottom-up approach applying technology-rich sector models. Finally, at the micro level, a mitigation project can be best evaluated by a cost-benefit analysis, preferably supplemented by a multi-criteria analysis in order to take account of the wider socio-political aspects in the selection and decision-making process of mitigation options.

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ANNEX A OVERVIEW OF COUNTRIES COVERED BY NATIONAL ABATEMENT STUDIES

Country	Emissions in 1995 [mln tonnes CO_2 eq.]	Reduction potential in 2010 [mln tonnes CO_2 eq.]	Share in total non-Annex I emissions in 1995 [%]	Share in total non-Annex I reduction potential in 2010 [%]
Original 24 countries				
China	3192	645	35.0	27.7
India	909	410	10.0	17.6
Egypt	79	105	0.9	4.5
Mexico	358	67	3.9	2.9
Korea, Rep (South)	374	57	4.1	2.5
Pakistan	85	55	0.9	2.4
Thailand	175	37	1.9	1.6
Nigeria	91	36	1.0	1.6
Argentina	129	25	1.4	1.1
Indonesia	296	19	3.2	0.8
Philippines	61	15	0.7	0.6
Vietnam	32	13	0.3	0.6
Tanzania	55	8	0.6	0.4
Venezuela	58	8	0.6	0.4
Zimbabwe	16	7	0.2	0.3
Bangladesh	21	5	0.2	0.2
Mongolia	8	4	0.1	0.2
Zambia	14	3	0.2	0.1
Bolivia	10	3	0.1	0.1
Myanmar	6	2	0.1	0.1
Botswana	4	2	0.0	0.1
Senegal	5	0	0.1	0.0
Jordan	13	0	0.1	0.0
Kazakstan, Rep	221	0	2.4	0.0
Total original 24 countries	*6213*	*1528*	*68.2*	*65.6*
Additional 3 countries				
Brazil	306	139	3.4	6.0
Lebanon	13	6	0.1	0.3
Ecuador	23	2	0.3	0.1
Total 27 countries	*6555*	*1675*	*71.9*	*71.9*
All non-Annex I countries	*9114*	*2329*	*100*	*100*

Source: World Bank (1999) and country abatement studies.