Marginal Abatement Cost curves for the non-Annex I region

Assessment of potential and cost of CDM options

Draft

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Acknowledgement/Preface

The study presented in this report covers work package III of the Technology Transfer and Investment Risk in International Emissions Trading (TETRIS) project carried out in the framework of the EC Sixth Framework Programme. The report was prepared by ECN Policy Studies. The report is registered under ECN project number 77689 and can be downloaded from the TETRIS project website (www.zew.de/TETRIS), or the ECN website (www.ecn.nl).

Abstract

The study aimed to identify the potential and costs of CDM options to enable the development of realistic and policy-relevant marginal abatement cost (MAC) curves for GHG emissions reduction options in non-Annex I countries.

Potential ands costs of GHG emission reduction technology from 30 non-Annex I countries have been collected, reviewed, evaluated and aggregated to construct an aggregated MAC curve which covers some 80 per cent of the non-Annex I region. A simple extrapolation method has been applied to derive the MAC curve for all non-Annex I countries. In addition, separate MAC curves have been constructed for the largest non-Annex I countries and regions and for specific sectors in these countries.

In a parallel activity, cost information from proposed and/or approved CDM project has been gathered from more than 60 CDM projects. One would expect to get more detailed and accurate cost information from concrete CDM projects, which have been submitted to the UNFCCC. This CDM project information is compared with the information obtained from the abatement costing studies for the 30 countries.

The identified GHG emissions reduction potential in non-Annex I countries is significant. The inventory of reduction options reveals that the reduction potential in 2010 at costs up to 50 \$/ton CO_2 eq is approximately 2.5 Gt CO_2 eq. However, this estimate should be viewed with caution, as there are several limitations to aggregating the information obtained from the various abatement costing studies on which this estimate is based.

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1. Introduction

1.1 Background

During the last decade, emissions trade (ET) has emerged as a chief instrument for controlling anthropogenic emissions of greenhouse gases (GHG). 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.[1] 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 46% of total CO_2 emissions in the European Union.

The Clean Development Mechanism (CDM) and Joint Implementation (JI) represent project-based emissions trading. They will be linked to the EU trading scheme according to a recently released proposal for an amendment of the ET Directive (European Commission, 2003b). The proposed amendment of the EU ET Directive provides recognition of JI and CDM credits as equivalent to EU emission allowances.

Given the advanced status and large size of the European GHG 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 TETRIS project for policy makers has been formulated as the full exploitation of the economic and environmental benefits of emissions trading. To this end technology transfer and investment risk in international emissions trading have been studied. In order to reach the overall 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, indicator of the investment climate for GHG abatement projects are developed. These describe both

[1] See DEFRA (2001), Ellerman (2000), Janssen and Springer (2001), Williams et al. (2002).

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.

Part of the work related to the first objective was carried out within work package 3. 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 reduce the cost-effectiveness of an emissions trading regime. In particular, WP3 focused on permit supply from CDM projects. Potentials and marginal costs of reducing GHG emissions under the CDM are inventoried. The present chapter reports on this work.

1.2 Objectives of WP3

The objectives of WP3 are twofold, namely:

1. To derive realistic and policy-relevant MAC curves for carbon dioxide in major developing countries and regions.
2. To analyse technologies transferred to and used in developing countries to achieve emission reductions.

For the work carried out to meet the first objective point of departure was the inventory of project-based carbon credits completed by Sijm (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 realized. The inventory of abatement options compiled by Sijm (2002) will be updated and disaggregated in this chapter. New MAC curves will be constructed, both for emission reductions in a number of major CDM host countries, and for whole non-Annex I region. The curves will represent mainly CO_2 and only to a very limited extent other greenhouse gases. The curves will be used as an input for the analysis in WP6, which aspires to project the magnitude as well as price and cost impacts of including carbon credits from CDM projects on the global emissions markets.

The analysis of technologies transferred to and used in non-Annex I countries as a result of the CDM (second objective) will be done together with the economic analysis conducted in WP6. Once an equilibrium price has been established in WP6, the type of energy technologies that will be transferred at the equilibrium price level will be determined using the MAC curves developed in WP 3.

1.3 Outline of the report

In Chapter 2 the approach to the study will be presented. First, a general overview of the approach to constructing bottom-up marginal abatement cost studies is presented in Paragraph 2.1. Next, an analysis of the transaction costs of CDM projects is given in Paragraph 2.2and finally the limitations to the study are explained (2.3). Chapter 3 presents the results. First, a MAC curve for the whole non-Annex I region is presented and discussed (3.1). Then MAC-curves for selected CDM host countries are explained, specifically for China, India and South Africa (3.2. -3.5). 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 is based on a review, comparison, evaluation and aggregation of GHG emissions reduction studies and concrete 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 concrete CDM projects which have been (are being) implemented.
- Comparing the two sources of information and developing a database of GHG reduction options.
- Assessing the 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 the Figure 2.1. The components within the dotted area are part of work package III.

Potential and costs of GHG reduction technology options have been collected from country abatement costing studies and this information is stored in a data base to facilitate the development of MAC curves for the non-Annex I region. In addition, technology specific transaction costs have been assessed and included in the cost information.

In a parallel activity, cost information of concrete 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.

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 will take place.

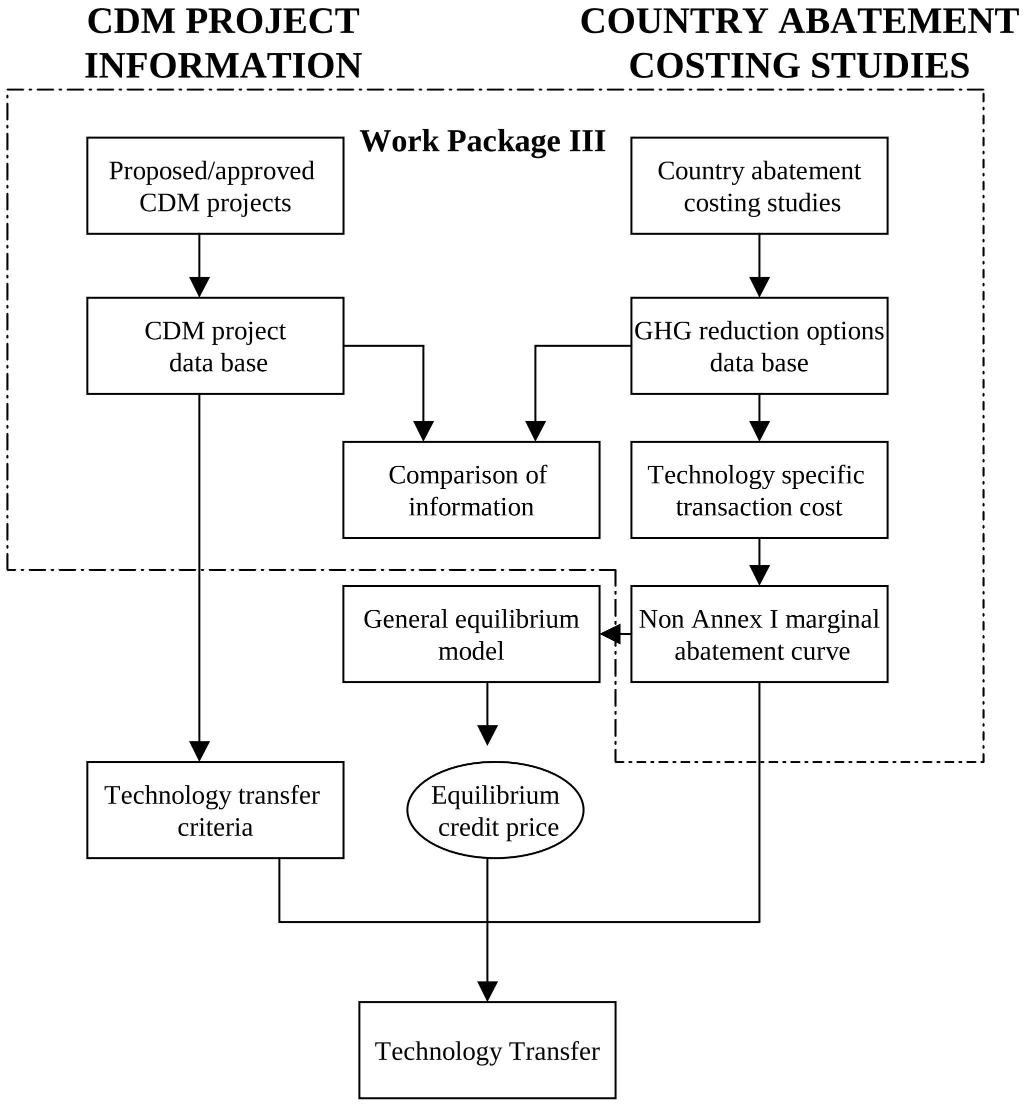

Figure 2.1 *Schematic overview of the approach*

2.1.1 Inventory of technology 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 that reason, a number of available abatement studies for non-Annex I regions were analysed and the results compiled in an inventory of the technology options, their projected potential for the year 2010, and their associated GHG abatement costs.

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.[2] Underlying studies use $/t$CO_2$ as an indicator of the cost effectiveness of restraining carbon dioxide emissions. Cost data are collected for a mitigation option of a nominal size and with characteristics of an average option.[3] For the reason that a single technology characterization is often used to represent a range of technologies with varying charac-

2 UNEP, 1994
3 UNEP, 1994

teristics, the abatement potential is only indicative of that which might be incurred in actual situations.

Total global GHG emissions (without LULUCF) for the latest available years (ranging from 1990 to 2003) are estimated at 29 Gt CO_2 eq. by the UNFCCC. Roughly 40% of this amount stems from 121 Non-Annex I countries. The present study acquired potential and costs for technology options for 30 non-Annex I countries, of which 9 are situated in Africa, 14 in Asia and seven in Latin America.[4] 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 unit abatement cost. 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 PCF, HFC and SF_6 because the amount of emissions from these gasses in the non-Annex I countries is very limited (although rapidly growing especially in the emerging economies). However, N_2O emissions constitute a significant part of total GHG emissions in non-Annex countries and therefore it is expected that CDM projects will be developed in the near future.

The project team gathered information on 383 technology options that are eligible for CDM. Not all of the technology options identified are eligible for CDM projects. Firstly, in the forestry sector only afforestation/reforestation options present opportunities for CDM projects. Avoided deforestation 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 (cdmwatch.org). 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 14 options for GHG emissions reduction reported in the abatement costing studies are considered not eligible for CDM and have been left out for the development of the MAC curves.

2.1.2 Inventory of options based on 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 concrete CDM projects, which have been submitted to the UNFCCC. For the purpose of the present study, information on potential and investment costs were obtained from different CDM projects under implementation. Although the total GHG reduction brought about by these projects is small in terms of total estimated reduction potential and the sectoral coverage is heavily biased towards the electricity sector, this data nevertheless offers the possibility to verify at least part of the abatement cost information collected in the country abatement studies.

The data has been collected from the Project Design Document (PDD) for CDM projects, which can be downloaded from the UNFCCC-website. All PDDs include an ex ante projection of estimated CO_2 savings. Whereas only some PDDs include investment costs retrieved

[4] 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).

by feasibility studies. By early 2006, approximately 432 CDM projects were planned or under implementation. Of these 432 CDM projects, 47 PDDs 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 and electronic equipment.

Table 2.1 *Breakdown of GHG reduction options by sector*

Sector	CDM projects	Abatement costing studies
Energy-intensive sectors		
Coal	-	2
Crude Oil	-	3
Natural gas	-	1
Petroleum and coal products	-	-
Electricity	31	115
Iron and steel industry	4	4
Paper product	1	4
Non-ferrous metals	-	-
Mineral products	-	-
Non-energy intensive sectors		
Agricultural products and forestry	-	32
Transport	-	19
Rest of Industry -		86
Manufactures and serv.	2	
Households	-	105
Landfill gas	8	
N_2O capture	1	
Total number of reduction options	47	371

2.2 Transaction Costs

Introduction

Transaction costs for CDM include 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 the 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 Chapter, an analysis is presented that aims to determine the transaction costs for various technologies to reduce greenhouse gas emissions. The analysis builds on previous research carried by ECN (Bhardway 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 ton CO_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). Tables 2.2 and 2.3F 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 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 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[5] 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 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[6]:
    - 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
    - crediting period

[5] 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.

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

- 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 cost 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 (Jayant et al., 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*

		Category I	Category II	Category III	Category IV	Category V
Upfront	[$]	*67,800*	*59,800*	*55,900*	*37,600*	*32,600*
1. Project preparation and review		9,000	9,000	9,000	4,800	4,800
2. Project Design Document		4,800	4,800	5,400	10,800	10,800
3. Validation		6,000	6,000	6,000	6,000	6,000
4. Appraisal phase		42,000	34,000	29,500	13,000	8,000
5. Initial verification (start-up)		6,000	6,000	6,000	3,000	3,000
Operation	[$]	*90,000*	*132,000*	*132,000*	*21,000*	*405,000*
6. Periodic verification		30,000	72,000	72,000	6,000	390,000
7. Certification (yearly)		60,000	60,000	60,000	15,000	15,000
Total transaction costs	[$]	*157,800*	*191,800*	*187,900*	*58,600*	*437,600*
GHG reductions per year	[tCO_2 eq/yr]	4,700,000	200,000	100,000	28,000	10,000
Transaction costs	[$/t$CO_2$ reduced]	0.003	0.1	0.2	0.2	4.4

Notes:

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

2.3 Limitations to the analysis

It is important to note some limitations of the analysis in the previous Chapters. 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 cost curves derived here 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 discount rates, fuel prices, global warming potentials, technology characteristics, etc. These assumptions strongly affect the calculated GHG savings potential and cost.
3. *Estimates of abatement potential and incremental costs depend very sensitively on 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 incremental costs of abatement options However, different definitions of what is incremental (for instance barrier removal) were used by different studies. Economic benefits were excluded in some instances and apparently double-counted in others Several studies noted that the cost calculations were preliminary, uncertain or qualitative.
5. CDM transaction costs were assumed to be similar across world regions (see Chapter 2.2).

3. Results

3.1 MAC curves for the whole non-Annex I region

The Marginal Abatement Cost (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 per cent 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 GHG emissions MAC curve in year 2010 for the whole non-Annex I region for technology options in the unit cost range of -50 to +50 \$/ton CO_2 equivalents.

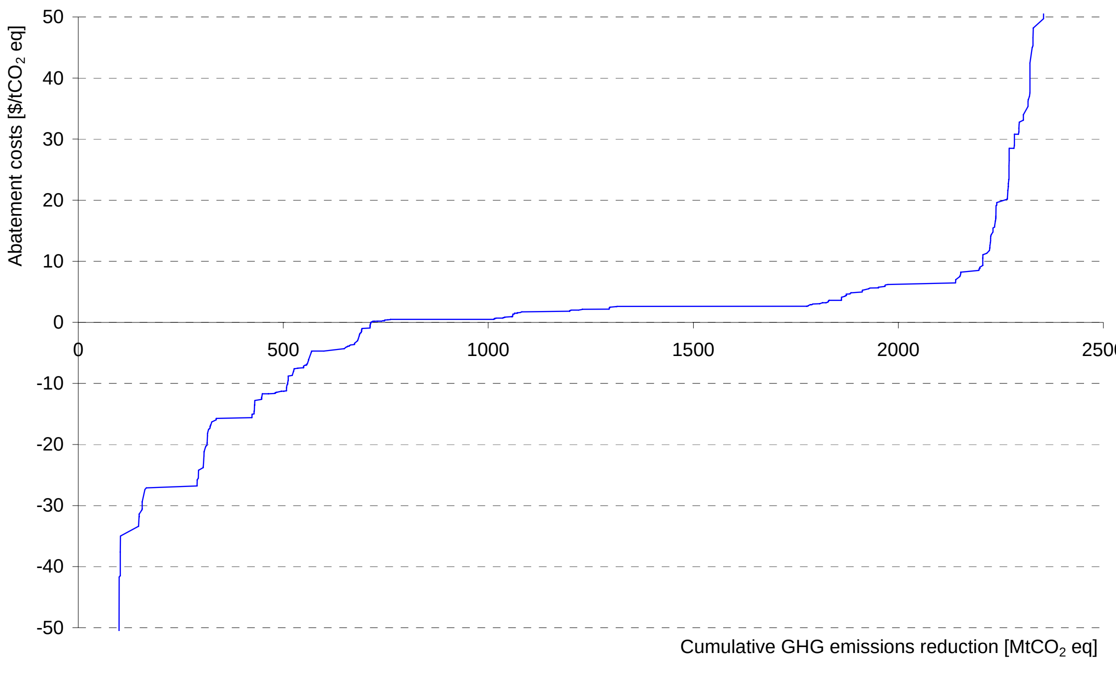

Figure 3.1 *Extrapolated MAC curve for the whole non-Annex I region*

Out of the total 371 eligible reduction options included in the database, the unit costs of 15 options are below -50 \$ and for 34 options the unit costs exceed 50 \$. Consequently, the MAC-curve in Figure 3.1 includes 323 GHG emissions reduction technology options.

The total abatement potential in the year 2010 at a price of 50 \$/ton CO_2 equivalents or lower is estimated at about 2.4 Gt CO_2 equivalents. Roughly 37% of this potential is projected to be achievable at negative or zero incremental costs. Approximately 1,9 Gt CO_2 equivalents. appears feasible at costs of up to 4 $/ton CO_2 equivalents . It should be noted that these costs include abatement costs as well as transaction costs.

Of the total identified abatement potential, 64 per cent arises from reduction options in only two countries, namely China and India.

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

In addition to the MAC curve for the whole non-Annex I region, the general equilibrium model also needs sectoral MAC curves to determine the equilibrium price of tradable CO_2 allowances. The sector classification used by the equilibrium model consists of energy intensive and energy extensive sectors (see Table 3.1). Meaningful MAC curves could only be constructed for three sectors: electrification (energy intensive), rest of industry (energy extensive) and the household sector (demand side management reduction options). Figure 3.2 presents the extrapolated MAC curve for the electricity sector for the whole of the non-Annex I region. This curve is constructed based on 97 reduction options.

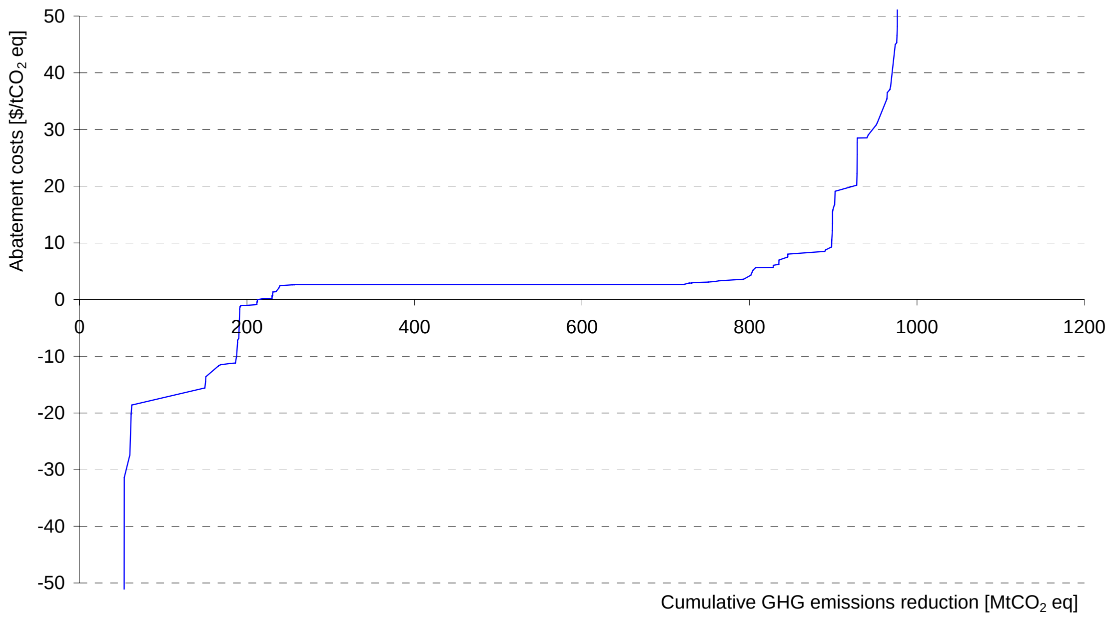

Figure 3.2 *Extrapolated MAC curve for the electricity sector for the whole non-Annex I region*

Total identified GHG emissions reduction potential at cost up to $50 per ton CO_2 eq. in the electricity sector amounts to about 1 Gt CO_2 eq. Approximately 22 per cent of this potential can be realized at net negative cost. In total 115 GHG emissions reduction options have been identified in the electricity sector in the 30 non-Annex I countries. For 2 options the costs are below $ -50 per ton CO_2 eq (electricity conservation in Brazil and Indonesia) and for 16 options the unit costs exceed $ 50 per ton CO_2 eq. Consequently, the MAC-curve in Figure 3.2 includes 97 GHG emissions reduction technology options.

Figure 3.3 shows the estimated potential in 2010 in the non-Annex I region for the sector ‘rest of industry’. In total, 86 reduction options have been identified in this sector. Most options are in the sub-sectors machinery and equipment, motor vehicles and metal products.

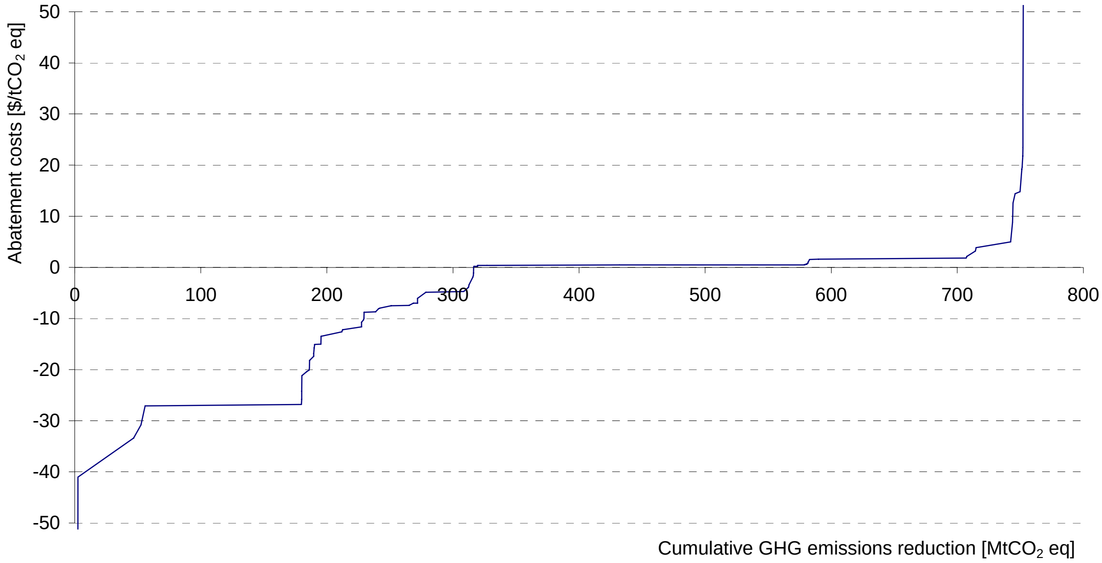

Figure 3.3 *Extrapolated MAC curve for the rest of industry sector for the whole non-Annex I region*

The identified GHG emissions reduction potential in the sector ‘rest of industry’ is about 0.8 Gton CO_2 eq. This is the aggregated potential of 86 GHG emissions reduction technologies. The costs of only two technology options are above $ 50 per ton CO_2 eq. The unit costs of 3 technologies, all in Thailand, are below $ -50 per ton CO_2 eq. This last observation does not necessarily imply that very low no-regret costs for GHG emissions technologies could 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 limitations to the analysis, 2.3)

Figure 3.4 shows the estimated reduction potential in the ‘household’ sector is shown. 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.

By the year 2010, total potential in this sector will be around 0.3 Gton CO_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.

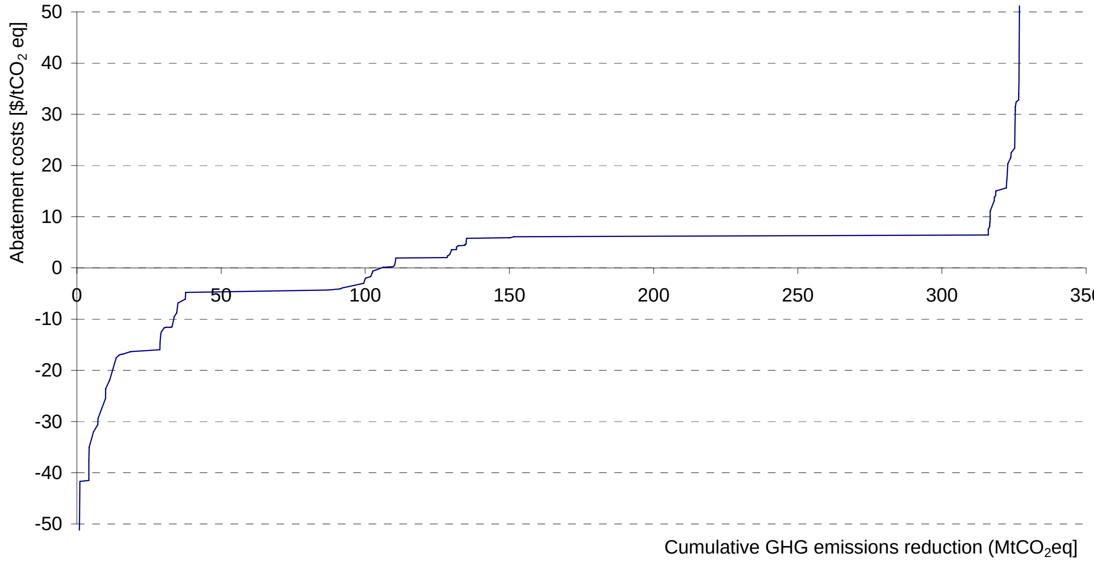

Figure 3.4 *Extrapolated MAC curve for the household sector for the whole non-Annex I region*

In Figure 3.5, the MAC curve for the agricultural & forestry sector is depicted. The figure is derived from 9 reduction options in agriculture and 23 forestry reduction options.

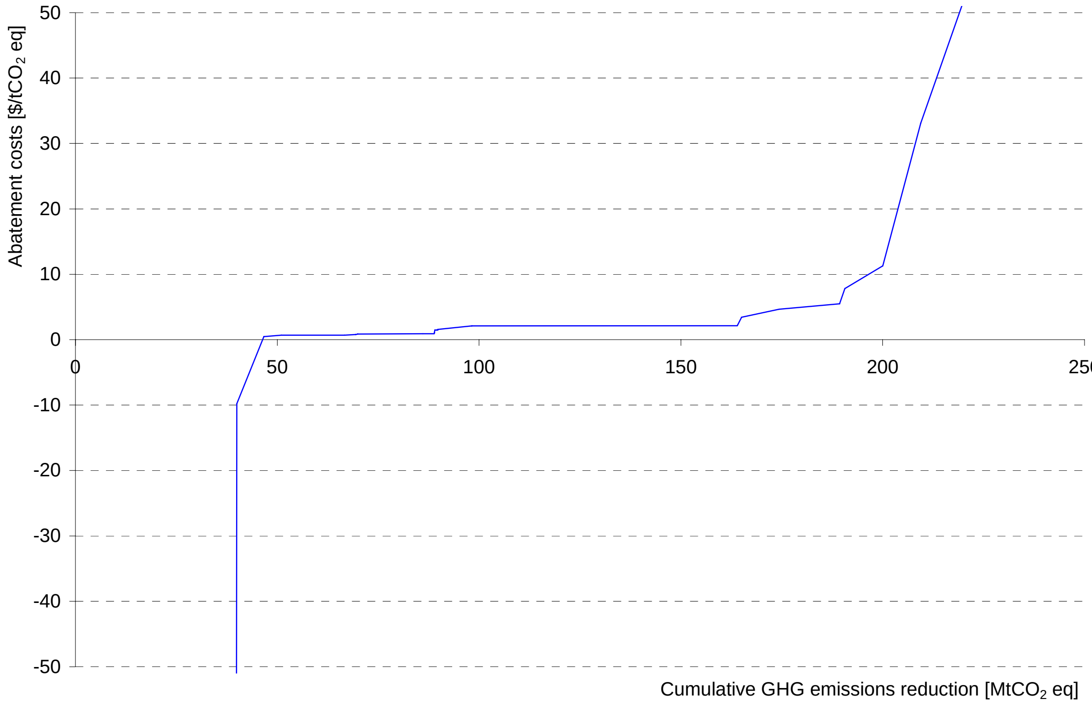

Figure 3.5 *Extrapolated MAC curve for the agricultural & forestry sector sector for the whole non-Annex I region*

The identified total abatement potential in this sector is limited compared to the other sectors. The estimated potential in 2010 amounts to about 225 Mt CO_2 eq. Some 20 per cent 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 3.5 might be much higher or lower for concrete CDM projects.

Finally, in Figure 3.6 the MAC curve for the transport sector is presented. The options include energy-efficient engine designs and equipping of the existing cars with gas fuelled engines. The estimated potential in 2010 amounts to about 35 Mt CO_2 eq. Some 35 per cent of this potential can be achieved at negative net costs.

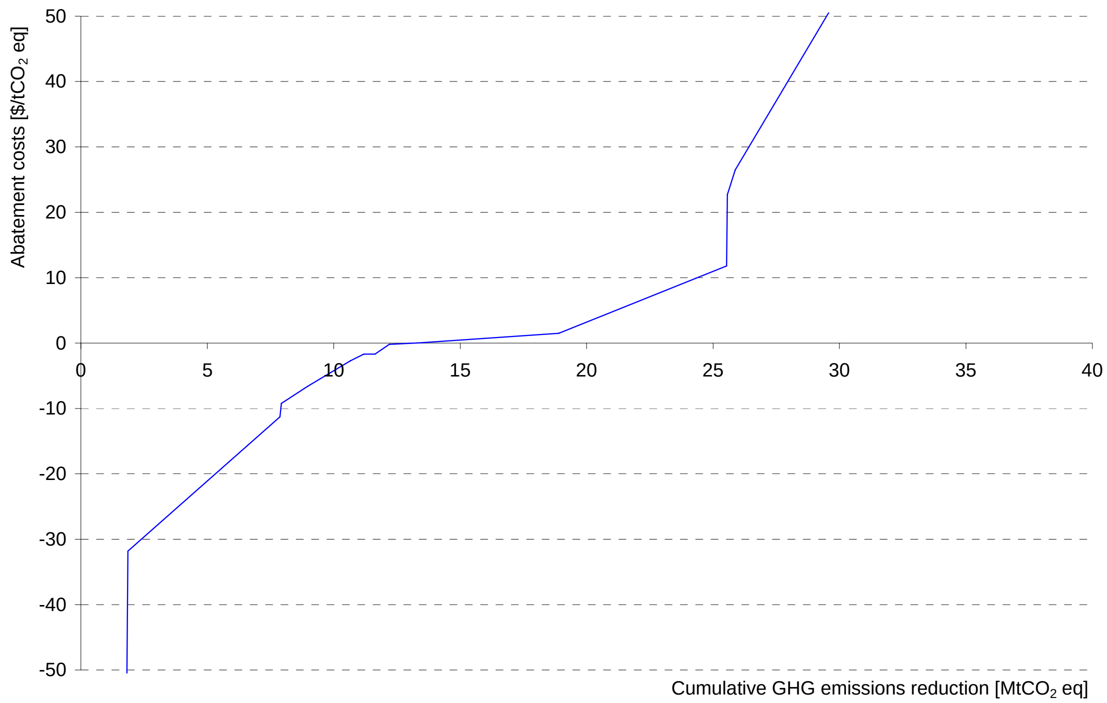

Figure 3.6 *Extrapolated MAC curve for the transport sector for the whole non-Annex I region*

3.2 MAC curves for China

China is the second largest emitter of greenhouse gases emissions worldwide, only exceeded by the US[7]. Consequently, China is a key actor in solving the global climate change problem which is expressed in its leading role in the climate change negotiations within the 'Group of 77 and China'. 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 local pollution problems.

Widespread adoption of advanced technologies or environmental friendly technologies is seen as the key solution for future GHG mitigation in China. Compared with technologies already used and produced in China, several advanced technologies presently used in the developed world could be much more effective in meeting the objectives of CDM (NSS China, 2005). 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.

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

3.2.1 Greenhouse gas emissions

The National Greenhouse Gas Inventory for China in 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. As can be seen from Table 3.1, 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.[8]

Table 3.1 *Greenhouse gas emissions in China, 2000*

Gas	MtC	Percent of World Total	World ranking
CO_2	948.0	14.54	3
CH_4	212.4	13.2	1
N_2O	176.0	19.12	1
PFC	1.4	5.4	7
HFC	10.1	16.19	2
SF_6	0.9	7.8	4
Total	1348.8	14.74	2

Source: World Resources Institute 's Climate Analysis Indicators Tool. 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_20 emission figure of 176 MtC. Presently, little information is available for emissions of PFC, HFC and SF6 in China. The emissions in table 1 for these 3 high-GW_p gases are based on expert opinions and production surveys.

The major issues affecting China's future GHG emissions are: population growth and increasing urbanization, the changes in the pattern of economic development and consumption, the expansion in people's daily necessities, the adjustment in economic structure and technological progress and the changes in forestry and ecological preservation and construction.

3.2.2 Identified GHG emissions reduction options

In total 35 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.

[8] The people's Republic of China Initial National Communication on Climate Change (Summary), 2004

Table 3.2 *Identified GHG emissions reduction options for China, 2010*

Mitigation option	Potential [Mt CO_2/yr]	Costs [$/tCO2]
Agricultural products and forestry		
- Forestry Rotation and Regeneration options	31.9	-143.6
- Seeding or dry nursery and thinnig planting	6.8	1.9
- Multinutrient block	7.5	32.9
- Ammonia treatment straw	12.6	60.5
Electricity		
- CFBC (Circulating Fluidized bed combustion)	0.5	-2.0
- Renovation and reconstruction of conventional thermal power plant	13.9	2.9
- Supercritical coal	2.5	5.4
- Hydro power	20.7	20.0
- Natural gas	0.4	22.1
- Scrap & Build (modify smaller coal power plants)	35.6	8.3
- Modification option (modify larger coal power plants)	9.2	28.3
- IGCC and other advanced conventional thermal power technologies	1.3	28.8
- Biogas and other biomass energy	9.2	35.2
- Wind energy (Grid In)	2.6	36.8
- Wind Power	0.5	57.4
- Fuel-switching (Coal to Natural gas)	45.6	61.5
- Solar thermal	0.6	99.6
Residential		
- Energy-saving lighting	39.6	-8.7
- Demand side management	2.9	-4.3
Iron and Steel		
- Cutting ratio of iron/steel in steel & iron industry	9.5	-24.0
- Pulverized coal injection into blast furnace	0.3	-4.9
- Continuous casting of steel making	7.7	-3.8
Rest of Industry		
- Renovation of kilns for wet cement production	13.2	-12.8
- Cement (innovation of wet process kilns)	0.3	-12.4
- Cement (dry kilns replacing wet kilns)	0.3	-10.2
- Comprehensive process renovation of synthetic ammonia	11.4	-7.6
- Industrial boilers (optimizing combustion)	84.3	0.3
- Industrial boilers (operational improvement)	77.0	0.3
- Industrial boilers (prefuel process)	40.3	0.3
- Anaerobic technology for wastewater treatment and energy recovery in alcohol plants	5.5	3.0
- Industrial boilers (high-efficiency boilers)	22.0	4.8
- Technical renovation of motor for general use	99.4	-27.0
Total identified potential	*615*	

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 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 can 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)[9] indicates that the energy intensity of China's GDP would fall greatly from 1,92 kgce/$ (1990 price) in 1995 to 0.72 kgce/$ in 2020, making efficiency technology the 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 as the primary energy source 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.[10]

Using 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

Research indicates that by 2020 it is expected that China will double the amount of floor space it had in 2000 (CDM Country Guide 2005). With increased standards of living, more energy is used for heating, air-conditioning, lighting and electrical appliances. The identified reduction options are shown in table 3.3. Recently the CDM Country Guide for China has claimed that 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, 4 reduction options have been identified for which potential and cost information could be found.

Rest of Industry

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9 Zhihongm Wei (2002): Clean development mechanism project opportunities in China. Global Climate Change Institute. Tsinghua University

10 PewCentre(2002)

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 3.2 shows a total abatement potential for industrial boilers of 223,7 MtonCO2eq in 2010. Except for high-efficiency boilers, the abatement costs for efficiency improvements of industrial boilers are modest.

The information on potential and costs of GHG emission reduction options has been obtained from the following sources:

- J.A. Sathaye et al. (2001): Carbon mitigation potential and costs of forestry options in Brazil China, India, Indonesia, Mexico, The Philippines and Tanzania. Mitigation and Adaption Strategies for Global Change 6: 185-211, 2001.
- Wang et al. (2006): Scenario analysis for China's Energy and major Industry sectors.[11] Tsinghua University Beijing (2005)
- Mitsutsune Yamaguch (2005): CDM potential in the power-generation and energy-intensive industries of China. Climate Policy 5 (2005) 167-184.
- Wo Zongxin and Wei Zhihong (1998): Identification and implementation of GHG mitigation technologies in China. Institute of Nuclear Energy Technology. Tsinghua University.
- IAEA (2000): Nuclear Power for Greenhouse Gas Mitigation.
- Asian Least-Cost Greenhouse Gas Abatement Strategy study.
- Zou Ji and Li Junfeng (2000): China CDM opportunities and benefits. World Resources Institute.

3.2.3 National and sectoral MAC curves for China

The forecasted GHG marginal abatement cost curve for China is presented in Figure 3.7. The total abatement potential in China in the year 2010 is estimated at roughly 615 $MtCO_2$eq. Approximately 38 per cent of this potential can be achieved at net negative costs.

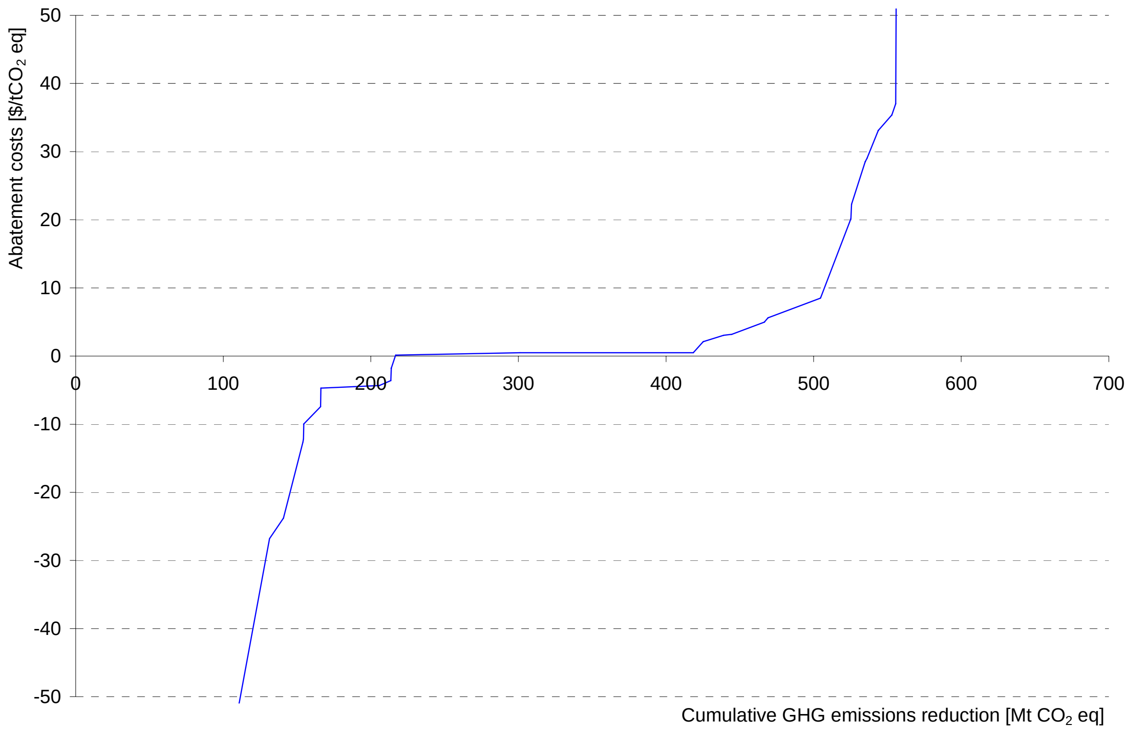

Figure 3.7 *Marginal abatement cost curve for China*

[11] The study conducted by the Tsinghua University of Beijing presents an update of the ALGAS study

Realistic sectoral MAC curves could only be constructed for the sectors electricity and rest of industry. In Figure 3.8 the MAC curve for electricity sector is presented.

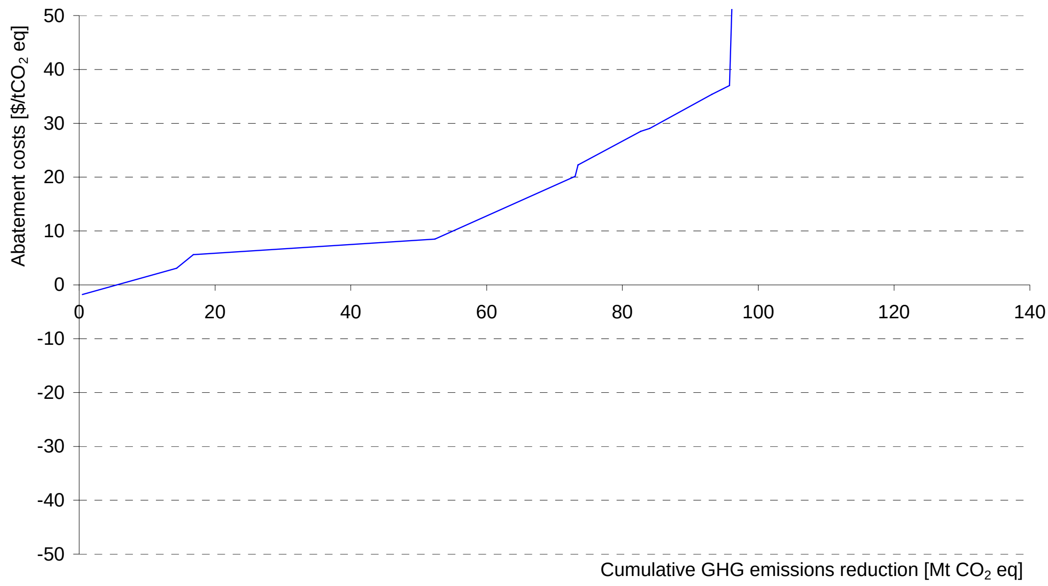

Figure 3.8 *Marginal abatement cost curve for the the electricity-producing sector in China*

Total potential identified in the electricity sector amounts to about 142 MtCO2 eq. Some 32 per cent 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 combustion). There is also significant potential for renewable energy projects, especially biogas and mini hydro, but the abatement costs form a barrier.

Figure 3.9 shows the projected marginal abatement cost curve for the sector 'rest of industry'in 2010. This curve is based on 10 identified reduction options with aggregated reduction potential of 354 MtCO_2 eq.

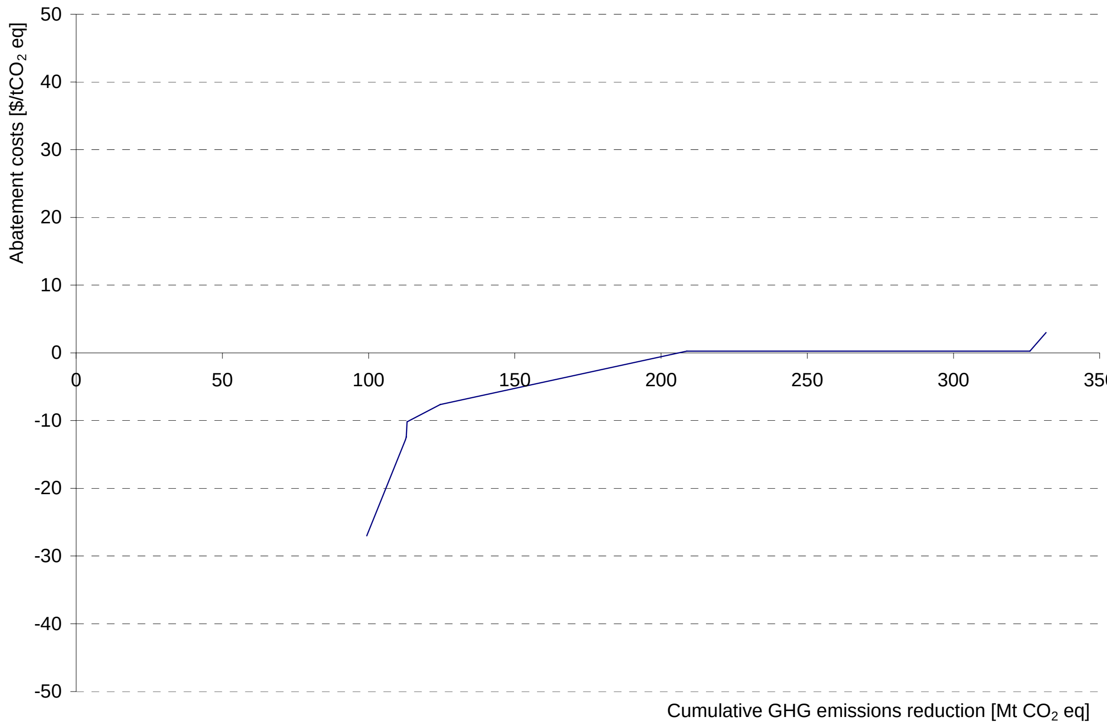

Figure 3.9 *Marginal abatement cost curve for rest of industry sector in China*

3.3 MAC curves for India

3.3.1 Greenhouse gas emissions

India is a major emitter of greenhouse gases. Aggregated emissions in 1994 amounted to 1229 Mt CO2 eq (excluding fluorinated gases; see Table 3.3), 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 live stock (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 CO2 emissions was emitted by 100 largest stationary sources. These included 73 power plants, 7 steel plants, 16 cement plants, 3 fertilizer plants and a petrochemical plant.

Table 3.3 *Greenhouse gas emissions in India , 1994*

	CO2 [Mt]	CH4 [Mt]	N2O [Mt]	Aggregated [Mt CO2 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
Commerical	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: India's National Communication, 2004

3.3.2 Identified GHG emissions reduction options

Major options to mitigate climate change under the CDM in India are summarized in Table 3.4 and briefly described below. Most are in the energy sector.

Table 3.4 *Average costs of abatement and national mitigation potential in selected sectors* (based on Pew Centre, 2002, Rana and Shukla, 2001, and ALGAS, 1998). Cost estimates include transaction costs.

	Incremental cost of abatement [$/t CO2]	National potential [Mt CO_2]
Demand-side energy efficiency	2.0 (0-4.1)	132
Supply-side energy efficiency	1.6 (0-3.3)	94
Renewable electricity technologies	2.5 (0.8-4.1)	68
Fuel switching (gas for coal)	3.4 (1.4-5.5)	24
Forestry	2.0 (1.4-2.7)	53
Enhanced cattle feed	0.7 (1.4-8.2)	13
Anaerobic manure digesters	0.3 (0.8-2.7)	7

Supply-side energy efficiency, transmission, and fuel switching

Coal power plant using IGCC (integrated gasification combined cyle) is one of the technologies being explored to improve the efficiency of 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%. Additional benefits of IGCC generated power are reduce emissions of SO2, NOx and 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 CO2 emitted. The option will result in lower SO2 and NOx 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 SO2, NOx and SPM.

Renewable energy
Wind-based power generation (grid-connected). India is a leading nation in wind power production with an installed capacity of 1700MW (CHECK) and a gross wind power potential of 45000MW (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.

*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.

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.

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) convertors; installation of continuous casting lines to maximize yields; reducing energy consumption and using computers.

Continuous pulp digesters in the pulp and paper industry. With an increasing demand for paper and paper products, large pulp and paper plants are expected to be installed during the next two five-year plans. The actual penetration level of continuous digester technology is only 9% of the total installed capacity, but there is a scope for increase to 30%.

Demand-side management: efficient motors. Electricity-intensive industries are textile, chemicals, iron and steel, aluminium fertilizer, cement, paper, non-ferrous, and collieries. It has been estimated that 60%-70% of total electricity consumed by these industries is consumed by electric motors used in applications such as pumps, compressors, fans, and blower, agitators crushers, pulverizers, and conveyors. Types and size vary widely, but AC squirrel cage induction motors are the most common. Since electric motors comprise a single relatively homogenous end-use category, small savings will have a significant potential for energy conservation within the industrial sector.

3.3.3 National MAC Curve for India

Figure 3.10 shows the marginal costs of abatement versus the reduction potential realized across all economic sectors. No options with negative costs have been included in the MAC curve. 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. 130 Mton CO2 eq may be reduced at a cost under 2 $/ton CO2 eq, and 530 Mton for less than 3 $/ton CO2 eq.

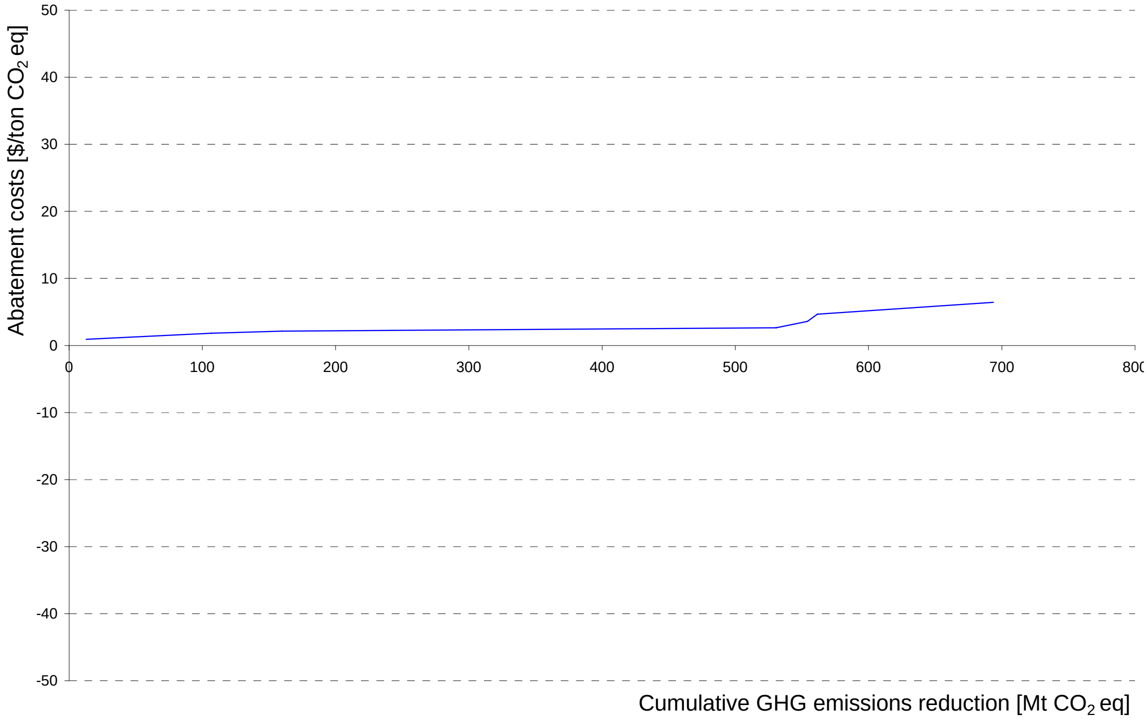

Figure 3.10*Marginal abatement cost curve for India*

3.4 MAC curves for South Africa

3.4.1 Greenhouse gas emissions

Aggregated emissions amounted to 380 Mt CO2 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 3.5 Greenhouse gas emissions of CO_2, CH_4 and N_2O in South Africa, 1994 (South Africa's Initial National Communication, 2004)

	CO2 [Mt]	CH4 [Mt]	N2O [Mt]	Aggregated [Mt CO2 eq]
Energy	288	376	5.9	298
Energy industries	168	0.47	2.6	
Industry	53	6.2	0.78	
Transport	43	11	1.9	
Commercial	0.78	0.07	0.01	
Residential	7.4	0.60	0.08	
Agricultural/Forestry/Fishing	0.48	31	0.53	
Fugitive emissions		327		
Industrial processes	28	1.3	7.3	30
Mineral products	5.3			
Chemical industry	2.0	1.3	7.3	
Metal production	21			
Agriculture		937	51	35
Enteric fermentation		844		
Manure management		78	0.07	
Agricultural soils			50	
Savanna burning		0.61	0.61	
Agricultural residues Burning		0.12	0.14	
Land use change and forestry	-19			
Changes in biomass stocks	-11			
Soil removals	-7.7			
Waste		743	2.7	16
Solid waste on land		722		
Wastewater handling		21	2.7	
International bunkers	10			10
TOTAL (excl bunkers)				380

3.4.2 Identified GHG emission reduction options

A wide range of important 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 mining, the energy sector (mostly electricity generation), the commercial and residential sectors and land use.

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.

Coal mining

Various mitigation options exist in coal mining. For a number of these costs and mitigation potential have been estimated. *Improved combustion technology to burn discard.* 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.

Catalytic combustion of methane. 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.

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 significant 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.

Energy sector
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%.
Substitution of coal with gas in synthetic fuel production. In the synthetic fuel production industry, the substitution of 10% coal consumption with natural gas would resulting a total reduction of 168 Mt CO2 eq (World Bank, 2002).

Super-critical coal. There is considerable potential to reduce CO2 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, 1995).

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

Commercial and residential sectors
Direct GHG emissions in these sectors are substantially less than those from the energy sector. Therefore there is not a huge potential for reducing emissions through CDM projects. However, despite not having the potential to reduce huge volumes of GHG emissions the options, which relate to energy efficiency measures or fuel switching, offer manageable and in many cases, cost effective options (
). Collectively they could provide significant CO2 emission reduction opportunities. 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.

Land use
Various mitigation options exist in the agricultural and land use sector (
). However, for a number of these (animal management, manure management, fire frequency control, reduced tillage and burning of agricultural residues) sources are dispersed over a wide area, which creates difficulties for maintaining a consistent and acceptable level of emission verification and subsequent certification. This will significantly increase transaction costs per tonne of CO2 reduced

Table 3.6 *Identified GHG emissions reduction optionsin Soutg Africa.* Only options for which reduction potential and costs could be quantified with some certainty have been included (World Bank, 2002). Abatements costs include the costs for transaction.

Mitigation option	Potential	Costs

	Mt CO2/yr	$/tCO2
Combustion of discard coal	0.79	-117
HVAC retrofit	1.37	-20
Efficient new HVAC systems	1.67	-20
Electricity to natural gas	0.6	-19
New building thermal design	2.67	-17
Lighting retrofit	0.7	-17
New lighting systems	0.53	-17
VSDs for fans	0.53	-17
Efficient use of hot water	0.73	-12
Efficient lighting practices	0.6	-12
Replace incandescents	0.37	-12
Heat pumps for hot water	0.63	-10
Heat pumps	0.67	-8.8
Catalytic combustion of methane	5.67	0.4
Hot plate to gas cooking	0.17	1.2
Gas-coal substitution for synfuel feed	5.8	1.6
Paraffin to gas cooking	0.07	2.3
Efficient wood/coal stove	0.17	2.4
Super-critical coal	3.63	3.3
Insulation of geysers	0.83	6.1
IGCC power generation	4.37	6.2
Hybrid solar water heaters	2.93	16
Fuel to natural gas	0.43	17
Electricity to gas space heating	0.83	22
Solar water heaters	0.07	31
Solar water heating	0.73	33
Distributed wind generation	0	34
Solar home system	0.07	51
Improved mining operations - ashfilling	0.02	534

3.4.3 National and sectoral MAC curves for South Africa

The Figure 3.11 to Figure 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, and in the household, electricity and rest of industry sectors respectively.

Up to 17 Mt CO2 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 and efficient use thereof; 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 $/t CO2 eq is around 34 Mt CO2 eq. Insulation of geysers in the household sector is such an economical reduction opportunity. Super-critical coal plants and power generation in integrated gas combined cycles are cost-effective options in the electricity sector. In industry, options at a cost under 10$/tCO2 comprise the catalytic combustion of methane from mining operations, and the replacement of coal by natural gas in the production of synthetic fuels.

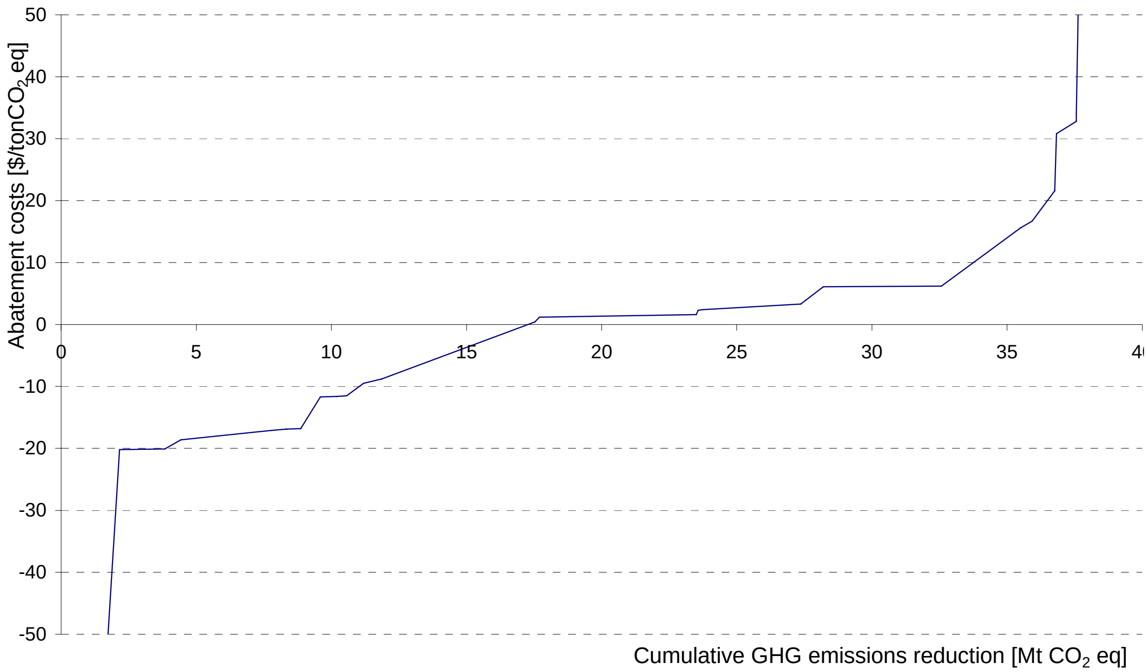

Figure 3.11*Marginal abatement cost curve for South Africa*

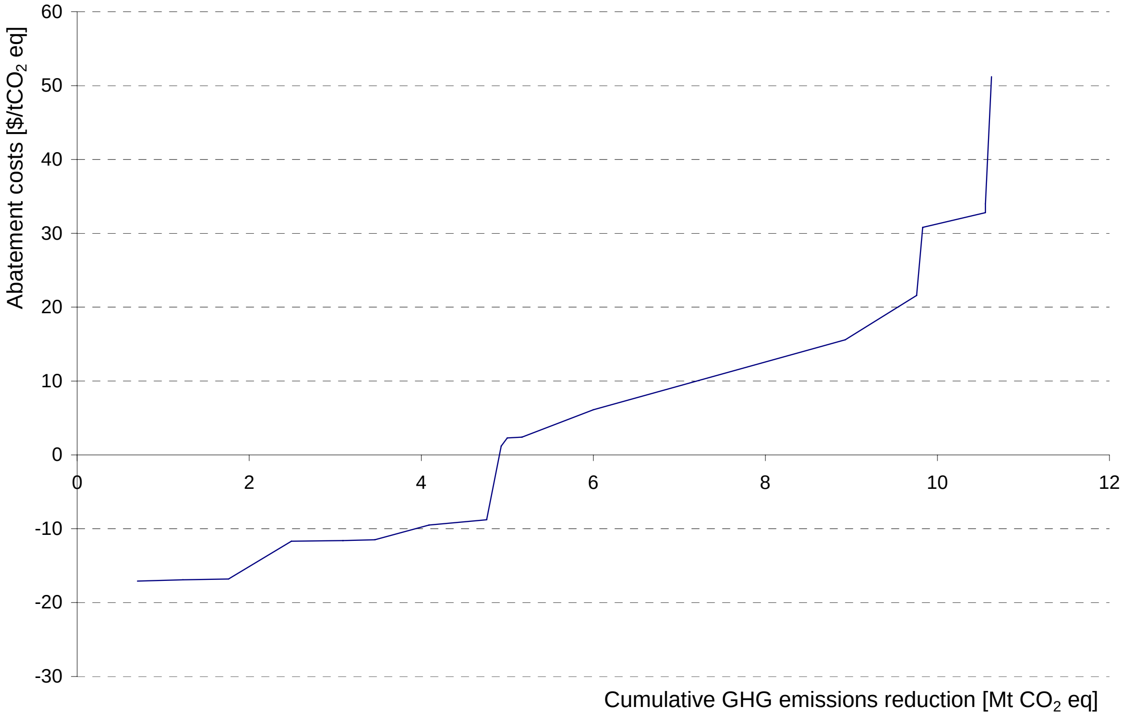

Figure 3.12*Marginal abatement cost curve for households in South Africa*

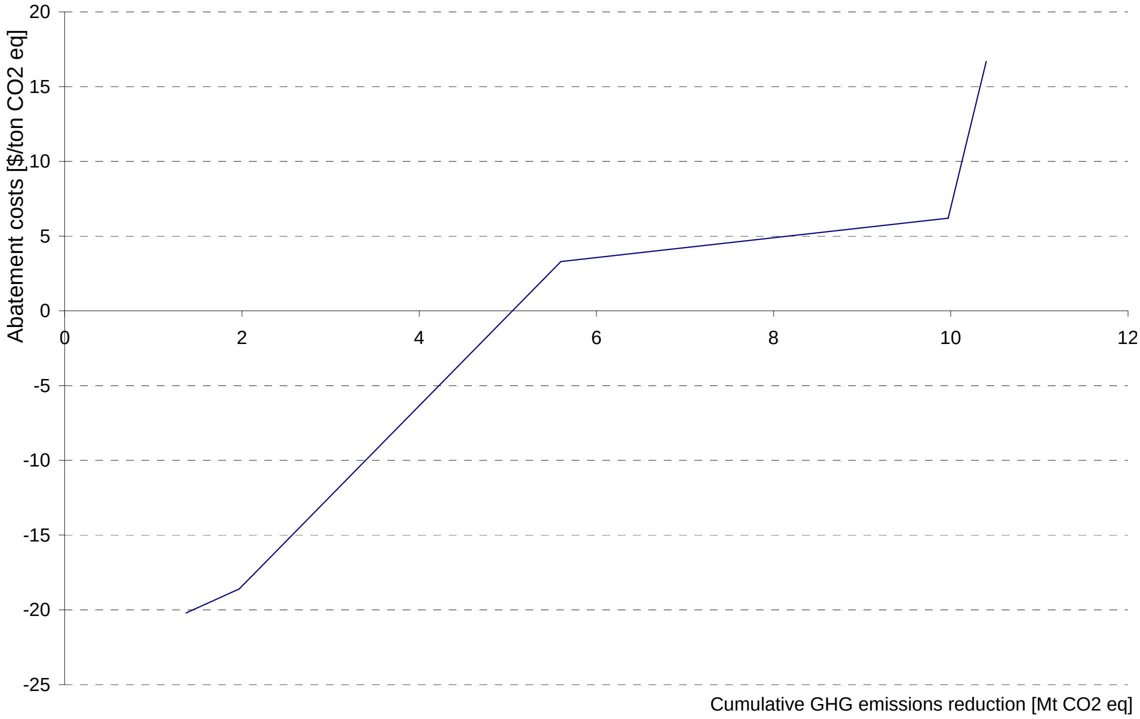

Figure 3.13*Marginal abatement cost curve for the electricity-producing sector in South Africa*

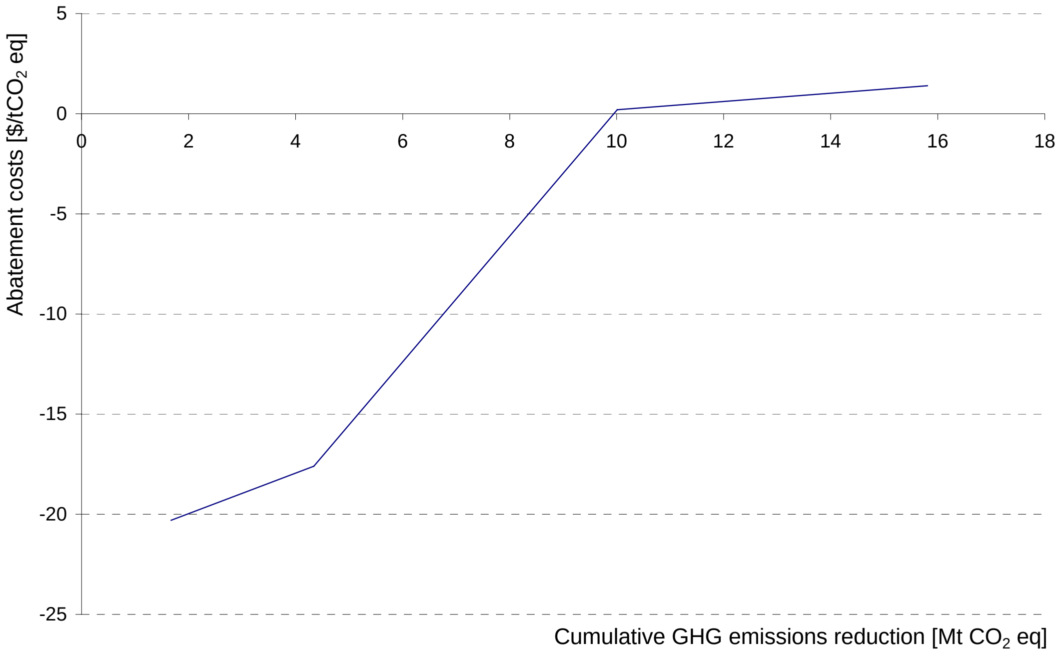

Figure 3.14*Marginal Abatement Cost curve for rest of industry sector in South Africa*

3.5 MAC curves for Brazil

The MAC-curve for Brazil has been derived from only 5 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, this finding does not serve as an eye-opener. 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 3.7 *Greenhouse gas emissions of CO2, CH4 and N2O in Brazil, 1994 (Brazil's Initial National Communication, 2004)*

		Brazil
Data by sector	[Mt CO_2 eq]	
Energy		247716
Industrial processes		21273
Agriculture		369311
Waste		20676
LULCF		818080
Total		*1477056*
Data by gas	[Mt]	
CO_2 (with LUCF)		1029706
CH_4		238728
N_2O		166873
Total		*1435307*

Table 3.7 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 5 options have been identified from different sources. The potential and costs of these options are presented in Table 3.8 for the sectors agricultural products & forestry and electricity.

Table 3.8 *Identified GHG emissions reduction options for Brazil in 2010*

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

With Brazil's enormous forest resources and the present emission scenario's 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.[12] 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 tonne CO_2. It should be noted these abatement costs heavily depend on land prices. However, as Seroa de 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 MtCO2 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 et al. (2000) note, cogeneration is viewed as a political priority, because it has a significant scope for expansion. Regarding wind power, Chandeler et al. (2002) indicate 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

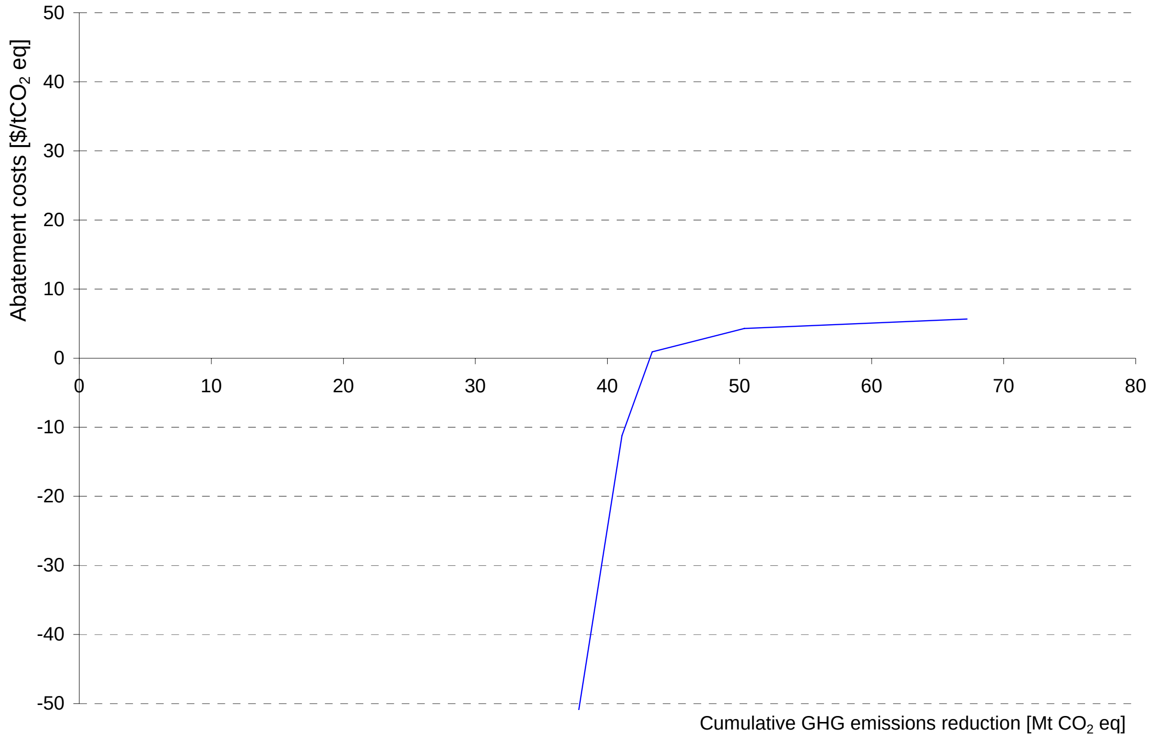

Figure 3.15*Marginal Abatement Cost curve for Brazil*

3.6 MAC curves for Rest of Central & South America

[12] According to estimates from IPAM, a research institute based in Belém, Brazil

The MAC curve for Brazil presented in Chapter 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 presented in figure 3.16.According to the World Bank, the remaining 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, Venezuela.

Information for current GHG emissions could be obtained from 19 'National Greenhouse Gas Inventories' that estimated net anthropogenic GHG emissions classified by sectors and by gases. Information about GHG reduction options has been collected from national abatement costing studies for the following countries: Argentina, Bolivia, Ecuador, Colombia and Mexico. These countries account for roughly 72 per cent of total GHG emissions in the Rest of Central and South America region.

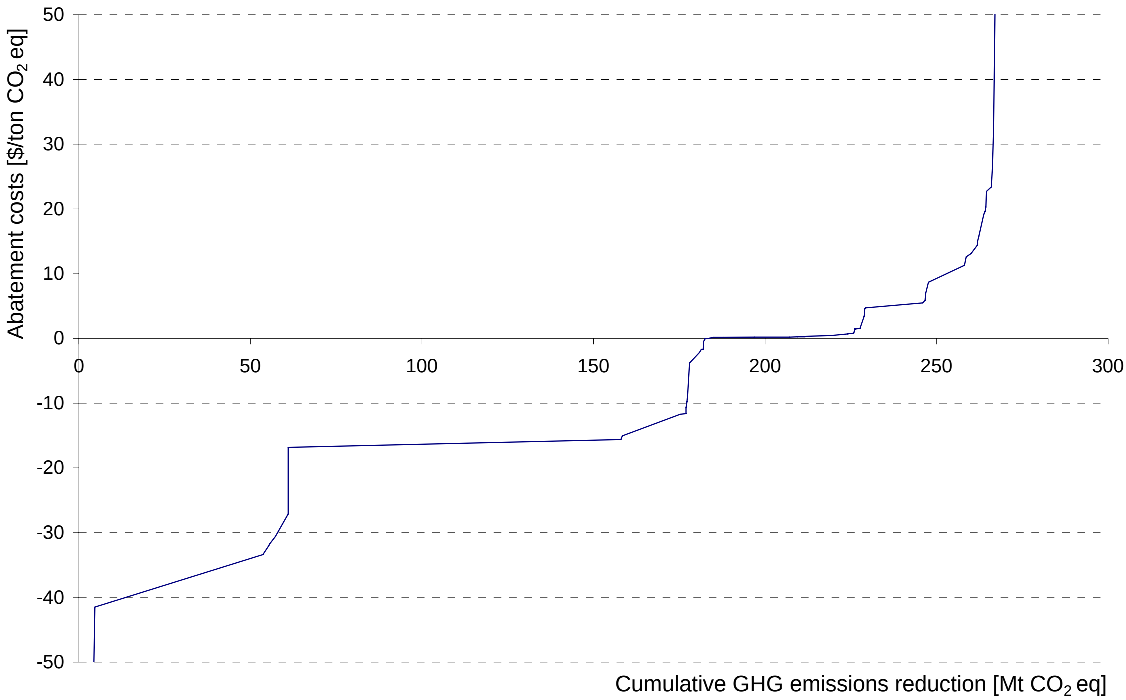

Figure 3.16 *Extrapolated Marginal abatement cost curve for rest of Central & South America*

Again, 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.

The forecasted GHG marginal abatement cost is presented in Figure 3.16. It should be noted that the projected GHG abatement potential for the six countries (Argentina, Bolivia, Ecuador, Colombia and Mexico), is extended to the remaining countries in the Rest of Central and South America region. For that purpose, the above mentioned extrapolation factor of 1.4 has been used. The total abatement potential in the Rest of Central and South America region in the year 2010 is estimated at roughly 270 $MtCO_2$eq. Approximately two third of this potential can be achieved at net negative costs.

3.7 MAC curves for Rest of East South Asia

The MAC curves for China and India presented in Chapters 3.2 & 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 for current GHG emissions could be obtained from 18 'National Greenhouse Gas Inventories' that estimated net anthropogenic GHG emissions classified by sectors and by gases. Afghanistan and Myanmar have not conducted such an inventory yet. Information about GHG reduction options has been collected from national abatement costing studies for the following countries: Indonesia, Myanmar, Mongolia Philippines, Thailand Vietnam Bangladesh, Pakistan and Sri Lanka. These countries account for roughly 70 per cent 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 3.9 shows that the energy sector in Indonesia contains the largest share, namely 69%. Furthermore, table 3.9 shows that the energy-related GHG-emissions are comparatively low in Bangladesh and Vietnam.

Table 3.9 *GHG emissions by sector and by gas for seven countries in the region Rest of East south Asia*

	Indonesia	Myanmar	Philippines	Thailand	Mongolia	Vietnam	Bangladesh	Pakistan	Sri Lanka
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*

3.7.2 Identified GHG emissions reduction options

In total, 115 reduction options have been identified from different sources. Reduction options with a emission reduction potential larger than 1 Mt CO_2 in 2010 are presented in Table 3.3 for the sectors agricultural products & forestry, electricity, households, rest of industry, transport and crude oil. This paragraph covers general information about the most familiar mitigation options in the region. The GHG emissions reduction option analysis is focused on four sectors: forestry, electricity, households and rest of industry.

Forestry
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, see also Table 3.3

Electricity
A diverse range of options were 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
Numerous options exist in the Rest of East South Asia that reduces energy consumption on the demand site. Table 3.3 presents the most relevant and feasible energy efficiency options like higher efficiency lighting and higher efficiency household electrical appliances All 29 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 3.10 *Identified GHG emissions reduction options with a emission reduction potential larger than 1 Mt CO_2 for Rest of East South Asia region in 2010*

Mitigation option	Potential [Mt CO_2/yr]	Costs [$/tCO2]
Agricultural products and forestry		
- Planting of protective specialized forests (Vietnam)	12.5	0.7
- Plantation (Indonesia)	2.3	0.8
- Utilization of biogas (Vietnam	1.1	7.8
Electricity		
- Energy conservation (Indonesia	7.0	-60.8
- Co-generation (Pakistan)	5.3	-27.4
- Fuel switch from coal to natural gas (Thailand)	3.0	2.0
- Substitution of oil & coal with natural gas (Pakistan)	11.9	2.6
- Natural gas combined cycle gas turbine (Philippines)	1.8	2.6
- BIGCC (Thailand)	6.7	3.2
- Wind power (Vietnam)	1.3	4.8
- Solar energy (Vietnam)	1.0	6.2

- Further fuel switching from coal to natural gas for power generation: 22% coal; 73% natural gas	3.0	9.3
- Solar energy (Indonesia)	1.4	16.6
- Geo thermal (Indonesia)	7.6	30.8
- Biomass steam power plant (Indonesia)	1.3	45.3
- Wind (Pakistan)	3.3	62.2
Households		
- Incandescent to CFL (Vietnam)	2.1	-25.5
- Use of CFL (Thailand)	1.1	-21.9
- Energy efficient air conditioners	2.0	-6.1
- Energy efficient refrigerators (Vietnam)	3.4	-4.1
- High-efficient Air conditioning systems (Philippines)	1.5	-1.7
- Improving coal cooking stoves	2.8	0.3
Rest of Industry		
- Compact Fluorescent Lamp (Commercial)	4.7	-30.8
- Efficient Industrial motors	3.0	-20.4
- Efficient Boiler	3.9	-15.0
- Energy-efficient boilers	1.3	-10.3
- Cogeneration option in industrial sector	1.8	-8.1
- High efficiency electric motors	2.7	-7
- Improving efficiency of industrial motors	2.7	-7
- Heat Rate Improvement	5.3	-4.9
- Waste heat recovery systems	2.7	-4
- Co-generation & heating system reconstruction in textile industry	1.2	8.8
Transport		
- Hi-Efficiency Transport System (fuel efficiency improvements)	1.3	-2.7
- Energy-efficient engine designs	5.3	11.8
Crude Oil		
- Utilization of flared gas	2.7	1.7
TOTAL IDENTIFIED POTENTIAL (including options with a emission potential less than 1 Mt CO_2 in 2010)	*150.1*	

3.7.3 National MAC curve for Rest of East South Asia region

The forecasted GHG marginal abatement cost 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 Sooth Asia region. For that purpose, the above mentioned 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 roughly 213 $MtCO_2eq$. This potential is more than 400 $MtCO_2eq$ less than the national potential of China. Approximately 44 per cent of this potential can be achieved at net negative costs.

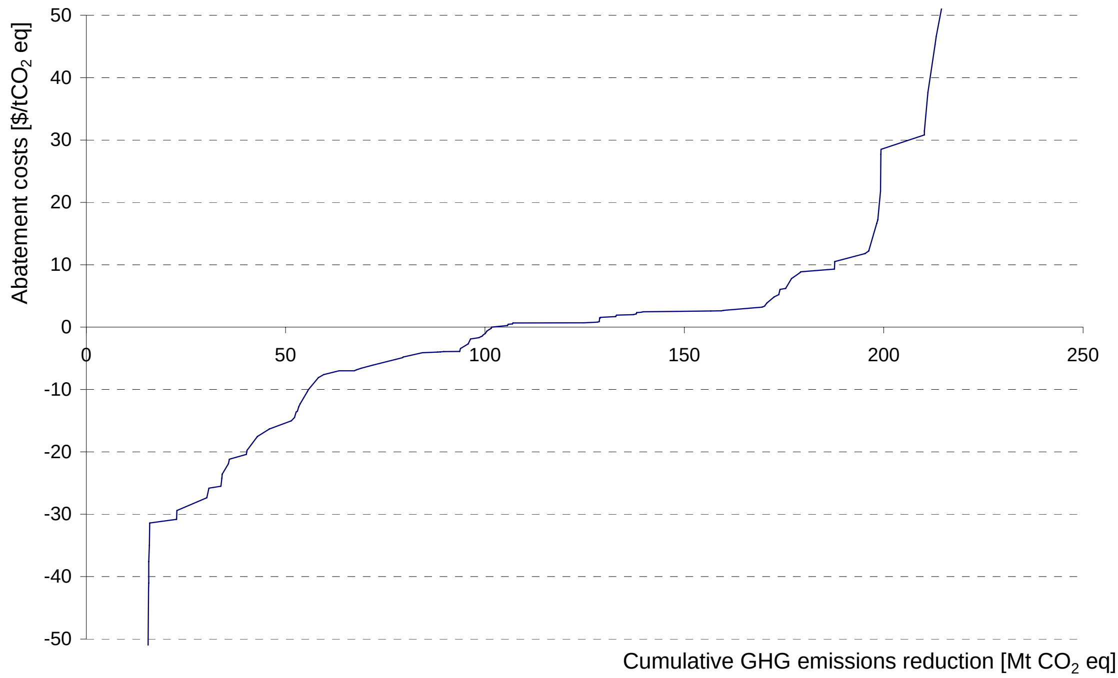

Figure 3.17 *Extrapolated Marginal abatement cost curve for rest of East South Asia region*

3.8 MAC curves for Rest of the World

to be inserted

3.9 Analysis of CDM projects

Table 3.11 *Comparison abatement costs between CDM projects and technology options*

		CDM projects [$]	Country abatement study [$]
Vietnam	Hydro	20	92.5
India	Fuel switch	2-3	3.4
India	Wind	42-46	31
China	Wind	27-102	36.8
China	Biomass	49	35.2
China	Hydro	26	20

The purpose of Table3.11 is to validate the abatement cost curves as shown in the above figures. However, this appears not to be possible because the CDM projects information collected so far is too limited too establish a sound link with the about 383 technology options obtained from the country abatement studies. As is shown in the table, a comparison of cost information between CDM projects and the country abatement studies revealed only 6 corresponding technology-region combinations. No meaningful conclusions can be drawn from this small sample.

4. Conclusions

The analysis presented in the previous chapters was carried out as part of the TETRIS project of 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 per cent of total anthropogenic GHG emissions originating from all non-Annex I countries. In addition, the cost and savings of 60 proposed and approved CDM projects were analyzed and compiled.

In total, more than 400 GHG emissions reduction options have been identified, of which 371 reduction options appear eligible for the CDM. Most reduction options identified are in the power sector (115 options), demand side management options in household sector (105 options), 'rest of industry' sector (86 options), agricultural products and forestry sector (32 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. Only few options have been identified that reduce N_2O emissions and no options are included in the country abatement costing studies for mitigating 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 significant amount of GHG emissions abatement potential exists in non-Annex I countries compared with the Annex I reduction requirements in the first budget period of 800 $MtCO_2$ eq. The estimated GHG reduction potential in 2010 for all non-Annex I countries together up to $ 50 amounts to about 2.4 Gt CO_2 eq. Approximately .9 Mton CO_2 eq is achievable at net negative marginal cost (no-regret options) and about 1.9 Gt CO_2 eq. can be realized at costs less than $ 4 per ton CO_2 eq .The 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. Through the link with the EU emission trading system, it is likely that this market will further expand and is going to play a serious 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 other studies only CO_2 emissions reduction technologies have been examined. 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 economic costs and the project investor may be unable to claim the benefits that accrue to other stakeholders.
- The GHG abatement potential data collected from the country abatement costing studies suggests that a large fraction of total identified abatement potential can be realized in a limited number of non-Annex I countries. The identified potential in India and China already constitutes some 64% of the total identified reduction potential.
- 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 revenues stream from the sales of credits have been realized. However, the transaction costs per unit CO_2 reduction is limited for all technologies except the very small technologies used at household level.

- The information collected from 60 CDM projects to a large extent confirms the above observations. A more detailed comparison of the costs resulted in only 6 corresponding technology-country combinations and no meaningful conclusions could be drawn from this small sample.