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GHG Marginal Abatement Cost curves for the Non-Annex I region

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Abstract
The study presented in this report aimed to identify the potential and costs of greenhouse gases emission reduction options in non-Annex I countries to enable the development of realistic and policy-relevant Marginal Abatement Cost (MAC) curves for the non Annex I region.

The study has gathered potential and cost information of some 550 GHG emissions reduction options from 30 non-Annex I countries. A simple extrapolation method has been applied to extend the estimated GHG reduction potential for the 30 countries to the remaining non-Annex I countries. Based on this information an aggregated Marginal Abatement Cost curve has been constructed for the whole non-Annex I region.

The estimated theoretical GHG emissions reduction potential in 2010 for all non-Annex I countries together amounts to approximately 2 $GtCO_2$ eq.

However, the time available for fully realising this potential is too short. Based on the CERs generated by registered CDM projects and projects in the pipeline, it is estimated that approximately 14% of this potential can be realised by 2010.

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Summary

The study aimed to identify the potential and costs of greenhouse gases emissions reduction options in non-Annex I countries to enable the development of realistic and policy-relevant Marginal Abatement Cost (MAC) curves for the non Annex I region.

Potential and costs of GHG emission reduction options from 30 non-Annex I countries have been collected from national abatement costing studies conducted mostly in the framework of capacity building programmes. This information has been reviewed, evaluated and aggregated to construct an aggregated MAC curve. In addition, separate MAC curves have been constructed for the largest non-Annex I countries and regions and for specific sectors in these countries.

The transaction costs related to bringing the GHG reduction option under the CDM have been assessed for various types of projects. The absolute CDM transaction costs can be a significant portion of total project investments and could form a barrier for potential investors because these costs are incurred upfront when no revenues from the sales of credits have been realized. However, the CDM transaction costs per unit CO_2 eq reduction are limited and ranges from $ 0.01-0.7 per tCO_2 eq, depending on the specific technology. The CDM transaction costs have been included in the MAC curves.

Total GHG emissions in the non-Annex I region for the latest available year (for most countries 1994) is estimated at 6.4 $GtCO_2$ eq (without LUCF) by the UNFCCC. The identified GHG emissions reduction potential for this region is significant. The inventory of reduction options reveals that the reduction potential in 2010 at costs up to 50 $ per tCO_2 eq is approximately 2 $GtCO_2$ eq. The realizable GHG emission reduction potential in 2010 will be lower than the theoretical GHG emission potential, because the remaining implementation time is way too short. So, it is essential to differentiate between theoretical emission potential and realizable emission reduction potential. Based on information of projected annual average CERs of 1571 projects in the CDM project pipeline, it is estimated that approximately 14% of the total identified abatement potential can be realized in 2010.

There are clearly two types of reduction options that contain the most reduction potential: reduction options in the power sector (efficiency improvements, fuel switch and renewable energy) and demand side energy efficiency measures (together 62 per cent of total reduction potential). Of the total identified reduction potential in the non-Annex I region, 66 per cent arises from reduction options in only four countries, namely China, India, Brazil and South Africa.

According to China's initial national communications, aggregated GHG emissions in 1994 amounted to 3,650 $MtCO_2$ eq. The national greenhouse gas inventory, developed by the World Resources Institute, concluded that 4,938 $MtCO_2$ eq of anthropogenic greenhouse gases emissions were emitted in China in 2000. This makes China the second largest emitter worldwide, only exceeded by the US. In total 32 GHG reduction options have been identified for China, with a total reduction potential of 615 $MtCO_2$ eq in 2010. About 35 per cent of this potential can be achieved at net negative costs ('no-regret' reduction options). More than 44 per cent of the reduction potential has been identified in the industry sector.

Total greenhouse gas emissions in India in 1994 were 1,229 $MtCO_2$ eq and this level grew to an estimated 1,884 $MtCO_2$ eq in 2000. The identified national GHG reduction potential for 2010 amounts to approximately 390 $MtCO_2$ eq. Most potential can be realized through demand and supply-side energy efficiency measures. Renewable energy technologies account for some 17 per cent of total reduction potential.

Total estimated GHG emissions for Brazil in 1994 amounted to 1,477 $MtCO_2$ eq. It is estimated that about two thirds of total GHG emissions in Brazil stem from tropical deforestation. The total identified reduction potential in 2010 that would be eligible for CDM is 67 $MtCO_2$ eq. The most important reduction option in terms of potential is electricity conservation followed by ethanol with electricity co-generation.

Aggregated GHG emissions in South Africa in 1994 amounted to 380 $MtCO_2$ eq and have increased to 417 $MtCO_2$ eq in 2000. Some 29 reduction options have been identified with a total reduction potential of more than 37 $MtCO_2$ eq. Some 33 per cent of total potential can be implemented at net negative cost.

The results presented in the report should however be viewed with caution, as there are several limitations to aggregating the information obtained from the various abatement costing studies on which these estimates are based. These studies do not always aim to make an exhaustive assessment of the reduction potential in a country and different assumptions and approaches about baselines scenarios make it difficult to aggregate the results. Furthermore, almost all reduction options identified concern CO_2 and CH_4 emissions and no options are included in the country abatement studies for mitigating N_2O, HFC, PFC and SF6 emissions.

In addition to the potential and cost information obtained from country abatement costing studies, cost information from proposed and/or approved CDM project has been gathered from 120 CDM projects. One would expect to get more detailed and accurate cost information from (potential) CDM projects, which have been submitted to the UNFCCC. The CDM project cost information has been compared with the information obtained from the abatement costing studies for the 30 countries. Although no firm conclusions could be drawn, indications are that for biomass, mini-hydro and landfill gas project the cost information from the country abatement studies is of the same order of magnitude as used for (potential) CDM projects. However, the costs for wind projects used in (potential) CDM projects are much higher compared to the figures used in the country studies.

1. Introduction

1.1 Background

During the last decade, emissions trading (ET) has emerged as a chief instrument for controlling anthropogenic emissions of greenhouse gases (GHGs). Many transactions in emissions trading involve technologies deployed in an energy, industrial or other setting that generate carbon credits. The precise characteristics of such technologies are often disregarded in emissions trading analyses, but they represent an important feature for policymakers and many stakeholders.

The international market for tradable GHG emission permits has been established by the Kyoto Protocol. Recently, ET schemes have been planned or implemented in a number of European countries such as Denmark, Poland, Slovakia, the United Kingdom, and Switzerland (See Defra (2001), Ellerman (2000), Janssen and Springer (2001), Williams et al. (2002)). In October 2003, the European Parliament and the Council adopted a Directive establishing a common market for tradable emission allowances in the European Union (European Commission, 2003a). The European ET system will be the world's largest and most comprehensive trading system for GHG. It covers emissions of carbon dioxide (CO_2) from large stationary sources including power and heat generators, oil refineries, ferrous metals, cement, lime, glass and ceramic materials, and pulp and paper in all member states. The system is expected to cover approximately 45% of total CO_2 emissions in the European Union.

The Clean Development Mechanism (CDM) and Joint Implementation (JI) represent project-based emissions trading. In 2004, these mechanisms were linked to the EU ETS Directive (2003/87/EU) through the linking Directive (2004/101/EC) which provides recognition of JI and CDM credits as equivalent to EU emission allowances.

Given the advanced status and large size of the European CO_2 emissions trading scheme, linking or integrating their own national trading scheme (in) to the European system offers several advantages for other countries. The ET Directive explicitly states that "Agreements should be concluded with third countries [...] for the mutual recognition of allowances between the Community scheme and other greenhouse gas emissions trading schemes …" (Article 25). Advantages of linking or connecting their trading schemes for third countries include greater liquidity, lower volatility of prices, potentially lower prices, and a potentially higher market transparency.

Against this background the overall strategic objective of the Technology Transfer and Investment Risk in International Emissions Trading (TETRIS) project for policy makers has been formulated as the exploration of the economic and industrial impacts associated with the implementation of the Kyoto flexible mechanisms. In order to reach this overall strategic objective a number of partial objectives were formulated. These are:

1. *To explore technology transfer related to the implementation of the Kyoto mechanisms in developing and EU accession countries.*
   The Kyoto mechanisms can initiate or facilitate technology transfer to developing or transition countries. Key determinants for technology transfer are identified using the literature and recent case studies.
2. *To develop composite indicators of the investment climate for GHG abatement projects and incorporate them into the analysis of emissions trading markets.*
   Risks of investment in climate change mitigation are substantial, but often ignored in analyses of climate policy and emission trading. To account for these risks, indicators of the investment climate for GHG abatement projects are developed. These describe both costs and risks of investments and take into account macroeconomic stability, the institutional environment for JI and CDM, and political risks.

3. *To assess the potential and problems of linking different emissions trading schemes.*
   Non-EU emissions trading schemes are analysed, both in non-EU European countries (Norway, Switzerland), and in countries outside Europe (Japan, Canada). Fundamental differences between the design of ET systems and national climate polices in and outside the EU are highlighted.
4. *To analyse quantitatively the economic and industrial impacts of international emissions trading.*
   A general equilibrium model of international trade and energy is used to analyse the economic consequences of a European carbon market, and a worldwide carbon market including JI and CDM carbon credits. The model covers a wide range of regions and sectors.

In order to fully exploit the benefits of the European Trading Scheme it needs to be linked to carbon credits that have been obtained in projects under one of the Kyoto mechanisms, since these often involve cost-effective options to reduce GHG emissions. Including the carbon credits obtained therein could greatly increase the cost-effectiveness of an emissions trading regime.

The TETRIS project is structured according to eight Work Packages (WPs). WP3 is looking in particular at carbon credits that could be obtained under the Clean Development Mechanism (CDM). In WP3 potentials and marginal costs of reducing GHG emissions under the CDM are inventoried. The present report explains the methodology applied to assess the potential and costs of GHG reduction options in non Annex I countries and presents the Marginal Abatement Cost Curve (MAC) for the non-Annex I region as a whole and for a number of selected regions.

1.2 Objectives of Work Package 3

The objectives of WP3 are to derive realistic and policy relevant MAC curves for GHG emissions reduction options in major developing countries and regions. For the work carried out to meet this objective, point of departure was the inventory of project-based carbon credits completed by Sijm et al (2002). This inventory comprised potentials and costs of reduction options in Western Annex I countries, Annex I countries in Eastern Europe and the Former Soviet Union and non-Annex I countries. From this overview a MAC curve was compiled, describing how the additional costs resulting from the reduction of an additional unit of emissions increase with the total reduction achievable. The inventory of abatement options in the non-Annex I region compiled by Sijm et al (2002) has been updated and disaggregated in this report. New MAC curves are constructed, both for emission reductions in a number of major CDM host countries, and for the whole non-Annex I region. The curves represent mainly CO_2 and only to a very limited extent other greenhouse gases. The curves are used as an input for the economic analysis conducted as part of the TETRIS project with the aim to project price and cost impacts of including carbon credits from CDM projects on the global emissions markets.

1.3 Outline of the report

In Chapter 2 the approach to the study is presented. First, a general overview of the approach to constructing bottom-up marginal abatement cost curves is presented in Section 2.1. Next, an analysis of the transaction costs of CDM projects is given in Section 2.2 and finally the limitations to the study are explained in Section 2.3. Chapter 3 presents the results. First, a MAC curve for the whole non-Annex I region is presented and discussed in Section 3.1. Then MAC-curves for selected CDM host countries are explained, specifically for China, India, Brazil and South Africa (Section 3.2 to 3.8). Next, abatement cost information from (potential) CDM projects is gathered and analysed in Section 3.9. Finally, a series of conclusions relevant for both the research community and policy makers is put forward in Chapter 4.

2. Approach

2.1 General overview of the approach to the study

The approach adopted for developing the MAC curve for the non-Annex I region[1] is based on a review, comparison, evaluation and aggregation of GHG emissions reduction studies and potential CDM projects in the non-Annex I countries. The approach consists of the following components:

- Collecting information on potential and cost of GHG reduction options from country abatement costing studies (mitigation studies) and (potential) CDM projects which could have been (are being) implemented.
- Comparing the two sources of information and developing a database of GHG reduction options.
- Assessing the CDM transaction costs of CDM projects.
- Developing MAC curves for the whole non-Annex I region and for selected non-Annex I countries.

The approach is schematically presented in Figure 2.1. The components within the dotted area are part of Work Package 3.

Potential and costs of GHG reduction technology options have been collected from country abatement costing studies. These national studies aimed to assess the national GHG emissions reduction potential and have been conducted by local experts often in the framework of a capacity building programme. This information has been stored in a database to facilitate the development of MAC curves for the non-Annex I region. In addition, technology specific CDM transaction costs have been assessed and included in the cost information.

In a parallel activity, cost information of (potential) proposed and approved CDM projects has been collected from the Project Design Documents to enable a comparison with the cost information obtained from the country abatement costing studies. A separate CDM database has been created for this purpose.

Within the TETRIS project, the non-Annex I MAC curves are used by the General Equilibrium of International Trade and Energy Use model to calculate the equilibrium price of tradable CO_2 allowances and to determine which technologies will be used for reducing GHG emissions and the extent to which transfer of technology from outside the host country will take place.

[1] Non-Annex I countries are all countries that do not have binding GHG emissions reduction requirements for the first period (2008-2012) of the Kyoto Protocol.

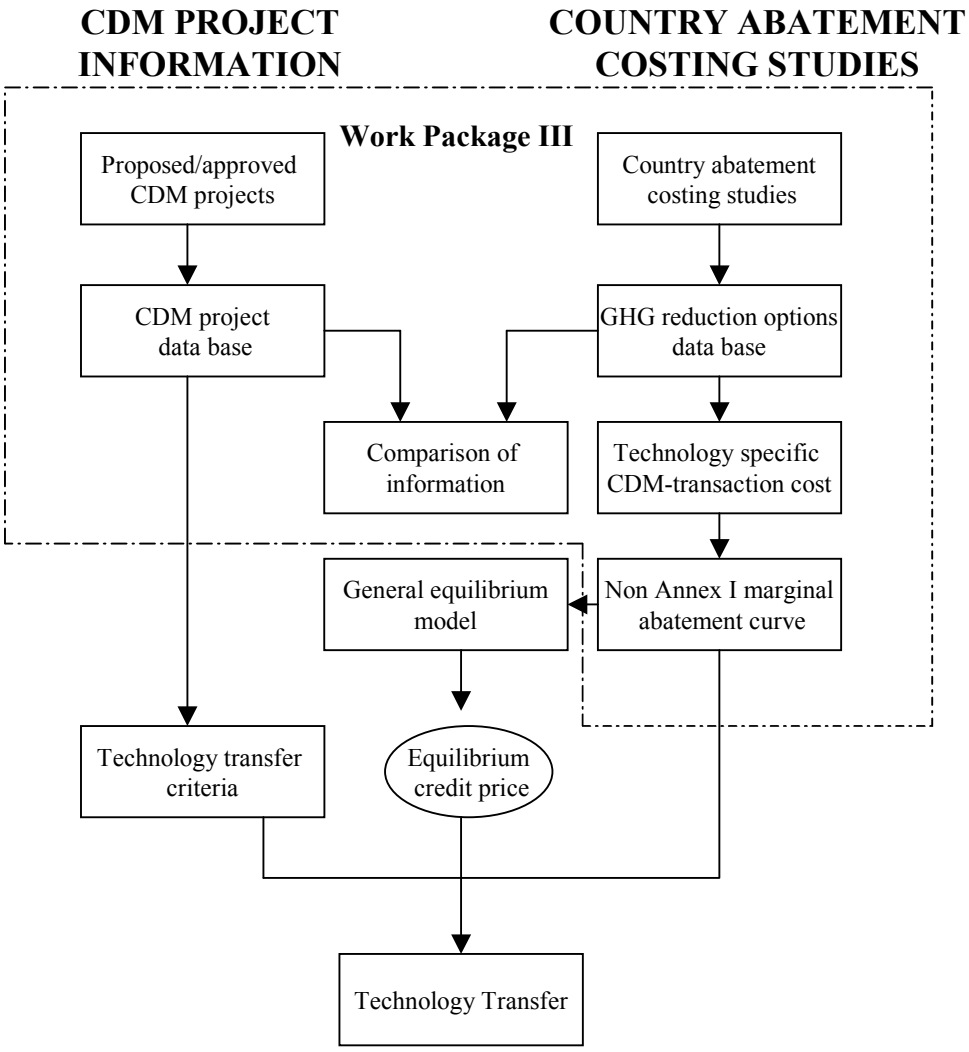

Figure 2.1 *Schematic overview of the approach. The components within the dotted area are part of Work Package 3 of the TETRIS project*

2.1.1 Inventory of GHG emissions reduction options based on country abatement costing studies

The aim of a country abatement costing study is to identify a broad range of available technology options to reduce the GHG emissions and to determine the reduction potential and associated cost for each technology option. For the construction of the non-Annex I MAC curve, a number of available abatement studies for non-Annex I countries were analysed and the results compiled in an inventory of the technology options, their projected potential for the year 2010, and their associated abatement costs[2]. These studies have been carried out in the framework of capacity building programmes (for example ALGAS project) or national studies with the aim to assess the potential for CDM.

Since the benefits of a less-carbon intensive world economy are hardly measurable, the country abatement studies rank the options on the basis of their cost effectiveness for reducing carbon emissions. Underlying studies use $/t$CO_2$ eq as an indicator of the cost effectiveness of restraining GHG emissions. Cost data are collected for a mitigation option of a nominal size and with

[2] In the context of country abatement costing studies, abatement costs are defined as the costs of GHGs reduced that are expressed as the net (cost minus benefit) incremental cost per unit of GHG reduction compared to the baseline scenario.

characteristics of an average option. For the reason that a single technology characterization is often used to represent a range of technologies with varying characteristics, the abatement potential is only indicative of that which might be incurred in actual situations.

Total global GHG emissions, without land-use, land-use change and forestry (LULUCF), for the latest available year (ranging from 1990 to 2003) are estimated at 23.8 $GtCO_2$ eq by the UNFCCC. Roughly 27% of this amount stems from 121 non-Annex I countries. The present study acquired potential and costs for GHG reduction technology options for 30 non-Annex I countries, of which 9 are situated in Africa, 14 in Asia and 7 in Latin America.[3] According to the Greenhouse Gas Emissions Data for 1990-2003 of the UNFCCC, for the year 1994 these 30 non-Annex I countries accounted for more than 80% of total GHG emissions in the non-Annex I region. As a consequence, approximately 20% of total GHG emissions in non-Annex I countries remain uncovered in this study.

Each of the above studies offers a set of GHG abatement options and their projected abatement costs. The GHG emissions reduction options obtained from the 30 country studies include only the gases CO_2 and CH_4. No options have been reported in these studies to reduce the other greenhouse gases. This is not surprising for Perfluorocarbons (PCFs), Hydrofluorocarbons (HFCs) and Sulphur hexafluoride (SF_6), because the amount of emissions from these gases in the non-Annex I countries is very small (although rapidly growing especially in the emerging economies). However, N_2O emissions constitute a significant part of total GHG emissions in non-Annex I countries and already 17 N_2O reduction-CDM projects were registered by the UNFCCC at the end of 2006.

The project team gathered information on 552 options for reducing GHG emissions. Not all of the options identified are eligible for CDM. Firstly, in the forestry sector only afforestation/reforestation options present opportunities for CDM projects. Avoided deforestation, forestry management and agroforestry are not likely to be allowed as CDM projects. Secondly, a switch from fossil fuel-based electricity generation to nuclear generation is not considered as a possible CDM project. Thirdly, large hydropower is heavily criticised as being an unsustainable CDM option. For that reason potential and cost of these options are also left out in the results in Chapter 3. Finally, some technology options in the transport sector are not eligible for CDM (e.g. promotion of the use of public transport, paved roads and vehicle inspection). In total, 180 options for GHG emissions reduction reported in the abatement costing studies are considered not eligible for CDM, of which 54 are avoided deforestation options, 54 as agroforestry and 72 other options. All these non-eligible options have been left out for the construction of the MAC curves.

2.1.2 Inventory of options based on proposed and/or accepted CDM projects

The country abatement costing studies provide information at the macro level. Abatement potential and abatement costs of a particular technology are not based on actual cases, but on model simulations and expert opinions of the total potential and the average costs. One would expect to get more and detailed investment cost information from (potential) CDM projects, which have been submitted to the UNFCCC. For the purpose of the present study, information on potential and investment costs was obtained from different CDM projects under implementation. Although the total GHG reduction brought about by the CDM project portfolios small in terms of total estimated reduction potential and the sectoral coverage is heavily biased towards the electricity sector, these data nevertheless offer the possibility to verify at least part of the abatement cost information collected in the country abatement studies.

[3] Latin America (Argentina, Mexico, Columbia, Bolivia, Ecuador, Venezuela and Brazil), Africa (Zimbabwe, South Africa, Egypt, Zambia, Botswana, Nigeria, Tanzania, Senegal, Tunisia), Asia (China, India, Vietnam, Kazakhstan, Uzbekistan, Bangladesh, Sri Lanka, Philippines, Republic of Korea, Indonesia, Mongolia, Myanmar, Thailand and Pakistan).

The data has been collected from the Project Design Document (PDD) for CDM projects, which can be downloaded from the UNFCCC website, and the Project Idea Note (PIN), which are provided by project developers. All Pads include an ex ante projection of estimated CO_2 eq savings. Whereas only some PDDs include investment costs. By early 2006, approximately 432 CDM projects were planned or under implementation. Of these 432 CDM projects, 47 PDDs and 71 PINs were gathered that included investment cost information.

2.1.3 Description of the databases

To assist the processing of country and CDM project information two separate databases have been constructed which contain all the bottom-up cost information extracted from the country abatement costing studies and the CDM project information. The bottom-up approach provides a disaggregated picture of mitigation options. Thereby, it allows for estimation of potential emission reduction in energy demand and supply (Sathaye & Ravindranath, 1998). The main purpose of the database is to systematically store the large amount of potential and costs data to facilitate easy construction of MAC curves for the non-Annex I region.

The following table shows the allocation of technology options and CDM projects over the sectors and sub sectors distinguished by the general equilibrium model used in TETRIS to determine the equilibrium credit price. The equilibrium model distinguishes energy intensive and non energy-intensive sectors. With respect to the sectoral coverage in the technology database, it must be stressed that the options concentrate in the following sectors: electricity, transport, agricultural products, forestry, rest of industry (other manufactures and services) and households.

Table 2.1 *Breakdown of GHG reduction options by sector*

Sector	(Potential) CDM projects	Country Abatement costing studies
Energy-intensive sectors		
Coal	3	4
Crude Oil	1	3
Natural gas	-	1
Petroleum and coal products	1	-
Electricity	66	116
Iron and steel industry	4	5
Paper product	-	4
Non-ferrous metals	1	-
Mineral products	-	-
Non-energy intensive sectors		
Agricultural products and forestry	7	31
Transport	2	19
Rest of Industry	27	84
Manufactures and services		
Households	8	105
Total number of reduction options	120	372

2.2 CDM transaction Costs

Transaction costs for bringing the project under the CDM include cost for the identification of the CDM project, the development and validation of the project design document and verification and certification of emissions reduction. The absolute transaction costs can be a significant portion of the total project investments and are to a large degree fixed and independent of the

size of the project. Because the costs can be significant, investors are particularly interested in larger projects as they have relatively low transaction cost per unit of emission reduction.

Because small-scale CDM projects can potentially contribute significantly to local sustainable development in terms of job creation and poverty reduction, the CDM Executive Board has developed and adopted simplified procedures for small-scale projects to reduce the transaction costs and make them more attractive for potential investors. The different components of the project cycle are the same as for regular CDM projects but the CDM Executive Board has adopted simplified and thus less costly procedures for baseline development, monitoring requirements, additional requirements, project boundary and leakage.

In this section, an analysis is presented that aims to determine the CDM transaction costs for various technologies to reduce greenhouse gas emissions. The analysis builds on previous research carried out by ECN (Bhardwaj et al., 2004) and takes into account the difference in costs between regular and small-scale CDM projects and the average amount of annual greenhouse gas emission reductions of the project's technology type. This results in an estimation of the transaction cost expressed in $ per tCO_2 eq for inclusion in the MAC curves presented in Chapter 3.

Categorizing greenhouse gas emission reduction technologies

The greenhouses gases defined under the Kyoto Protocol comprise six gases: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Table 2.2 and 2.3 show the relative contribution of each greenhouse gas and the sectoral shares to total GHG emissions in Annex I and non-Annex I regions.

Table 2.2 *Contribution by gas to total GHG total emissions in Annex I region (2003) and non-Annex I region*[1]

Greenhouse gas	Annex I region [%]	Non-Annex I region without LUCF [%]
CO_2	82.7	63.1
CH_4	10.0	25.7
N_2O	5.6	11.2
HFCs, PFCs, SF6	1.7	

[1] Latest available year
Source: Key GHG Data, Greenhouse Gas Emission Data for 1990-2003 (UNFCCC, 2005).

Table 2.3 *Sectoral share in total GHG emissions in Annex I (2003) and non-Annex I without LUCF) region*[1]

Sector	Annex I region [%]	Non-Annex I region [%]
Industrial processes	5.4	6.0
Agriculture	7.4	25.9
Waste	2.6	4.3
Energy	84.4	63.9
Others	0.2	

[1] Latest available year
Source: Key GHG Data, Greenhouse Gas Emission Data for 1990 - 2003 (UNFCCC, 2005).

Since the CDM transaction costs per unit of emission reduction vary significantly with project size, the GHG emissions reduction technologies have been grouped into six categories based on

the average annual amount of greenhouse gas emission reduction that is achieved by a particular technology. Table 2.4 presents an overview of the technologies per category.

Table 2.4 *Categorization of GHG emission reduction technologies*

Category	Technology	Average emission reduction [tCO_2 eq/yr][1]
I	• Hydrofluorcarbons (HFCs) • Nitrous oxide (N_2O)	4,700,000
II	• Methane capture (CH_4) • Landfill gas (CH_4) • Methane reduction from manure (CH_4)	200,000
III	• Large-scale renewable energy technologies (more than 15 MW) • Large-scale industrial efficiency (more than 15 GWh) (no examples in the 1-Jan portfolio) • Fuel switch (more than 15 MW) (example in project portfolio has a reduction of only 19,500 tCO_2/yr) • CO_2 capture and storage (no examples in the 1-Jan portfolio) • Clean coal technologies (no examples in the 1-Jan portfolio)	100,000
IV	• Small-scale renewable energy technology (wind, bio energy, hydropower);systems less than 15 MW • Small scale industrial efficiency (no examples in the 1-Jan portfolio) • Transport sector	28,000
V	• Distributed renewable system (solar, biogas, wind) and demand side energy efficiency	10,000
VI	• Forestry mitigation options (afforestation and reforestation)	370,000-3,400,000

1) Where possible, the numbers are based on average project size of registered CDM projects on 1 January 2006

For categories I-V, a detailed assessment of the transaction costs based on an estimation of the various cost components has been made. The transaction costs at the project level[4] consist of the upfront costs that are incurred before any benefits of the project have been generated and the cost for monitoring and verification once the project is operational. The upfront costs involve the following components:

1. *Project preparation and review*: costs related to the identification of a suitable CDM project, preparation of the Project Idea Note and discussing the note with the Designated National Authority to assess the eligibility of the project for the CDM.
2. Preparation of *Project Design Document*: the PDD is required under the CDM and is the core component of the CDM project cycle. The PDD consists of the following elements[5]:
   - description of the proposed CDM project
   - definition of the baseline methodology (already approved by the CDM EB or new methodology)
   - formulation of the project boundaries
   - establishing additionality within the boundaries
   - estimation of the emissions reduction achieved by the project

[4] In addition to the costs incurred at the project level there are also costs incurred at the national level such as running costs of national CDM authority, establishing of CDM guidelines and procedures and staff cost at various Ministries.

[5] Some of these are not required for small-scale projects.

- crediting period
- monitoring methodology (already approved by the CDM EB or new methodology) and plan
- environmental impact assessment

3. *Validation*: emissions reduction achieved by the CDM project cannot be self-declared but have to be validated, verified and certified by an independent validator who must be hired by the project participants. Validators must be designed operational entities that have been accredited by the CDM EB.
4. *Appraisal Phase* involves the costs related to the negotiations between the CDM EB and the project developer and an initial administration fee which will be charged by the UNFCCC for registration of the project. The level of the fee depends on the size of the project in terms of GHG reductions.
5. *Initial verification* (start-up) involves the costs for the Designated Operational Entity (DOE) to do the first verification, before more routinely performed periodical verification can take place.

The operational costs consist of:

6. *Periodic verification* involves an independent review and ex post determination by the DOE of the reductions in emissions that have occurred as a result of a registered CDM project during the verification period.
7. *Certification* is the written assurance by the DOE that, during a specified time period, a project achieved the reductions in emissions as verified and includes a request for issuing of the CDM credits.

For each of the above cost components a cost estimate has been made based on the number of days needed to carry out the activities, the tariff per day and the registration fee charged by the UNFCCC. The estimated total transaction costs for the various categories of technologies are presented in Table 2.6.

For CDM forestry projects (category VI), no information is available on the various cost components of the transaction costs (identification, feasibility, insurance, negotiation, regulatory, monitoring & verification). More general transaction cost information (Sathaye and Antinori, 2004) is therefore used for the present study. Table 2.5 summarizes the transaction costs for forestry mitigation projects.

Table 2.5 *Transaction costs of forestry projects*

Amount of CO_2 eq reduced annually [tCO_2 eq]	Transaction costs per tCO_2 eq reduced [$]
less than 370,000	1.4
370,000 - 3,400,000	0.7
more than 3,400,000	0.1

Source: Cost figures based on data gathered from 11 forestry projects in India, Bolivia, Brazil, US and Chile and presented by Jayant A. Sathaye, Camille Antinoiri (LBNL, Berkeley and Ken Andrasko (US Environmental protection) at workshop on Modeling to Support Policy, Shepherdstown 2004.

Table 2.6 *Transaction costs related to bringing the project under the CDM*

		Category I	Category II	Category III	Category IV	Category V
Upfront	[$]	*387,800*	*73,300*	*55,900*	*21,500*	*27,600*
1. Project preparation and review		9,000	9,000	9,000	4,800	4,800
2. Project Design Document		4,800	4,800	5,400	3,600	10,800
3. Validation		6,000	6,000	6,000	3,000	6,000
4. Appraisal phase		362,000	47,500	30,500	7,100	3,000
5. Initial verification (start-up)		6,000	6,000	6,000	3,000	3,000
Operation	[$]	*90,000*	*132,000*	*132,000*	*21,000*	*405,000*
6. Periodic verification		30,000	72,000	72,000	6,000	30,000
7. Certification (yearly)		60,000	60,000	60,000	15,000	15,000
Total transaction costs	[$]	*477,800*	*205,300*	*188,900*	*42,500*	*72,600*
GHG reductions per year	[tCO_2 eq/yr]	4,700,000	200,000	100,000	28,000	10,000
Transaction costs	[$/$tCO_2$ eq reduced]	0.01	0.1	0.2	0.2	0.7

Notes:
- cost estimates partly based on previous research
- Assuming a ten year crediting period
- cost figures are not discounted
- assuming approved methodologies are used

Table 2.6 reveals that the CDM transaction costs per tCO_2–eq reduction are small compared to the credit price. For example, assuming a credit price of 20 $/$tCO_2$ eq, the transaction costs are in the range of .05-3.5% of the credit price.

2.3 Limitations to the analysis

It is important to note some limitations of the analysis presented in the previous sections. To some extent, the abatement costing studies on which the analysis is based have been carried out as capacity building exercises without peer review - they should not be viewed as definitive, technically rigorous, exhaustive, analyses of national GHG abatement potential. Therefore, the inventory of options and the marginal cost curves presented in the next chapter are subject to the same shortcomings, and should be interpreted cautiously.

Specifically, the following limitations should be noted:

1. *The abatement costing studies are far from comprehensive.* The studies do not always exhaustively consider all options, or even most options in some cases.
2. *Different assumptions and approaches across abatement costing studies make it difficult to reconcile and combine results.* In calculating GHG reduction potential and cots, studies make different assumptions about important parameters such as base year for abatement costs, discount rates, fuel prices, global warming potentials, technology characteristics, etc. These assumptions strongly affect the calculated GHG savings potential and cost. Moreover, in many country studies it remains unclear which assumptions have been used.
3. *Estimates of abatement potential and net incremental costs are very sensitive to assumptions about the baseline scenarios.* Baseline scenarios are supposed to reflect what would have occurred if the CDM project hadn't been implemented, but no definitive methodology has been, nor can be, designed to unambiguously predict what would have happened. The selection of baseline scenarios in the abatement costing studies therefore depends on the subjective judgement of the analysts. This subjectivity influences many critical assumptions – growth rates of populations and economies, rates of autonomous efficiency improvement, presumed future fuel choices, infrastructural changes, etc.
4. *Definition of costs was not consistent across studies.* In general the abatement costing studies attempted to calculate the net incremental costs of abatement options from the perspective of the national economy. However, different definitions of what is incremental (for instance barrier removal) were used by different country abatement studies. Economic benefits were excluded in some instances, apparently double-counted in others. Besides, the private investor costs are not properly reflected in the net incremental costs. The investor may not recoup many of the incremental benefits on national level that accrue to other stakeholders as the result of a CDM project. Next to these inconsistencies, it appears that several country abatement studies presented cost calculations which were preliminary, uncertain or qualitative.
5. CDM transaction costs were assumed to be similar across world regions (see Section 2.2).

3. Results

3.1 Non-Annex I region

3.1.1 Marginal Abatement Cost curve for the whole non-Annex I region

The MAC curve pertaining to all non-Annex I countries together has been derived from the identified abatement potential of 30 non-Annex I countries. As no comprehensive studies about abatement technologies for the other non-Annex I countries have been found, a simple extrapolation method has been applied to extend the projected GHG emissions reduction potential of the 30 countries to the remaining non-Annex I countries. This extrapolation can only be done in an admittedly rough manner and it is based on the premise that the remaining non-Annex I countries have an abatement potential that is similar to the abatement potential of the 30 investigated countries, as a fraction of total emissions. The following simple extrapolation method has been applied: the 30 countries for which potential and cost information have been gathered cover approximately 80% of the GHG emissions of all non-Annex I countries. Based on this observation, the MAC curve for the whole non-Annex I region is derived from the MAC curve for the 30 non-Annex I countries by scaling up the abatement potential by a factor of 1.25.

Figure 3.1 depicts the projected MAC curve in year 2010 for the whole non-Annex I region for technology options in the unit cost range of -50 to +50 $/tCO_2$ eq that reduce CO_2 and CH_4 emissions.

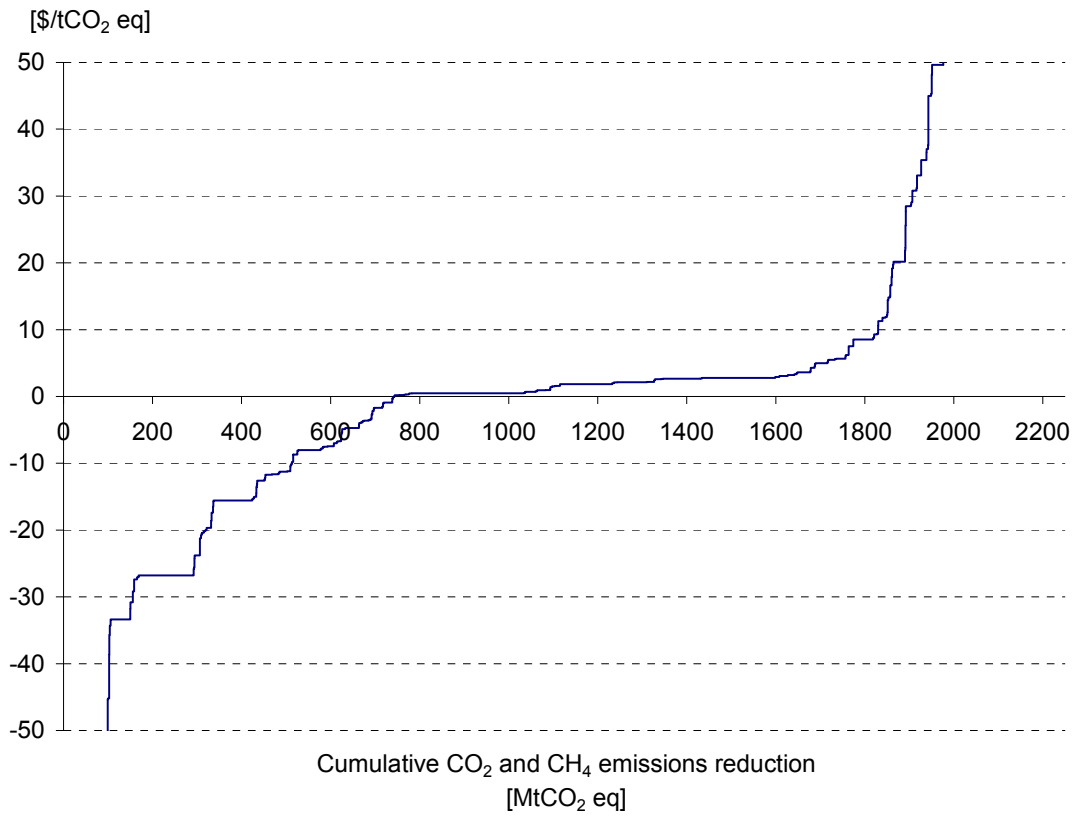

Figure 3.1 *Extrapolated MAC curve for the whole non-Annex I region*

Out of the total 372 eligible reduction options included in the database, the unit costs of 15 options are below $ -50 and for 33 options the unit costs exceed $ 50. Consequently, the MAC-curve in Figure 3.1 includes 324 technology options.

The total abatement potential in the year 2010 for the whole non-Annex I region at a price of 50 $/tCO_2$ eq or lower is estimated at about 2 $GtCO_2$ eq. Of this potential, 66% arises from reduction options in only four countries, namely China (37%), India (23%), Brazil (4%) and South Africa (2%). Roughly 37% of this potential is projected to be achievable at negative or zero net incremental costs. Approximately 1.7 $GtCO_2$ eq appears feasible at costs of up to 4 $/tCO_2$ eq. It should be noted that these costs include abatement costs as well as CDM transaction costs.

The estimated potential of GHG reduction options with net negative costs (no-regret options) is significant. No-regret reduction options are identified in most of the country costing studies reviewed, but seem to conflict with rational behaviour. The reasons often mentioned in the literature for the existence of no-regret options include market imperfections leading to lack of knowledge about the reduction option, lack of priority, lack of investments due to limited financial markets and the definition of cost (social versus financial cost). It is often suggested that in order to remove these market barriers, additional costs are incurred that should be added to the technology costs. In the present study however we have not attempted to assess these additional costs.

In Figure 3.2 the identified CH_4 emission reduction potential is shown. Options for reducing CH_4 emissions were obtained for ten non-Annex I countries. Table 3.1 presents an overview of only 14 options, a number which prevents conducting a profound analysis. However, there is reasonable ground to belief that CH_4 reduction technologies are cheap (only three options need to be realized with abatement costs above 10 $/tCO_2$ eq). The abatement costs of gas flare reduction in Nigeria can be characterised as extraordinarily high in comparison to the abatement costs of the other 13 options.

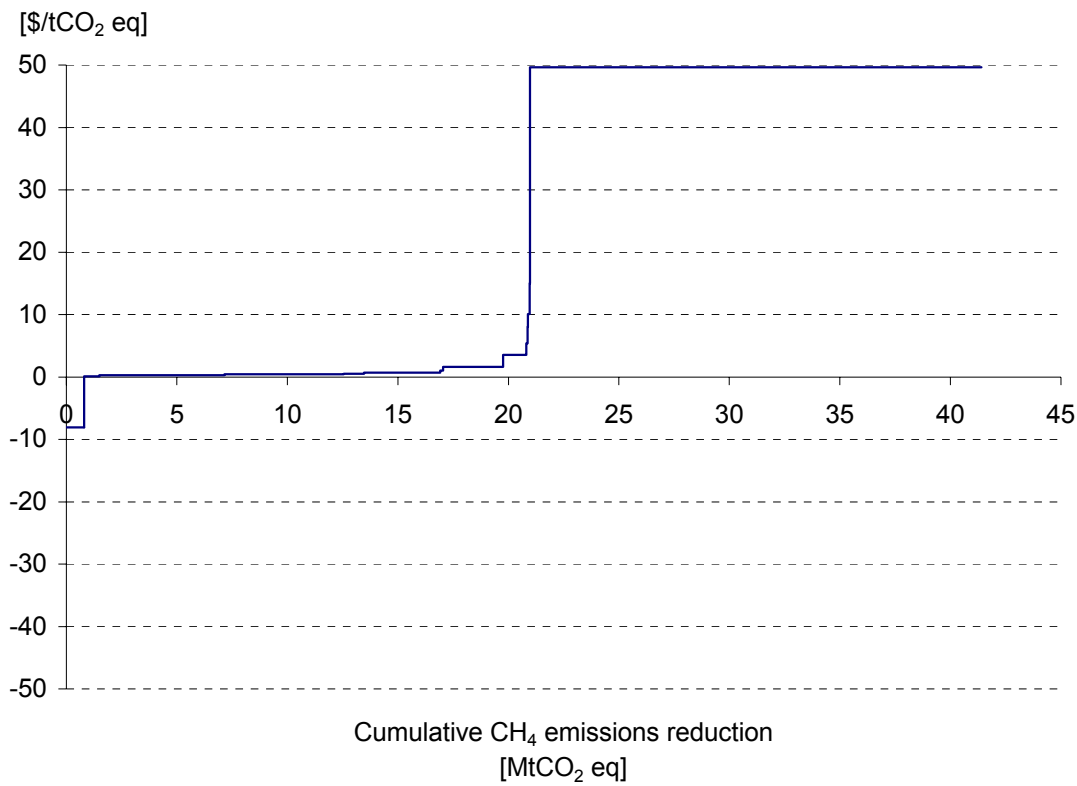

Figure 3.2 *CH_4 MAC curve for ten non-Annex I countries*

Table 3.1 *Overview of identified CH_4 emission reduction options in ten non-Annex I countries*

Mitigation option	Potential [Mt CO_2 eq/yr]	Costs [\$/t CO_2 eq]
Agricultural products and forestry		
- Methane from landfills (Colombia)	3.50	0.7
- Utilization of biogas (Vietnam)	1.10	3.5
Electricity		
- Sanitary landfill gas (Argentina)	5.40	0.5
- Biogas from landfills (Botswana)	0.10	1.0
- Power production from sewage plant methane (Zimbabwe)	0.02	8.0
- Development of biogas energy (capture and use of methane in Tunisia)	0.02	15.0
Oil		
- Utilization of flared gas (Indonesia)	2.70	1.6
- Gas flare reduction (Nigeria)	20.40	49.6
Gas		
- Reduction in natural gas flaring at gas fields (Bolivia)	0.70	0.1
Rest of Industry		
- Coal bed methane (Zimbabwe)	0.80	-8.1
- Catalytic combustion of methane (South Africa)	5.70	0.3
- Biogas digester (Zimbabwe)	0.90	0.5
Households		
- Biogas for domestic use (Zimbabwe)	0.10	5.4
- Biogas for rural households (Botswana)	0.10	10.1
Total identified potential	*41.50*	

3.1.2 Sectoral MAC curves for the whole non-Annex I region

The general equilibrium model used in the TETRIS project to determine the global equilibrium price of tradable CO_2 allowances is based on a sector classification comprising energy intensive and energy extensive sectors (see Figure 2.1). Therefore, sectoral MAC curves for the whole non-Annex I region have been constructed for the following sectors: electricity sector (energy intensive), rest of industry (energy extensive), household sector, agricultural products and forestry and transport sector. Figure 3.3 presents the extrapolated MAC curve for the electricity sector for the whole of the non-Annex I region.

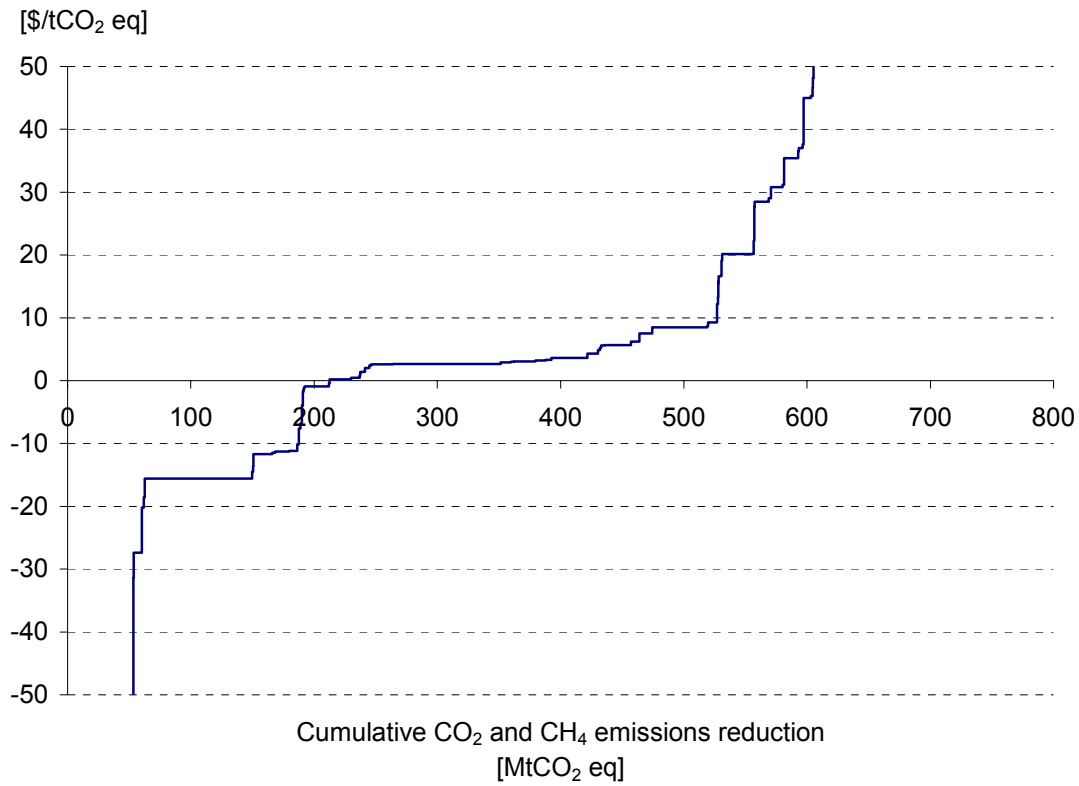

Figure 3.3 *Extrapolated MAC curve for the electricity sector in the whole non-Annex I region*

Total identified GHG emissions reduction potential at cost up to $ 50 per tCO_2 eq in the electricity sector amounts to more than 0.6 $GtCO_2$ eq in 2010. Approximately 35% of this potential can be realized at net negative cost. In total, 116 GHG emissions reduction options have been identified in the electricity sector in the 30 non-Annex I countries. For two options the costs are below $ 50 per tCO_2 eq (electricity conservation in Brazil and Indonesia) and for 16 options the unit costs exceed $ 50 per tCO_2 eq. Consequently, the MAC-curve in Figure 3.3 includes 98 GHG emissions reduction technology options.

Figure 3.4 shows the estimated potential in 2010 in the non-Annex I region for the sector 'rest of industry'. Most options are in the sub-sectors machinery and equipment, motor vehicles and metal products.

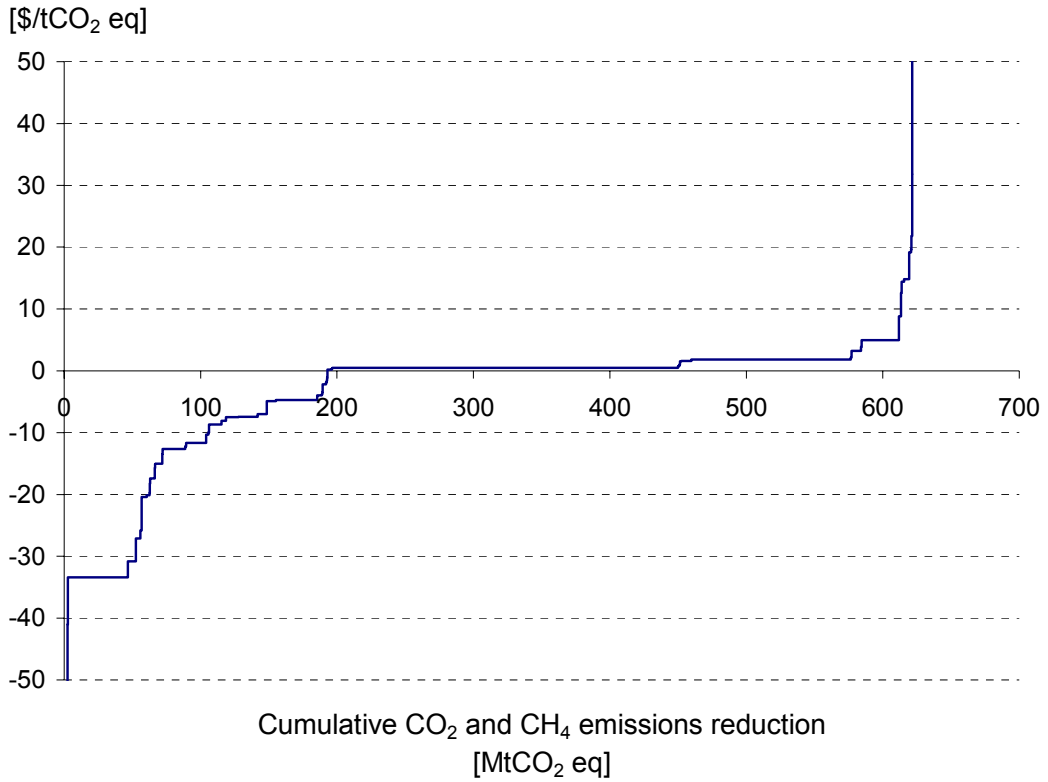

Figure 3.4 *Extrapolated MAC curve for the rest of industry sector in the whole non-Annex I region*

The identified GHG emissions reduction potential in the sector 'rest of industry' is about 0.62 $GtCO_2$ eq in 2010. This is the aggregated potential of 84 GHG emissions reduction technologies. The costs of only two technology options are above $ 50 per tCO_2 eq. The unit costs of 3 technologies, all in Thailand, are below $ -50 per tCO_2 eq. This last observation does not necessarily imply that very low no-regret costs for GHG emissions technologies can only be found in Thailand. It could also be caused by different approaches of country study teams or by other limitations in the analysis (see Section 2.3).

Figure 3.5 shows the estimated reduction potential in the household sector. Options to reduce the demand for energy in households (demand side management options) are put under the household sector. These options include more efficient appliances and energy conservation programmes.

The estimated potential in 2010 in this sector is around 0.45 $GtCO_2$ eq, of which energy efficiency programs in India have the biggest share. In total, the potential and costs of 105 reduction options in different countries have been identified.

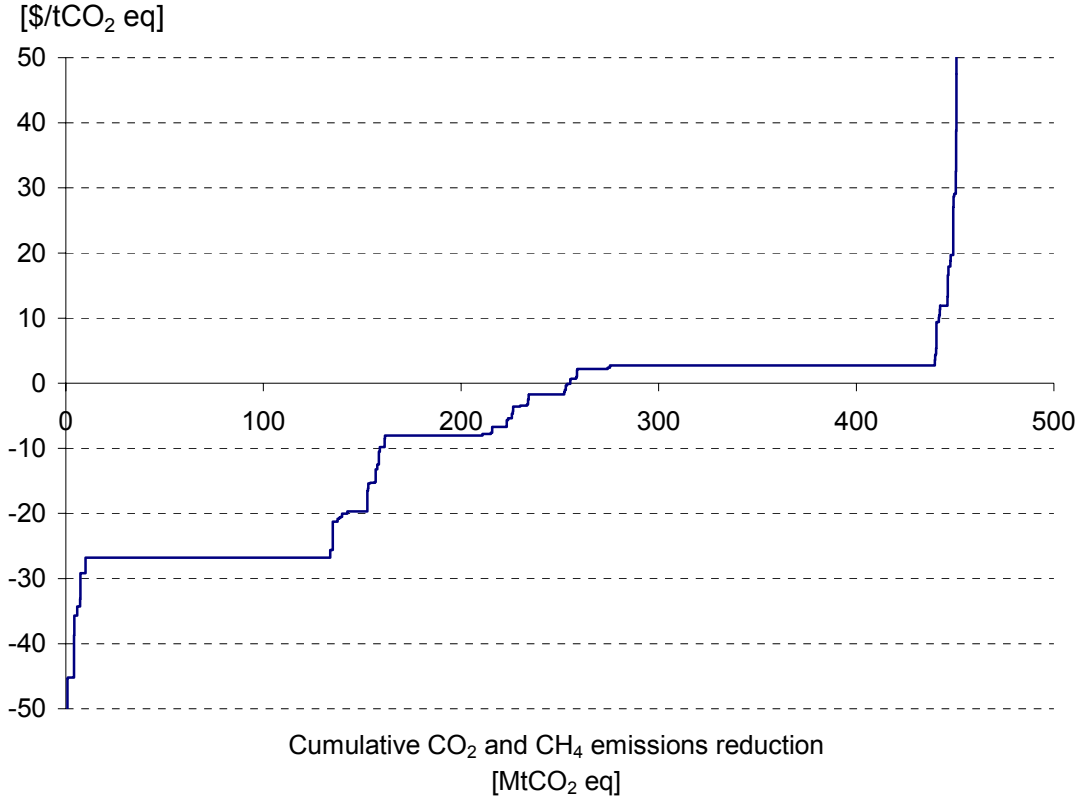

Figure 3.5 *Extrapolated MAC curve for the household sector in the whole non-Annex I region*

In Figure 3.6, the MAC curve for the agricultural & forestry sector is depicted. The figure is derived from eight reduction options in agriculture and 23 forestry reduction options. The identified total abatement potential in this sector is limited compared to the other sectors. The estimated potential in 2010 amounts to about 220 $MtCO_2$ eq. Some 20% of this potential can be achieved at negative net costs. In the case of the forestry options, abatement costs are extremely site dependent, thus the average cost figures for the identified 23 options in Figure 3.6 might be much higher or lower for concrete CDM projects.

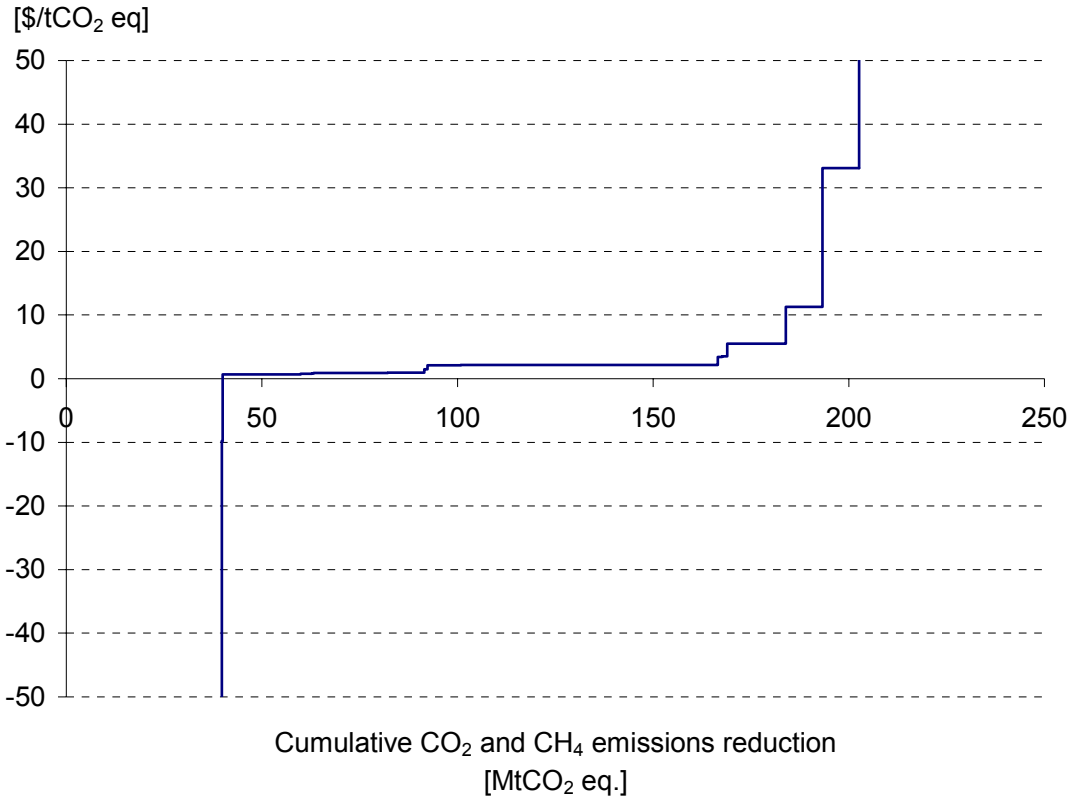

Figure 3.6 *Extrapolated MAC curve for the agricultural & forestry sector in the whole non-Annex I region*

Finally, in Figure 3.7 the MAC curve for the transport sector, derived from 19 reduction options, is presented. The options include energy-efficient engine designs and equipping of the existing cars with gas fuelled engines. Biofuels were not taken into account by country abatement costing studies. The total estimated potential in 2010 amounts to about 35 $MtCO_2$ eq. Some 35% of this potential can be achieved at negative net costs. Total identified GHG emissions reduction potential at cost between -$ 50 per tCO_2 eq and $ 50 per tCO_2 eq in the transport sector amounts to about 24 $MtCO_2$ eq.

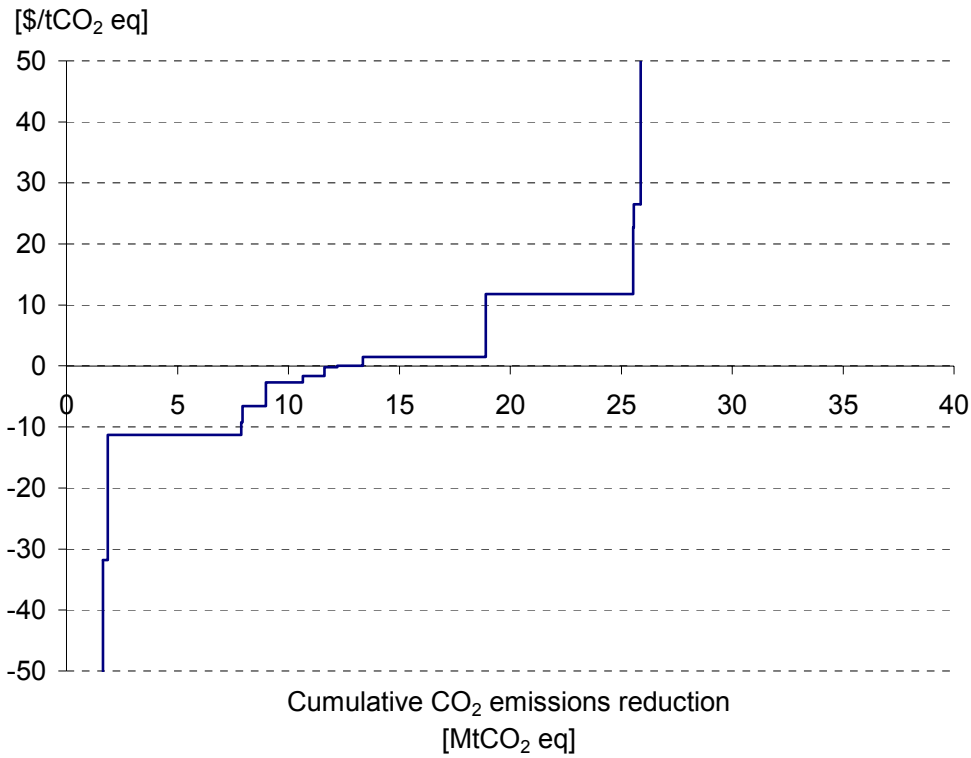

Figure 3.7 *Extrapolated MAC curve for the transport sector in the whole non-Annex I region*

3.2 China

China is the second largest emitter of greenhouse gases emissions worldwide, only exceeded by the US[6]. Initially, China's position towards the Clean Development Mechanism was very sceptical but this attitude has changed over the years and now the CDM is seen as an opportunity for China to acquire modern efficient technology that can also contribute to reducing local pollution.

In China, as in all emerging countries, widespread adoption of advanced technologies or environmental friendly technologies is seen as the key solution for future GHG mitigation. Compared with technologies already used and produced in China, several advanced technologies presently used in the industrialised world could be much more effective in meeting the objectives of CDM (The World Bank, 2004). In this chapter, potential and cost of technology options to reduce GHG emission in China are presented and the marginal abatement cost curve constructed from this information is explained.

3.2.1 Greenhouse gas emissions

The National Greenhouse Gas Inventory for China for the year 2004 includes estimated net anthropogenic GHG emissions from the energy sector, industrial processes, agriculture, land-use change and forestry as well as wastes (UNFCCC, 2004a). As can be seen from Table 3.2, CO_2 emissions in China accounted for around 15% of the global CO_2 emissions in 2000. Consumption of fossil fuels in the energy sector is the main CO_2 emission source. Other important energy activities cover emissions of CH_4 from coal mining and post-mining activities, fugitive emissions of CH_4 from oil and natural gas installations and emissions of CH_4 from the combustion of biomass fuels (UNFCCC, 2004a).

[6] On a per capita basis China's emissions are still relatively low.

Table 3.2 *Greenhouse gas emissions in China in 2000*

Gas	MtC	Percent of World Total	World ranking
CO_2	948	15	3
CH_4	212	13	1
N_2O	176	19	1
PFC	1	5	7
HFC	10	16	2
SF_6	0.9	8	4
Total	1349	15	2

Source: WRI (2005)

According to the results of the inventory, agricultural activities like large-scale growth of croplands and animal waste management are largely responsible for a N_2O emission figure of 176 MtC. Presently, little information is available for emissions of PFC, HFC and SF6 in China. The emissions in Table 3.2 for these three high-Global Warming Potential gases are based on expert opinions and production surveys.

3.2.2 Identified GHG emissions reduction options

In total 32 reduction options have been identified from different sources. The potential and costs of these options are presented in Table 3.3 for the sectors agricultural products & forestry, electricity, households, iron & steel and rest of industry.

Table 3.3 *Identified GHG emissions reduction options for China, 2010*

Mitigation option	National potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
Agricultural products and forestry		
- Forestry rotation and regeneration options [a]	31.9	-143.6
- Seeding or dry nursery and thinning planting [b]	6.8	1.9
- Multinutrient block [b]	7.5	32.9
- Ammonia treatment straw [b]	12.6	60.5
Electricity		
- CFBC (Circulating Fluidized bed combustion) [c]	0.5	-2.0
- Renovation and reconstruction of conventional thermal power plant [c]	13.9	2.9
- Supercritical coal [c]	2.5	5.4
- Hydro power [c]	20.7	20.0
- Natural gas [c]	0.4	22.1
- Scrap & Build (modify smaller coal power plants) [e]	35.6	8.3
- Modification option (modify larger coal power plants) [e]	9.2	28.3
- IGCC and other advanced conventional thermal power technologies [c]	1.3	28.8
- Biogas and other biomass energy [b]	9.2	35.2
- Wind energy (Grid In) [d]	2.6	36.8
- Wind Power [c]	0.5	57.4
- Fuel-switching (Coal to Natural gas) [e]	45.6	61.5
- Solar thermal [c]	0.6	99.6
Households		
- Technical renovation of electric motor for general use [b]	99.4	-27.0
- Energy-saving lighting [b]	39.6	-8.7
- Demand side management [c]	2.9	-4.3
Iron and Steel		
- Cutting ratio of iron/steel in steel & iron industry [d]	9.5	-24.0
- Pulverized coal injection into blast furnace [b]	0.3	-4.9
- Continuous casting of steel making [b]	7.7	-3.8
Rest of Industry		
- Renovation of kilns for wet cement production [b]	13.2	-12.8
- Cement (innovation of wet process kilns) [d]	0.3	-12.4
- Cement (dry kilns replacing wet kilns) [d]	0.3	-10.2
- Comprehensive process renovation of synthetic ammonia [b]	11.4	-7.6
- Industrial boilers (optimizing combustion) [f]	84.3	0.3
- Industrial boilers (operational improvement) [f]	77.0	0.3
- Industrial boilers (prefuel process) [f]	40.3	0.3
- Anaerobic technology for wastewater treatment and energy recovery in alcohol plants [f]	5.5	3.0
- Industrial boilers (high-efficiency boilers) [f]	22.0	4.8
Total identified potential	*615.0*	

Source: [a] Sathaye et al. (2001)
[b] ADB/GEF/UNDP (1998)
[c] Wang et al. (2005)
[d] Zongxin and Zhihong (1998)
[e] Yamaguchi (2005)
[f] Zou and Junfeng (2000)

Agricultural products and forestry
Various GHG emission reduction options have been identified in the 'agricultural products and forestry' sector. For example, the use of the multinutrient block that provides micro-organisms for animals rich in sources of fermentable nitrogen, minerals, vitamins, amino-acids and peptides. Besides raising the livestock production and reducing the animal production costs, it also reduces CH_4 emissions.

Although China has a relatively low proportion of 11% of the land area covered by forests, major afforestation development schemes have been undertaken already since 1978. Especially, the tropical and sub-tropical regions profit from these afforestation policies and a large afforestation potential still exists and could be brought under the CDM.

Electricity
An important priority area of mitigation options in the electricity sector is to improve thermal power generation efficiency by adopting several effective options:
- Modification of low and medium pressure generators.
- Construction of large-capacity coal-based power generating units with coal washing and combined-cycle units.
- Development of cogeneration plants.
- Expanding the construction of the electric power grid.

Zhihong (2002) indicates that the energy intensity of China's GDP could fall greatly from 1.92 kgce/$ (1990 price) in 1995 to 0.72 kgce/$ in 2020, making efficiency technology the probably most important strategy for reducing GHG emissions.

In addition to energy efficiency options, fuel switch options from natural gas to coal represent another priority area. Coal ranks first among the primary energy sources in China. In the future the installed capacity of coal-based generators will still dominate the national power supply. This will present a long-term major challenge for the country in dealing with its coal reserves. For that reason, Chinese authorities have increased exploration and development of natural gas fields and have made economically viable discoveries in central and western China (Pew Centre, 2002).

Renewable energy technologies should also be considered for potential CDM projects. The selection of these technologies is based on mitigation potential and local availability. Landfill projects are renewable energy options that explore the potential of landfill gas recovery for power generation. It captures CH_4 produced in a landfill. Such a project is of particular importance of China, where cheap to run and large quantities of CH_4 are discharged from urban landfills. Although landfill gas-based power generation is a new concept in China, the technology is quite attractive.

It should be stressed at this point that environmental institutions and governance structure need to be restructured, because economic decision-making nowadays does not integrate sufficiently environmental considerations. When this condition is met, market mechanisms can be used to protect the environment and the above mitigation options can help reduce GHG emissions effectively.

Households
The most important mitigation option is the technical renovation of electric motors, which are main electricity consumed devices for providing mechanical power. Table 3.3 shows a huge potential of almost 100 Mt CO_2 eq in 2010. Low-efficiency motors are still widely used, for example about half of fans and pumps need to be replaced in order to improve their efficiency (Zongxin and Zhihong, 1998).

IGES (2005) indicates that by 2020 it is expected that China will double the amount of floor space it had in 2000. With increased standards of living, more energy is used for heating, air-conditioning, lighting and electrical appliances. Demand side management programs can be launched to promote widespread use of energy efficient devices. IGES (2005) has also claimed energy-saving lighting, as one of the identified technologies, can save from 70 to 90 percent compared to standard lighting.

Iron and Steel
In its aim to implement energy-saving targets, the iron and steel industry has various mitigation options at its disposal. As shown in Table 3.3, three reduction options have been identified for which potential and cost information could be found.

Rest of Industry
Mitigation options in 'the rest of industry' sector entail a substantial amount of abatement potential. This especially applies to efficiency improvement of industrial boilers. Table 3.3 shows a total abatement potential for industrial boilers of 224 $MtCO_2$ eq in 2010. Except for high-efficiency boilers, the abatement costs for efficiency improvements of industrial boilers are modest.

3.2.3 National and sectoral MAC curves for China

The forecasted GHG marginal abatement cost curve for China is presented in Figure 3.8. The total abatement potential in China in the year 2010 is estimated at roughly 615 $MtCO_2$ eq approximately 38% of this potential can be achieved at net negative costs.

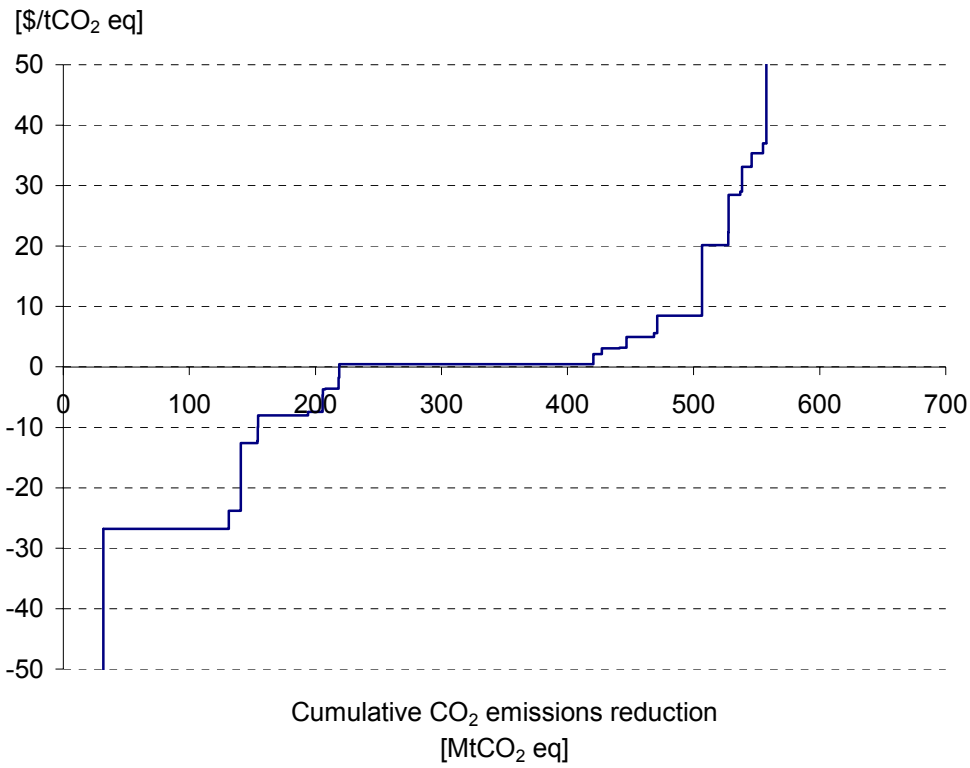

Figure 3.8 *MAC curve for China*

Total identified GHG emissions reduction potential at cost between -$ 50 per tCO_2 eq and $ 50 per tCO_2 eq in China amounts to about 560 $MtCO_2$ eq.

Realistic sectoral MAC curves could only be constructed for the sectors electricity and rest of industry. In Figure 3.9 the MAC curve for electricity sector is presented.

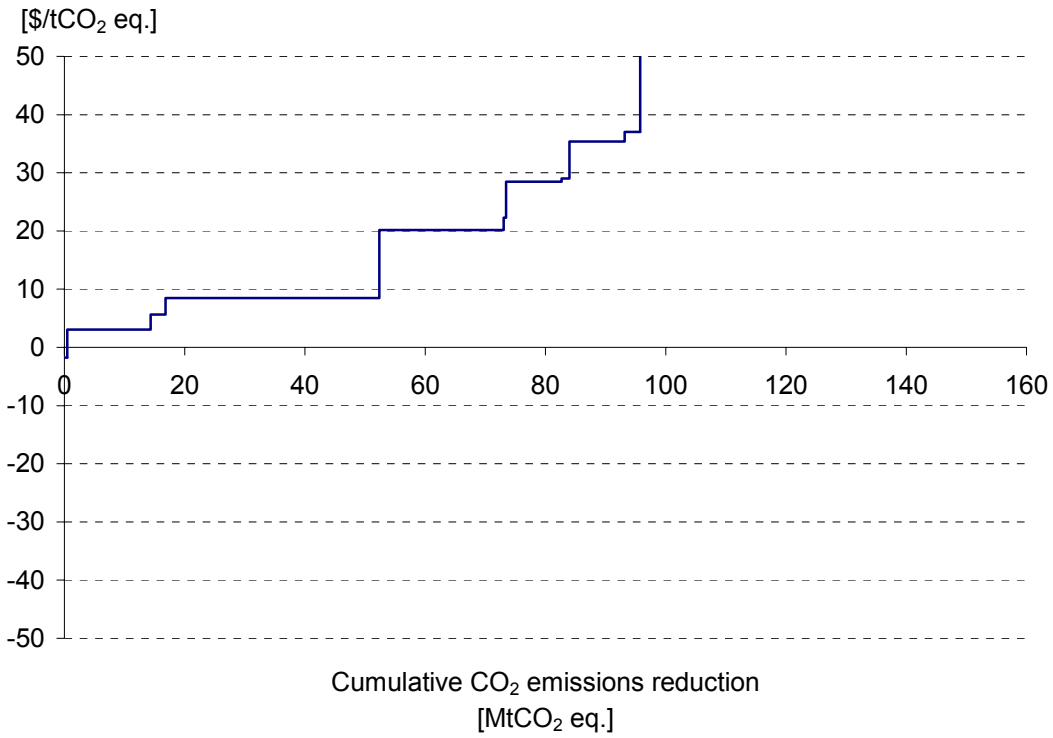

Figure 3.9 *MAC curve for the electricity sector in China*

Total potential identified in the electricity sector amounts to about 142 $MtCO_2$ eq. Some 32% of this potential concerns a switch from coal to gas as fuel for electricity production. Only one no-regret option has been identified (efficiency technology Circulating Fluidized bed coal combustion). There is also significant potential for renewable energy projects, especially biogas and mini hydro, but the higher abatement costs form a barrier. Total identified reduction potential at cost between -$ 50 per tCO_2 eq and $ 50 per tCO_2 eq in the Chinese electricity sector amounts to about 100 $MtCO_2$ eq in 2010.

Figure 3.10 shows the projected marginal abatement cost curve for the sector 'rest of industry' in 2010. This curve is based on 9 identified reduction options with aggregated reduction potential of 255 $MtCO_2$ eq. Having mentioned this, it is a striking result that none of these reduction options entail abatement costs out of the range -$ 50 per tCO_2 eq and $ 50 per tCO_2 eq.

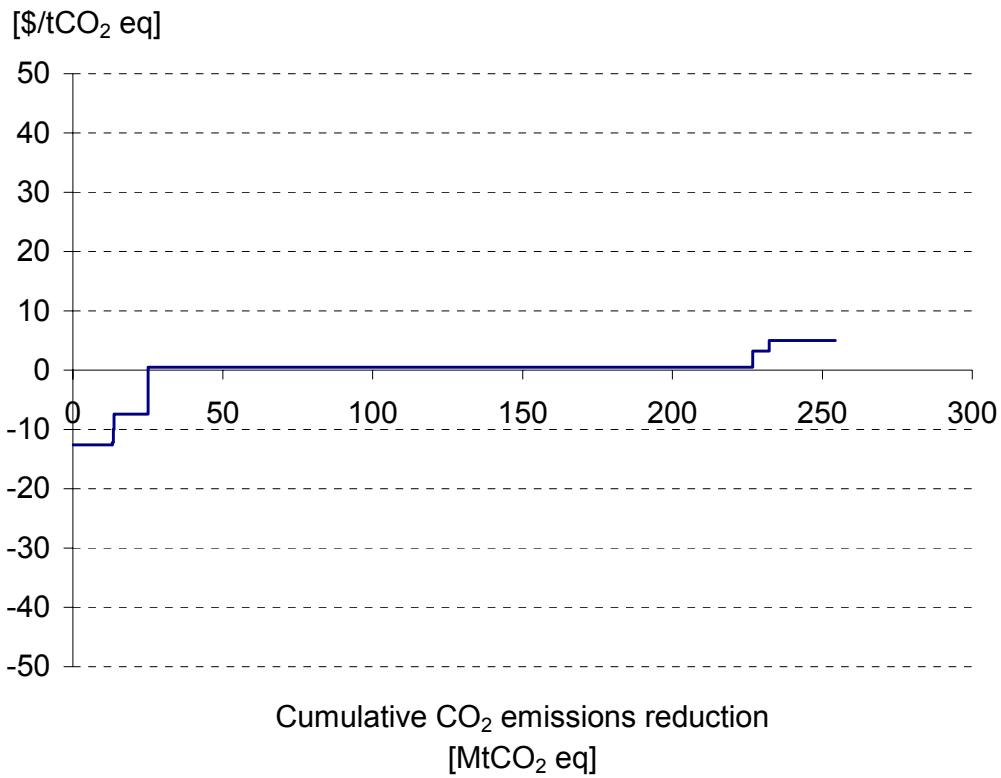

Figure 3.10 *MAC curve for the rest of industry sector in China*

3.3 India

3.3.1 Greenhouse gas emissions

India is a major emitter of greenhouse gases. Aggregated emissions in 1994 amounted to 1229 $MtCO_2$ eq (excluding fluorinated gases; see Table 3.4), of which 60% from energy combustion and conversion. Major sources are the energy and transformation industries (29%), fuel combustion in industry (12%) and industrial processes (8%), and enteric fermentation in livestock (15%). In particular sectors with a large number of stationary sources are likely to offer large and relatively cost-effective mitigation options. In 1995, 57% of national CO_2 emissions were emitted by 100 largest stationary sources. These included 73 power plants, 7 steel plants, 16 cement plants, 3 fertilizer plants and a petrochemical plant (TERI, 2004).

Table 3.4 *Greenhouse gas emissions in India, 1994*

	CO_2 [Mt CO_2 eq]	CH_4 [Mt CO_2 eq]	N_2O [Mt CO_2 eq]	Aggregated [Mt CO_2 eq]
Energy	**679**	**2.9**	**0.011**	**744**
Fuel combustion				
Energy and transformation industries	354		0.0049	355
Industry	150		0.0028	151
Transport	80	0.009	0	80
Commercial	21		0	21
Residential	44		0	44
Other	32		0	32
Biomass		1.6	0.002	35
Fugitive emissions				
Oil and gas		0.6		13
Coal mining		0.7		14
Industrial processes	**100**	**0.002**	**0.009**	**103**
Agriculture		**14**	**0.151**	**344**
Enteric fermentation		9.0		188
Manure management		0.95	0.001	20
Rice cultivation		4.1		86
Agricultural crop residue		0.17	0.004	4.7
Emissions from soils			0.15	45
Land use and forestry	**14**	**0.0065**	**0**	**14**
Changes in biomass stock	-14			-14
Forest and grassland conversion	18			18
Trace gases from biomass burning		0.0065	0	0.2
Uptake from abandonment of managed lands	-9			-9
Emissions from soils	20			20
Waste		**1.0**	**0.007**	**23**
Municipal solid waste		0.58		12
Domestic		0.36		7.6
Industrial		0.062		1.3
Human sewage			0.007	2.2
International bunkers	**3.4**			**3.4**
Aviation	2.9			2.9
Navigation	0.5			0.5
TOTAL	**817**	**18**	**178**	**1229**

Source: UNFCCC (2004b).

3.3.2 Identified GHG emissions reduction options

Seven major options to mitigate climate change under the CDM in India are summarized in Table 3.5. Only demand-side energy efficiency, supply-side energy efficiency and renewable electricity technologies are briefly described below. The list of options within each group is not exhaustive.

Table 3.5 *Identified GHG emissions reduction options in India, 2010*

	National potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
Demand-side energy efficiency	132	2.7
Supply-side energy efficiency	94	1.8
Renewable electricity technologies	68	2.7
Fuel switching (gas for coal)	24	3.6
Forestry	53	2.1
Enhanced cattle feed	13	0.9
Anaerobic manure digesters	7	1.0

Source: Pew Centre (2002).

Demand-side energy efficiency

Direct reduction process in the iron and steel industry. Many plant owners in this sector are currently modernizing and expanding their facilities. Major changes include: switching from open hearth furnaces (OHFs) to basic oxygen furnaces (BOFs); greater use of LD (Linz-Donowitz) converters; installation of continuous casting lines to maximize yields; reducing energy consumption and using computers.

Supply-side energy efficiency

Coal power plants using IGCC (integrated gasification combined cycle) is one of the technologies being explored to improve the efficiency of coal-based power generation. Two technologies are involved: (1) a gasification plant that converts the fuel into a combustible gas and purifies the gas, and (2) a combined cycle power plant which produces synthetic gas that fuels a gas turbine whose hot exhaust gases are used to generate steam to drive a steam turbine. While the present stock of thermal power plants (existing and sanctioned) have net efficiencies in the order of 36%, state-of-the-art IGCC plants have net efficiencies of 46% (TERI, 2002). Additional benefits of IGCC generated power are reduce emissions of SO_2, NO_x and Small Particulate Matter (SPM), as well as a solid waste disposal

Coal power plant using PFBC (pulverized fluidised bed combustion) is a clean and efficient technology for coal-based power generation. In this technology, the conventional combustion chamber of the gas turbine is replaced by a repressurized fluidised bed combustor. The products of combustion pass through a hot gas clean-up system before entering the turbine, thereby reducing the amount of CO_2 emitted. The option will result in lower SO_2 and NO_x emissions as well.

Renovation and modernization of power plants. Most of the small plants running on coal in India operate below 30% efficiency. Many old and inefficient power plants that feed into the grid could be upgraded to work efficiently. So far however renovation and modernization has been very slow though due to paucity of funds. Renovation would also result in lower emissions of SO_2, NO_x and SPM.

Renewable energy

Wind-based power generation (grid-connected). India is a leading nation in wind power production with an installed capacity of 1,700MW and a gross wind power potential of 45,000MW (at 50-m hub height). The Ministry of Non-conventional Energy Sources aims to raise the share of renewable energy in total installed grid capacity to 10% in 2012 (TERI, 2002).

*Solar thermal energy for power generation (grid-connected).*The utilization of solar thermal energy for power generation is high on the list of priorities of the Ministry of Power and the MNES (TERI, 2002).

Wind pumps for agriculture. Apart from an estimated potential of 45000 MW of wind-based power, the country can use wind energy directly to pump out water for irrigation and drinking purposes. If harnessed effectively, this option would reduce considerably the use of diesel and grid electricity in conventional pumps. There are about 5 million diesel and 4 million electric pumps operating in this sector (TERI, 2002).

3.3.3 National MAC Curve for India

Figure 3.11 shows the marginal costs of abatement versus the reduction potential achievable across all economic sectors. Negative costs are not visible in the MAC curve, because no-regret options are not identified (see Table 3.5). Such options may be found in the residential sector, where more efficient cooking and lighting systems may contribute to limiting greenhouse gas emissions. However, no cost estimates for these options were found in the literature. A large potential at relatively low abatement cost exists however. 114 $MtCO_2$ eq may be reduced at a cost under 2 $\$/tCO_2$ eq.

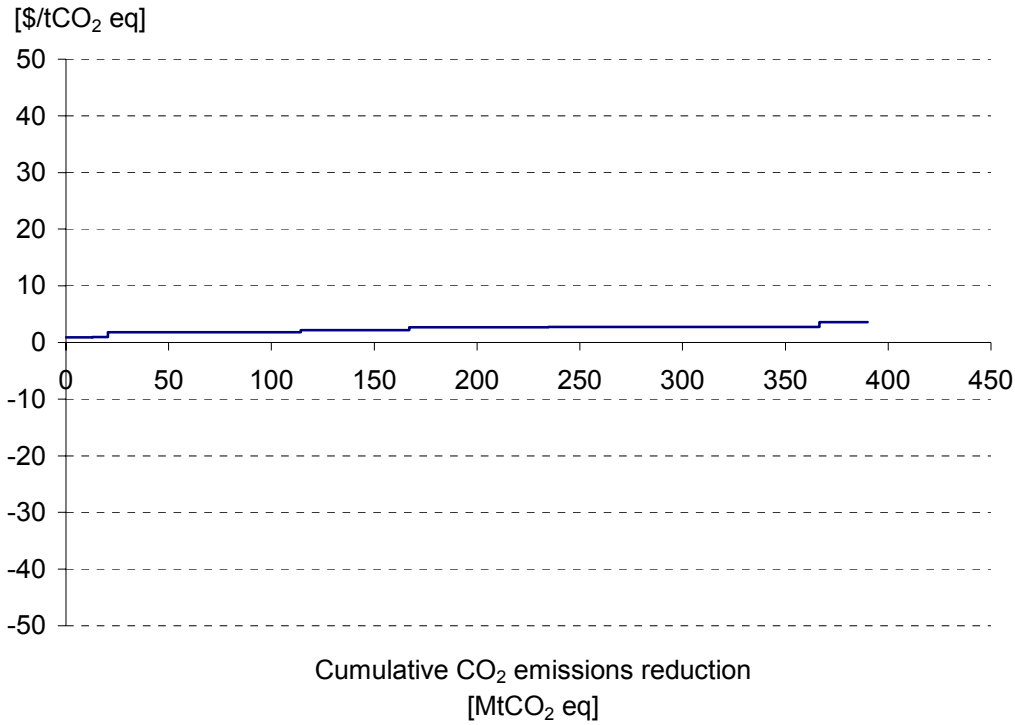

Figure 3.11 *MAC curve for India*

3.4 South Africa

3.4.1 Greenhouse gas emissions

As can be seen from Table 3.6, aggregated emissions in South Africa amounted to 380 $MtCO_2$ eq in 1994. 78% of these were from energy combustion, 9% from agriculture and land use, 8% from industrial processes and 4% from waste handling.

Table 3.6 *Greenhouse gas emissions in South Africa, 1994*

	CO_2 [$MtCO_2$ eq]	CH_4 [$MtCO_2$ eq]	N_2O [$MtCO_2$ eq]	Aggregated [$MtCO_2$ eq]
Energy	288.00	376.00	5.90	298
Energy industries	168.00	0.47	2.60	
Industry	53.00	6.20	0.78	
Transport	43.00	11.00	1.90	
Commercial	0.78	0.07	0.01	
Residential	7.40	0.60	0.08	
Agricultural/Forestry/Fishing	0.48	31.00	0.53	
Fugitive emissions		327.00		
Industrial processes	28.00	1.30	7.30	30
Mineral products	5.30			
Chemical industry	2.00	1.30	7.30	
Metal production	21.00			
Agriculture		937.00	51.00	35
Enteric fermentation		844.00		
Manure management		78.00	0.07	
Agricultural soils			50.00	
Savanna burning		0.61	0.61	
Agricultural residues		0.12	0.14	
Burning				
Land use change and forestry	-19.00			
Changes in biomass stocks	-11.00			
Soil removals	-7.70			
Waste		743.00	2.70	16
Solid waste on land		722.00		
Wastewater handling		21.00	2.70	
International bunkers	10.0			10
TOTAL (excl bunkers)				380

Source: UNFCCC (2000a).

3.4.2 Identified GHG emission reduction options

A wide range of important GHG emission reduction mitigation options to be brought into play under the Clean Development Mechanism can be identified in various economic sectors. The options for which both amounts and costs could be evaluated with some degree of certainty have been listed in (World Bank, 2002). Identified options are in coal-related sector, electricity, households and rest of industry.

Coal-related sector

Various mitigation options exist in the coal-related sector. For three of these costs and mitigation potential have been estimated. First, improved combustion technology to burn discard has been analysed by (World Bank, 2002). At present there are difficulties in burning discard coal because of the high ash content that leads to excessive erosion of boiler internals. Eskom is undertaking a pilot study of fluidised bed combustion that would allow coal discards to be used, and thus reduce the amount of coal that would need to be mined. This option has negative costs, which may put into question the eligibility of the option as a CDM project. Second, catalytic combustion of methane is also a mitigation option within the coal-related sector. An investigation is being undertaken in Canada to evaluate the catalytic flow reversal process, which catalyses the exothermic conversion of methane to carbon dioxide and water. The heat generated by the combustion can also be recovered. The third option is adopting higher extraction ratios underground. Pillar methods of mining leave considerable quantities of coal not mined in the form of support pillars from which methane diffuses into the atmosphere. However, there are signifi-

cant limitations on the widespread use of total extraction underground. The disadvantages of total extraction would be reduced if other means of roof support, such as ash filling, could be employed. The latter is extremely costly however (World Bank, 2002).

Electricity

Electricity generation is a major emitter of greenhouse gases in South Africa, and numerous mitigation options exist. Specifically, the options for improving power station efficiencies would almost certainly attract international investors, and seem to be possible at a 'competitive' price. Not all options can be considered certain to meet the anticipated eligibility criteria for CDM projects, such as the use of nuclear power. In addition, some of the opportunities and the assumed emission reductions are mutually exclusive, since the reductions for all technologies were based on a maximum penetration rate of 50%. Consequently, the abatement potential and abatement costs for only five options are given in Table 3.7. The total abatement potential in the electricity sector of South Africa in the year 2010 is estimated at roughly 10.4 $MtCO_2$ eq.

In the synthetic fuel production industry, substitution of 10% coal consumption with natural gas would result in a total reduction of 168 $MtCO_2$ eq (World Bank, 2002). There also is considerable potential to reduce CO_2 emissions from coal use by applying existing state-of-the-art technology. Currently, pulverised coal based sub-critical steam cycle technology is well established. Efficiencies up to 45% have been reached (IEA/CIAB, 2005).

IGCC systems first gasify coal or other fuel before using it in a combined cycle gas turbine, thus benefiting from a high efficiency. Finally, it has been estimated that commercially available coal- or wood-fired IGCC plants with efficiencies over 60% may be feasible by 2020 (Moomaw, 2001).

Households

As can be seen from Table 3.6, direct GHG emissions in this sector are substantially less than those from the energy sector. Furthermore, it should be mentioned that Figure 3.13 and Figure 3.14 are comparable concerning abatement potential. Therefore there seems not to be a huge potential for reducing emissions through CDM projects. However, despite not having the potential to reduce huge volumes of GHG emissions, the options relating to the household sector efficiency offer manageable and in many cases, cost effective options. Collectively they could provide significant CO_2 emission reduction opportunities. From Figure 3.13 it can be seen that the abatement potential reaches an amount of 10.6 $MtCO_2$ eq. This figure is almost the same as the figure reported the electricity sector. Note that some of the reductions reported are mutually exclusive. For example, efficient lighting practices would reduce the savings achieved by conversion to fluorescent lights.

Remaining sectors

For the industrial processes opportunities in the coming decades are limited. In the transport sector, mitigation options comprise a fuel tax, fuel switching, or energy efficiency improvements. While these options would have clear benefits in terms of reduced local air pollution, implementation as a CDM project would seem problematical, since the number of stakeholders involved is large and emissions sources are dispersed. Various mitigation options exist in the agricultural and land use sector. However, a number of these options could be non-eligible for CDM (animal management, manure management, fire frequency control, reduced tillage and burning of agricultural residues). In addition, sources are dispersed over a wide area, which creates difficulties for maintaining a consistent and acceptable level of emission verification and subsequent certification.

Table 3.7 *Identified GHG emissions reduction options in South Africa*

Mitigation option	National potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
Coal		
- Combustion of discarded coal	0.79	-117.0
- Improved mining operations - ash filling	0.02	534.0
- Catalytic combustion of methane	5.67	0.2
Electricity		
- HVAC retrofit	1.37	-20.0
- Fuel switch to natural gas	0.43	17.0
- IGCC power generation	4.37	6.2
- Super-critical coal	3.63	3.3
- Electricity to natural gas	0.60	-19.0
Households		
- Solar water heaters	0.07	31.0
- Solar water heating	0.73	33.0
- Solar home system	0.07	51.0
- Lighting retrofit	0.70	-17.0
- New lighting systems	0.53	-17.0
- Variable Speed Drive systems for fans	0.53	-17.0
- Efficient use of hot water	0.73	-12.0
- Efficient lighting practices	0.60	-12.0
- Replace incandescents lights with fluorescent lights	0.37	-12.0
- Heat pumps for hot water	0.63	-10.0
- Heat pumps	0.67	-8.8
- Hot plate to gas cooking	0.17	1.2
- Paraffin to gas cooking	0.07	2.3
- Efficient wood/coal stove	0.17	2.4
- Insulation of geysers	0.83	6.1
- Hybrid solar water heaters	2.93	16.0
- Electricity to gas space heating	0.83	22.0
- Efficient new HVAC systems	1.67	-20.0
- New building thermal design	2.67	-17.0
Rest of Industry		
- Gas-coal substitution for synfuel feed	5.80	1.6
Total identified potential	38.00	

Source: World Bank (2002): only options for which reduction potential and costs could be quantified with some certainty have been included

3.4.3 National and sectoral MAC curves for South Africa

The Figures 3.12 to 3.14 depict the cost of abating a marginal unit of greenhouse gas emissions versus the cumulative amount of emissions reduced. The figures represent abatement of emissions nation wide, the household sector and the electricity sector respectively.

Up to 17 MtCO_2 eq can be reduced at negative cost. Most no-regret reduction options are in the household sector. They comprise the retrofit and replacement of lighting systems, including traditional incandescent light bulbs, and efficient lighting practices; variable speed drive controls for fans; heat pumps for hot water; replacement of paraffin and hot place cooking systems to gas systems, and the introduction of efficient wood and coal stoves. In the electricity sector negative cost options are the retrofit of heating, ventilation and air-conditioning (HVAC), and the conversion to natural gas based power generation. In industry no-regret options comprise new HVAC systems and improved thermal designs in new buildings.

The reduction potential at a cost lower than 10 \$/t CO_2 eq is around 34 $MtCO_2$ eq. Insulation of geysers in the household sector is such an economical reduction opportunity. Super-critical coal plants and power generation in integrated gas combined cycles are cost-effective options in the electricity sector. In industry, options at a cost under 10 \$/tCO_2 eq comprise the catalytic combustion of methane from mining operations, and the replacement of coal by natural gas in the production of synthetic fuels.

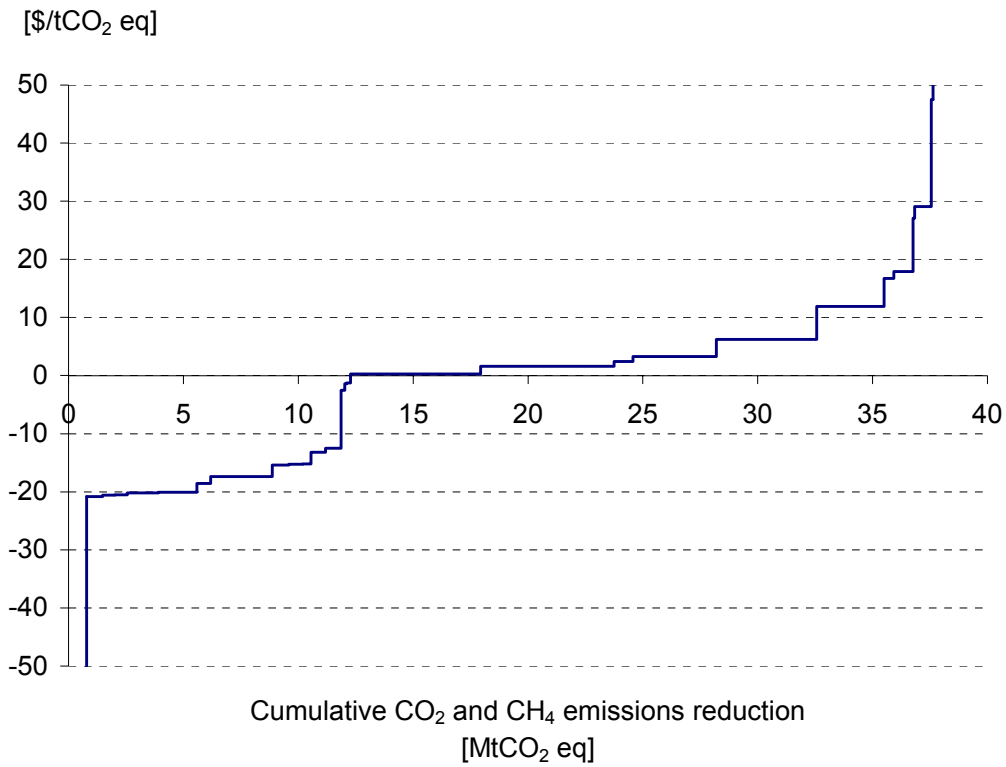

Figure 3.12 *MAC curve for South Africa*

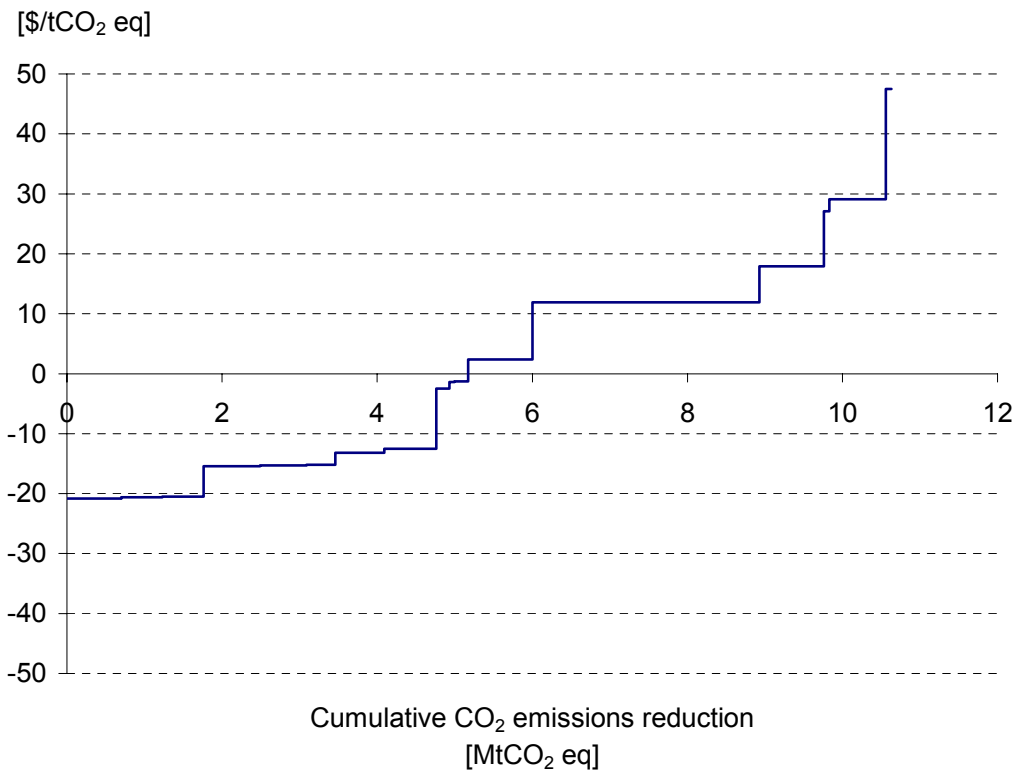

Figure 3.13 *MAC curve for the household sector in South Africa*

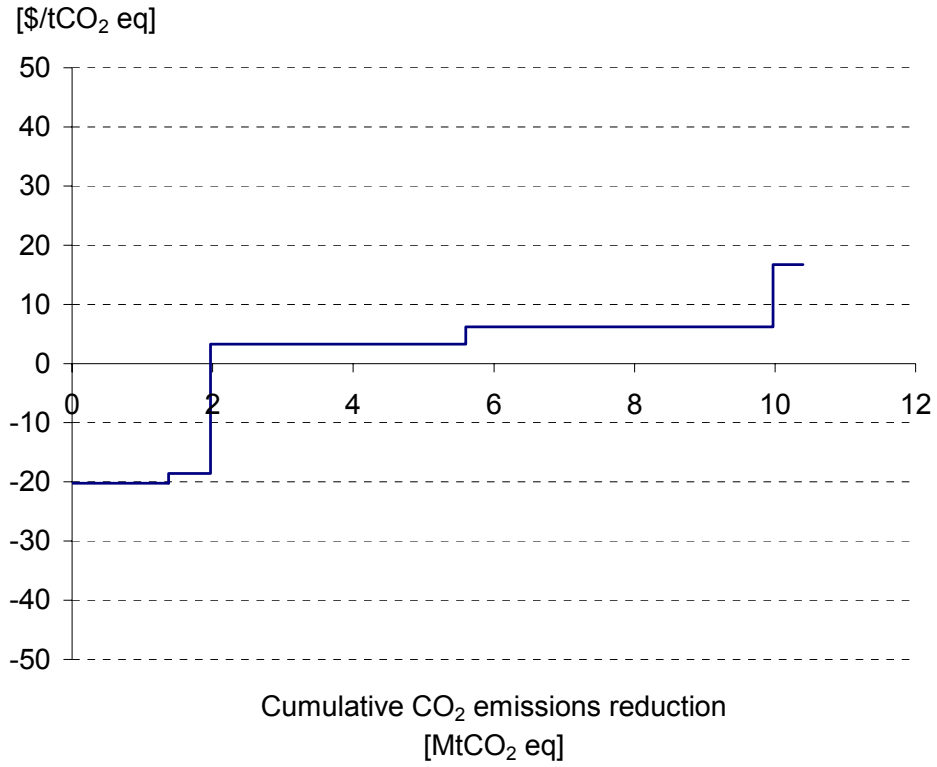

Figure 3.14 *MAC curve for the electricity sector in South Africa*

3.5 Brazil

The MAC-curve for Brazil has been derived from five broad categories of GHG emissions reduction options. As Brazil's GHG emissions are among the lowest in the world relative to the population and size of the economy, it is not surprising that total identified GHG reduction potential is limited.

The country's electricity supply sector heavily depends on hydropower. In this connection it is worth noting the comments of Seroa da Motta et al. (2000). These authors note that the penetration of natural gas and fuel oil is still quite small, although business-as-usual scenarios indicate a greater reliance on these fossil fuels in the nearby future.

3.5.1 Greenhouse gas emissions

Table 3.8 *Greenhouse gas emissions in Brazil, 1994*

	Brazil [Mt CO_2 eq]
GHG emissions by sector	
Energy	248
Industrial processes	21
Agriculture	369
Waste	21
LULUCF	818
Total	*1477*
GHG emissions by gas	
CO_2 (with LUCF)	1030
CH_4	239
N_2O	167
Total	*1435*

Source: UNFCCC (2004c).

Table 3.8 shows that land use change and forestry were the most important sources of CO_2 emissions, followed by agriculture, energy, industrial processes and waste. So, the largest share of Brazil's GHG emissions derives from non-energy intensive sectors. This observation holds, if deforestation in the Brazilian Amazon stays eminent.

3.5.2 Identified GHG emissions reduction options

As mentioned above, only five options have been identified from different sources. The potential and costs of these options are presented in Table 3.9 for the sectors agricultural products & forestry and electricity.

Table 3.9 *Identified GHG emissions reduction options for Brazil in 2010*

Mitigation option	Potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
Agricultural products and forestry		
- Plantation [a]	2.3	0.9
Electricity		
- Electricity conservation [b]	35.9	-74.3
- Natural gas [a]	5.2	-11.2
- Wind energy [c]	7.0	4.3
- Ethanol with electricity cogeneration [c]	16.9	5.7
Total identified potential	*67.3*	

Source: (a) Jung (2003)
(b) UNDP/GEF (1999)
(c) Seroa da Motta et al. (2002) and Pew Centre (2002)

With Brazil's enormous forest resources and the present emission scenarios related to deforestation, forestry opportunities offer huge potential. Deforestation is responsible for an estimated 200 million tons of carbon emissions annually. This represents two thirds of Brazil's emissions of GHGs and about 2.5% of global carbon emissions (Naess and Schjolden, 2002). Nevertheless, curbing deforestation is no straightforward undertaking and has no potential yet to become eligible for CDM projects.

On the other hand, country abatement studies conducted by Jung (2003) and Sathaye et al. (2001) suggest that plantation can be seen as an eligible CDM project in Brazil's forestry sector. The predicted abatement costs are calculated at $ 0.9 per mitigated tCO_2 eq. It should be noted these abatement costs heavily depend on land prices. However, as Seroa da Motta et al. (2000) note, even including high land prices, CDM plantation projects are still low-cost mitigation options. Abatement potentials of plantations differ widely among country abatement studies. This literature study uses the data presented by Jung (2003). Plantation projects in Brazil result in a mitigation potential of 2.3 $MtCO_2$ eq for the year 2010.

The abatement options considered for the energy sector focus on natural gas, ethanol with electricity cogeneration and wind energy. As Seroa da Motta et al. (2000) note, cogeneration is viewed as a political priority, because it has a significant scope for expansion. Regarding wind power, PEW Centre (2002) indicates that this mitigation option could supplement hydropower in some regions of Brazil. Finally, electricity conservation in Brazil is extremely cost-effective. Besides that, possible CO_2 eq savings from electricity conservation far outweigh the potential of other options.

3.5.3 National MAC curve for Brazil

Figure 3.15 represents the analysis of comparing only five mitigation options, based on available costing and abatement potential detailed above. For this reason, the Brazilian MAC curve has a different form compared to other MAC curves. None of the mitigation options comprises abatement costs above $ 6 per tCO_2 eq. As indicated above, total identified GHG emissions reduction potential at cost up to $ 6 per tCO_2 eq amounts to 67.3 Mt CO_2 eq. A high share of this potential, approximately 61%, can be achieved at net negative cost.

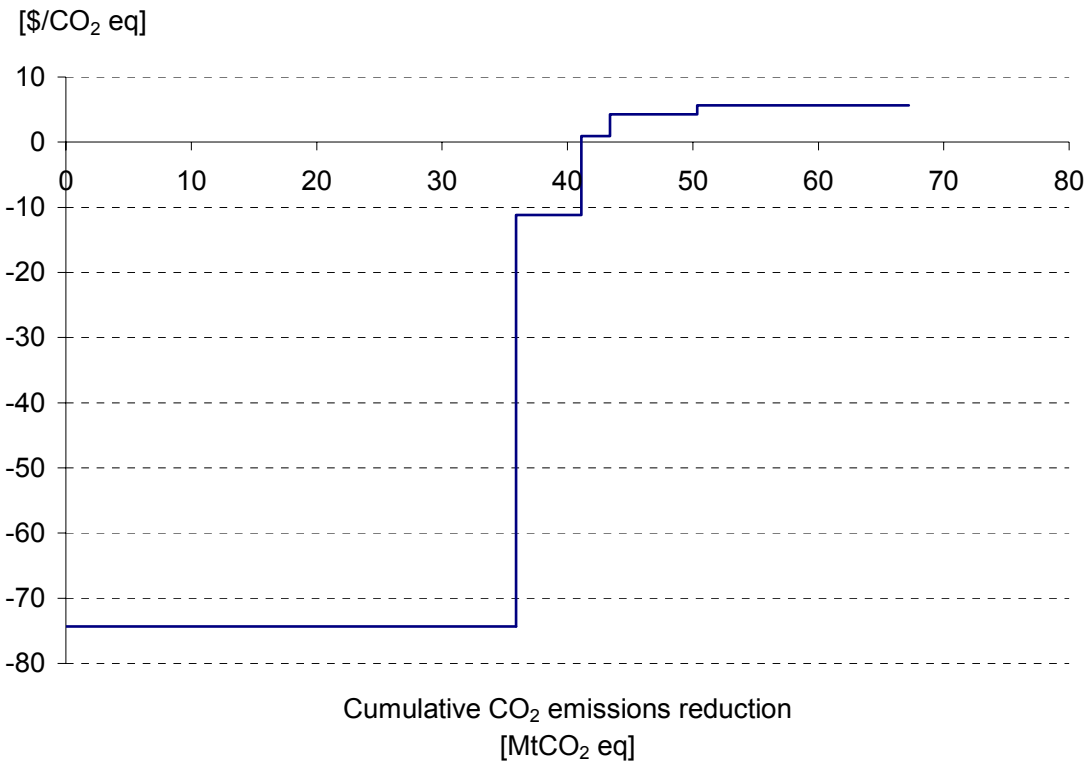

Figure 3.15 *MAC curve for Brazil*

3.6 Rest of Central & South America region

The MAC curve for Brazil presented in Section 3.5 covers the most important country in the Central and South America region. For all 78 eligible mitigation options in the Rest of Central and South America, emission reduction potentials and costs in 2010 were assessed and the resulting MAC is presented in Figure 3.16. According to the definition used by the World Bank, the remaining 19 countries in this region include Argentina, Belize, Bolivia, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela.

3.6.1 Greenhouse gas emissions

Information about GHG reduction options has been collected from national abatement costing studies for the following countries: Argentina, Bolivia, Ecuador, Colombia, Mexico and Venezuela. These countries account for roughly 72% of total GHG emissions in the Rest of Central and South America region. As in the case of the whole Non-Annex I region, a simple extrapolation method has been employed to estimate the reduction potential for the missing countries. Extrapolating to all 19 countries corresponds to scaling up the abatement potential by a factor of approximately 1.4.

Drawing a parallel between the different contributions of countries in the Rest of Central & South America region to the total GHG emissions, Table 3.10 illustrates that the Mexico contains the largest share by far. What is also noteworthy in the data presented in Table 3.10 is that the agriculture sector in Argentina is by far the largest source of CO_2 eq emissions of all agricultural sectors in the Rest of Central & South America region.

Table 3.10 *GHG emissions by sector and by gas for six countries in the Rest of Central and South America region*

	Argentina[a]	Bolivia[b]	Ecuador[c]	Colombia[d]	Mexico[e]	Venezuela[t]
Data by sector [Mt CO_2 eq]						
Energy	140	8.0	20.0	62	321	144
Industrial processes	8	0.6	1.0	5	12	9
Agriculture	115	12.0	8.0	61	39	33
Waste	16	1.0	1.0	8	11	6
Total	*280*	*21.0*	*31.0*	*137*	*383*	*192*
Data by gas [Mt CO_2 eq]						
CO_2 (without LUCF)	131	8.0	20.0	61	309	114
CH_4	88	13.0	11.0	48	71	62
N_2O	60	1.0	0.1	28	3	16
Total	*280*	*21.0*	*31.0*	*137*	*383*	*192*

Source: (a) UNFCCC (1997), emissions for 1997
(b) UNFCCC (2000b), emissions for 2000
(c) UNFCCC (2000c), emissions for 1990
(d) UNFCCC (2001a), emissions for 1994
(e) UNFCCC (2001b), emissions for 1990
(f) UNFCCC (2005), emissions for 1999

3.6.2 Identified GHG emission reduction options

Potential and costs of 78 GHG emission reduction options have been collected for the Rest of Central & South America region. Of these 78 options, the technologies eligible for CDM and contributing significantly to the emission reduction potential are listed in Table 3.11. It was es-

timated that in 2010, a total non-extrapolated reduction of roughly 196 $MtCO_2$ eq could be achieved.

Table 3.11 *Identified GHG emissions reduction options with a non-extrapolated emission reduction potential larger than 1 Mt CO_2 for nine countries in the Rest of Central & South America region in 2010*

Mitigation option	Potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
Agricultural products and forestry		
- Methane from landfills (Colombia) [d]	3.5	0.7
- Restoration plantations (Mexico) [a]	12.0	5.5
- Afforestation (Colombia) [d]	1.1	19.2
Electricity		
- Combined cycle (Mexico) [a]	70	-15.6
- Wind power (Mexico) [a]	12.2	-11.7
- Hydro power (Argentina) [b]	13.9	0.2
- Sanitary landfill gas (Argentina) [b]	5.4	0.5
Households		
- Residential Lighting (Mexico) [a]	2.5	-45.2
- Efficient water pumps (Mexico) [a]	1.2	-35.7
- Efficient biomass cook stoves (Bolivia) [c]	1.2	-15.3
Rest of Industry		
- Commercial Lighting (Mexico) [a]	4.7	-30.8
- Industrial cogeneration (Mexico) [a]	35.4	-33.4
- Industrial boilers (Mexico) [a]	2.7	-27.1
- Industrial boilers (Colombia) [d]	2.1	-2.2
- Energy efficiency measures in cement industry (Argentina) [b]	1.5	0.2
- Energy efficient industrial motors (Equador) [b]	1.3	14.4
- Wet to dry switch in cement industry (Colombia) [d]	1.1	19.2
Paper product		
- Energy efficiency measures in paper industry (Argentina) [b]	1.6	0.3
Crude Oil		
- Energy efficiency measures in oil industry (Argentina) b	1.7	0.3
TOTAL IDENTIFIED POTENTIAL for six countries in the Rest of Central & South America region including options with an emission reduction potential less than 1 $MtCO_2$ in 2010)	*195.6*	

Source: (a) Sheinbaum and Masera (2000)
(b) UNDP/GEF (1999)
(c) World Bank (2000a)
(d) World Bank (2000b)

3.6.3 MAC curve and sectoral MAC curves for Rest of Central & South America region

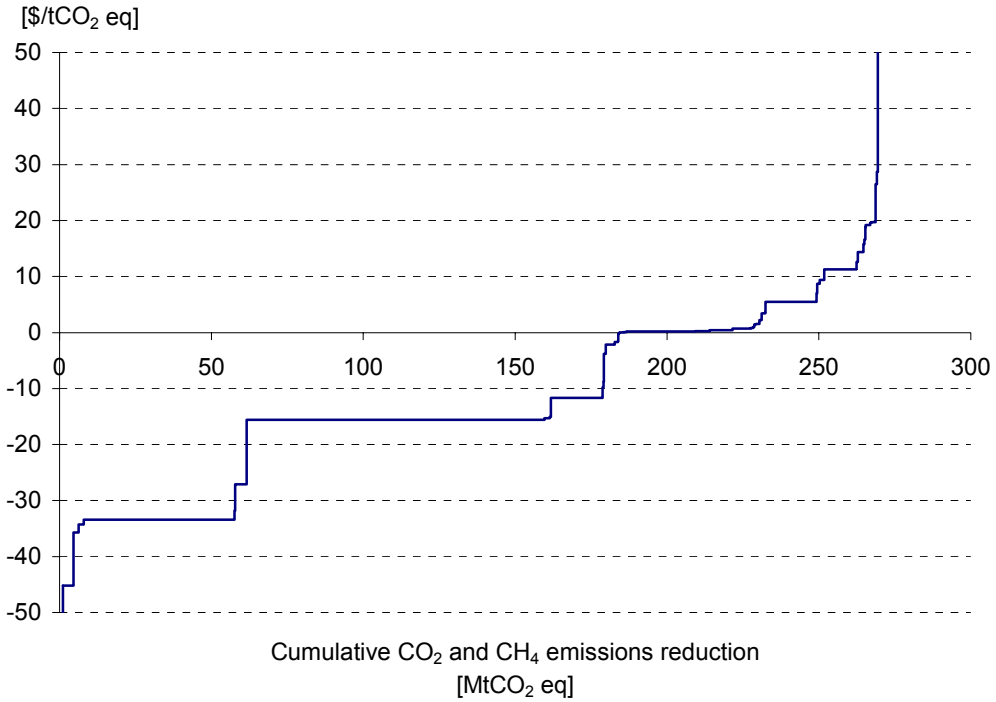

Figure 3.16 *Extrapolated MAC curve for the Rest of Central & South America region*

The estimated MAC Curve is presented in Figure 3.16. This curve has been derived from the potential and cost information contained in the database and applying a factor of 1.25 to account for the missing countries.

Figures 3.17, 3.18 and 3.19 present the sectoral MAC curves for respectively the electricity sector, rest of industry sector and agricultural & forestry sector. No abatement potentials are presented for the transport sector and household sector because potentials are very small for those sectors (5 $MtCO_2$ eq and 15 $MtCO_2$ eq, respectively).

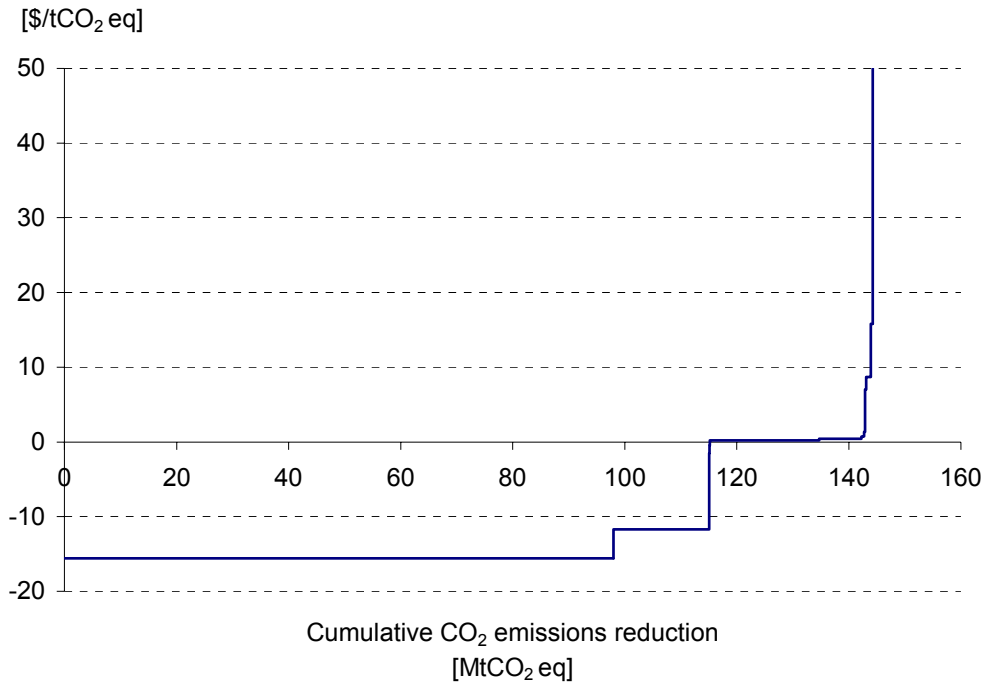

Figure 3.17 *Extrapolated MAC curve for the electricity sector in the Rest of Central & South America region*

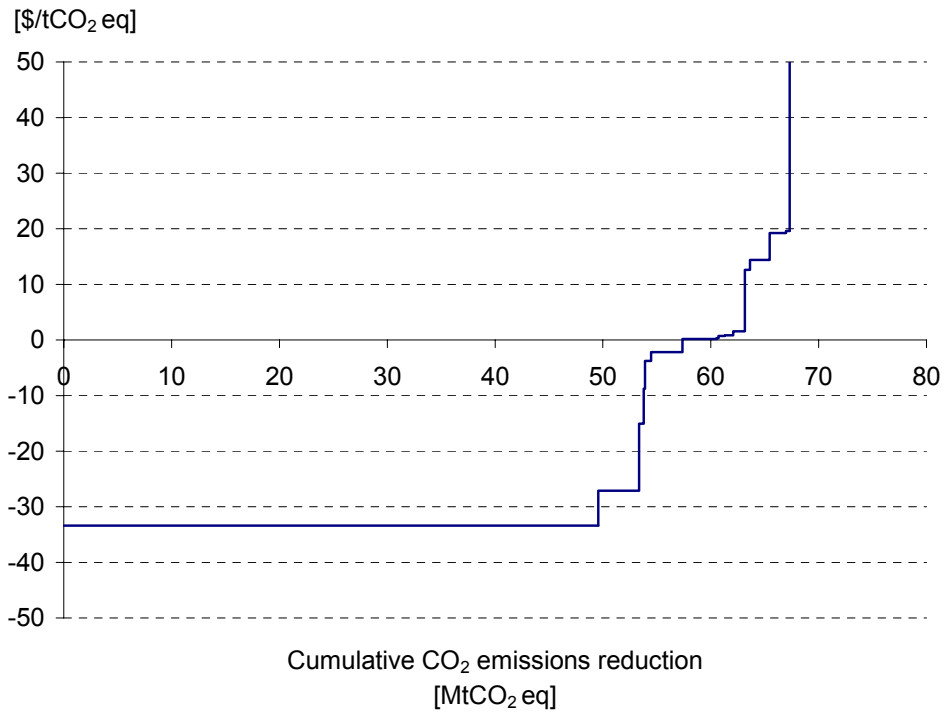

Figure 3.18 *Extrapolated MAC curve for the rest of industry sector in the Rest of Central & South America region*

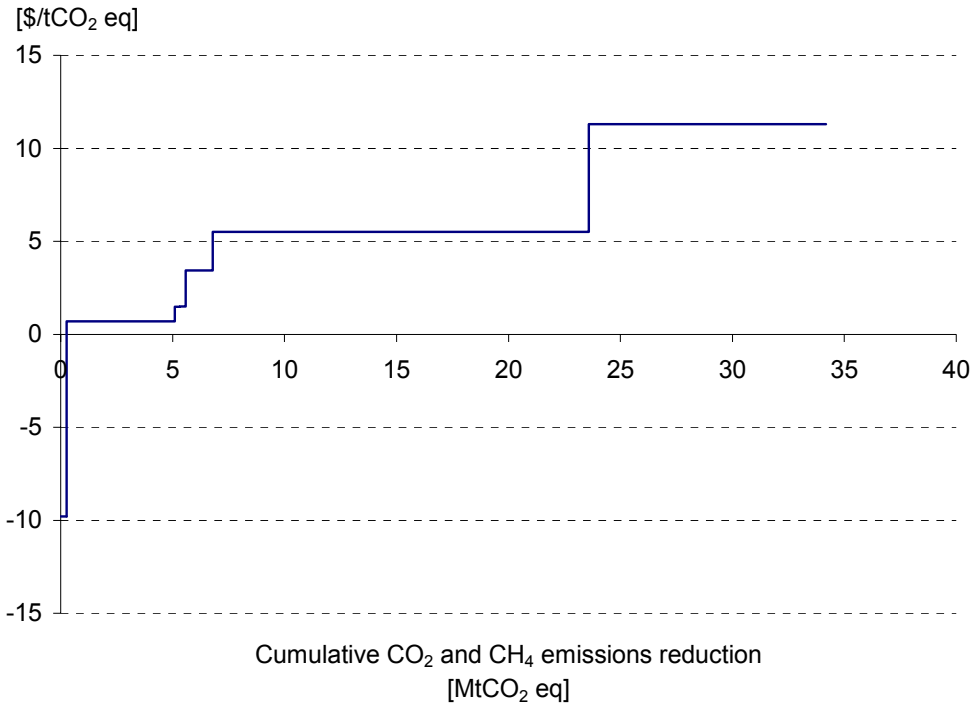

Figure 3.19 *Extrapolated MAC curve for the agricultural & forestry sector in the Rest of Central & South America region*

3.7 Rest of East South Asia region

The MAC curves for China and India presented in Section 3.2 and 3.3 cover the two most important countries in the East South Asia region. According to the World Bank, the remaining countries in this region include Afghanistan, Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Democratic Republic of Korea, Lao PDR, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Thailand and Vietnam.

3.7.1 Greenhouse gas emissions

Information on potentials and costs for mitigation options could be obtained for 9 countries: Indonesia, Myanmar, Mongolia Philippines, Thailand, Vietnam, Bangladesh, Pakistan and Sri Lanka.

These nine countries account for roughly 70% of total GHG emissions in the Rest of East South Asia region. Again, a simple extrapolation method has been employed to estimate the reduction potential for the missing countries. Extrapolating to all 20 countries corresponds to scaling up the abatement potential by a factor of approximately 1.4.

When comparing, in a relative way, the contribution of the energy sector to the total GHG emissions, then table 3.12 shows that the energy sector in Indonesia contains the largest share, namely 69%. Furthermore, table 3.12 shows that the energy-related GHG emissions are comparatively low in Bangladesh and Vietnam.

Table 3.12 *Greenhouse gas emissions by sector and by gas for seven countries in the region Rest of East south Asia in 1994*

	Indonesia [a]	Myanmar	Philippines [b]	Thailand [c]	Mongolia	Vietnam [d]	Bangladesh [e]	Pakistan [f]	Sri Lanka [g]
Data by sector [Mt CO_2 eq]		-							
Energy	222.102	-	50.040	129.868	-	25.633	15.210	83.267	6.773
Industrial processes	8.213	-	10.603	15.977	-	3.807	1281	11.270	0.273
Agriculture	84.507	-	33.129	77.393	-	52.445	28.122	61.940	11.461
Waste	8.440	-	7.095	0.740	-	2.565	1.312	4.123	10.621
Total	*323.262*	-	*100.867*	*223.977*	-	*84.450*	*45.926*	*160.600*	*29.429*
Data by gas [Mt]									
CO_2 (without LUCF)	178.215	-	57.932	141.453	-	25.383	16.460	88.441	5.644
CH_4	126.881	-	28.932	65.335	-	48.894	25.008	60.713	16.023
N_2O	18.166	-	14.003	17.190	-	10.173	4.458	11.445	7.440
Total	*323.262*	-	*100.867*	*223.977*	-	*84.450*	*45.926*	*160.600*	*29.429*

Source: (a) UNFCCC (1999)
(b) UNFCCC (2000d)
(c) UNFCCC (2000e)
(d) UNFCCC (2003a)
(e) UNFCCC (2002)
(f) UNFCCC (2003b)
(g) UNFCCC (2000f)

3.7.2 Identified GHG emissions reduction options

In total, 130 reduction options have been identified from different sources. Reduction options with an emission reduction potential larger than 1 $MtCO_2$ in 2010 are presented in Table 3.13 for the sectors agricultural products & forestry, electricity, households, rest of industry, transport and crude oil. This paragraph covers general information about the most important mitigation options in the region. The GHG emissions reduction option analysis is focused on three sectors: electricity, households and rest of industry.

Electricity

A diverse range of options was discussed in the different country abatement costing studies, including: gas combined cycle, hydro, mini hydro, co-generation, gas turbine, geothermal, solar thermal, solar PV and biomass in Indonesia; fuel-switching from coal to natural gas, mini hydro, (biomass) integrated gas combined cycle and clean coal technologies in Thailand. The Pakistan fuel-switching option from oil & coal to natural gas, as a large scale mitigation option, has a substantial emission reduction potential, however pose significant challenges (e.g. defining baselines and claiming additionally).

Households

In the Rest of East South Asia region numerous options exist that reduce energy consumption on the demand side. Table 3.13 presents the most relevant and feasible energy efficiency options like higher efficiency lighting and higher efficiency household electrical appliances. All 34 identified options could potentially be developed as small-scale CDM projects.

Rest of Industry

Companies involved in manufacturing activities have a number of mitigation options at their disposal, including: upgrade boiler design, higher efficiency industrial motors and waste heat recovery systems.

Table 3.13 *Identified GHG emissions reduction options with an extrapolated emission reduction potential larger than 1 $MtCO_2$ for nine countries in Rest of East South Asia region in 2010*

Mitigation option	Potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
Agricultural products and forestry [7]		
- Planting of protective specialized forests (Vietnam)[a]	12.5	0.7
- Plantation (Indonesia)[b]	2.3	0.8
- Utilization of biogas (Vietnam)[a]	1.1	3.5
Electricity		
- Energy conservation (Indonesia)[c]	7.0	-60.8
- Co-generation (Pakistan)[c]	5.3	-27.4
- Fuel switch from coal to natural gas (Thailand)[c]	3.0	2.0
- Substitution of oil & coal with natural gas (Pakistan)[c]	11.9	2.6
- Natural gas combined cycle gas turbine (Philippines)[c]	1.8	2.6
- BIGCC (Thailand)[d]	6.7	3.2
- Wind power (Vietnam)[a]	1.3	4.8
- Solar energy (Vietnam)[a]	1.0	6.2
- Further fuel switching from coal to natural gas for power generation: 22% coal; 73% natural gas (Thailand)[c]	3.0	9.3

[7] The types of forestry mitigation options eligible for the CDM projects in the first commitment period (2008-2012) are limited to afforestation and reforestation only. From analysis of potential sink projects in the East South Asia region, it can be concluded that the abatement costs are rather low.

Mitigation option	Potential [Mt CO_2 eq/yr]	Costs [\$/tCO_2 eq]
- Solar energy (Indonesia)[d]	1.4	16.6
- Geo thermal (Indonesia)[d]	7.6	30.8
- Biomass steam power plant (Indonesia)[e]	1.3	45.3
- Wind (Pakistan)[f]	3.3	62.2
Households		
- Efficient Boilers (Bangladesh)[c]	4.7	-30.8
- Incandescent to CFL (Indonesia)[e]	2.1	-29.2
- Use of CFL (Philippines)[c]	1.1	-25.6
- Energy efficient air lighting (Pakistan)[c]	1.8	-21.2
- Energy efficient fans (Pakistan)[c]	2.1	-20.0
- Energy efficient air conditioning systems (Vietnam)[c]	2.0	- 9.8
- Energy efficient refrigerators (Vietnam)[c]	3.4	-7.8
- High-efficient Air conditioning systems (Philippines)	1.5	-5.4
- Improving coal cooking stoves (Vietnam)[a]	2.8	-3.5
- Efficient fluorescent lamps and CFLs (Republic of Korea)[c]	14.3	-1.7
Rest of Industry		
- Efficient Industrial motors (Thailand)[c]	3.0	-20.4
- Efficient tube wells (Pakistan)[c]	3.9	-15.0
- Energy-efficient boilers (Pakistan)[c]	1.3	-10.3
- Cogeneration option in industrial sector (Thailand)[c]	1.8	-8.1
- Condensing gas boilers, solar hot water systems, insulation standards (Republic of Korea)[c]	7.7	-7.5
- High efficiency electric motors (Vietnam)[c]	2.7	-7.0
- Improving efficiency of industrial motors (Vietnam)[a]	2.7	-7.0
- Heat Rate Improvement (Philippines)[c]	5.3	-4.9
- Efficient motors and inverter systems (Republic of Korea) [c]	24.2	-4.7
- Waste heat recovery systems (Pakistan)[c]	2.7	-4.0
- Co-generation & heating system reconstruction in textile industry (Indonesia)[e]	1.2	8.8
Transport		
- Hi-Efficiency Transport System (fuel efficiency improvements) (Philippines)[c]	1.3	-2.7
- Energy-efficient engine designs (Pakistan)[c]	5.3	11.8
Crude Oil		
- Utilization of flared gas (Indonesia)[e]	2.7	1.6
TOTAL IDENTIFIED POTENTIAL for nine countries in Rest of East South Asia region (including options with an emission reduction potential less than 1 MtCO_2 in 2010)	*213.1*	

Source:
(a) UNFCCC (2003a)
(b) Jung (2003)
(c) ADB/GEF/UNDP (1998)
(d) ARRPEEC (2002)
(e) World Bank (2001)
(f) Rogner (2000)

3.7.3 MAC curve and sectoral MAC curves for Rest of East South Asia region

The forecasted MAC for rest of East South Asia is presented in Figure 3.20. It should be noted that the projected GHG abatement potential for the nine countries (Indonesia, Thailand. Vietnam, Sri Lanka, Bangladesh, Myanmar, Philippines, Pakistan and Mongolia) is extended to the remaining countries in the Rest of East South Asia region. For that purpose, the above men-

tioned extrapolation factor of 1.4 has been used. The total abatement potential in the Rest of East South Asia region in the year 2010 is estimated at about 300 $MtCO_2$ eq/year. This potential is approximately 315 $MtCO_2$ eq less than the national potential of China. Approximately 56% of this potential can be achieved at net negative costs.

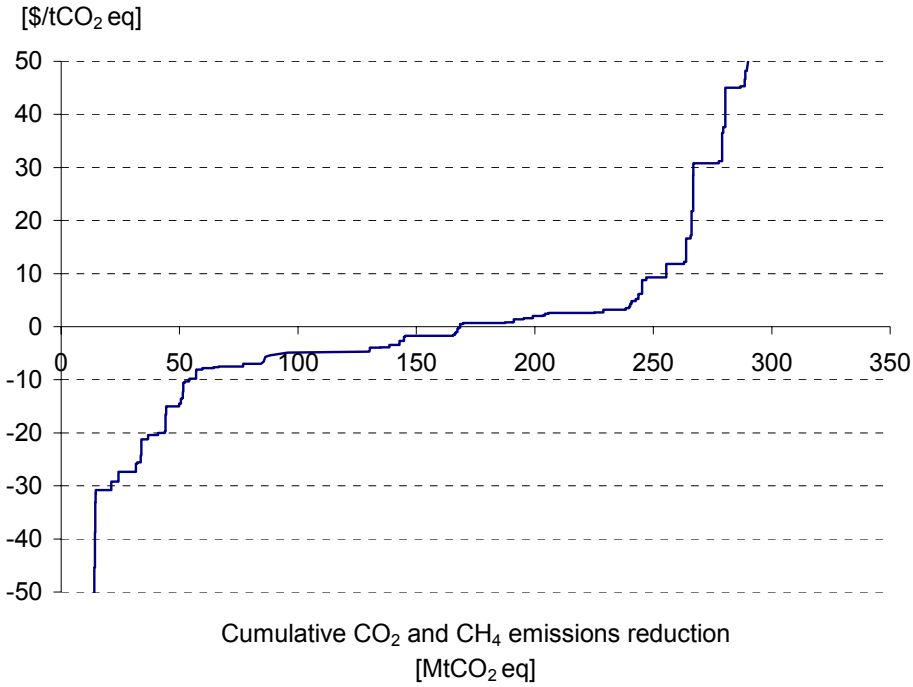

Figure 3.20 *Extrapolated MAC curve for the Rest of East South Asia region*

Figure 3.21 depicts the MAC curve for the electricity sector for the Rest of East South Asia region. Total identified reduction potential in 2010 in this sector amounts to 110 $MtCO_2$ eq A CO_2 permit price of 10 $/$tCO_2$ would, in theory, result in a reduction of approximately 77 $MtCO_2$ eq in the electricity sector.

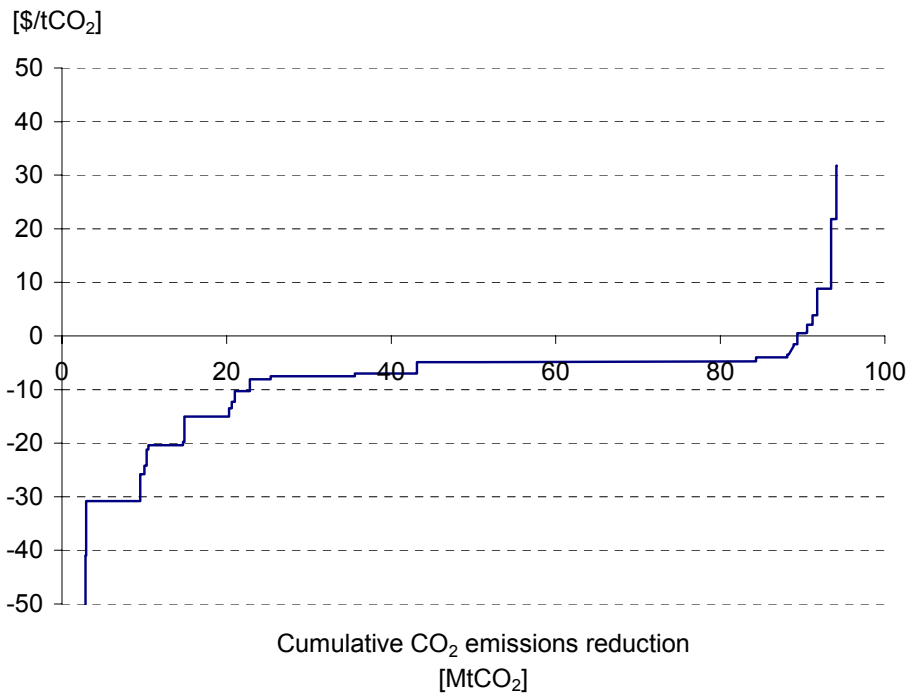

Figure 3.21 *Extrapolated MAC curve for the electricity sector in the Rest of East South Asia region*

The estimated abatement potential in the household sector in 2010 is about 50 $MtCO_2$ eq. Figure 3.22 shows that most reduction options are 'no-regret' options with net negative abatement costs.

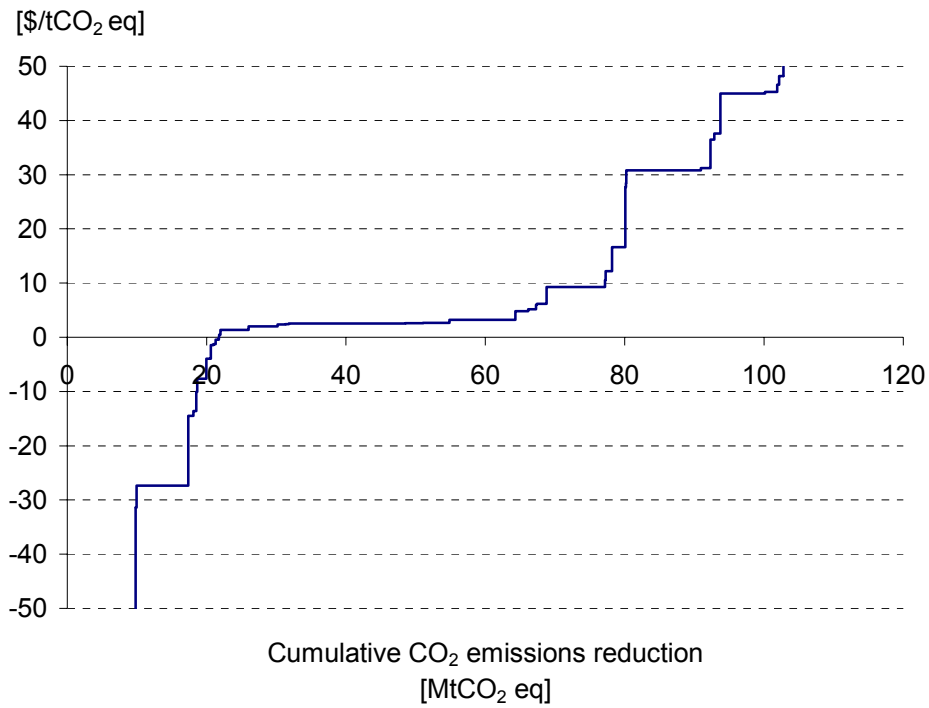

Figure 3.22 *Extrapolated MAC curve for the household sector in the Rest of East South Asia region*

Finally, the marginal abatement costs and abatement potentials of the mitigation options for the 'rest of industry sector' are shown in Figure 3.23. Quite a significant reduction potential (94 $MtCO_2$) has been identified in this sector and similar as in the household sector many options have net negative costs.

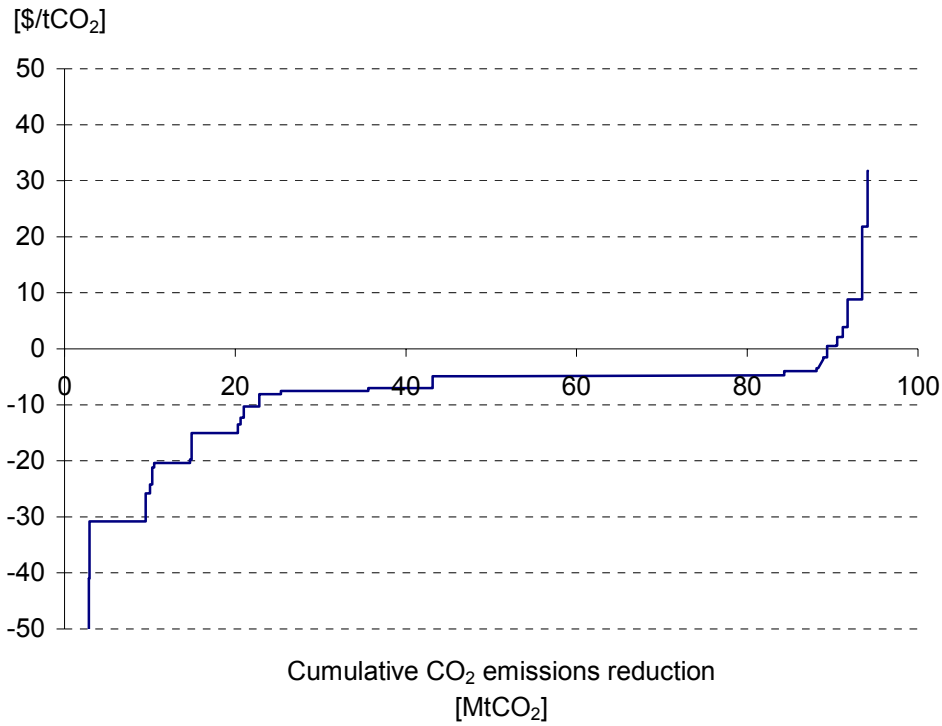

Figure 3.23 *Extrapolated MAC curve for the rest of industry sector in the Rest of East South Asia region*

3.8 Analysis of proposed and/or approved CDM projects

The MAC curves presented above are based on average cost information for a particular technology presented in country mitigation studies. In this section, the general information from country abatement studies is compared with more accurate and detailed cost information from (potential) CDM projects that have been or will be implemented. For this purpose, a separate database has been developed containing cost information of 120 (potential) CDM projects. This information has been retrieved by dividing total project cost estimates by total CO_2 eq emissions reductions during the project lifetime. Both estimates are written down in many Project Identification Notes and Project Design Documents. It appears that for only 14 CDM projects, a technology-country match between the two data bases could be established. These 14 projects are presented in Table 3.14.

Table 3.14 *Comparison of abatement costs between (potential) CDM projects and identified technology reduction options*

		Potential CDM projects [$/tCO$_2$ eq]	Registered CDM projects [$/tCO$_2$ eq]	Country abatement study [$/ tCO$_2$ eq]
Argentina	Landfill gas[8]		0.4	0.5
Bolivia	Micro power hydro stations[9]	269		188.4
Bolivia	Plantation[10]	0-7		1.5
Ecuador	Hydro[11]		76	8.7
Vietnam	Hydro[12]	31-45		92.7
Vietnam	Wind[13]	46		4.8
Vietnam	Plantation[14]	8		0.7
Indonesia	Solar[15] cookers		3	98.1
Indonesia[16]	Biomass		7-9	45
Philippines[17]	Wind		43	-1.6
China[18]	Wind		27-102	36.8
China[19]	Biomass		49	35.2
China[20]	Hydro		26	20
Colombia[21]	Landfill gas	0.1		0.7

[8] Two sources : (1)Argentina CDM PDD Olavarría Landfill Gas Recovery Project, November 2005 (2) The World Bank, carbon finance unit, Project summaries and project documents for ERPA-signed projects http://carbonfinance.org/.
[9] Oficina de Desarrollo Limpio de Bolivia, Carbon Expo 2006 Energy portofolio, http://www.andeancarbon.com.
[10] Oficina de Desarrollo Limpio de Bolivia, Carbon Expo 2006 Energy portofolio, http://www.andeancarbon.com.
[11] Equador CDM PDD Sibimbe Hydroelectric Project, November 2005.
[12] Vietnam CDM PIN Za Hung Hydropower project, January 2006 Vietnam CDM PIN Nam Chim Hydropower project, January 2006.
[13] Vietnam CDM PIN Commune Nhonchau wind farm city Quy Nhon, December 2005.
[14] Vietnam CDM PIN Rừng Vàng Reforestation and Carbon Programme, March 2005.
[15] Indonesia CDM PDD Solar Cooker project Aceh, October 2005.
[16] Indonesia CDM PDD MSS Biomass 9.7 MWe Condensing Steam Turbine Project, April 2006 and Indonesia CDM PDD MNA Biomass 9.7 MWe Condensing Steam Turbine Project, April 2006.
[17] Phillippines CDM PDD NorthWind Bangui Bay Project, December 2005.
[18] China CDM PDD Inner Mongolia Chifeng Dongshan., April 2006.
China CDM PDD Inner Mongolia Huitengxile Jingneng Wind Project, January 2006
China CDM PDD Saihanba North Wind project, April 2006.
China CDM PDD Saihanba East Wind project, April 2006
China CDM PDD Datang Jilin Shuangliao Wind farm project, April 2006.
China CDM PDD Huafu Muling Wind Park Project, March 2006.
China CDM PIN Windfarm Xiaguan, July 2003.
[19] China CDM PDD Henan Luyi Biomass project, March 2006.
[20] China CDM PDD Gansu Dang River Hydropower Project, January 2006.
[21] Columbia CDM PIN Recovery the La Esmeralda landfill gas, March 2005.

Firm conclusions can not be drawn from the comparison, because the sample of only 14 projects is too small. However, some observations can be made:

1. The costs for landfill gas-based CDM projects are in line with the costs used in country mitigation studies for this technology
   - Abatement costs of less than 1 $/tCO_2$ eq are reported both for the CDM projects (PIN and PDD) and mitigation studies (National Strategy Studies) for Colombia and Argentina.
2. The costs for small hydro are in the same order of magnitude for CDM projects and mitigation studies
   - The costs for small hydro are in the range of 20-45 $/tCO_2$ eq for (potential) CDM projects in Ecuador, Vietnam and China. In the mitigation studies, these costs are higher in the case of Vietnam but lower for Ecuador.
3. The costs for wind projects are significantly higher in (potential) CDM projects than the average figures used for wind options in the country mitigation studies.
   - CDM wind projects implemented in Vietnam, Philippines and China have significantly higher costs per reduced tCO_2 eq than the wind options identified in the mitigation studies in these countries. Cost information on seven CDM wind projects in China has been gathered. The investment costs of these projects are very site specific and vary between 27-102 $/tCO_2$ eq

4. Conclusions

The analysis presented in the previous chapters was carried out as part of the TETRIS project for the European Commission. The analysis aimed to develop marginal abatement cost curves for non-Annex I countries based on information obtained from country GHG abatement costing studies. Potential and costs information has been assembled from 30 non-Annex I countries. Together, these countries contribute about 80% of total anthropogenic GHG emissions originating from all non-Annex I countries. In addition, the cost and savings of 120 proposed and approved CDM projects were analyzed and compiled.

In total, 552 GHG emissions reduction options have been identified, of which 372 options appear eligible for the CDM. Most reduction options identified are in the power sector (116 options), demand side management options in household sector (105 options), 'rest of industry' sector (84 options), agricultural products and forestry sector (31 options) and transport sector (19 options). Only few options have been identified in the other economic sectors.

Almost all reduction options identified are in the energy sector and concern a reduction of CO_2 or CH_4 emissions. No options are included in the country abatement costing studies for mitigating N_2O, HFC, PFC and SF_6 emissions.

Based on the results of the analysis presented in this report the following observations are relevant:

- The inventory of reduction options reveals that a large amount of GHG emissions abatement potential exists in non-Annex I countries compared with the western (except USA and Australia) Annex I countries reduction requirements of 860 $MtCO_2$ eq in 2010 (Sijm et al., 2000).[22] The estimated GHG reduction potential in 2010 for all non-Annex I countries together up to $ 50 amounts to about 2.1 $GtCO_2$ eq. Of this theoretical potential, approximately 0.7 $GtCO_2$ eq is achievable at net negative marginal cost. This last outcome seems to conflict with rational behaviour. The reasons often mentioned in the literature for the existence of no-regret options include market imperfections leading to lack of knowledge about the reduction option, lack of priority, lack of investments due to limited financial markets and the definition of cost (social versus financial cost). It is often suggested that in order to remove these market barriers, additional costs are incurred that should be added to the technology costs. In the present study however we have not attempted to assess these additional costs.
- In theory, 1.7 $GtCO_2$ eq can be achieved at costs less than $ 4 per tCO_2 eq in 2010. This high potential available at low cost makes the CDM an attractive instrument for parties with GHG emissions reduction commitments. This is confirmed by a rapidly growing CDM market in 2006. Through the link with the EU emission trading system, it is likely that this market will further expand and is going to play a significant role in meeting the reduction obligation of European companies under the emission trading system.
- The potential and costs estimates presented in this report however should be viewed with caution. Not all country studies reviewed present a complete list of GHG reduction options. In some studies the focus is on one particular sector (power sector, forestry); in most studies only CO_2 emissions reduction technologies have been examined. Besides, many country studies are characterised by limitations regarding unmentioned assumptions about discount

[22] These requirements are defined as the difference between the expected (baseline) emissions in the year 2010 and the so-called 'Kyoto-target', i.e. the assigned amount of GHG emissions in 2010 based on a certain percentage (for instance, 90 or 95%) of the emissions level in the reference year. The western Annex I countries consist of : Belgium, the Netherlands, Germany, Italy, Sweden, Finland, Denmark, France, Greece, Portugal, Spain, United Kingdom, Austria, Ireland, Luxembourg, Switzerland, Norway, Japan, USA, Canada, Australia, New Zeeland, Iceland.

rate, base year for abatement cost and technology characteristics etc. There is also reason to believe that the real cost for the project investors are underestimated as the cost estimates in the country abatement costing studies generally concern net incremental costs (i.e. costs and benefits from the perspective of the national economy) and the (private) project investor may be unable to claim the benefits that accrue to other stakeholders.

- It is very unlikely that the identified reduction potential can be fully realised by 2010 because the remaining implementation time is way too short. A more realistic estimation of the potential that can be realised up to 2010 can be based on UNEP/Risø figures of the GHG reduction generated by 1571 CDM projects in pipeline (988 projects in registration phase, 91 projects in the process of registration phase and 492 registered CDM projects. Based on this information (UNEP/Risø, 2007), it is estimated that some 14% of the identified potential can be realised by 2010.
- The GHG abatement potential data collected from the country abatement costing studies suggests that a large fraction of total identified abatement potential is situated in a limited number of non-Annex I countries. The identified potential in India and China already constitutes some 60% of the total identified reduction potential in the Non-Annex I region.
- The transaction costs related to the identification and development of a CDM project vary with project size and can form a major barrier for project investors because these costs are incurred up front when no revenue streams from the sales of credits have been realized. However, the transaction costs per unit CO_2 reduction are limited for all technologies except the very small technologies that generate less than 10,000 tCO_2 eq per year.
- The information collected from 120 (potential) CDM projects to a large extent confirms the above observations. A more detailed comparison of the costs resulted in only 14 corresponding technology-country combinations and although no firm conclusions can be drawn from this small sample indications are that for biomass, mini-hydro and land fill gas projects, cost figures used in the country abatement studies are of the same order of magnitude compared to (potential) CDM projects. For wind projects however the costs appear much higher in practice.

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