Economics of Greenhouse Gas Limitations

MAIN REPORTS

Methodological Guidelines

K. Halsnæs (Lead)

J.M. Callaway

H.J. Meyer

Contributors: J. Fenhann, A. Markandya, J. Painuly, R. Redlinger and J. Turkson

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UNEP Collaborating Centre on Energy and Environment
Risø National Laboratory
P.O. Box 49
DK 4000 Roskilde
Denmark
Phone: +45 46 32 22 88
Fax: +45 46 32 19 99

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1 Introduction

The current guidelines have been developed as part of the GEF project *The Economics of Greenhouse Gas Limitations*. Their aim is to establish a methodological framework for climate change mitigation assessment, with particular emphasis on the needs of developing countries.

The project has included country studies for Ecuador, Argentina, Senegal, Mauritius, Vietnam, Indonesia, Estonia and Hungary and regional studies for The Andean Pact and the Southern African Region.

The guideline document establishes a general overview of the main components of climate change mitigation assessment. This includes an outline of key economic concepts, scenario structure, common assumptions, modelling tools and country study assumptions. The guidelines are supported by Handbook Reports that contain more detailed specifications of calculation standards, input assumptions and available tools.

The major objectives of the project have been to provide a methodology, an implementing framework and a reporting system which countries can follow in meeting their future reporting obligations under the FCCC and for GEF enabling activities. The project builds upon the methodology development and application in the UNEP National Abatement Costing Studies (UNEP, 1994a). The various elements provide countries with a road map for conducting climate change mitigation studies and submitting national reports as required by the FCCC.

Various materials developed by international country study programmes and research activities have influenced the development of these guidelines. One of the main sources of inspiration has been The Second Assessment Report by Working Groups II and III of The Intergovernmental Panel on Climate Change, IPCC (IPCC 1996a, b).

A large number of country study activities, involving climate change mitigation assessments in developing countries, are currently under way. These includes the U.S. Country Studies programme, the ALGAS project conducted by the ADB and UNDP, and a large number of bilateral country study activities including the German GTZ projects, Canadian projects, Dutch projects and studies funded by Overseas Development Agencies in the Scandinavian countries.

A number of co-ordinated international country study efforts have developed and tested mitigation assessment methodologies. Some of the main methodological frameworks have been developed in the UNEP National Abatement Costing Studies (UNEP 1994a, b, c) and in the U.S. Country Study programme (Sathaye & Meyers, 1995). The methodological frameworks developed in these studies involve the use of a common analytical structure, cost concepts, assumptions and scenario concepts. Their strengths and limitations have been discussed extensively in the IPCC Second Assessment Report and in a recent UNEP report on mitigation and adaptation cost concepts (Christensen, Halsnæs and Sathaye, 1998).

Other important background materials for national mitigation assessments include the IPCC guidelines for greenhouse gas inventories and for adaptation and impact assessments.

Policy Issues

1 Policy framework and international initiatives

Climate change is probably the most complex and challenging environmental problem facing policy makers today. Some of the complexities involved include the wide range of greenhouse gas emissions sources and sinks, the long time lags between these emissions and their effects on climate, the global nature of the problem, equity and sustainability issues, and, last but not least, the persistent scientific uncertainties related to climate change.

The Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP), assesses the most up-to-date scientific, technical and socio-economic research in the field of climate change. In December 1995, the Panel published its *Second Assessment Report*. The report states that since the late 19th century, global mean surface air temperature has increased by about 0.3-0.6 degrees Celsius, and that this change is unlikely to be entirely natural in origin. It furthermore indicates that "the balance of evidence suggests that there is a discernible human influence on global climate". Different scenarios developed by the IPCC project that the global mean surface air temperature will rise by between 1 and 3.5 degrees Celsius between 1990 and 2100, with potentially large regional variations.

The IPCC Second Assessment Report examines a wide range of options to reduce emissions of greenhouse gases and to enhance their sinks. These include energy efficiency measures, fuel-switching to less carbon-intensive and carbon-free fuels, measures to enhance sinks or reservoirs of greenhouse gases and the development of new options for reducing methane, nitrous oxide and other greenhouse gas emissions. The report suggests that significant reductions in net greenhouse gas emissions are technically possible and economically feasible.

Truly significant reductions in current net greenhouse gas emissions, however, can only be achieved if a large number of countries take action at the national level, and at the same time collaborate at the international level to reduce emissions. The legal framework for national action and international co-operation in the field of climate change is provided by the United Nations Framework Convention on Climate Change. This convention commits the world community to address the climate change issue by limiting emissions of greenhouse gases, enhancing greenhouse gas sinks and facilitating adaptation to climate change.

The rest of this section is designed to provide the reader with an introduction to the climate-related activities that are ongoing at the international and national levels, as well as the policy frameworks in which they are being developed.

1.1 International climate change policy developments

1.1.1 The United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (FCCC) entered into force in March 1994, less than two years after it had been signed by more than 150 countries during the United Nations Conference on the Environment and Development in Rio de Janeiro, Brazil (June, 1992). It establishes a set of commitments that should contribute to the overall objective of the FCCC which is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Article 2). Guiding principles to achieve this objective include that all Parties to the FCCC should "protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities" and that Parties should "take precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects" (Article 3).

The FCCC specifies three categories of commitments. There are general commitments that apply to all Parties to the FCCC, commitments that only apply to Parties listed in Annex I of the Convention and commitments that apply only to Parties listed in Annex II.[1] General commitments include the preparation and communication of national greenhouse gas inventories; the development and communication of programmes containing measures to mitigate climate change and to facilitate adaptation to climate change; to promote and co-operate in the development, application and diffusion of relevant technologies, practices and processes; and to take climate change considerations into account in relevant social, economic and environmental policies and actions.

Parties listed in Annex I are more specifically committed to adopt policies and to take measures aimed at mitigating climate change, by limiting their anthropogenic emissions of greenhouse gases and protecting and enhancing their greenhouse gas sinks and reservoirs. The articles in the FCCC that apply to Annex I countries also refer to a return by the end of the century to earlier levels of anthropogenic greenhouse gas emissions, with the aim of returning individually or jointly to 1990 levels. These provisions are generally interpreted as a commitment by Annex I Parties to stabilise their greenhouse gas emissions at 1990 levels by the year 2000. Annex I Parties are furthermore committed to communicate information on their climate change policies and measures and resulting projected net greenhouse gas emissions. Most Annex I Parties submitted their first national communication during 1994, and a second round of communications was due in April 1997.

Those Parties listed in Annex II of the FCCC are also committed to providing financial resources to assist developing country Parties in the preparation of their national communications, and to provide financial resources, including the transfer of technology, needed by developing country Parties to meet the agreed full incremental costs of implementing climate change policies and measures.

The first Conference of the Parties to the FCCC (COP-1) was held in Berlin in March / April 1995. One of its major decisions is referred to as the "Berlin Mandate", which concludes that the current commitments of Annex I Parties are inadequate. It initiates a process for the period beyond the year 2000 that focuses on action to elaborate policies and measures and to set quantified greenhouse gas limitation and reduction objectives within specified timeframes, such as 2005, 2010 and 2020. The third Conference of the Parties to the FCCC (COP-3), held in Kyoto in December 1997, adopted a protocol that outlines a general framework for these common actions.

1.1.2 The Kyoto Protocol

In the Kyoto Protocol, Parties in Annex I of the FCCC agreed to commitments with a view to reduce their overall emissions of six greenhouse gases (GHG's) by in average 5 % below 1990 levels between 2008 and 2012. The protocol also establishes an initial framework for emissions trading, joint implementation between developed countries, and a "clean development mechanism" to encourage joint emission reduction projects

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[1] Annex II lists the 24 countries that were members of the Organisation for Economic Co-operation and Development (OECD) at the time of this signing of the FCCC and the EEC. Annex I also lists these 24 countries and the EEC, as well as 12 countries in Central and Eastern Europe and in the Former Soviet Union that are in the process of transition to a market economy.

between developed and developing countries. The Protocol will enter into force 90 days after the signatures of 55 countries, incorporating Parties included in Annex I which accounted in total for at least 55 % of the total Annex I CO_2 emissions in 1990.

The commitments of the Annex I countries are differentiated; the group of countries including the EU, the Check Republic, Bulgaria, Estonia, Romania, Poland, Slovakia, Slovenia and Switzerland shall reduce their emissions by 8 %; USA by 7 %; and Canada and Japan by 6 %. Some countries are allowed to increase their GHG emissions compared to 1990 levels. They include Australia with an 8 % increase, Iceland with a 10 % increase and Norway with a 1% increase. New Zealand, the Russian Federation and the Ukraine are allowed to maintain their 1990 GHG emissions. The GHG's included in the Protocol are CO_2, CH_4, N_2O, HFCs, PFCs and SF_4, and the sectors are energy, industrial process, solvent and other product use, land use, and waste management.

Article 4 of the Protocol states that a group of countries can agree to fulfil their commitments jointly. Joint implementation between Annex I countries is allowed when the reductions are verified to be additional to already adopted reduction policies in the countries. More specific guidelines for verification and monitoring of such reductions will be established during upcoming meeting of the Parties to the convention.

In Article 12 the Protocol establishes a Clean Development Mechanism that should help Annex I and non-Annex I countries to achieve emission reduction and sustainable development goals. Ultimately, the mechanism will require rules for financial and technology transfer in exchange for certified emission reductions. This Article will be specified further at later COP meetings.

Each Party to the Convention and the Protocol are obliged to report regularly on national GHG emissions and reduction policies according to standards defined by the Conference of the Parties.

1.1.3 Incremental costs

One of the key concepts in the FCCC is incremental cost as defined by the FCCC article 4 (3). Incremental costs are by definition the additional cost of undertaking a climate mitigation project compared with the cost of the activity that the project substitutes. Such an activity can for example be power production, where the incremental cost will be measured as the difference between the cost of power production with high and with low carbon emissions. The climate change mitigation project is in this way compared with a non-policy case specifically defined as the baseline case for the purpose at hand.

The FCCC distinguishes between *full agreed incremental cost* and simply *agreed incremental cost. Full agreed incremental cost* compensation is valid in cases where countries undertake new activities that by definition do not substitute other ongoing activities. An example of such activities are the development of national reports to the convention. The *agreed incremental cost* concept, on the other hand, is the relevant concept when a climate change mitigation project substitutes activities in the non-policy case. Such activities can be ongoing production practices as well as future expected development patterns. A *full agreed incremental cost* compensation is meant to cover all costs of an activity while the cost compensation according to the *agreed incremental cost* concept is only meant to cover the difference between running the mitigation project and a baseline case.

The current methodological framework defines an analytical structure and a number of cost concepts that are generally consistent with the incremental cost concepts. It is recommended that countries structure their analysis as a comparison of mitigation and baseline cases, and define the cost assessment as a comparative assessment of the costs of these two cases. The analytical structure and cost concepts are outlined in detail in section *Cost concepts in relation to GHG mitigation*.

1.1.4 The UNFCCC secretariat

To help to fulfil the objectives of the FCCC, the Conference of the Parties has established a permanent secretariat in Bonn, Germany. The Secretariat has two main functions, which are to arrange sessions and prepare supporting documentation for the Conference of the Parties and to facilitate assistance to the Parties, particularly developing country Parties, for the preparation of their national communications. The Secretariat, for instance, organises regional workshops, which offer general information on the FCCC and on the financial and technical assistance available to developing country Parties. Moreover, it has established a number of formal mechanisms to encourage information exchange, networking and training. They include the following programmes:

- *CC:INFO* (Climate Convention Information Exchange Programme). The main objective of CC:INFO is to improve the exchange of information relevant to the FCCC's implementation.
- *CC:TRAIN*. The aim of the programme is to support the efforts of developing country Parties with their implementation of the FCCC by providing training, technical and financial support to the national teams responsible for the preparation of national communications.
- *CC:FORUM*. This is an informal consultative forum among policy-makers from developing countries, countries with economies in transition, non-governmental organisations and multilateral and bilateral agencies.

1.1.5 The Global Environment Facility

The FCCC has designated, on an interim basis, the Global Environment Facility (GEF) as the body entrusted with the operation of the mechanism for the provision of financial resources for projects that address climate change. The GEF was launched in 1991 as a joint international effort to address global environmental problems. It was initially established for a three year pilot phase, and has since been extended in operational phases. It provides new and additional funding to meet the incremental costs of projects and activities in four focal areas (biological diversity, climate change; international waters and ozone layer depletion). These projects and activities are implemented by the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP) and the World Bank.

1.2 The national decision framework

1.2.1 National climate change policy

Reducing greenhouse gas emissions is not an easy task, since in both developed and developing countries the sources and sinks of these emissions are directly tied to key economic sectors, particularly the energy, industry, transport, agriculture, forestry and waste management sectors. Having ratified the FCCC, however, numerous countries now recognise that the threat of climate change is real and that action needs to be taken.

Most developed country Parties to the FCCC have by now developed comprehensive climate change strategies, with policies and measures in all or at least most of the above sectors. While most developing countries also recognise the seriousness of the issue, the limitation or reduction of greenhouse gas emissions is generally not a policy priority for them. Instead, emphasis is placed on economic and social development needs, while environmental policy focuses primarily on local environmental problems. In addition, many developing countries consider, correctly, industrialised countries as being largely responsible for climate change due to their past levels of greenhouse gas emissions. Given also that on a per capita basis current levels of greenhouse gas emissions of developing countries are low compared to those of industrialised countries, it is only natural for developing countries to argue that industrialised countries should pay for the incremental costs of climate change mitigation.

In many cases, however, developing countries have started implementing measures which, while designed for social and economic policy goals, will also contribute to the aim of limiting greenhouse gas emissions. Areas where climate change policy objectives can be achieved simultaneously with social and economic policy objectives include efficiency improvements in energy production and consumption, sustainable agriculture and forest management practices, and increased institutional capacity for sustainable development.

1.2.2 Assistance to developing countries and countries with economies in transition

A number of national governments have launched programmes designed to provide technical assistance to developing countries and countries with economies in transition.

All non-Annex I countries are eligible for support from GEF under Enabling Activities to prepare their first national communication for the FCCC. Most non-Annex I countries are (early 1998) undertaking enabling projects or are in the final stages of preparation. In addition, internationally co-ordinated enabling activities are being carried out by international organisations and country study programmes.

The largest country study programme has been the *U.S. Country Studies Program (USCSP). USCSP* provides technical assistance to countries through workshops, guidance documents and analytical tools, and consultations with technical experts. Of the 55 countries participating in the USCSP, 18 have received assistance in using their study results to prepare national climate action plans.

Another major initiative was launched by the German Government in 1992, when the German Ministry of Economic Co-operation and Development (BMZ) commissioned the *Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)* to set up a programme to help developing countries implement the FCCC. The resultant programme focuses upon drawing up national inventories of sources and sinks of greenhouse gases, as well as strategies to abate emissions. A number of studies have been completed, while others are just about to begin. The programme is scheduled to run until at least the end of 1998.

Similarly, the Danish Overseas Development Agency, Danida has supported capacity building in developing countries. The main focus has been climate change mitigation, but some country studies supported by Danida have also included the establishment of national GHG emission inventories.

One last example of a recent initiative is the Climate Change Studies Assistance Programme, launched in July 1996 by the *Dutch Ministry of Foreign Affairs, Directorate-General for Development Cooperation*. The studies are wide-ranging – including, for example, national inventories of emissions, mitigation and adaptation investigations, and vulnerability studies.

1.3 Beyond national mitigation studies

The present guidelines focus on the definition of main concepts in relation to formal national climate change mitigation assessments. This is one of the important building blocks in the establishment of a national decision process leading up to the implementation of climate change mitigation strategies.

The full development of the national decision process is beyond the scope of the guidelines presented here. National governments, political institutions, non-governmental organisations, businesses and researchers in the countries will be important actors in the establishment of action plans and project implementation in the foreseeable future. The implementation of climate change mitigation policies will also involve large cross-cutting efforts. Because climate change mitigation is already closely integrated in key sustainable development issues, new greenhouse gas mitigation efforts will, in many cases, involve only "incremental" changes to existing development programmes for the power sector, agriculture, forestry, and infrastructure. The success of climate change mitigation efforts will therefore be highly dependent on how well projects can support and be linked to local interest groups and populations as well as to implementing agencies in the sectors concerned.

Some of the key components in the development of a national action plan are therefore (U.S. Country Studies Program, 1996):

- A diverse group of governmental agencies and departments, which should be actively involved in plan development;
- Participation of non-governmental stakeholders (for example, non-governmental organisations, businesses and other representatives of civil society) in the planning process;
- A planning process that identifies and maintains a focus on a well-defined set of objectives;
- Planning that has a practical orientation and emphasises implementation;
- Action plans that are viewed as living documents and are part of an ongoing process to address climate change;
- A planning processes under local control and not driven by the priorities of the donors;
- Increasing awareness of climate change issues, which may be required for a planning process to gain momentum.

Thus the full development of national decisions leading to implementation of climate change mitigation strategies will be a long-term process, during which time the awareness and participation of local stakeholders and decision makers will grow and evolve.

Analytical Structure

1 Basic common country study approach

1.1 Analytical steps

National climate change mitigation studies will vary in coverage, details and sophistication of assessment efforts involved. This is a consequence of different national institutional capacities, analytical tools and statistics. Some countries have participated in other similar study activities and can utilise already implemented models, while others have few experiences in climate change assessment.

The guidelines are purposely defined broadly to enable national analysis to be carried out with different focus and ambitions. A common analytical structure, however, should be followed by all countries. The common steps in this analytical structure are:

1. **Comprehensive evaluation of national social and economic development framework for climate change mitigation**
   - Comprehensive description of national framework for CC mitigation including: base year statistics on GDP structure, social conditions, energy balance, aggregate GHG inventory, major land use activities, population.
   - Evaluation of main national economic and social national development trends and the GHG emissions that are expected to occur as a result of economic development.
   - Overview of other climate change studies including impact-, adaptation-, inventory and mitigation studies.
2. **Baseline scenario projection**
   - 10-15 year baseline scenario projection for CO_2 emissions from energy consumption and land use activities.
   - 30-40 year baseline evaluation of main development trends.
3. **Mitigation scenario(s) projection(s)**
   - Identification of mitigation options related to the most important future sources and sinks sectors.
   - Assessment of reduction potential and cost of mitigation scenarios.
   - Integration of GHG reductions and costs across measures and sectors, through construction of GHG mitigation marginal cost curves.
4. **Macroeconomic assessment**
   - Qualitative description of main macroeconomic impacts of national climate change mitigation strategies.
   - Assessment of key macroeconomic parameters.
5. **Implementation issues**
   - Identification of main implementation requirements including: financial support, technologies, institutional capacity building, regulation policies and further improvements of the national decision framework.

These country study steps can be conducted at many different levels of sophistication ranging from a broad description of main development trends and statistics to a formalised modelling at sector and macroeconomic level.

The focus of the current guidelines is on mitigation assessment at the sector and national levels. Country studies should, therefore, provide an overview of the main national GHG emission sources and sinks in the context of national development programmes and priority sectors as a background for detailed technology assessment.

These basic country study elements emphasise the establishment of a broad overview of the most important national activities related to future GHG development trends as a background for a more detailed assessment of individual mitigation options. The aim is to support a long-term development of national capacity, where climate change mitigation objectives become an integrated part of general national social- and economic development priorities.

1.2 The common analytical structure

The formal mitigation assessment focuses on the assessment of economic costs and benefits and other impacts of implementing climate change strategies in relation to a national non-mitigation policy[2] case, here called the baseline scenario. The guidelines define a common analytical structure broad enough to allow national studies to use different scenario concepts, analytical tools and models.

Ideally, the country studies performed for this (GEF) study should be broadly comparable, i.e.:

1. Each study should follow the same general research steps.
2. Each study should use a common set of cost concepts, definitions, and fundamental structures.
3. Each study should use a common methodology for defining, accounting for and quantifying GHG reductions.

Each country study should use the same *core*[3] type of assumptions, inputs and outputs in developing the baseline and GHG emissions reductions scenarios and their associated projections, but not necessarily the same parameters. For example, each country study will be required to project future population.

The formal analytical structure of the methodological framework comprises cost concepts, prices and discounting principles, scenario structure and a number of technical assumptions.

The common analytical structure of the country studies is shown in Diagram 1.

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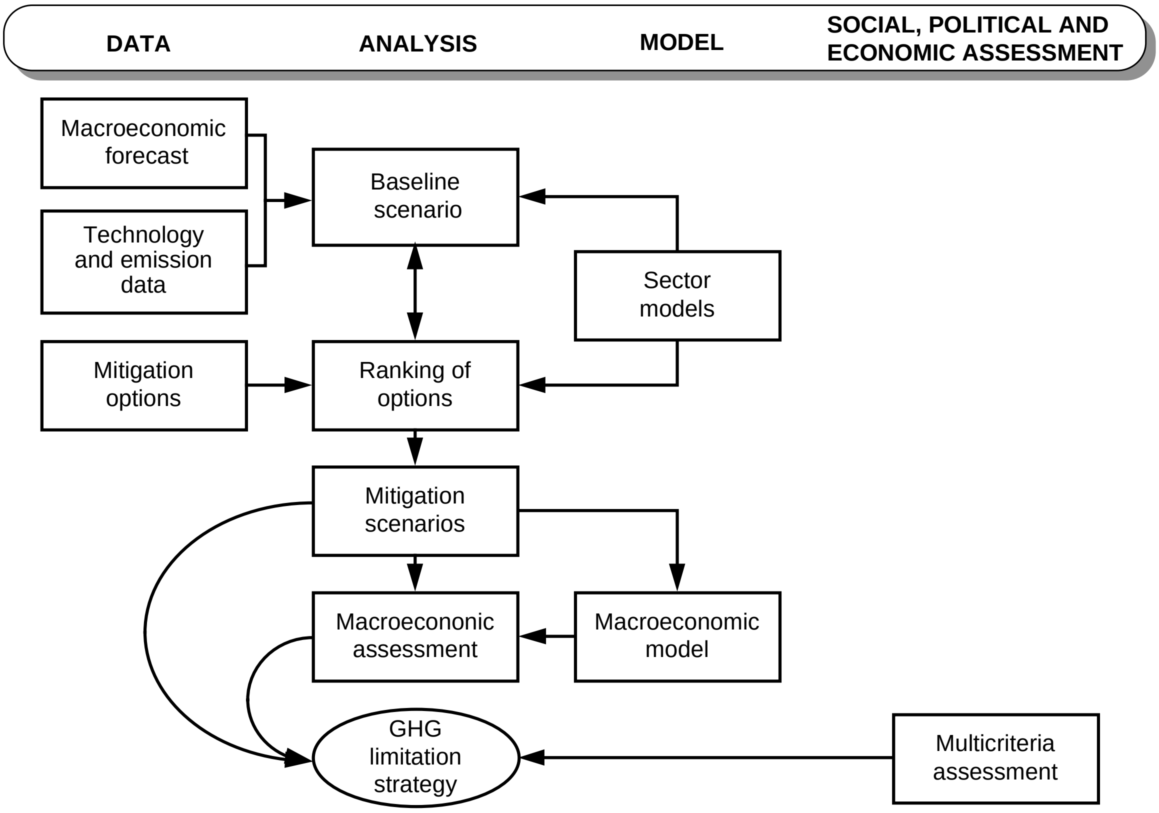
[2] The non-policy case refers to a case where no national climate change mitigation actions are taken.

[3] Since different models and methods will be used in different studies, it is not in general possible to define all of the inputs and outputs that will be common across the various country studies.

Diagram 1 Common analytical structure of the country studies.



2 Formalisation of the national mitigation objectives

National climate change mitigation assessments examine the impacts of implementing alternative projects and policies in relation to future GHG emission sources and sinks. This implies that the assessment must include assumptions on future development trends in GHG emissions, technology and policy options and on the impacts of implementing these options.

2.1 Timeframe of the national analysis

The time frame of national climate change mitigation studies must be long enough to reflect the economic lifetime of major energy supply and infrastructural investments (typically 30-40 years) and the long-term nature of atmospheric greenhouse gas concentration (up to 100 years for CO_2). The development of long-term projections and assessments for developing countries, on the other hand, will be very uncertain and difficult due to fluctuating economic growth and limited statistical data for the development of formalised models. The long-term projections should therefore focus on more aggregate parameters in relation to technological development in the main GHG emitting sectors and to land use patterns. In the short- to medium-term (10 to 15 years ahead) it is possible to develop more detailed national projections on the basis of an assessment of national plans, sectoral assessments and modelling studies.

The common time-frame of national studies includes two focal time steps:

- *Short- to medium-term (focal year 2005/10).* Detailed assessment of main development trends in economic sectors and GHG emissions. Assessment of mitigation options related to end use demand, production and energy supply technologies.
- *Long-term (focal year 2030/40).* Assessment of most import long-term trends in GHG emissions including GDP growth, population, energy requirements, land use patterns, technological progress. Assessment of mitigation options related to new advanced technologies in the energy sector, manufacture and transportation and to major infrastructure projects.

2.2 Mitigation policies and options

National mitigation assessments should consider implementing policies and technological options relating to the most important future GHG emission sources and sinks. The aim is to identify cost-efficient mitigation options that can be implemented in the national context. In that context, mitigation options include technical options related to energy systems, transportation etc., while policy instruments include the policy actions used to introduce and encourage these options. Specific types of policy instruments, like carbon taxes, can be viewed either as GHG reduction options in their own right as the approach of top-down models or as a policy instrument for achieving various technical options.

It is not the purpose of the current framework to cover a full menu of technical options in the sectors. It is, instead, recommended to select a portfolio of options that include:

- *short-term reduction options* related to end-use energy demand and efficiency improvements, forest management practices, small-scale renewable technologies, efficiency improvements in conventional power production etc.
- *long-term reduction options* as for example power production technologies, infrastructure projects and transportation policies.
- *large scale investment projects* as well as *demand side projects.*

The aim is to assess the cost-effectiveness of national reduction options. This means that the mitigation potential and cost should be assessed for individual options and policy packages. The idea is, in this way, to construct a number of national scenarios for alternative emission reductions targets for different time frames. The projections associated with these scenarios– projections of GHG reductions, costs, and associated measures of cost-effectiveness – are what will be used to assess the different options and to make cross-sectoral and cross-country comparisons in the mitigation assessment.

One important result of a bottom-up mitigation assessment is the marginal cost curve of GHG emission reduction where the marginal costs of options are depicted in ranking order. An example of such cost curves is shown in Figure 5. A more detailed discussion about how one constructs these types of cost curves is given in Section 1.8 Reporting of quantitative project impacts.

The individual country study teams may find it useful to organise their studies around *ranges* for reducing GHGs. This is not intended to imply that a country is committed to any set of GHG reduction targets, but is rather a useful organising principle for the country studies in developing the various mitigation options and policy instruments. The GHG reduction ranges can be expressed in terms of percentage reductions in net GHG emissions (net emissions = sources - sinks). They can be defined for several different ranges, from small to large, to ensure that the country study includes the widest possible range of reasonably achievable emissions reductions. GHG reduction ranges can also be defined for specific points in time, as follows:

- *Short- to medium-term focal reduction ranges.* The assessment can for example consider about 10% to 25% reduction ranges in relation to baseline emissions in 2005/10.
- *Long-term ranges.* The assessment can for example consider reduction ranges amounting to up to 30%-50% reductions of baseline emissions in 2030/40.

3 The development of baseline and mitigation scenarios and projections

3.1 National scenario concepts

National mitigation assessment should consider the impacts of implementing climate change mitigation strategies in relation to a "business-as-usual" baseline projection in which there are no policies in place designed explicitly to reduce GHG emissions. Thus, the baseline projection will be generated using a set of assumptions that would depict the expected pattern of economic development, as currently formulated in formal government plans, or as interpreted through current governmental policy objectives. This baseline projection is used to assess the "sacrifices" of allocating *additional* resources to mitigation policies compared with the non-policy case. The non-policy case will in the following be termed as the baseline scenario

Climate change mitigation involves the implementation of *individual projects, sectoral strategies and comprehensive national action plans*. To the extent possible, this should also include the assessment of various policy options for achieving these options. The assessment involves a systematic comparison of the mitigation- and the baseline scenario and these two scenarios should therefore be constructed on the basis of consistent assumptions.

Major scenarios include:

- Activity projections for main GHG emitting sectors and sinks. For most countries, this will include the energy sector, industry, transportation, agriculture, forestry, other land use activities and waste management.
- Technological development related to the main GHG emitting sectors and sinks.
- Technological development related to mitigation projects.
- Market behaviour and implementation aspects related to mitigation projects.
- Another set of assumptions should be defined for alternative sensitivity cases. These include assumptions on technology costs, discount rates, fuel prices and other international background parameters.
- Alternative policy instruments for achieving sectoral and national level goals.

In the case of national analysis, the scenario assumptions should reflect the decision problem facing the individual country given a set of assumptions on economic development and mitigation efforts in a broader international context. Most individual countries will not significantly influence international development trends in fuel prices or economic growth through their mitigation efforts, and international scenario assumptions can therefore in most cases be assumed exogenous to national baseline- and mitigation scenarios.

The mitigation assessment can consider individual projects, sector strategies and cross-sectoral national strategies. Baseline definitions should be defined in accordance with these aggregation levels. Scenarios can, following that, be defined at *project, sector* and *national* level.

Project assessment considers the implementation of individual mitigation projects. A baseline case will in this case be defined to show how the same activity would develop without the mitigation project.

Sector assessment considers the total impacts of implementing either a large number of mitigation projects in a sector or making structural changes to the system, such as large-scale fuel-switching. The technical potentials and costs of individual mitigation projects are in many cases interdependent and the project impacts should therefore be assessed at sector level. A very straightforward example is electricity savings where the GHG reduction associated with specific options depends on the electricity supply system which at the same time is an integral part of the mitigation potential considered. Similarly the potential benefits of reduced electricity demand depend on production costs of the electricity supply system. Sectoral models for the system as a whole represent a preferable approach. Sectoral assessments should also include efforts to evaluate different types of policies to achieve sector-level goals.

National assessment focuses on the total impacts of implementing mitigation projects and system changes in one or more sectors. The focus should here be on the wider sectoral and macroeconomic impacts such as land allocation, capital and foreign exchange demand, trade, employment, consumption, production, and other macroeconomic impacts. National assessments should also include efforts to evaluate different types of policies to achieve sector-level and national goals.

3.2 Baseline scenario and projections

As previously stated, the assumptions that are used to define the baseline scenarios should assume that the government has not instituted any policies specifically to limit GHG emissions. Since climate change mitigation is not among the key national social and economic development priorities of developing countries, the participation of developing countries in global climate change efforts must be structured in a way where main national development priorities can be fulfilled alongside the implementation of mitigation strategies. Thus, national baseline scenarios should reflect national development priorities assuming climate change mitigation is not an objective as such. The mitigation assessment that follows will consider the cost and other impacts of integrating mitigation policies in broader national development programmes.

The baseline scenario assumptions should be developed to reflect the costs of climate change mitigation in relation to a non-policy case. The assessment involves a comparison of GHG emitting activities in the mitigation- and baseline scenarios. The assumptions on technological development, sectoral production practices and cost parameters in these two scenarios have major implications on the assessed mitigation potentials and costs.

3.3 Baseline typology

Cost is always measured as an incremental cost relative to a given baseline case, and the costs are, therefore, to a high degree, given by the assumptions underlying such baseline cases. Baseline definition is following that one of the most critical issues in mitigation costing studies.

Three main typologies of baseline definitions are:

1. The economic efficient case
2. The business-as-usual case.
3. The most likely case.

The economic efficient case reflects what in economics is called efficient resource allocation. The economy is here assumed to utilise all production factors efficiently implying that the implementation of mitigation projects always will imply economic losses (costs).

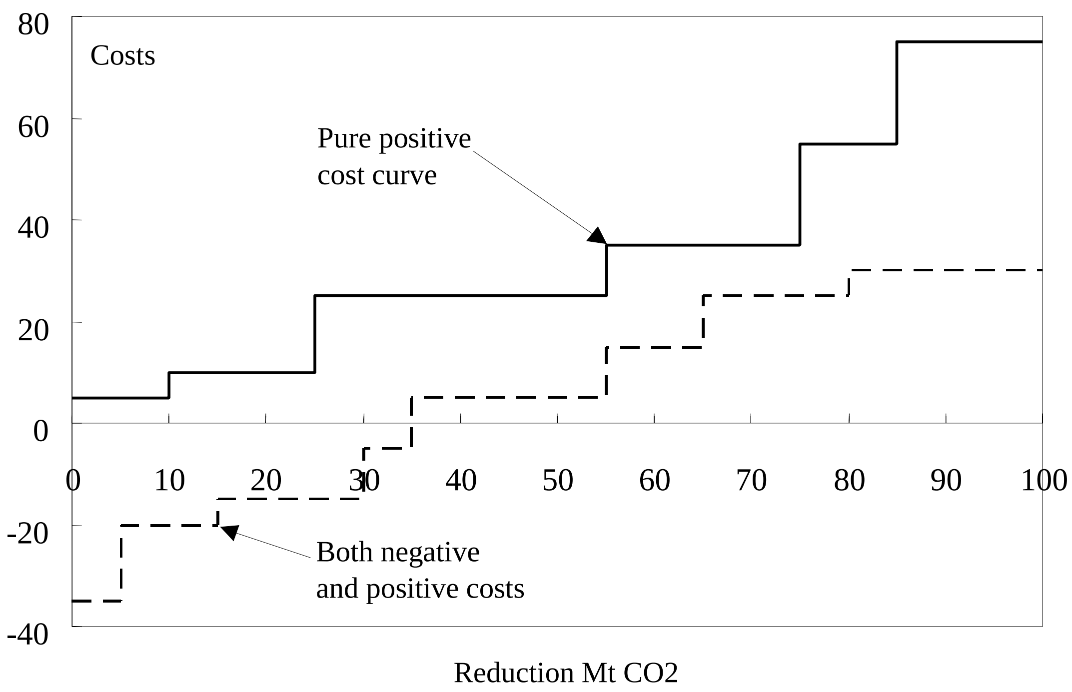
The business-as-usual case. The baseline case is here constructed as a continuation of current trends. It can for example be that the structure of energy supply systems, agricultural production and other land use activities with the exception that already approved sectoral development plans are integrated in the baseline scenario.

The most likely case is the compromise between *The economic efficient case* and *The business-as-usual case.* This implies that the most likely case can include assumptions on a gradual transformation to market liberalisation policies and other adjustment programmes.

The business-as-usual case and *The most likely case* are both reflecting a state of the economy, where markets and institutions do not behave perfectly (according to the principles of efficient resource allocation). No-regret mitigation options (defined as climate change mitigation options with negative costs) will in these two latter cases exist if it is furthermore assumed that it is possible to identify policies that have the ability to correct these market and institutional failures without incurring larger implementations costs than the benefits incurred (IPCC 1996b, ch. 8; Halsnæs et. al 1994; Halsnæs, 1996).

The implication of alternative baseline definitions on mitigation costs is illustrated in Figure 1.

Figure 1 Examples of a cost curve with both negative costs (no-regret options) and positive costs, and a cost curve with only positive costs.



3.4 Discussion of major baseline assumptions

Baseline scenarios have often in energy analysis been understood in a very simplified way as “business-as-usual” scenarios where a continuation of existing trends and structures have been assumed. The “business-as-usual” concepts implicitly limits the analysis to be strictly linked to the present characteristics of economic development and technical systems.

Future development trends can also, in the baseline, be seen as an “open decision framework” in which present trends can give some guidance on the consequences of current practices but do not determine policy choices. In this case a baseline scenario aims at reflecting alternative economic, social and environmental development trends and priorities. This explorative approach to baseline construction is especially relevant to apply for long time horizons, where economic and technological development allow major structural changes to take place. The scenario construction will in this case typically include more than one baseline. IPCC highlights the following major long-term scenario assumptions for developing countries: economic growth, population growth, urbanisation, land use changes, infrastructural investments and development of the economy of the informal sector (IPCC 1996b, ch. 8).

A crucial assumption in baseline definition relates to the efficiency of energy markets and other markets of importance for the main GHG emission sources and sinks. An incremental cost assessment at project and sector level implies that baseline activities are compared with new efficient technologies and practises. It means that a baseline projection which embodies activities that do not meet a pure economic efficiency criteria will have a tendency to lead to the assessment of low or negative mitigation costs.

Many examples can be found in developing countries of economically inefficient technologies relating to end-use sectors, power plants, industrial plants, transportation etc. Such technologies will, if compared with new economic efficient mitigation projects, end up with the assessment of negative or very low mitigation costs. This phenomena is sometimes described as the “efficiency gap”. Such an “efficiency gap” is interrelated with general development problems in these countries including market imperfections and constrained capital and foreign exchange.

A baseline projection for 30-40 years as suggested here needs to consider the likeliness of a persistent “efficiency gap” over this long time horizon. The high level of economic growth rates, amounting to more than 3 % per annum to be expected for many developing countries implies large scale investment programmes to be undertaken in the countries. This means that present “inefficient” technologies in place will be of minor importance compared with new projects. Consequently, the baseline projection involves a large degree of freedom in the choice of assumptions of how economically efficient future technologies will be.

Future implementation of technologies that do not meet a pure economic efficiency criteria can be explained in different ways. The narrow economic explanation would be that the markets are distorted and barriers exist. Another explanation could emphasise broader cultural, social, environmental and political reasons for not following a narrow economic efficiency paradigm to project the implementation of new technologies. In conclusion, the baseline should entail explicit assumptions about activities and technologies related to main projects to be analysed in mitigation scenarios. These assumptions should, in addition to cost and efficiency parameters, include parameters relating to non-market goods like environmental quality and social impacts.

3.4.1 Inclusion of climate change impacts in the baseline scenario

In making a baseline projection, it may be important to include the impact of climate change on climate sensitive sectors in which mitigation takes place. This is because both emissions reductions and the costs of mitigation can depend on the impacts of climate change. This is especially true for the forest and land use sectors, the agricultural sector, and the energy sector. For example, in the forestry sector a warmer, drier climate in a heavily forested region has the potential to reduce the size of carbon sinks in the baseline scenario, adversely effect the potential to sequester carbon by means of mitigation options, as well as to increase the costs of carbon sequestration.

Projecting the effects of climate change on climate sensitive sectors in the base-line as well as the mitigation scenario requires additional modelling and data that may or may not be available. However, the body of literature on climate impacts in climate sensitive sectors is growing rapidly. I the absence of studies like these, it may be possible to treat climate impacts parametrically, using expert judgements to determine the sensitivity of emissions reductions and carbon sequestration and incremental cost estimates to climate change impacts.

3.5 Sources for national baseline development

Important data sources for national baseline scenario construction are official economic development programmes, environmental development programmes and specific sector planning documents. Such official planning documents should be critically assessed as background material for national baseline construction. This includes an evaluation of consistency, reality and policy implications of the projections.

An important starting point for baseline scenario construction is the assessment of macroeconomic development trends that are connected to the major GHG emitting sectors, as projected under a development path assuming climate change mitigation is not a policy objective. The aim of this macroeconomic assessment is to identify key national economic priority areas and the implications for future GHG emission and policy options.

The availability of macroeconomic plans and formalised models is generally very limited in developing countries, and the existing material typically only covers a time frame of five to ten years. This means that a detailed macroeconomic analysis typically only can be carried out for the short-term while longer term analysis must be limited to an assessment of the main factors connected to future greenhouse gas emissions. This suggests that the baseline scenarios need to include a broader evaluation of short-term economic development policies and should especially focus on sectors where climate change mitigation projects might be integrated.

A large number of assessments and modelling efforts can be valuable inputs in such broad assessments. These include:

- National Development Programs and economic statistical reviews.
- Formalised macroeconomic models (input-output models, macroeconometric short-run models and computable general equilibrium models, CGE).
- National sector plans for the energy system, agriculture, forestry and non-GHG environmental impacts.
- Detailed project assessments carried out in relation to general aid programs.
- Models for the energy sector, agriculture, transportation, forestry etc.
- Detailed site specific assessments of land use activities.
- Implementation studies for specific technical options (including DSM studies for the power sector).
- Broader implementation studies for the financial sector.

As previously stated, it is often the case that the time horizon of official national plans will be no more than five to ten years. This means that a special analysis will be required to extend the projections to cover the longer time horizons we are recommending for mitigation studies. The longer term projections can be more aggregate than the short-term projections, due to lack of information and uncertainty about developments in specific sectors. The focus should be on the main future tends in population, sectoral economic growth and technological progress in parallel with a number of specific development factors. These factors include future development of the informal sector, major infrastructural investments, land use changes and natural resource management. It is, in the long-term, important to assess the main structural changes in the productive sectors and the shift from the informal- to the formal sector of the economy.

3.6 Mitigation scenarios

The national mitigation scenarios serve as a structural framework for assessing the impacts of implementing alternative climate change mitigation policies. These policies include the implementation of individual projects, sectoral strategies and national action plans.

The mitigation scenarios should be based on a screening of potential individual projects for the sectors. A partial but by no means extensive or highly detailed list of main categories of mitigation options is shown in Box 1.

Box 1 Examples of mitigation options in different sectors.

1. Energy sector
- 1.1 End-use efficiency improvements in household, industry, service.
- 1.2 Transmission systems.
- 1.3 Fuel substitution.
- 1.4 Renewable technologies (decentralised).
- 1.5 Supply technologies (centralised): fossil fuels, nuclear and renewable.

2. Agricultural sector
- 2.1 Fertiliser control schemes.
- 2.2 Introduction of crops with enlarged carbon sequestration capability.
- 2.3 Livestock management: Manure treatment, feeding.
- 2.4 Cultivation of rice paddies.

3. Forestry sector
- 3.1 Afforestation projects.
- 3.2 Increasing the carbon sequestration capability of growing forests (increasing biomass density).
- 3.3 Recycling or permanent storage of carbon sequestered in harvested biomass.
- 3.4 Reforestation.

4. Transportation
- 4.1 Efficiency improvements for vehicles.
- 4.2 Switch to fuel systems with lower emissions.
- 4.3 Improve transport system efficiency.
- 4.4 Modal shifts.
- 4.5 Manage transport demand.

5. Waste management
- 5.1 Gas recovery from landfills.
- 5.2 Biogas plants.
- 5.3 Recycling.
- 5.4 Composting.

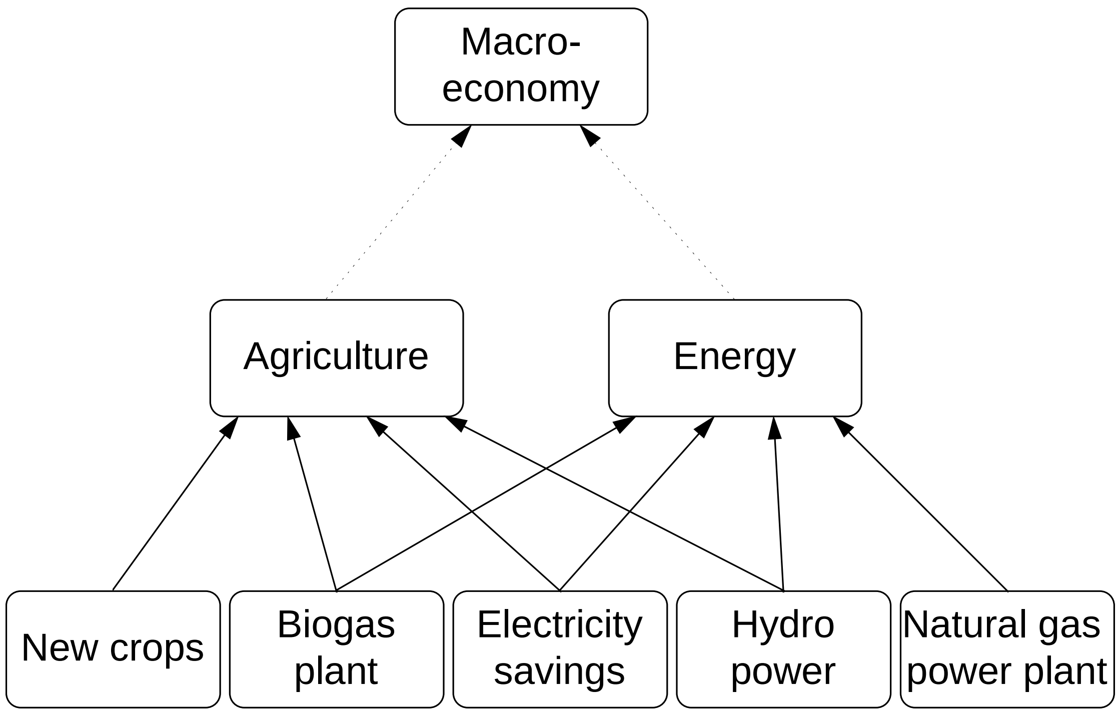
6. Industry
- 6.1 Cement production.
- 6.2 Aluminium production.

National studies should not try to be exhaustive in the selection of mitigation projects in the sectors or across sectors but should rather focus on projects relating to the most important national sources and sinks. The mitigation analysis should, therefore, focus on the assessment of individual mitigation projects for sectors where the mitigation effort can be expected to have significant impacts. Furthermore the selection of projects should as far as possible, furthermore include low, medium and high cost options to provide a general overview of the economic implications of alternative emission reduction targets.

The implementation of mitigation policies will have implications on a variety of parameters including: environmental effects, social impacts, GHG emissions and monetary costs and benefits. The parameters to be quantitatively assessed should be chosen specifically for the project being analysed. The integration of non-economic parameters in the decision process is addressed in more detail in section 1.9.

The GHG emission reduction potential and costs often will be interrelated between projects in one sector and across sectors as shown in the following example (see Figure 2) where a biogas plant and other power production projects are evaluated simultaneously. The GHG emissions reduction potential and cost of the biogas plant are dependent on agricultural input and on the value of residual fertiliser products from the plant. Seen from an energy system perspective the emission savings of the biogas plant depend on the carbon intensity of the emissions from the substituted electricity production. The carbon intensity of these emissions are related to a broad menu of GHG reduction options in the energy sector.

Figure 2 Example on project linkages across sectors.



Consequently, the full assessment of GHG emission reduction and costs for the biogas plant and other power production projects can only be assessed in an integrated way where a full power production scenario is included. An integrated assessment can be done for combinations of projects in one specific sector alone and on a cross-cutting sectoral basis, where a scenario includes options for more than one sector.

Cost Assessment

1 Cost concepts in relation to GHG mitigation

1.1 Introduction

Actions taken to abate GHG emissions or to increase the size of carbon sinks will generally divert resources from other alternative uses. The purpose of the current methodological framework is to estimate the value of the resources which society must give up when an action is taken to mitigate the effects of climate change, as opposed to not taking that action. These resources are measured in relation to a “no action” base case or reference which represent a scenario in which the economy follows its normal development path, without any policies to mitigate the effects of climate change. In this way the cost concept applied is *incremental costs.*

The aim of climate change mitigation activities are to reduce potential damages from global climate change. The damages are related to total atmospheric GHG concentrations independent of the location of emission sources and sinks. National benefits of conducting climate mitigation policies therefore are dependent on the total outcome of internationally co-ordinated policy efforts. In this way national impacts of climate change policies should be assessed in relation to a common international policy goal.

The cost assessment should ideally consider all changes in resources demanded and supplied by a given mitigation project or strategy in relation to a specific non-policy case. The assessment as far as possible should include all resource components and implementation costs. In many cases some of the cost components will be negative, meaning that there are benefits to be gained by undertaking a mitigation action. Both the benefits and the costs of a mitigation action should be included in the estimation. In some cases, the sum of all the benefits and costs associated with a mitigation action will be negative, meaning that society benefits from undertaking the mitigation action.

Mitigation projects will have a large number of different impacts including economic impacts, and social and environmental impacts. Some of these impacts are traditionally measured as economic impacts while others, for example environmental impacts, in some cases are measured as damage costs and in other cases measured as physical impacts. Monetary assessments, following that, will be used together with physical impact measures in a comprehensive decision making framework.

The assessment of economic impacts will be done in monetary units where prices are used to value the different impacts. The prices can for example be market prices or monetary estimates of environmental externalities (See 1.4.2 External cost, private costs and social costs). Physical environmental impacts can be measured in a large number of different units – these impacts will by nature not be directly comparable with the monetary impact assessments.

It is difficult in practice to develop a consistent and comprehensive definition of all important project impacts to be measured. National assessments have therefore in many cases started with a traditional assessment of a limited number of impacts that can be measured in monetary units. This information has then been used as screening criteria for a selection of options that should undergo a more elaborate assessment of broader social, environmental, and political impacts. The danger of this approach is obviously that the “narrow” assessment of economic impacts in monetary units shortcuts the national decision process, ignoring other import impacts.

The aim of this section is to define the main economic impacts to be assessed in the formalised cost assessment. These impacts should, as already been said, be supplemented with the assessment of other important decision parameters. The chapter defines the key concepts to be assessed starting with definition of cost concepts, expanding with broader impacts like environmental externalities and sustainability indicators.

The current framework will focus on the assessment of direct and indirect costs measured at project or sector level. This will be supplemented with a macroeconomic impact assessment as described in section 3 Macroeconomic assessment.

1.2 Cost assessment approach

The cost concepts are, in these guidelines, defined on the basis of traditional cost-benefit analysis as applied in international guidelines for project assessment. The aim of the cost-benefit analysis is to measure the project impacts in comparable units. The term costs is used here to denote negative impacts while benefits denote positive impacts. Benefits, following that, can also sometimes be denoted as negative costs.

It is important to note that social cost-benefit analysis is not a technique, but an approach that provides a rational framework for project choice on the basis of specified national objectives and values. The aim is in this way to integrate the national cost assessment in a broader national decision framework for climate change mitigation.

Social cost-benefit analysis can be carried out in different ways depending on the assumptions applied to the impacts considered. A further development of the cost-benefit analysis is the multiattribute-analysis where monetized costs and benefits as well as other quantitative impacts are considered in an integrated objective function. Box 2 gives an overview of valuation techniques.

Climate change mitigation assessment involves a comparison of broad range of costs, benefits, environmental, social impacts and the benefits of reduced climate change. The assessment of benefits of reduced climate change is by nature difficult and uncertain. The current methodological framework therefore suggests not to include monetary climate change damage estimates but to focus on GHG emission reduction targets (see a more detailed discussion on the issues in section 1.6 Measuring the benefits of reduced climate change). Following that it is recommended to conduct a *cost-effectiveness* analysis (defined in Box 2) where the costs of meeting alternative emission reduction targets are assessed. The current cost assessment framework structures how such a *cost-effectiveness* analysis can be conducted.

Box 2 Cost assessment approaches.

Cost benefit analysis
The basic idea is to measure all negative and positive project impacts in the form of monetary costs and benefits. Market prices are used as the basic valuation as long as markets can be assumed to reflect "real" resource scarcities. It is in other cases recommended using shadow prices. Shadow prices are meant to reflect prices that would occur in a "perfect" market.

Cost effectiveness analysis[4]
A special sort of cost benefit analysis where all costs of a portfolio of projects are assessed in relation to a policy goal. The policy goal in this case represents the benefits of the projects and all other impacts are measured as positive or negative costs (negative costs, with the exception of the benefits of the policy goal, will correspond to benefits of the policy). The policy goal can for example be a specified goal of emission reductions for GHG's. The result of the analysis can then be expressed as the costs ($/ton) of GHG emission reduction.

Multiattribute analysis
The basic idea of the multiattribute analysis is to define a framework for integrating different decision parameters and values in a quantitative analysis without assigning monetary values to all parameters. Examples of parameters that can be controversial and very difficult to measure in monetary values are human health impacts, equity, and irreversible environmental damages.

1.3 Incremental costs

Mitigation costs by definition should be assessed as the costs of following a mitigation strategy measured as the "incremental" change in relation to a non-greenhouse gas policy case – the so-called baseline scenario as defined in III.3 The development of baseline and mitigation scenarios and projections

The rationale for focusing on incremental costs is that the resources demanded by a mitigation activity have an opportunity cost - they are, in principle, taken away from other alternative uses. The prices used to value the specific resource components therefore should reflect their value in best alternative use which either can be reflected in market prices, shadow prices or opportunity costs.

The incremental cost concepts is an integral part of the FCCC (UN, 1992) and is here used to establish a set of principles for financial transfer to non-Annex I countries. The Global Environment Facility following that has used the incremental cost concept in as the financing principle in their Operational Strategy (GEF, 1994).

From a country's point of view there is a distinction between the cost of a project (total or marginal) and the incremental cost. Both concepts are relevant for decision making. The incremental cost concept is the relevant one to reflect social welfare, while the total cost of a project reflects more the financial requirements.

1.4 Outline of the main cost concepts

One can distinguish the assessment of *social- and private costs and benefits*. *Social* costs reflects all costs to society including private costs and externalities, while private costs include only the costs faced by the private sector. Another often used concept is

4 The term cost-effectiveness analysis is sometimes used in more narrow way, where only the financial costs and no indirect positive and negative costs - of a private agent in meeting a specific policy goal is considered.

financial costs which measures expenditures, or outlays, of money seen from the perspective of an implementing entity.

The current methodological framework has been defined with a main focus on social costs.

In this section, a discussion of the full economic cost concept is provided. This is then employed to show the kind of adjustments that need to be made to private costs, in order to derive the economic costs.

1.4.1 Economic opportunity costs or economic costs

The key idea behind an economic cost of something (call it X) is the value of the scarce resources that have been used in producing X. That in turn is measured in terms of the value of the next best thing which could have been produced with the same resources and is called *economic opportunity costs.* This notion of cost may differ from a narrow notion of cost. For example, take the case of sequestering carbon by growing trees on a tract of public land. In estimating the costs of such a programme, what should be taken as the cost of the land? In some cases no ”cost” is attached, because the land is not rented out and no money actually flows from the project implementers to the owner (the State in this case). This, however, is ignoring the opportunity costs. The cost of the land is to be measured in terms of the value of the output that would have been received from that land had it not been used for forestry. Such values may be direct (e.g. agricultural output), and / or indirect (e.g. recreational use).

Often a resource is used and there is a financial flow associated with it. Working with the same example, the government may have leased the land to a farmer, who keeps livestock on it. If it is used for forestry the government often does not demand payment from the forestry authority. In that situation the ”opportunity cost” might be interpreted as a loss of revenue to the government. Although that is an opportunity cost to the government it is incorrect to take it as the *economic opportunity costs.* The reason is that the price of the original lease may not be equal to the opportunity cost of that land. Even assuming that the highest value use is livestock, the value of the land is the *net income* from livestock grazing, after deducting all expenses. Frequently the leases are for much less than that, so the opportunity cost is not equal to the financial flow to the government[5].

The key points of note with regard to opportunity cost are the following:

- there may be an *economic opportunity cost* to the use of a resource even if there are no financial flows associated with that use;
- if there are any financial flows, the *economic opportunity costs* may or may not be equal to the value of those flows.

In designing mitigation cost strategies the objective is to minimise the *economic opportunity costs* of the programme. *Economic opportunity cost* is sometimes called just the *economic cost* and is closely related to *social cost* and is in this context used interchangeably. It is also related to the concept of *shadow price,* both of which are discussed below. For a more complete discussion of these concepts see Markandya, Halsnæs & Milborrow (1998).

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5 It can be shown that, under competitive markets with no taxes, the market price-based costs will be equal to the economic opportunity costs. This is important in the estimation of opportunity costs from market data.

1.4.2 External cost, private costs and social costs

The term *external cost* is used to define the costs arising from any human activity that are not accounted for in the market system. For example, emissions of particulates from a power station affect the health of people in the vicinity but there is no market for such impacts. Hence, such a phenomenon is referred to as an *externality,* and the costs it imposes are referred to as the *external costs.* These external costs are distinct from the costs that the emitters of the particulates do take into account when determining their outputs (e.g. prices of fuel, labour, transportation and energy). Categories of costs influencing an individual's decision-making are referred to as *private costs.* The total costs to society is made up of both the *external costs* and the *private costs* and together they are defined as *social cost.*

Social Cost = External Cost + Private Cost

Estimation of mitigation costs necessitates working with social costs[6]. Often, however, the data will only provide information on the private costs. In these situations a correction has to be made for the missing costs. For further material on external costs the reader is referred to Baumol & Oates (1988), and Tietenberg (1996).

1.4.3 Shadow prices

The above discussion concluded that the proper cost to consider in GHG projects is one based on *economic opportunity cost.* As noted above, where markets operate competitively and efficiently, the prices will reflect the opportunity costs and can be used to estimate the correct costs. In many instances, however, this will not be the case, and some correction will need to be made. The corrected market price, which should be equal to the *economic opportunity cost* of the resource, is called the *shadow price.* One important case of this is related to the change in status from "unemployed" to "employed". A low shadow price can be assigned to unemployed while the market salary rate can be used for employed. The true opportunity cost of employment is then the difference between the two. For example, if a project uses labour that is paid a wage of $20 a day but the benefits of employment are $8, then the true *economic opportunity cost* of that labour is only $12, and the *shadow price* of labour is $12. Adjustments to market prices to obtain shadow prices will be needed when:

- there are distortionary taxes and subsidies, so market prices deviate from economic opportunity costs;
- there are monopolies and other market imperfections making the market price higher or lower than the shadow price.

The simplest way to correct for such distortions, *where the resources are tradable*, is to take the international prices of the resources. Assuming well functioning markets, these prices are seen to be "optimal". If a good is exported, for example, the export price can be taken, or where it is imported the import price can be taken. These prices should then be corrected for taxes and subsidies (i.e. the former should be deducted and the latter added).

Where the good is not traded, the shadow price should be calculated on the basis of the cost of producing the good with the inputs being valued at their economic opportunity cost. A method for doing this has been developed by Little & Mirrlees

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6 Where the pricing of commercial goods is such that it includes both the private cost and the external cost (i.e. it is based social cost) it is referred to as *full cost pricing.*

(1969), Ray (1984), and Squire & van der Tak (1975), and subsequently used by several researchers to estimate shadow prices in a number of developing countries.[7]

A summary of shadow price rules suggested is given in Box 3.

When applying this framework to a project (e.g. wind powered irrigation for increased agricultural yields) three important shadow prices are typically required. They are the prices of:

- Capital
- Labour
- Foreign exchange

For these, detailed analysis of the relevant sectors are required. The price of labour are dealt with in more detail in the report The Indirect Costs and Benefits of Greenhouse Gas Limitation (Markandya, 1998). For capital and foreign exchange, the analyst carrying out a GHG estimation is advised to obtain the relevant values from economists who have worked on the sectors concerned. The World Bank and other bodies involved with Global Environment Facility (GEF) projects appraise projects in most developing countries and would have a set of values that are used; these can presumably be accessed from their databases (as can the shadow prices for many inputs and outputs). For example, in the case of India, the Institute of Economic Growth in New Delhi has recommended a coefficient value of 1.4 for capital, materials and equipment but a value of one for foreign exchange. The value of 1.4 indicates that capital is 40 percent more scarce than its market price would suggest, so that when estimating the costs of the project the capital value should be increased by that amount. A value of one for foreign exchange implies that the exchange rate is in market equilibrium and there is no need to make any other adjustments in going from domestic to foreign prices and vice-versa.

Box 3 Shadow pricing (price correction rules)

Suggested price correction rules:

Tradable goods: International prices of the resources can be used. This approach is based on the assumption that international markets are well functioning.

Capital markets: A shadow price can be based on the marginal return on capital in the private sector. This reflects the return foregone in the private sector by demanding capital to climate change mitigation activities.

Labour: The shadow price can reflect the opportunity cost of the labour in the best alternative use. Skilled labour then should be valued with the current market rate, while unskilled labour should be valued based on the value added of their current activity. The value will in this case be low if the labour is unemployed.

Foreign exchange: The shadow price can here be determined as an index of import and export prices to reflect the value of substituted imports by allocating foreign exchange to mitigation activities.

1.4.4 Baseline definition and opportunity cost concepts

In this way, opportunity costs and shadow prices are reflecting a number of the same issues as inherit in baseline definitions. In the “simple” case, where the baseline is

[7] The difference between using international or national based prices are often referred to as *first* and *second* best shadow pricing corresponding to a first and second best situation.

defined as “the optimal case” (see section 3 The development of baseline and mitigation scenarios and projections) the prices used in the baseline as well as in the mitigation case already reflects opportunity costs and no further price corrections will be needed. If it is assumed that some market failures will persist in the baseline case, the mitigation case should consider this and use price corrections according to the above specified procedures.

Similarly the different price correction rules have important implications for the assessment of no-regrets policies. Many mitigation studies have concluded that there are options that could be implemented with negative or negligible costs. Many economists will argue that such economic attractive options would already have been implemented by the market if they existed. The point, however, is that there can be market failures, which create barriers for the implementation of the options, and these barriers should be addressed in the studies. One way to include implementation policies targeted to remove barriers can be to include costs of barrier removal policies. A framework for assessing these costs are outlined in Section 2 Implementation costs.

1.4.5 Cost assessment levels

The costs assessed at project, sector and macroeconomic level are defined in accordance with the system boundaries outlined in Section 3.1 on national scenario concepts. This means that the assessment at *project level* considers an individual project assuming that this project is an isolated implementation without affecting any other part of the economy. The project assessment also assumes that the project is small and marginal implying that the implementation creates no changes in factor prices or final product prices. The assessment at *sector level* considers a case where a number of mitigation projects are implemented in one specific sector. Technical interdependencies between projects in that sector and impacts on production inputs and final products of that sector are to be included, but the macroeconomic development and other economic sectors are assumed exogenous. The *macroeconomic assessment*, finally, considers the full socio-economic impacts of implementing mitigation strategies in one or more sectors, and the interaction of the different sectors and the economy.

The economic impacts of implementing a climate change mitigation project will imply that the society gives up alternative resource use and final consumption. The “value” of these sacrifices depends on the supply and demand in the related factor and final goods markets. A full assessment of all project impacts is very complicated especially if the project generates non-marginal changes in factor markets or final consumption or if the project has significant indirect impacts. Indirect impacts can be generated in sectors that supplies production inputs or demands final products related to the specific mitigation activity. Significant impacts on other markets or indirect economic impacts can only be completely integrated in the cost assessment in a Computable General Equilibrium (CGE) modelling framework. The development of such a framework is generally very demanding and the section on macroeconomic assessment therefore outlines a framework for a simplified assessment of a number of the key general equilibrium impacts.[8]

[8] The main problems in developing countries are the lack of data for a CGE model and the potential rapid growth and shift between sectors. These two problems together make the output of CGE models for developing countries very uncertain.

1.5 Assessment of broader social and environmental impacts of mitigation policies

Climate change mitigation policies as stated in the introduction will have a number of important impacts additional to those measured in monetary units in the cost-effectiveness analysis. These impacts include indicators that can be measured in physical units and more qualitative information. The following sections will outline a framework for assessing such impacts in relation to employment, income distribution, environmental changes, and sustainability indicators.

1.5.1 Evaluating employment effects of GHG projects and policies

If a project creates a job, this has a benefit to society, to the extent that the person employed would otherwise not have been employed. In other words, the benefits of employment are equal to the social costs of the unemployment avoided as a result of the project. These benefits will depend primarily on the period that a person is employed, what state support is offered during any period of unemployment, and what opportunities there are for informal activities that generate income in cash or kind.

A physical measure of the extent of the employment created is therefore the first task of any project assessment. The data that have to be estimated are:

- the number of persons to be employed in the projects,
- the duration of time for which they will be employed,
- the present occupations of the individuals (including no formal occupation),
- their gender and age (if available).

This physical information should be reported in a summary table for the project, to be used in the selection criteria discussed in section 1.7.2 Quantitative non-monetary information. In addition, however, it is possible to place some money value on the employment, or to deduct from the payments made to the workers the value of the benefits of the reduced unemployment.

Before setting out the framework for such an evaluation, it is important to set out the theoretical reasons for arguing that unemployment reduction has a social value. In neo-classical economic analysis, no social cost is normally associated with unemployment. The presumption is that the economy is effectively fully employed, and that any measured unemployment is the result of matching the changing demand for labour to a changing supply. In this way possibly existing unemployment is viewed as voluntary. In a well functioning and stable market, individuals can anticipate periods when they will be out of work, as they leave one job and move to another. Consequently, the terms of labour employment contracts, as well as the terms of unemployment insurance, will reflect the presence of such periods, and there will be no cost to society from the existence of a pool of such unemployed workers.

However, these conditions are far from the reality in most of the developing countries in which the GHG projects will be undertaken. Many of those presently unemployed have bleak prospects of finding stable employment. In general unemployment is a primary worry among those who are presently employed, and the political pressure not to take measures that will further increase this level is very high.

In these circumstances, therefore, it seems entirely appropriate, to treat the welfare gain of those made employed as a social gain. Traditionally this welfare gains defined as:

(a) the gain of net income as a result of new job, after allowing for any unemployment benefit, informal employment, work-related expenses etc.

\- (b) the value of the additional time that the person has at his or her disposal as a result of being unemployed and that is lost as a result of being employed.

\+ (c) the value of any health related consequences of being unemployed that are no longer incurred.

To calculate the social benefits (the unemployment avoided as a result of the project), one has to multiply the welfare cost (a) minus (b) plus (c) by the period of employment created by the project.

1.5.2 Income distribution and poverty

The impacts of GHG limitation projects on income distribution and poverty are of great importance and merit careful attention and treatment. The main effort has to be devoted to collecting information on which income groups and which sections of the population are affected by the measures proposed. The measures will impose costs as well as benefits and both are important. The breakdown of data on who is impacted need not take the form of household income alone, but could include, for example, rural and urban households, households classified by race etc. A matrix of the distribution of gains and losses is required, classified in the categories that are believed to be important both for a correct estimate of the true costs of the project as well as for a successful implementation of the project. If the analysis fails to identify groups who would lose as a result of the project, but who have the power to block it or to thwart its effective implementation, the whole exercise will be a failure.

The inclusion of data on gainers and losers from the project provides a separate dimension by which the desirability of the project should be judged. This is discussed further in section 1.7.1 Quantitative monetary data on the project. It is also possible, however, to incorporate equity considerations into money measures of social costs by using weights.

1.5.3 Valuation of joint environmental products

While it is appropriate to include the value of the climate change damages avoided as a result of a mitigation option in the cost assessment, there nevertheless may be environmental impacts, not related to climate change, which can be valued in the cost assessment, provided the data are available to do so. If data are not available to do this, it is still important to assess the environmental impacts of a mitigation action and, then, in a subsequent step of the analysis integrate these and other important project impacts with the cost estimate.

Climate change mitigation projects will in many cases have other environmental impacts than decreased GHG emissions. Substituting coal fired power production with hydro power will, for example, result in reduced sulphur and particulate emissions in addition to reduced GHG emissions. On the other hand, hydro power projects have a number of other environmental impacts such as changes in the aquatic ecosystem and biodiversity. The negative or positive values of such joint products should in principle be integrated in the project assessment. It is however difficult to value many of such impacts. The valuation is especially difficult to carry out for environmental impacts that cannot be meaningfully related to market goods (See section 1.7.2 Quantitative non-monetary information for a discussion of physical indicators).

There exists a number of valuation techniques that economists have applied to valuation of environmental impacts. They all try to assess values in a sort of “market evaluation framework”(IPCC 1996b, ch. 5). An overview of such market valuation approaches is given in Table 1.

Table 1 Market valuation approaches related to environmental impacts

	Conventional market	Implicit market	Constructed market
Based on actual behaviour	Effect on production Effect on health Defensive or preventive costs	Travel cost Wage differences Property values Proxy marketed goods	Artificial market
Based on intended behaviour	Replacement cost Shadow project		Contingent valuation

Source: IPCC, 1996b, Box 5.3.

The valuation techniques listed in Table 1 can be illustrated in relation to a case example where the impacts of acid emissions from a power plant are valued. A conventional market valuation could consider preventive costs related to fluegas desulpherisation systems, medical care costs for human health impacts and economic impacts from acid deposition on forest growth. An implicit market valuation of the same project could consider property values of land exposed to the acid emissions or travel costs that people are willing to pay to get access to fishing resources similar to the ones that could be lost by the acid emissions. Finally, valuation with a constructed market approach can take the form of an interview of people on their willingness to pay for avoiding the impacts of acid emissions (specified in the form of health impacts etc.). The conventional market approach, in most cases, is the only feasible methodology due to data and time constraints.

The market-related techniques can be criticised for assigning market values to phenomena that by nature are non-economic. These can for example be biodiversity, loss of human lives, and irreversible damages on eco-systems. A way out of these problems is to use physical indicators to measure such impacts.

A number of international studies have assessed monetary values for environmental externalities. Most studies are done for industrialised countries. Two major fuel-cycle studies are the EU ExternE project (ExternE, 1995) and the US DOE study by Ottinger et al. (PACE, 1990). In Estimates of damages from industrialised countries a short overview over these studies and the assessment of the damages are shown. In the annex the data can therefore not directly be transferred to a developing country context.

A number of studies are now underway for developing countries where externality adders related to health damages from air pollution in urban areas are assessed (Pearce, 1996). It is concluded on the basis of a number of country case studies that the highest economic losses relate to particulate matter and lead emissions. Particulate matter and lead are especially associated with vehicle emissions. Acid emissions from for example power production are in these studies assessed to have a low economic cost. Another important health damage area in developing countries is indoor air pollution from cooking systems.

1.5.4 Sustainability

The issue of sustainability arises here because environmentalists are concerned that the policies followed should contribute to the longer term resolution of the conflicts between protection of the natural environment and economic development. The issue, which was first brought into the public domain in a significant way by the Bruntland Report (World Commission, 1987) was posed as a search for a path of development that meets the needs of present generations without compromising the abilities of future generations to meet their needs. Subsequent developments of the idea refer to the concepts of “weak” and “strong” sustainability (Pearce, 1993). The notion of weak sustainability is that society should develop its resources in such a way as to ensure the passing on of a stock of wealth (including natural capital) to future generations at least as great as the one inherited by present generations. This stock is measured in money terms. The notion of strong sustainability is to ensure that critical parts of the natural capital are not degraded and that renewable resources are used in a manner that is as sustainability as possible, given other constraints on resource use and economic development. The appeal of weak sustainability depends on the degree of substitution between natural and man-made capital in the production process. There are significant difference of opinion about that among environmentalists and economists.

In the context of GHG limitation projects it is the strong sustainability notion that is the important one. In developing policies for this area, importance should be given to the achievement of the goals of sustainable resource use and of protection of critical natural capital. In addition greater importance should be paid to the long term implications of any policies introduced today.

The Annex of this report includes a list of Sustainability indicators that can be evaluated in relation to climate change mitigation policies. These measures of sustainability are useful complements to the monetary measures of the costs of GHG limitation projects.

1.6 Measuring the benefits of reduced climate change

The benefits of reduced GHG emissions vary with the time of the emission reduction, with the atmospheric GHG concentration at the reduction time, and with the total GHG concentrations more than 100 years after the emission reduction.

Reduced climate change has a benefit component and the domestic benefit should therefore in principle be included in the national strategy evaluation.

The benefits of reduced climate change are as already said very difficult to assess and a more operational approach is therefore to perform a cost-effectiveness analysis where the costs and benefits of project implementation are ranked according to a common metric representing the benefits of reduced climate impact. It will, in the following, be outlined how GHG emission reduction goals can be derived as a simplified case of a climate change damage function.

Sathaye, Norgaard & Makundi (1993) suggest the shadow value of reduced climate change (*VC*) to be determined as:

$$VC = \int_{0}^{\infty} P_c(t) e^{-rt} C_0 e^{-at} \, dt$$

where $P_c(t)$ is the shadow price of avoided carbon at time t, C_0 is a single year emission reduction, r is the discount rate and, a is the atmospheric decay rate of carbon.

The shadow price of avoided carbon $P_c(t)$ represent the damage function of climate change which due to large uncertainties cannot be estimated at present. It is therefore only possible to discuss the theoretical implications of different assumptions about this damage function.

If it is assumed that the emission reductions of a project, C_0 are small compared with the total atmospheric carbon stock, then $P_c(t)$ is constant for the project. The shadow price of avoided carbon $P_c(t)$ will probably vary over time as a function of the stock of atmospheric carbon. It is however difficult to determine that relation, and $P_c(t)$ will therefore for simplicity be assumed constant, P_c. Given this assumption and assuming constant r and a, VC can be written as:

$$VC = P_c \frac{C_0}{r + a} \qquad \textit{Eq. 1}$$

A project is worth pursuing, if VC is equal to or greater than the costs of implementing the project. A cost-effectiveness analysis can, following that, rank the projects on the criteria of VC versus costs. With the simplified assumption of a constant P_c, the ranking criteria then is reduced to a constant factor that converts future carbon emission reductions to a net present value.

It should be noted that projects would typically imply carbon reductions in multiple years. The total net present value of carbon emission reductions achieved in the total lifetime of the project (VCC) can for discrete time steps be calculated as:

$$VCC = \frac{P_e}{r + a} \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \qquad \textit{Eq. 2}$$

where C_t is the carbon emissions at the time t, and T is the time period where emission reductions occur.

1.7 A framework for integrating quantitative and qualitative impact assessments

The two previous sections discussed the application of cost concepts to traditional costs and benefits and to a wider range of impacts that should be included in either the cost assessment or an over-all evaluation of a mitigation action. In many cases, there will be important impacts from a project that either can not be valued in the cost assessment, due to lack of data, or should not be included in the cost assessment for sound economic accounting reasons. In the final analysis, it is important to integrate all of the cost and non-cost elements into an over-all framework that can be used to asses all of the impacts of a mitigation action.

The information collected on the impacts of a GHG limitation project or programme needs to be summarised so that different projects and programmes can be compared. There are three kinds of information to be summarised. These are:

1. Quantitative information in money terms.
2. Quantitative information in physical units.
3. Qualitative information.

The same impacts can, of course, be classified in all three categories, so that data on reductions in fossil fuel emissions can be quantified in money terms, reported in terms of tonnes of pollutants, and in terms of quantitative impacts on eco-systems etc. In preparing summary indicators it is important not to count the same information twice, so that it is unduly weighted in the final selection criteria.

1.7.1 Quantitative monetary data on the project

The cost effectiveness criterion

For programmes that estimate the cost of achieving a certain reduction in GHGs the main criterion is normally cost of GHG removed.

The cost-effectiveness criterion involves a comparison of final cost flows and GHG emission reduction occurring at different points in time. The cost flows can be compared in a net present value, NPV_c.

$$NPV_c = \sum_{t=0}^{T} \frac{C_t}{(1+i)^t} \qquad \text{Eq. 3}$$

where i is the interest rate and C_t is the cost at time, t.

The GHG emission reductions occur at different points in time in the same ways as the costs. Therefore the time specific value of these reductions have a major implication for the calculated emission reduction costs. There is a high uncertainty about climate change damages and it is therefore difficult to assign a time specific value to emission reductions. It is therefore suggested to use a simplified approach where the GHG reductions are discounted with the same discount rate as used in the above specified NPV_c formula. The net present value of emissions reduction (NPV_e) can then be calculated as:

$$NPV_E = \sum_{t=0}^{T} \frac{E_t}{(1+i)^t} \qquad \text{Eq. 4}$$

The costs can also be represented as levelised costs, where the annual costs - as well as GHG emission reductions - are transformed to constant annual flows over the lifetime of the investment. Mitigation projects that imply constant annual emission reductions can be directly compared with levelised cost at a given point in time. The total levelised cost, C_0 of a project can be calculated with the following formula:

$$C_0 = NPV_c \frac{i}{1-(1+i)^{-t}} \qquad \text{Eq. 5}$$

and the levelised GHG emission reduction can similar be calculated as:

$$E_0 = NPV_E \frac{i}{1-(1+i)^{-t}} \qquad \text{Eq. 6}$$

Guidelines for project assessment use a number of different concepts to compare cost-effectiveness of projects. The most often used concepts are net present values (NPV), internal rate of return (IRR) and levelised costs. These concepts basically provide similar project rankings. The relationship between the NPV, IRR and levelised costs is further explained in Box 4.

Box 4 The NPV, IRR and Levelised Cost Concepts.

The NPV concept

The NPV determines the present value of net costs by discounting the stream of costs back to the beginning of the base year (*t*=0).

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+i)^t}$$

The IRR concept

The IRR is defined as the rate of return on an investment, which will equate the present value of positive and negative cost components of an investment with zero. It is found by an iterative process and is equivalent to the discount rate *i* which satisfies the following relationship:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+i)^t} = 0$$

The levelised cost concept

The levelised cost is, as already shown, a transformation of the NPV using the formula

$$C_0 = NPV \frac{i}{1-(1+i)^{-t}}$$

The use of the concepts NPV, IRR and levelised costs as project ranking criteria is valid given a number of assumptions:

NPV

An investment I_1 is more favourable than an another investment I_2 if: the NPV of I_1 per unit GHG reduction is smaller than the NPV of I_2 per unit GHG reduction. It should here be noticed that the use of NPV's to compare the cost-efficiency of projects requires that some discounting principles be applied to the annual GHG emission reductions. The NPV can in terms of NPV/GHG reduction be used as ranking criteria for investments with different time horizon.

IRR

An investment I_1 is more favourable than another investment I_2 if the IRR of I_1 per unit GHG reduction is smaller than the IRR of I_2 per unit GHG reduction. This ranking criterion however is both neutral to the scale of the costs and the GHG emission reduction achieved by the project. The IRR can therefore only be used as an initial screening criterion. The IRR can be used as ranking criteria for investments with different time horizon.

Levelised cost

An investment I_1 is more favourable than an another investment I_2 if the levelised cost of I_1 per unit GHG reduction is smaller than the levelised cost of I_2 per unit GHG reduction. The levelised cost should be calculated for a similar lifetime of the investments of with the inclusion of a terminal value for long term investments.

The *full economic costs* of a project (in so far as they can be monetised) and not just the direct financial costs, measuring the cost effectiveness can be formulated as:

$$C_{full} = C/E \qquad \textit{Eq. 7}$$

Where *C* and *E* can either both in net present values (as defined in Eq. 3 and 4) or the levelised costs (as defined in Eq. 5 and 6).

The full economic costs, C_{full} is distinguished from the direct C_{fin} of the project and which will be discussed below. Note that for C_{full}, all costs are economic costs, as described in section 1.4.1 Economic opportunity costs or economic costs. The values of

C_{full} will depend on the precise value attached to the different components of costs and, as noted earlier, these costs are uncertain, with ranges of values rather than a single value. In view of this, it is important to present a range of such values and to indicate the impacts from which the uncertainty arises. Related to that, it will be useful to present a more detailed table of the components of the costs by time period, so that the policy-maker can draw on this information should it be considered necessary.

Choice of discount rates

The debate on discount rates is a long standing one (IPCC, 1996b). As that reports notes, there are two approaches to discounting; an ethical approach based on what rates of discount should be applied, and a descriptive approach based on what rates of discount people actually apply in their day-to-day decisions.

The ethical approach suggests that a discount rate that reflects the preferences of society to investments in long term sustainability impacts associated with climate change mitigation be used. This discount rate, according to theoretical arguments, should be the so-called social rate of time preference (Arrow et al. 1996). It can also in a more pragmatic way be argued that the discount rate should be a political choice – this approach often talks about “the social rate of discount”. The descriptive approach argues that the marginal rate of return on capital is the appropriate discount rate.

The former leads to relatively low rates of discount (around 3 percent in real terms[9]) and the latter to relatively higher rates (in some case very high rates of 20 percent and above). The arguments for either approach are unlikely to be resolved, given that they have been going on since well before climate change was an issue. Normally the cost effectiveness values are calculated for more than one rate and the results presented to provide the policy-maker with some guidance on how sensitive the results are to the choice of discount rate. The sensitivity is certainly there; at high rates energy projects with long gestation periods become unattractive compared to those with a shorter period. For the purposes of the broader analysis, it is recommended that a central real rate of 3 percent is applied and a sensitivity analysis is carried out for real rates of 1 percent and 10 percent.

In addition to discounting future costs and benefits there is the further issue of whether or not future emission reductions should be discounted when compared to present reductions. The justification for discounting is that emission reductions in terms of reduced impacts have a time specific value. The choice of the appropriate rate, however, remains an unresolved issue and, again, taking a range of plausible values is the only solution. This technical basis for this argument is further outlined in section 1.6 Measuring the benefits of reduced climate change.

One point perhaps which should be noted relates to the use of low discount rates for appraising GHG programmes in developing countries, where capital is scarce and market rates of discount are very high. This low real rate for mitigation programmes can be justified on the ethical grounds mentioned above. The scarcity of capital, on the other hand, can be dealt with by having a shadow price for capital that is greater than one, as discussed in section 1.4.3 Shadow prices.

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9 The real rate of discount is the market rate net of inflation. Thus if a market has a discount rate of 12% and inflation is 8% then the real rate is 4%.

1.7.2 Quantitative non-monetary information

Quantitative information in non-monetary units will be available for:

1. Employment impacts.
2. Income gains and losses of different groups.
3. Associated environmental changes.
4. Sustainability indicators of the share of energy derived from renewable sources, now and at the end of the planning period.
5. Macroeconomic impacts on GDP, trade and sectoral changes in GDP.

In addition, some of the other sustainability indicators may be quantified.

Some of this information will have been converted into monetary units, namely (1)-(3). There are two ways of integrating this information with the monetary information. One is to calculate the C_{full} value, which excludes the costs associated with (1)-(3) and then present the cost information as well as the information on (1)-(5) in table form. As with the values of C_{full}, there will be ranges of values for C_{fin} and the items (1)-(5). The second is to report the C_{full} value, which include the costs attached to (1)-(3), and then add the information from (4) and (5) in a new table. Both are important and should be carried out. Once the data have been presented, a further summary statistic can be developed based on weights for the different components of the project, both monetary and non-monetary. The weights can be derived through discussions with policy makers, or through reviews of related policy decisions. An evaluation of the project will then constitute a single value (or a range of values, each associated with different estimates of the impacts) summarising its overall impact. This will enable comparison with other projects in the same and related GHG fields. This method is called a multi-attribute analysis, further details of which are given in section 1.9 below. See also the Handbook Report: “Indirect Costs and Benefits of GHG Limitations” for a more detailed presentation of methodological issues and case examples.

1.7.3 Qualitative information

Qualitative information on impacts is important and should not be ignored. It cannot be integrated into the summary cost effectiveness values or the multi-criteria number, but it is relevant to the selection of the project and, more crucially, to the design of the project. Once a GHG-related project has been identified, a preliminary screening should generate important qualitative information. This should then be used to modify the design of the project so that the key negative impacts are mitigated wherever justified. The revised project will still have some impacts but these will have been passed as “acceptable”. This preliminary screening of projects will avoid serious environmental damages, as well as serious political blunders where projects that seem technically acceptable have such negative impacts on key stakeholders that they are bound to fail on political grounds.

1.7.4 Conclusions on selection criteria

Ultimately the decisions on which projects to undertake is a political one. The screening rules discussed above are a guide to those decisions. As has been noted these rules will not provide unique guidance on which policies or projects to choose. But they will provide a range of indicators on financial costs (C_{fin}), full economic costs (C_{full}) and on the other quantitative and qualitative impacts that are inputs to the decision-making process.

1.8 Reporting of quantitative project impacts

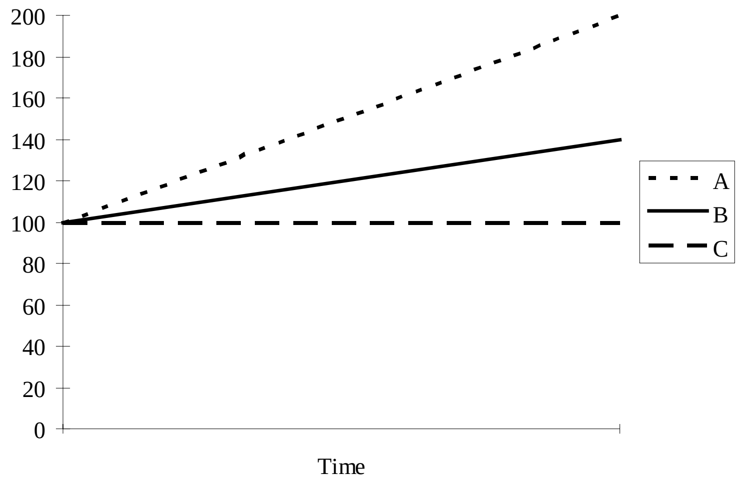
1.8.1 GHG emission reduction marginal cost curves

One way of presenting the mitigation scenario results is to use "GHG emission reduction marginal cost curves". This approach has been used for presenting mitigation cost assessments in the UNEP phase two project for CO_2 reductions in the energy sector. These marginal cost curves can, in some cases, be created using just information about emissions reductions and project outlays on individual projects. In other cases, the marginal cost curves should be constructed on the basis of integrated sectoral assessments.

The GHG emissions reduction marginal cost curve expresses the relationship between the minimum cost to society of reducing an additional ton of GHG emissions and the corresponding level of emissions reductions. GHG emission reductions are defined as reductions in relation to the baseline.

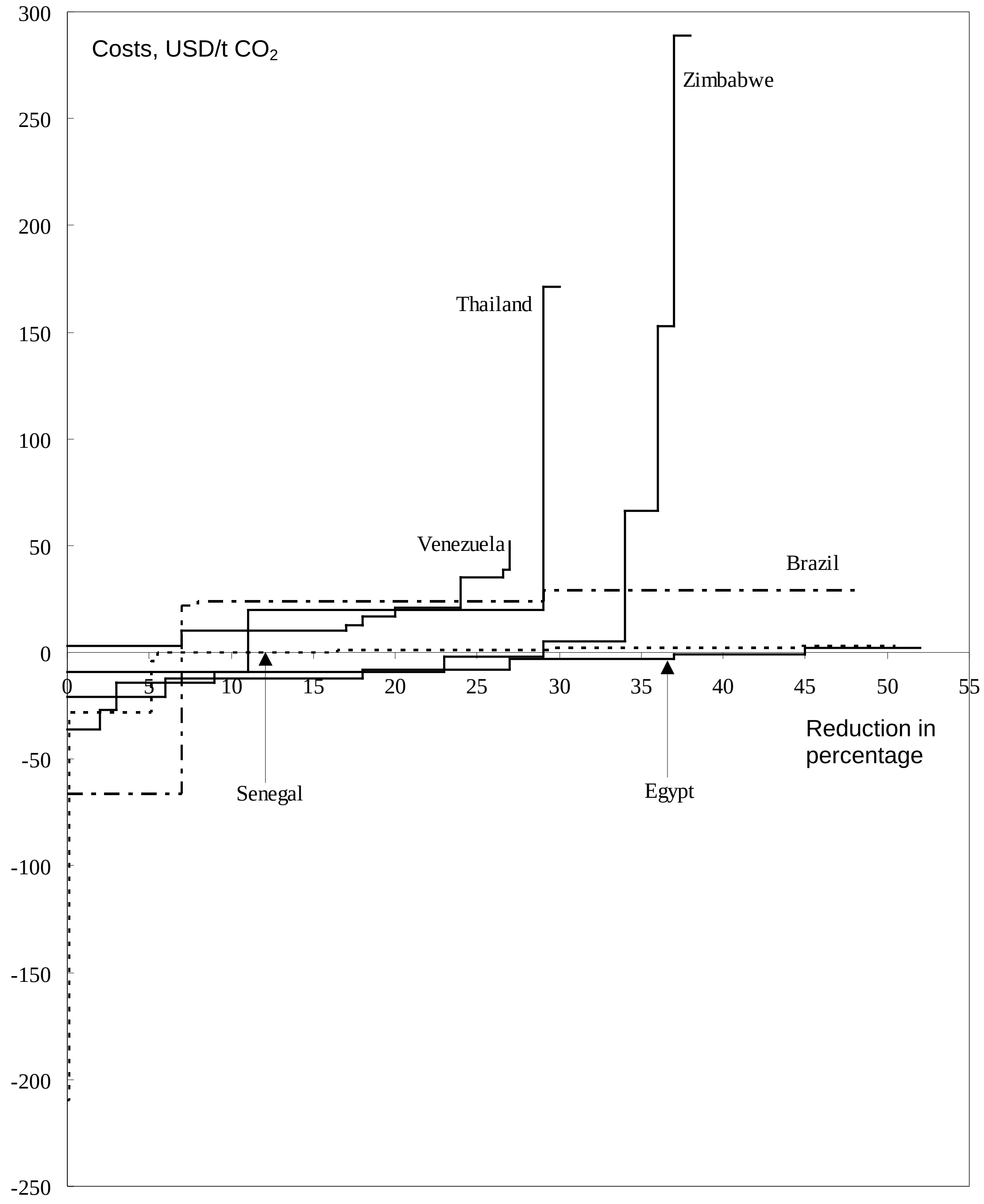
The emission reduction targets can either be defined in relation to a base year (as for example 1990 emissions) or in relation to future baseline scenario emissions. Figure 3 shows these alternative definitions of emission reduction targets. Line A illustrates future baseline emissions, line C corresponds to the base year emission level while line B represents a reduction scenario. Emission reductions in relation to the baseline scenario involves the comparison of line A and B, while reduction in relation to base year involves the comparison of line B and C.

Figure 3 GHG emission scenario cases.



The current framework for this project will involve an assessment of emission reduction targets in relation to future baseline scenario trends. This approach is chosen because it supplies the best possibilities for comparisons of reduction costs across sectors and countries in cases where future GHG emission growth rates will vary significantly for different sources and sinks.

Figure 4 Marginal cost curves of GHG emission reduction (UNEP country studies).



An example of the cost curve estimated in the UNEP format is shown in Figure 4. This cost curve is a comparison of marginal reduction cost for CO_2 reduction in the long-term assessed for the countries participating in the UNEP study (CO_2 reduction is measured in % in relation to future baseline emissions; costs are measured as levelised cost).

In the simplest case, where the marginal cost curves for GHG emissions reductions can be constructed on a project by project basis, from the bottom-up, the marginal reduction costs (US$ per tonne of CO_2) are calculated as the difference between the costs of following the baseline scenario and the mitigation scenario. A parallel cost assessment for these two scenarios has been done as follows:

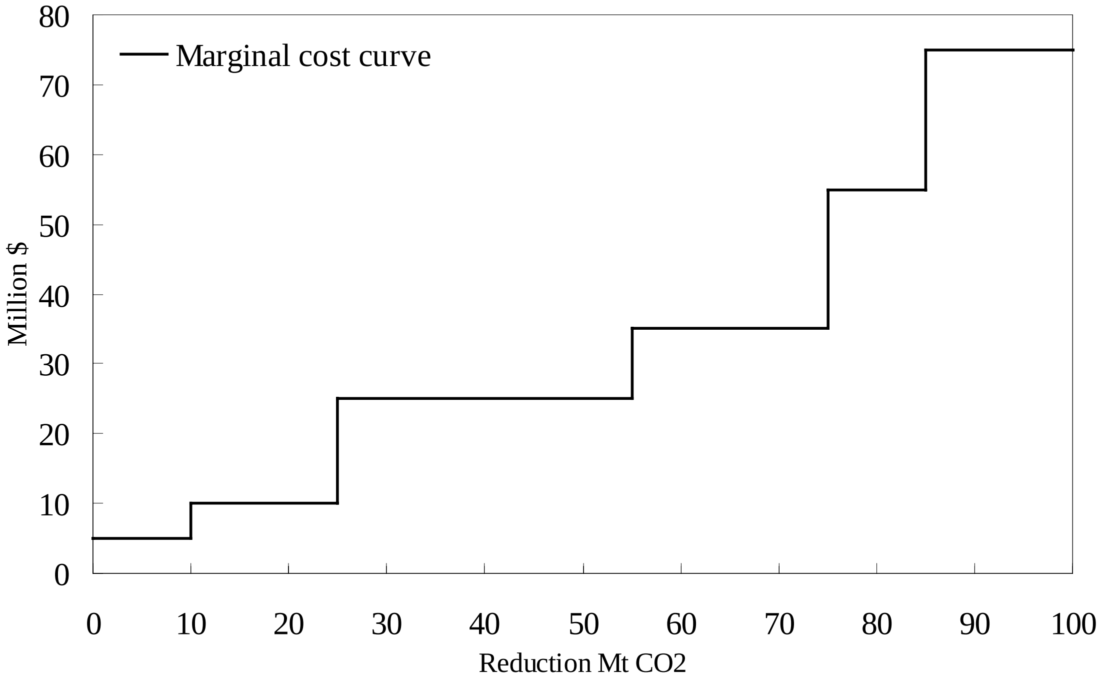
$$MRC_t = \frac{CR_t^{'} - CR_t}{R_t - R_t^{'}}$$

where:

MRC_t	Marginal reduction costs in the year *t*.
R_t	Total CO_2 emissions in the year *t*.
$R_t^{'}$	Total CO_2 emissions in the year *t* after the implementation of a given project.
CR_t	Total cost of a given scenario corresponding to the emission level *R(t)*.
$CR_t^{'}$	Total cost of a scenario corresponding to the emission level *R'(t)*.

The stepwise calculation of reduction cost is illustrated in Figure 5. The total reduction costs can then be calculated as the area below the marginal abatement cost curve.

Figure 5 Marginal cost curves of GHG emission reduction.



1.8.2 Alternative cost curve construction methods

The starting points for a cost curve construction is the individual mitigation options. The cost and mitigation potential achieved by the individual options, however can be integrated in cost curves in different ways. Some main methods for cost curve construction that have been used for energy sector assessment are described in the following:

1. *The partial solution*. Each mitigation option is evaluated separately, with respect to incurred costs and GHG emissions. Results are compared, project by project in relation to the baseline. The projects are ranked according to costs per unit of GHG reduction. The cost curve is built up of partial independent segments.
2. *The retrospective systems approach.* The first step in this approach is a separate ranking of mitigation options as outlined in *the partial solution*. In the next step the most valuable project is included in the assessment, and incremental results

compared to the reference case are calculated. Next the third most valuable project is included in the assessment and new calculations performed, and the next step on the cost curve is established. This approach has the advantage of taking into account the interdependence between the given project and every other previous project on the cost curve. Furthermore it is important to notice that the retrospective method implies that once an abatement option is included in a scenario, it will be a permanent part of all subsequent scenarios.

3. *The integrated systems approach.* This approach requires a fully developed energy system model. The idea is to determine any point on the cost curve as the least cost solution for the total energy system, where in principle all demand and supply system parameters can vary.

The procedure will in an energy system simulation model follow the following steps:

a) Ranking of possible mitigation options on partial basis.

b) Introduction of different "baskets" of mitigation options (chosen with starting point in the proceeding step) calculating a large number of scenarios for possible GHG reductions and related costs.

c) Choice of the lowest costs for a given GHG reduction, thus establishing and envelope curve for the annual GHG emission reduction and related costs.

This approach aim at taking into account all the interdependencies within the system as represented by the energy system model.

A probable result of the analysis is that a given GHG emission target can be fulfilled with several energy system solutions which on the whole are economically "close". Such energy system solutions may however be quite different technically, for example with regard to the dominant power production technology, or the weighting of investments in demand or supply technologies. This introduces the possibility of other parallel criteria for project assessment such as complementary environmental effects or specific national economic interests.

The alternative cost curve construction methods have been evaluated in the Danish country study of the UNEP Greenhouse Gas Abatement Costing Studies (Morthorst, 1994).

1.9 Multiattribute: two case examples

Climate change mitigation has a variety of important national social, political and environmental effects that cannot fully be captured within an economic framework of costs and benefits assessment. A number of other indicators can therefore provide important input to the national decision-making process.

Non-economic indicators could for example be applied in relation to the following areas:

- Non-market goods, as environmental quality influenced by mitigation projects where monetary externality assessments are found inappropriate.
- Broader development criteria than the traditional economic welfare concepts, including for example equity, democratic structure of the society and urbanisation.
- Long-term sustainability issues should include for example inter-generational equity, irreversibility in eco-system development and exhaustible resources.

The selection process of these non-economic indicators should be done in a transparent way that enables verification of data, methodology and results of the assessment. The methodological framework for mitigation assessment must furthermore be consistent as a whole. This requires assumptions about time frame, and relations between parameters and units.

A number of methodologies consider the assessment of broader impacts. One of the most commonly applied methodology is the multi-attribute methodology. This methodology is described in the literature, one of the most important sources for further reading is Keeney & Raiffa (1993).

Assessment of broader social and environmental or “non-cost” impacts should be carried out after the economic cost assessment. The suggested procedure is shown in Diagram 1 (p. 21) where the common analytical structure of the country studies is outlined.

1.9.1 Multi-attribute analysis

The present description is a short presentation on how a multi-attribute analysis can be used to support the assessment of climate change mitigation costs.

The basic idea of multi-attribute analysis is to base decisions upon several objectives. The focus is on identifying decision criteria specified in attributes and weights in order to measure and evaluate trade-offs between different criteria. Meier & Munasinghe (1994) outline the following five steps to be undertaken in a multi-attribute assessment:

1. Selection and definition of attributes, say A_i (i=1,....N) selected to reflect important planning objectives.
2. Quantification of the levels A_{ij} of the i attributes estimated for each of the j alternatives.
3. Scaling of attributes, in which the level of an attribute is translated into a measure of value, $V_i\,(A_{ij})$ (also known as the attribute value function). This is sometimes combined with a normalisation procedure (usually on a scale of zero to one where the lowest value of the attribute is assigned to zero, the highest attribute value assigned to one).
4. Selection of weights w_i for each attribute.
5. Determination and application of a decision rule, which amalgamates the information into a single overall value or ranking of the available options, or which reduces the number of options for further consideration to a smaller number of candidate plans.

A multi-attribute decision rule can then be specified as follows:

Select the option with the highest score on $\sum_i w_i V_i(A_i)$,

where w_i is the weight and $V_i(A_i)$ is the value function of attribute A_i.

One of the most complicated elements in the design of a multi-attribute analysis is the selection of attributes. It can seem to be attractive to select and evaluate as many attributes as possible, but this will not necessarily provide a good decision basis. The attributes must be selected carefully on the basis of methodological consistency and practical considerations. Some of the main methodological issues are related to double counting, value independence, proliferation of attributes, and importance of the attributes in relation to policy decisions (Meier & Munasinghe, 1994). Furthermore the attributes must also be measurable and predictable.

The determination of attribute weights is the most difficult issue. It should here be noted that several different methodologies offer a framework for the determination of weights. The assignment of monetary values to project impacts as done in cost-benefit analysis can be seen as one methodology for determining weights. In this case, the basic source of information is the consumer preferences as revealed on the markets. Other methodologies design systems to reveal preferences through interviews of decision makers, stakeholders or experts. The theoretical requirements for establishing weights in all these methodologies are very complex and restrictive and many multi-attribute analyses therefore only present quantified information about the individual attributes without any attempt to integrate this information in common units.

1.9.2 Two case examples

In the following the use of multi-attribute analysis will be exemplified through two cases. The first example shows how SO_2 emission reductions that emerge as a joint product to CO_2 reduction projects can be integrated in the cost curve framework. The example is simplified to include only one joint product with CO_2, namely SO_2. The example can be extended to include additional joint products. The second example compares the attribute score of five different mitigation projects.

Joint products

The main underlying assumption behind the concept *joint product* is that a relation between at least two different pollutants exists, i.e., there exists a functional (positive) relationship between for instance CO_2 and SO_2:

$$CO_2\uparrow \Rightarrow SO_2\uparrow \qquad \& \qquad CO_2\downarrow \Rightarrow SO_2\downarrow$$

The higher a degree of functional relationship there is between two or more products the more joint they are. For all practical purposes an approximation of the pure functional form is the most reasonable approach. The relation between joint products is often discontinuous.

It is possible to include for instance SO_2 in a traditional CO_2 cost curve. The most important condition for making the following analysis is that the product joint with CO_2 (in this case SO_2) can be measured in connection to the cost of reducing CO_2.

In Table 2 a hypothetical example is shown. The case consists of eight different options (A to H) which can be considered as different CO_2 reduction options, for example new CHP, improved energy efficiency, etc. With each option a specific CO_2 reduction is associated. Furthermore, a SO_2 reduction is related to the option, although this need not be proportional to the CO_2 reduction and could even be negative as in option C. To construct the CO_2 cost curve it is necessary to have a estimate of reduced CO_2 (column 1) and the associated cost of this reduction (column 2). In addition to this the amount of SO_2 reduced associated with the CO_2 reduction is listed (column 3). Finally the SO_2 reduction "benefit" per unit cost of CO_2 reduction (column 4) is listed. Column 4 is calculated as: $(4) = (3)/(1)\cdot(2)$. In this way the associated SO_2 reduction, (3), is related to the total costs of the CO_2 reduction, $(1)\cdot(2)$.

Table 2 Joint production example: the cost of CO_2 reduction and the associated SO_2 reduction.

Option	Amount of reduced CO_2 (1)	Cost of CO_2 reduction (2)	Amount of SO_2 reduction associated with CO_2 reduction (3)	SO_2 reduction "benefit" per unit cost of CO_2 reduction (4)
A	2	3	5	0.83
B	8	5	10	0.25
C	5	10	-5	-0.10
D	5	15	4	0.07
E	15	25	35	0.09
F	3	30	25	0.28
G	2	50	10	0.10
H	10	52	60	0.12

In Figure 6 the traditional CO_2 cost curve, composed of options A to H, is illustrated. It is possible to include the joint product in the form of the SO_2 reduction associated with the CO_2 reduction (corresponding to column 4 in Table 2). This additional benefit – the secondary benefit – from reduced SO_2 per unit of cost of CO_2 reduction is illustrated as vertical lines corresponding to the individual options. In Figure 7 both the cost curve and the SO_2 reduction per CO_2 cost is shown.

Figure 6 Cost curve for CO_2.

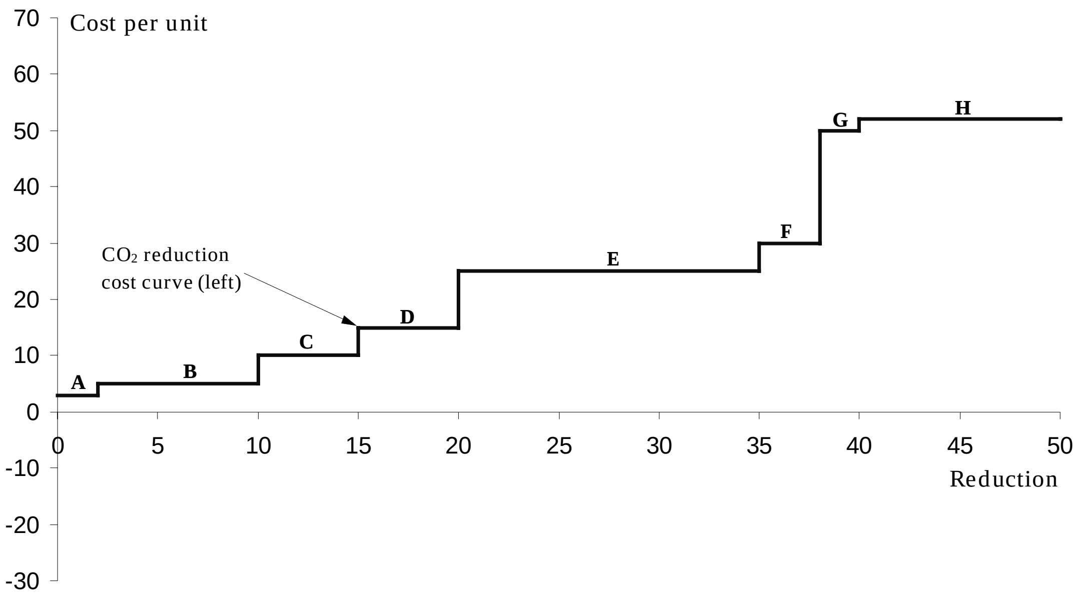
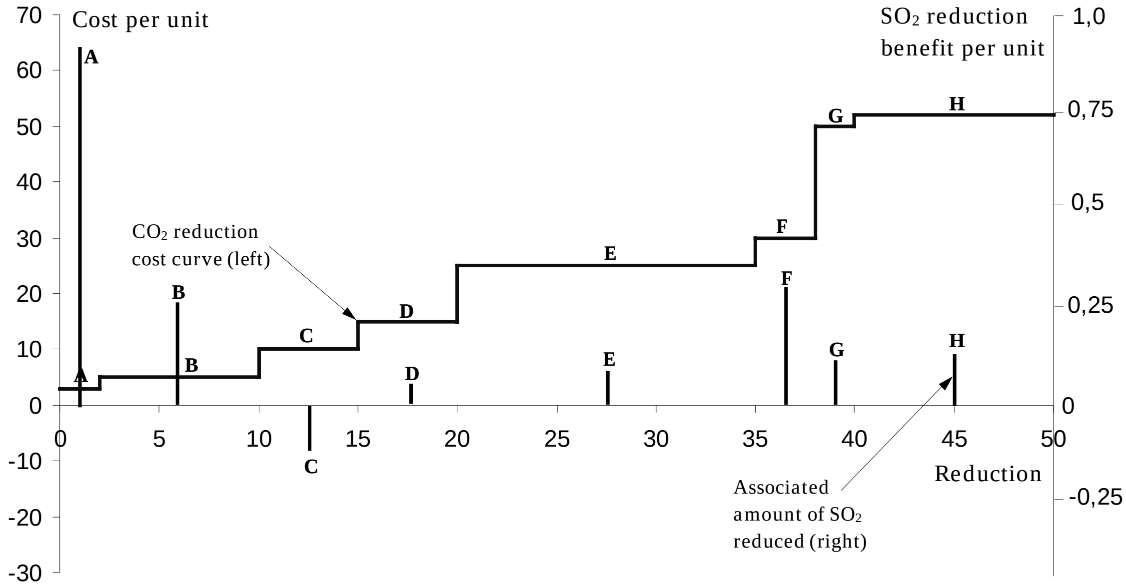


Figure 7 CO_2 cost curve including associated SO_2 reduction (hypothetical).



The ranking of the options, if only CO_2 reduction is considered, correspond to the cost curve in Figure 6, i.e., A is the most and H the least cost-efficient option. In this respect the cost curve is the cost-efficient path for the isolated CO_2 reduction cost. If, however, the additional SO_2 reduction is included in the assessment, as in shown in

Figure 7, the overall picture may change. It is obvious that option C as the only option in this example entails substantial "costs" in the form of increased SO_2 emissions. This could change the overall ranking of the options. Because of the small difference between the cost of reducing CO_2 for options C and D, and because of the large difference in the associated SO_2 "benefits" these two options are likely to change ranking if the joint CO_2-SO_2 product is considered. A possible ranking viewing CO_2 and SO_2 as joint products and assuming a CO_2 reduction target could therefore in this hypothetical example be: A, B, **D**, C, **F**, E, G, H. The actual ranking of the options would obviously depend on the externality value associated with the SO_2 emission. The externality of SO_2 would be strongly related to where the actual deposition of sulphur takes place.

It is important to recognise that the ranking in the example above is based on the underlying assumption that the CO_2 reduction will be carried out. Therefore the SO_2 reduction is linked to this. If the main objective, instead of CO_2 reduction, is to mitigate acidification of forests by SO_2 reduction the conclusion about ranking of the options would be different.

Attribute scores of five alternative mitigation projects

The analysis can also take the form as illustrated in the output reporting form in Table 3. Five alternative CO_2 reduction projects are here compared as a case example. It is assumed that all these projects result in a similar CO_2 reduction. The analysis then consider the impacts on four attributes associated with the implementation of the five alternative CO_2 reduction projects. The four attributes are:

- Cost.
- Employment.
- SO_2 emission reduction.
- Land area with special biodiversity quality.

Table 3 Output reporting form. Attribute values for alternative CO_2 reduction projects.

	Attribute 1 Cost ($US mill.)	***Attribute 2*** Employment (additional persons)	***Attribute 3*** SO_2 emission (reduction in tonnes)	***Attribute 4*** Land area with special biodiversity quality (decrease in ha)
Project 1 Landfill waste biogas plant substituting coal fired plant	15	30	20	1
Project 2 Efficiency improvements in industrial boilers saving fuel oil	10	0	10	0
Project 3 Solar water heaters substituting electric geysers	15	20	20	0
Project 4 Natural gas turbine substituting part of coal fired plant	5	0	20	0.1
Project 5 Biofuel forestry project substituting fuel oil boiler	40	40	10	100

The attribute values shown in Table 3 are afterwards transformed into normalised values defined for the interval (0, 1). The highest attribute value 1, is given to the best project score, while a 0 attribute value is given a 0 value on the attribute. It should here be noticed, that high values on attribute 2 and 3 (employment and SO_2 emissions) are considered as the best case, while low values on attribute 1 and 4 (cost and loss of land with biodiversity quality) are considered as the best case – a 0 normalised attribute value therefore applies in this case.

Table 4 Normalised attribute values for the projects shown in Table 3.

	Attribute 1 **Cost ($US mill.)**	***Attribute 2*** **Employment (additional persons)**	***Attribute 3*** **SO_2 emission (reduction in tonnes)**	***Attribute 4*** **Land area with special biodiversity quality (decrease in ha)**
Project 1 **Landfill waste biogas plant substituting coal fired plant**	0.71	0.75	1	0.99
Project 2 **Efficiency improvements in industrial boilers saving fuel oil**	0.86	0	0	1
Project 3 **Solar water heaters substituting electric geysers**	0.71	0.50	1	1
Project 4 **Natural gas turbine substituting part of coal fired plant**	1	0	1	0.9
Project 5 **Biofuel forestry project substituting fuel oil boiler**	0	1	0	0

The attribute scores for the five projects are illustrated in the following six figures. Figure 8 and Figure 9 show the attribute scores of the projects assigning equal weights to all attributes. The project with the highest total attribute score is in this case project 1: Landfill waste biogas plant. The project has a high overall score on all attributes, except for cost where it is only the third best. Project 3 (solar water heaters) and project 4 (natural gas) are relatively equal in total attribute score, but differ especially with respect to employment. Project 5 only has a score on the employment attribute.

The importance of the attributes are further analysed in a partial analysis in Figure 10 to Figure 13 where the project scores are compared for four cases each putting a zero weight on one of the attributes. The 0 weight is first put on the cost attribute in Figure 10, then on the employment attribute in Figure 11, on the SO_2 attribute in Figure 12, and finally on the biodiversity attribute in Figure 13.

It shows up that project 1 (landfill waste biogas plant) gets the highest in three of the cases, but is dominated by project 3 and 4 when employment is given a zero weight.

Figure 8   Attribute score for five case project.

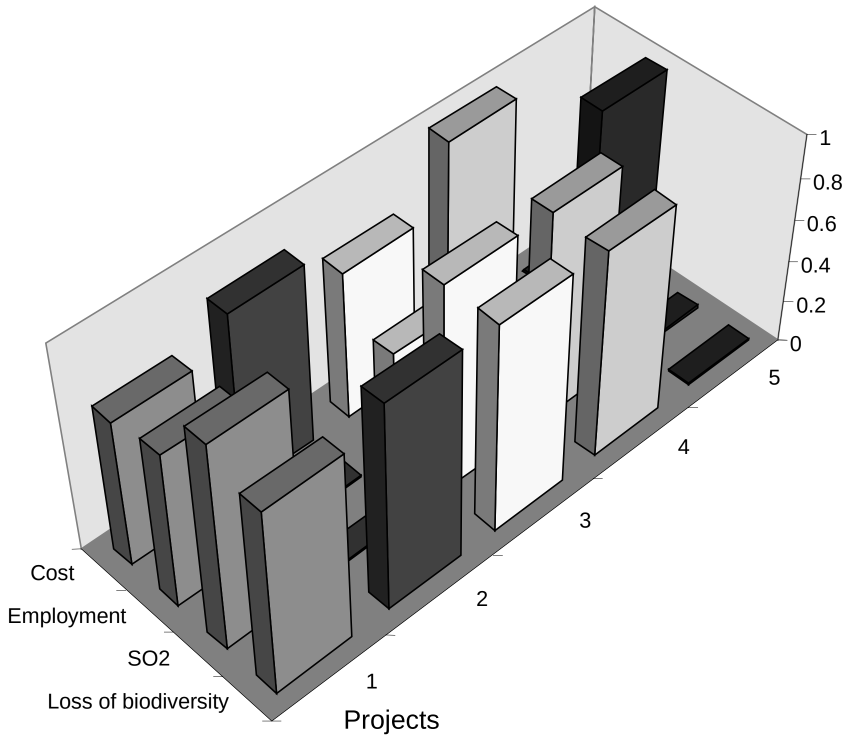


Figure 9   Total attribute score on five case projects assuming that all attributes are assigned an equal weight.

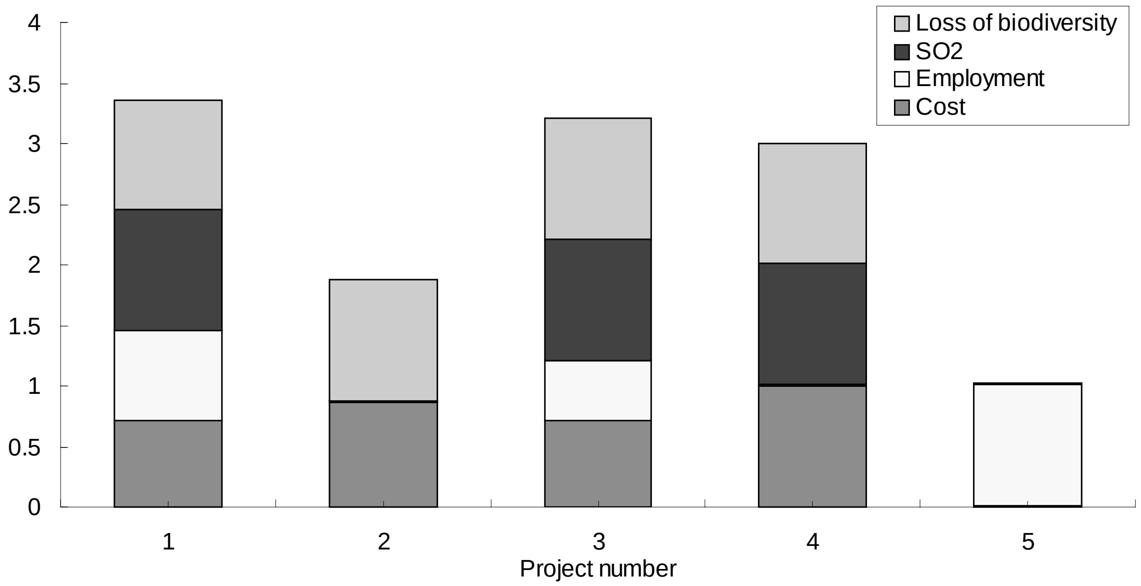


Figure 10 The zero weight: The cost attribute.

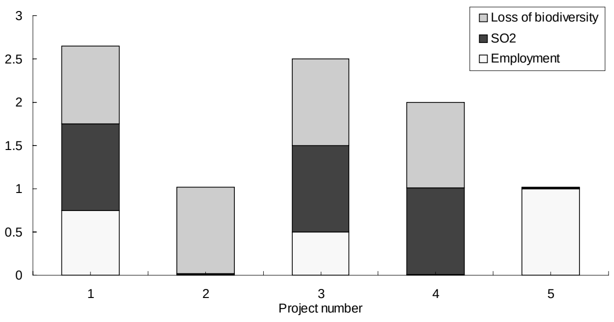


Figure 11 The zero weight: Employment.

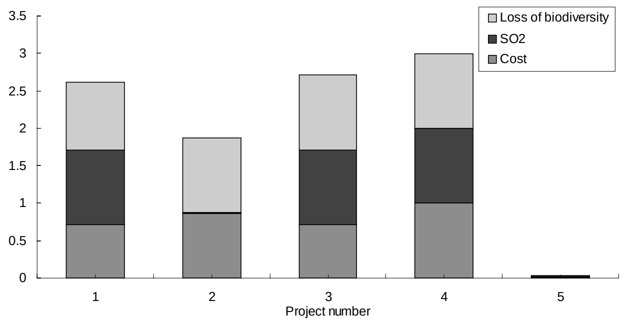


Figure 12 The zero weight: SO_2.

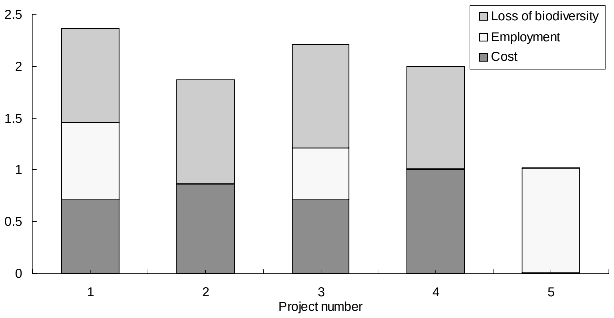
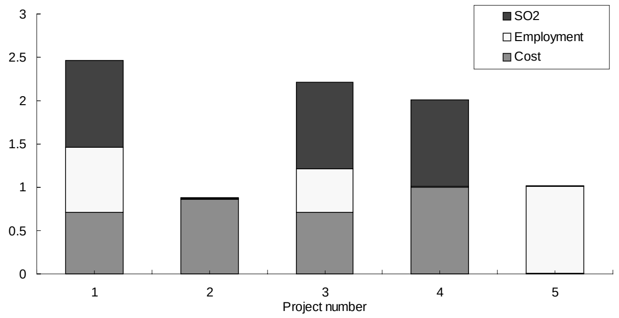


Figure 13 The zero weight: Biodiversity.



1.9.3 The use of MCA in national decisions

The MCA can be used to add broader information on social, environmental and other impacts to the cost assessment as a further development of the mitigation cost assessment.

A formal multicriteria analysis can be integrated in the mitigation analysis through the following steps:

- construction of baseline scenario on the basis of national development plans including a macroeconomic forecast. The baseline scenario projects the scale of activities in the sectors for the most important sources and sinks. Definition of main variables to supplement the mitigation cost assessment.
- identification of mitigation options. Assessment of mitigation potential and cost of individual projects.
- assessment of mitigation potential and cost at sector level for “baskets of projects”.
- assessment of non-cost variables for projects or baskets of projects. Presentation of the cost variables and the other variables as background information for the evaluation of trade-offs, priorities, dominance, etc.
- assessment of weights connected to cost and non-cost variables in the objective function.
- formal analysis using variables and weights as input to a well-defined criteria function.
- interpretation of results as input to the national decision making framework.

This assessment will in practice be a very difficult exercise where many actors need to be involved in the setting of priorities. This can also be seen as part of the inputs to a broader national decision making process where various stakeholders and policy makers consider the outputs of the formal mitigation assessment and take the further lead in the development of national action plans (see also section 2.5 on national action plans).

2 Implementation costs

2.1 Introduction

In the costs and benefits assessed in traditional CBA, bottom-up studies, and sector studies it is more or less assumed that, despite the costs of the resources involved, like production factors, technologies, final products, overhead costs, etc., no specific activities are necessary to promote policy implementation. It is implicitly assumed that the market itself establishes incentives for the agents to implement the project[10]. Implementation costs are given this only represented by the costs of planning activities, administration, information, training, monitoring and the like. These costs will in the following be termed *administration costs.*

Successful implementation of large scale environmental projects or strategies such as climate change mitigation strategies will, however, typically involve costs that exceed administration and training costs. The existence of market imperfections, imperfect information, institutional failure, externalities, ill-defined and/or not well enforced property rights etc., indicate that implementation will not be pursued as a friction less exchange process and transaction costs can be significant.

Implementation can then be supported by specific measures to remove and reduce barriers in order to realise the desired outcome of a given project or strategy. These additional measures will be termed *barrier removal measures* and the analogous costs *barrier removal costs*. Barrier removal measures are as defined here related to the *short and medium term reduction of transaction costs*. Their effects are not limited to the immediate project or strategy. Thus barrier removal is under what might be labelled *transaction cost policies*.

According to the above, implementation costs are defined as follows:

- *Implementation costs* cover all costs associated with the expected requirements to realise a project or a sectoral strategy. These costs consist of two separate elements: *administration costs* and *barrier removal costs*.
- *Administration costs* are the costs of activities that are directly related and limited to short term implementation of the project or sectoral strategy. They include costs of planning, training, administration, monitoring, etc.
- *Barrier removal costs* are the costs of activities aimed at correcting market failures directly or at reducing the transaction costs in the public and/or the private sector. These activities should support exchange processes related to project implementation in cases where the implementation meets significant barriers. Examples of barrier removal costs are; costs of improving the institutional capacity; reducing risk and uncertainty; enhancing market transactions; enforcing regulatory policies etc.

Implementation costs according to these definitions include all costs of policy realisation that are additional to other resource requirements such as technology,

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[10] This is the traditional neo-classical approach. Resource scarcity and rational behaviour imply that the exchange process will establish the efficient resource allocation. Most top-down models apply this approach. Different approaches are used in bottom-up models on implementation costs. Some studies in line with the neoclassical approach assumes that the economy in the baseline is efficient and only a minor overhead cost component is therefore assessed as a necessary implementation cost. Other bottom-up studies that are focussed on technology assessment assume that a specific implementation policy is carried out, where regulations and technical standards support specific technologies.

capital, land, and labour costs and should be assessed at project or sector level (see the more detailed definitions in section 1.4.5 Cost assessment levels).

Barrier removal costs should be measured as social costs[11]. They are incurred to reduce the social costs in the longer run by making regulation and policy instruments work[12]. This indicates that barrier removal must be seen in a dynamic perspective, i.e. the costs of barrier removal are time and context specific. Correspondingly, although barrier removal activities are aimed at the implementation of a specific project or sectoral strategy, their effects reach beyond that specific project or sectoral strategy.

Barrier removal in a national framework

Barrier removal, as defined in the previous section, is related to general structural policies specifically when these help the facilitating of exchange processes and thereby reduce transaction costs. Such policies include efforts to enhance the capacity of institutions and individual agents to undertake transactions and general market development policies. Thus barrier removal costs if the policies are success-full should be expected to be diminishing over time, depending on, among other things, the level of institutional integration, technological access and structure, the effect of learning processes as well as the degree of market imperfections, information, risk and uncertainty.

In the following, barrier removal will be related to institutions and transaction costs. Secondly, barrier removal will be seen in a national context and examples of barrier removal measures will be given.

Transaction costs and institutions

In mainstream economics, the emergence of institutions[13] among other factors is a respond on high transaction costs, and the aim of institutions in this way is help to increase economic efficiency. This causality[14] is rejected by new institutional economists, who stress that in developing countries, institutions change and emerge as a result of personal gains, rather than based on what represents the most efficient outcome for the economy as a whole. This perception is supported by the fact that the institutional structure is relatively weak in many developing countries.

Given the absence or unreliability of institutions, transaction costs are minimised by limiting the scale of exchange. This means that there will be a tendency not to develop a larger market because transaction costs prevent this process. An example on that can be food markets in rural areas of developing countries. The market exchange process are among other factors limited by weak infrastructure and the exchange is therefore geographically limited. Exchange will have a tendency to be limited to relatively few small societies, such as local villages, families or ethnic groups, keeping transaction costs low. The problem is that the market and production scale are low implying high production costs and weak demand.

Such weak market development can sometimes be mitigated by different sorts of vertical integration (Ensminger, 1992). This could in the rural food market case imply

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11 Social costs = Private costs + Costs of externalities.

12 The assessment of social implementation costs reflects the general welfare perspectives of the policies.

13 It is convenient to think of institutions as forums with implications for rules of interaction. They are not necessarily entities, as opposed to organisations. Examples of institutions are families, “social rules”, markets, etc.

14 It is difficult if not impossible to talk of causality in these matters and no attempts to determine causality will be made in the following.

that “dealers” can try to control the total food market by buying products directly from the farmers and transport them to larger markets than the established and control them self.

In this way the presence of high transaction costs have import implications for the development of markets, trade, specialisation, and efficiency. If markets are thin or missing, trade is on a very small scale and specialisation in areas of comparative advantage does not take place, growth is hindered and allocative efficiency is not reached.

When transaction costs in these ways are very high the traditional assumptions on efficient resource allocation and well functioning markets basically does not reflect real conditions for policy implication. A number of very specific assumptions must here be applied on how mitigation policies can be supported by specific barrier removal policies[15].

Barrier removal policies often will include efforts to increase the potential market and the number of exchanges. This can involve strengthening the incentives for exchanges (prices, capital markets, information efforts and the like), introduction of new actors (institutional and human capacity efforts), and reducing the risks of participating (legal framework, information, general policy context of market regulation).

Transaction costs and barrier removal costs can be expected to be particularly high during the transition from a low to a high degree of exchange.

The involvement of more actors can play a different role in different phases of a market development process. More parties must generally be expected to strengthen market competition, but at the same time can increase total transaction costs and likelihood of failure of co-ordination. This points to a possible role of public regulation or specific support activities especially in the earlier market development states. An example of such temporary support activities is suggested by the Global Environment Facility (GEF) and UNDP in key strategy papers that argue that a number of advanced renewable energy technologies if temporary supported can be developed to be competitive energy production technologies with very low or zero GHG emissions. The technologies considered here include wind turbines, photovoltaics, biogas, and biomass integrated gasifies.

The arguments rely on expected learning curves, where costs decline with increasing number of implemented plants. This cost “gain” is expected to emerge as a consequence of enhanced markets, development of local suppliers of technology components, and management experiences gained. The recommended implementation policy is then to provide the temporary support needed to ensure an implementation scale, where costs are “driven” down to the competitive level.

The argument is specifically outlined in the following way by UNDP (UNDP, 1996, p. 82) in the case of biomass integrated gasifiers. It is expected that the costs of the biomass integrated gasifiers will follow a learning curve. More specifically it is assumed that the costs of 10 units of a 25,000 kW plant that is scheduled to commence operation in the Northeast Brazil in the late 1990’s. Shell researchers (Elliot & Booth, 1993) will decrease with 20% for each cumulative doubling of production. This will imply an total cost of learning of 0.12 bill US$. It is difficult to judge how much of such

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[15] Under these circumstances, mainstream economics does not apply very well, as the assumptions necessary for most economic results and models are violated. Thus, dysfunctional institutions can be seen as one of the reasons why mainstream economics does not apply as readily in developing countries as it does in developed countries.

learning costs (or gained benefits) that can be transferred from one project to another especially if the projects are implemented in different national settings.

2.1.2 Categorisation of barrier removal policies

A number of complicated issues arise in choosing barrier removal policies due to intertwining of project, sector, and macro level with regard to transaction costs and policy instruments. The decision of which barrier removal measures to launch should, therefore, be based on assessment of the overall structure and functioning of the economy, including the policy and regulation framework. Such an assessment is necessary in order to obtain consistency and adequacy of the measures taken at different policy levels. Furthermore, it facilitates integration of the barrier removal measures into the existing policy framework.

The assessment could be organised around the following categories of possible barriers.

Market barriers:

- Markets tend to be missing or segmented.
- Monopoly and / or monopsony.
- Entry barriers.
- Externalities and public goods.
- Price distortions and absence of price signals.

In-flexibility and constraints of established technical systems:

- Capital irreversibility (turnover, infrastructure).
- Specific technology innovation and learning aspects (inertia, market development needs).
- Economics of scale.

Institutional barriers:

- Unreliability or absence of legal institutions → failure of enforcement systems, ill-defined property rights.
- Under-developed financial markets → weak institutions, risk, limited supply.
- Limited flow of information → inefficiency, inertia, collective action problems.
- Administrative capacity constraints → failure to implement legislated policies.

Human capacity barriers:

- Insufficient education level and coverage.
- limited supply of skilled labour and professionals.

Having made an ”inventory” of barriers specific to the country in question, it is appropriate to turn to the decision of barrier removal policy.

2.1.3 Examples of barrier removal policies

The basic nature of a barrier removal policy is, with reference to the bullet points above, to try to enhance the power of market forces and private incentives to implement projects. This policy can include a large number of different activities including price incentives, information, establishment of an institutional framework for market competition and access (e.g. capital market structure and institutions).

It should be emphasised that different combinations of barrier removal policies can be suggested to implement projects or strategies but the specific design and the cost of the different policies are dependent on the comprehensive barrier removal effort. This can be illustrated in the case of electricity saving effort for private households. This policy can be sought implemented through information campaigns and technical standards of with through market instruments like taxes or subsidies, or more realistically by a combination of all the mentioned policies. The cost of each of the individual barrier removal policies must be expected to decrease if they are combined with other policies - price signals work better if households are well informed and the other way around. However, in practice barrier removal policies maybe will not fully be able to take advantage of such synergism's because other political or social considerations prevent the use of certain instruments. Furthermore, as noted in the beginning of the section, conflicts between the instruments used at the different levels are possible, or even likely.

It is convenient to distinguish between three levels of intervention: macroeconomic level, sectoral level, and project level. Below is a box with examples of policies at the three levels targeted to reduce transaction costs. As will appear, implementation of one policy may be in conflict with the implementation of another.

Box 5 Examples on barrier removal policies

	Policy level	Specific policy example
Market barriers		
Market creation, possibly with public sector involvement in the transition period	Sector or project	Temporary support to specific demonstration projects
Privatisation for example through the establishment of well-defined property rights and enforcement	Sector or project	Afforestation programmes
Regulate competition by introducing more market actors	Sector or project	Information campaigns, soft loans to renewable technologies
Environmental taxes	Macro	Carbon taxes
Support efficiency in savings and investment decisions by deepening financial markets	Macro and sector	Support financing mechanisms (e.g. GEF)
Launch technical standards to be met in a given time frame	Sector	Efficiency standards for electricity appliances
Price liberalisation, support international competition	Macro	Exchange rate devaluation
In-flexibility and constraints of established technical systems		
Timing of infrastructure investments	Sector or project	Long term planning of power production and transmission
Subsidy to capital turnover projects	Sector or project	Specific capital grants
Subsidised credit to support research, development and learning processes	Project	Demonstration and research programmes
Co-ordination and integration of specific climate change mitigation efforts in general investment policies	Project	Information, capital subsidies
Institutional barriers		
Establish monitoring and enforcement systems	Project	Reporting systems
Establish and enforce property rights	Project and sector	Land reforms
Institutional set-up for the reduction of risks and/or risk pooling (notably capital market)	Macro and sector	Offset market
Establishment of specific organisations to reduce uncertainty and transmit information	Project and sector	
Establish international mechanism for technology transfer	Project and sector	"Clean technology mechanism"
Human capacity barriers		
Training and education activities	Macro, sector and project	
Improvement of decision making processes	Macro, sector and project	
NGO involvement in specific areas	Project or sector	

2.2 Examples of policies and instruments for their implementation

The following general steps will be use full to follow in deciding upon implementation policies:

1. Assess the functioning of the economy, identifying important barriers.
2. Assess necessary barrier removal measures and their ”level”.
3. Check for conflicts / inconsistencies.

Mitigation projects in practice often will require specific barrier removal policies that include a combination of different sub-elements from the above listed barrier removal policy categories. A number of examples will in the following be given on barrier removal policies that have been suggested and applied in relation to specific projects.

2.2.1 Case example 1: end use energy efficiency programmes

Many country studies for developing countries have identified energy end use efficiency improvements related to industrial motors and boilers as attractive low cost mitigation options (UNEP, 1994a, b, c; Halsnæs, 1996). In these countries industry as a consequence of capital constraints and inertia is using inefficient and economically outdated production equipment and new technologies therefore at the same time can save energy consumption and reduce GHG emission with a low cost and even sometimes with a benefit. The challenge is to identify barrier removal policies that can help the implementation of the options.

Several different barrier removal policies can support the implementation of new efficient boilers and motors in industry. These includes financing, information, training, and more specific market instruments such as tax and subsidy policies. The costs of specific financing options and information and training efforts can relatively easily be measured and integrated in the total cost assessment. The main uncertainty here related to the “efficiency” of the policies in getting the actors to implement the projects. The costs and consequence of using market instruments are more difficult to assess. Market instruments can for example include carbon taxes on fossil fuels, where part of the revenue afterwards are recycled to industry as investments grants for the boiler and motor options. The market instruments in this case have a number of general direct and indirect economic impacts in addition to the incentive to implement new boilers and motors. These “broader” impacts can only be assessed at sector or macroeconomic level, and the implementation cost assessment must for the market instruments therefore be directly related to these more general assessments. Another implication of the described very general character of impacts of market instruments is, that the introduction of such barrier removal policies should be considered for a larger group of sector policies, and not for individual projects alone.

A number of country studies for developing countries have made a qualitative assessment of implementation policies in relation to efficiency improvements in industrial boilers and motors. A study for Venezuela (UNEP, 1994a, b, c) assessed a large technical potential boiler efficiency improvements in industry with very low costs. The implementation of new efficient boilers however, were difficult due to a number of barriers. The barrier that particularly as emphasised as a priority in the companies to maintain established equipment because spare-parts were easily accessible, and the technology was well known. It was assessed that the decision makers in the companies had information about the new technologies but that they underestimated the potential efficiency gains of implementing them. The up-front installation cost of new boilers in relation to just maintaining the old was also seen as a significant implementation cost. On this background it was recommended to design an implementation strategy that included information campaigns, third-party financing or other financial mechanism, and general market creation activities where demonstration projects and local supply of spare parts for the new equipment should be sub-components.

Another broad category of end use efficiency options is electricity saving programmes, where an interesting case example is the ILUMEX project. The ILUMEX project is a programme for replacing 1.7 mill. ordinary light-bulbs with CLF's in two Mexican cities with an expected CO_2 reduction of 700,000 tons.

The ILUMEX project includes a very detailed implementation strategy (Sathaye et al., 1994). The project is specifically targeted to low income households, because these currently pay a low subsidised electricity price. Households with higher incomes pay a relatively high electricity price and savings by these consumers are therefore less profitable to the utilities. The CLF's are offered to a low subsidised price and the marketing includes a number of options such as direct sales from utility offices, financing via the electricity bill, and "mobile" information offices and sales campaigns in neighbourhood outreach offices. The programme also included a flexible monitoring system with feedback on incentives: lamp price, mobile sales offices, direct sales and installation force.

A number of expected implementation cost elements has been assessed in ILUMEX. The direct subsidised purchasing price of the CLF is decided to be 10$. The basis for fixing this price was an assumed 2 years pay back time for consumers. The costs of programme execution and evaluation were assessed to be 1.64$ per lamp increasing up to 2.02$ per lamp if all lamps had to be sold by mobile offices.

The ILUMEX project implies a number of interesting implementation policy issues. The first obvious question is if it is desirable to target the programme to low income households. These customers must be expected to have a relative low capacity and incentive to react, because they must be expected to have a short time horizon (implying low pay back time of the bulbs) and low information. Only the general electricity subsidies to this group suggest that a special effort should be done here, and it is a big question if it will not be more efficient to suggest a deregulation of the subsidies for this group and eventually support this group of households in another way. Another related question relates to the sustainability of the ILUMEX programme when special grants and marketing programmes have ended. It is difficult to see the long term incentives of low income households to buy new CLF's. The ILUMEX programme is therefore a very illustrative example on, the inter-linkages between market instruments and other barrier removal policies. The exclusion of electricity subsidy removal in the implementation policies must be expected to lead to increasing short- and long-term programme risks and implementation costs, and it would therefore be recommendable to see the ILUMEX programme in a more general sectoral policy context.

2.2.2 Case example 2: barriers rooted in interlinkages of markets and institutions

Developing country studies suggest that interlinkages from one transaction to another may be an important factor in explaining policy failure. It is appropriate to talk about an interlinkage when the terms and conditions of one contract[16] affects the terms and conditions of another contract. In a study of 110 villages in West-Bengal (Bardhan, 1997), the credit-labour interlinkage was found to be important. The peasants would

[16] The term "contract" is to be understood in broad sense, not necessarily as a legal contract.

get credit, in the form of food, from the landlord during one season and pay back providing the landlord with labour in the busy season.

This example has two implications worth emphasising in the present context. First, it is noticed that interlinkages raise the entry barriers, thereby possibly increasing the monopoly power of the stronger party (in this case the landlord). Second, if policymakers do not take the interlinkages into account, there is a risk that the policies will fail. In this specific case, land reform programmes may not succeed if not combined with credit reforms. If credit reforms are missing, the former tenant may not have access to credit and is, at the same time cut off from the previous contract with the landlord.

In relation to climate change mitigation policies, the example indicates that it may be appropriate to pay attention to the functioning of credit markets. A mitigation policy aiming at raising efficiency in the agricultural sector by the establishment of well-defined property rights, thereby reducing the pressure on marginal areas as well as forests, has a better chance of success if combined with appropriate credit schemes. Similarly, improved access to credit may reduce deforestation by making other options available to the private agents.

2.2.3 Conclusions

Implementation costs are one of the most critical components in providing more reliable estimates of mitigation potential and related policies. It is, however, as explained above not “trivial” to develop a framework for assessing implementation costs that addresses the many specific national issues that will be critical in strategy development.

The current section has primarily tried to design a definition of implementation cost concepts that can be addressed in national studies. The concepts distinguish between a case where implementation only requires a minor cost components to cover administration, training, monitoring and the like, and a more “complicated” case, where there is significant implementation barriers. The latter case is complicated to address, because the cost of barrier removal policies by nature needs to consider general price and market structures, institutional issues, human capacity and a number of other factors that are difficult to address in a quantitative cost calculation. A first, and very valuable step, however, will be to include information about barrier removal policies that will help the implementation of specific mitigation options. Such information can perform the basis for a critical evaluation of mitigation options that in the more formalised costing studies are suggested as cost-effective policy options. A very interesting final output of the implementation cost assessment then could be a reconciled list of recommended mitigation options qualified with a broader description of implementation requirements.

3 Macroeconomic assessment

The following section outlines the macroeconomic cost concepts in relation to GHG limitations. The macroeconomic cost concept differs from the specific project or sector cost definitions in the way that the macroeconomic cost concept aims to include the general impact to society of GHG limitation. In section 1 the cost concepts have already been discussed. However, it is essential to emphasise how the costs of limitation are defined in the concrete context of macroeconomics.

In relation to macroeconomic assessment of GHG limitations the cost concept – in principle – is as broad as possible. This implies that costs, or preferably impacts, in relation to macroeconomics include variables such as GDP, employment, imports and exports, public finances etc. The reason for including all these parameters is that they serve as proxies for the social welfare. It is assumed that a high degree of employment is regarded as a positive by society, following the same reasoning high economic growth (GDP) is generally regarded as positive.[17]

In industrialised countries, there exists a relative long tradition for making assessments with a macroeconomic view. Assessments in these countries have taken different directions, but in recent years the importance of focusing on the overall impact on the economy has been emphasised. The view of the macroeconomic assessment is normally general and therefore fairly *aggregated* and the approach is therefore often labelled top-down. The focus on possible instruments for GHG reduction is generally macroeconomic instruments such as taxes.

Another approach, which has shown its strengths especially in countries where data are scarce as in most developing countries, is more *detailed* assessments at project or sector level which also can be labelled as the bottom-up approach. This approach begins with the identification of different options for reducing GHG emissions. The options can include technologies as well as more behavioural policies such as information campaigns for end use energy efficiency improvements.

Both approaches have advantages and disadvantages. The biggest drawback of the top-down analysis is probably that it is very general and therefore is less useful for specific policy decisions. On the other hand, top-down analysis allows for long-run scenario analyses. The bottom-up analysis, with its detailed appraisal of different specific options, has limited long-run capabilities while accommodating more short-run policy questions (see IPCC, 1996b, ch. 8, p. 280-281 for a further discussion of top-down and bottom-up model approaches).

Macroeconomic assessment of GHG limitation offers a framework for analysing more fundamental and long-run reduction scenarios than a technical approach. This is above all because macroeconomic analysis focuses on feedbacks caused by changes in demand and supply in different sectors of the economy.

3.1 Background

Emissions of GHG are closely related to economic activities. Emissions stem from several different human activities such as energy generation, transport, agriculture, forestry, waste management, etc. This implies that the main determinant for CO_2 emissions from for instance the energy sector is the demand for energy as an industrial production factor and as a final consumption category. In other sectors like agriculture,

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17 It should here be noted that high economic growth could degrade the environment. It is, however, not the place to raise this discussion here.

forestry, transport and waste management, changes in the demand for final consumption goods supplied by a large number of production sectors will determine the activity of the sectors and therefore the emission of CO_2, CH_4 and N_2O. Human emissions of GHG are therefore closely related to the economic activity of the society.

3.2 Purpose of macroeconomic analysis

An essential reason for looking at macroeconomic consequences of GHG reduction is to create a broad decision making framework. By including some of the most important macroeconomic variables such as GDP, consumption, trade balance, public finance and employment it is possible to give an overview of the impacts or “costs” of GHG reduction at a macroeconomic level.

The macroeconomic assessment goes beyond the project and sector level analysis, largely because the macroeconomic analysis aims at including dynamic effects through changes in prices and quantities. In marginal cases, not entailing larger changes in prices and quantities, a project assessment approach makes good sense, but when changes in for instance the energy system are more substantial a marginal framework tends to underestimate the flexibility of the economic system. Through the macroeconomic assessment more realism can be introduced when analysing more substantial changes in GHG emitting sectors.

Macroeconomic analysis, in the context of climate change mitigation, has two main purposes:

- to create general background consistency in the economic assumptions. This is done to ensure that forecasts of different economic sectors do not conflict with general assumptions on economic development. This part includes creating consistencies between projections of different sectors such as energy, forestry and agriculture. This part could also support the construction of baseline scenario.
- to analyse how reduction of GHG influences economic growth. The key macroeconomic variables include variables as GDP, consumption, employment, investment, balance of payment, price etc.

3.3 Essential macroeconomic variables

Compared with traditional economic models the time horizon of GHG emission is *very* long, i.e., the impact of GHG is 25 years or more. This, together with larger mitigation options like long-term investments such as new power plants, implying that *feedbacks* can play an important role.

To fulfil the objectives of macroeconomic analysis an array of data related to the economy, energy and emission have to be made available. A number of economic variables are required if reasonable baseline scenarios, estimation or modelling are to be made. The simple relationship is that fewer indicators or variables limit the conclusions, while a broader range of indicators allow for a more detailed analysis.

Table 5 lists a number of macroeconomic variables. Together these data constitute required data to perform macroeconomic analysis. Beyond the macroeconomic data listed in Table 5 it is important to have access to reliable data on energy supply and demand, and GHG emissions. In Table 6 some important energy and emission related data are listed. Some of the data in Table 5 and Table 6 are interconnected, e.g., energy demand and general economic development.[18] More detailed national account figures like input-output tables (see below) can enable a more formalised macroeconomic modelling effort. With respect to both economic and technical data it is important to obtain as long and consistent time series of data as possible.

Table 5 Essential variables for macroeconomic modelling.

Category	Specifications
Demographic	Age distribution, etc. Urban-rural distribution Labour force Employed/unemployment
Land-use	Land quality Agriculture Forestry

National account figures	Gross domestic product (GDP) nominal and real
	Gross national income (GNI)
	Consumption, real
	  Government
	  Private
	Investment, real
	  Government
	  Private
	    Building
	    Transport
	    Machinery

Public finance	National debt, internal and external Public finance Financial transfers
Foreign trade	Balance of payments Imports and exports Exchange rates Purchasing power
Monetary	Prices Money supply Interest rates

The variables listed in Table 5 include the most important aggregated variables for a macroeconomic assessment. Some data are only included in Table 5 in a schematic form, for instance the land-use category. However, the purpose of including this category is to take into account the possible changes in land-use patterns between different land-use, for instance a shift from forest to agriculture.

Depending on the ambition fewer or more of the variables in Table 12 should be *disaggregated* in order to take into account changes between sectors caused by prices and quantity changes. Availability and resources must to a large extent play a role in deciding this. Summing up it is essential to gather as sound economic statistics as possible, including establishment of time series if possible.

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[18] In practice energy demand and general economic growth is modelled as a relationship where energy demand is a function of consumption, possibly subject to restrictions such as foreign exchange and demand for other goods.

Table 6 Important energy and emission related variables.

Category	Specifications
Energy demand	Historical demand of sub-groups
Energy supply	Existing energy system including constraints on future energy supply
Technical options	Identification of possible options for emission reduction, including energy supply and demand, and options for non-energy sectors.
Technological change	Autonomous energy efficiency improvements (AEEI) and economy (price) driven change
Other relevant emission sources	Forestry including deforestation and agricultural development

3.4 Economic modelling in relation to GHG emissions

3.4.1 Important parts to include in a general macroeconomic analysis

No matter how the GHG mitigation assessment is performed a number of assumptions about baseline scenario, economic growth, technical options and change must be done. It is important to consider the possibilities and limitations of performing a macroeconomic analysis of GHG limitations. The analysis should take the specific country's possibilities and interests into account. There is, for instance, no point in trying to carry out a detailed analysis if availability of data renders this impossible in practice. Another point is that elaborated models often exhibit decreasing returns to scale with respect to effort and resources put into the analysis.

However, regardless of availability of data it is always possible to carry out a minimal or simplified macroeconomic analysis. But it is important to identify the specific limitations to a macroeconomic assessment at an early stage of the analysis in order not to waste resources. After a preliminary "scanning" of existing data and models one or more of the following steps of a macroeconomic analysis can be performed. The following steps of data collection for a macroeconomic assessment of GHG reduction should not be taken as mandatory, but as a guide and starting point:

1. Energy demand, historical and projected.
2. Energy system, the supply of energy.
3. Non-energy emitting sectors, i.e., land-use.
4. Technical options for GHG reduction. This should include the following sectors, depending on the specific conditions in the country:
   - energy,
   - transportation,
   - forestry,
   - agriculture.
5. General socio-economic variables, including:
   - Population, age, demographic transition, etc.
6. Aggregated national accounts on a time series base, including:
   - GDP.
   - Consumption.
   - Investment (government, private).
7. Public finance.

8. Foreign trade:
   - Exchange rates and restrictions.
   - Imports and exports.

3.4.2 The informal sector in relation to macroeconomic assessment

A special issue in developing countries is the role of the informal economy. The informal economy or sector eludes statistical recording, because of its character of being non-market or only partially market based. In traditional macroeconomic analysis, especially in macroeconomic models, the informal sector is often disregarded because of lack of statistics for this sector. It is necessary to consider the development of this sector in order not to overestimate growth. The trend is that economic growth "drags" employment from the informal sector to the formal sector, e.g., increased employment in industry at the expense of informal employment in the agricultural sector. If this drag is not taken into account in the macroeconomic analysis the result will be an overestimation of the growth in GDP just because of shifts between sectors which are erroneously recorded as "new employment".

3.4.3 Macroeconomic modelling

Depending upon the availability of statistics, existing models and resources, different levels of macroeconomic analysis can be performed. In Table 7 different approaches to macroeconomic assessment are outlined.

Table 7 Macroeconomic analysis in relation to GHG emission.

Availability of economic data and models	Possibilities
1. Aggregated macroeconomic indicators	Rough macroeconomic analysis, consistency between sector forecasts, crude baseline scenarios
2. Disaggregated macroeconomic indicators	Macroeconomic analysis, baseline scenarios
3. Input-output tables, Social Accounting Matrix	Simple modelling and forecasting, possible refinement of baseline scenarios
4. Computable general equilibrium models	Development of models with market mechanism incorporated. Assessment of costs of mitigation options at macroeconomic level in the long run
5. Macroeconometric models	Possible adaptation of existing models to reflect impact of climate change in the long run

The first two cases in Table 7 are examples where the fundamental statistics are so incomplete that macroeconomic modelling is rendered impossible without a huge additional effort. In cases like this the obtainable statistics must be utilised as efficiently as possible in order to obtain a minimum of macroeconomic analysis. This kind of analysis can provide a good background for both baseline and mitigation scenarios, especially if disaggregated statistics are available. Furthermore, this kind of general macroeconomic analysis by considering a number of key macroeconomic policy variables can put a more detailed analysis of one sector in the right perspective.

Even though this kind of macroeconomic analysis will typically be more qualitative than quantitative it can still give a useful background in relation to the overall assessment of GHG reduction.

Model studies can be performed if data and resources permit. Below two of the main long-run possibilities for macroeconomic modelling are outlined.[19] Each of the approaches has its advantages and disadvantages.

3.4.4 Input-output tables and models

Availability of input-output tables greatly enhances the possibilities of making forecasts of the economy at a more detailed level. With input-output tables for more than one year the reliability of the baseline scenarios is strongly improved. It is a great advantage if the input-output table includes sufficiently detailed data on the energy sector, i.e., if coal, oil, renewable and electricity as a minimum appear. Otherwise it is necessary to construct shares of each of the sub-sectors from the aggregated energy sector statistics.

If the input-output table includes a social accounting matrix (SAM), it is possible to obtain a detailed picture of the economy, as well as the national accounts. Thus a fuller picture of the economy is possible. Availability of SAM makes it possible– with additional effort – to apply CGE types of models.

3.4.5 CGE models and macroeconometric models

In general macroeconometric models focus on the short-run and typically have a so-called Keynesian specification. The Keynesian assumptions imply that the economy is demand-driven with sticky prices causing non-equilibria with unemployment in the short-run and a considerable crowding-out effect. Because macroeconometric models focus on the short-run, typically less than ten years, and because of the non-equilibrium nature of most macroeconometric models these models are best suited for assessing short-run fluctuations in the economy.

An often-used alternative, when analysing climate change mitigation, is the computable or applied general equilibrium models (CGE models). The CGE model framework is based on the Walrasian equilibrium tradition. Nevertheless, most model builders in practice have abandoned the strong assumptions of neoclassical theory. In this way a number of restrictions, primarily perfect market clearing, can be introduced. In this way it is possible in incorporate inflexible markets by for instance introducing a degree of inflexibility in the labour market.

The strength of CGE models is that it includes multisectorial forecasts, displays possible (and unlikely) development potential and analyses structural changes between the sectors. A major drawback of the CGE models is the rather rigid neo-classical framework with emphasis on market clearing, an assumption that is obviously implausible in the short run. On the other hand a range of techniques exist to relax this assumption as already mentioned above.

A substantial advantage of the CGE model compared with input-output models is the possibilities for non-linear specification of the model. The input-output model normally relies on a linear framework. Especially when the objective is to perform long-run macroeconomic analysis, the limitations and inflexibility of linear models are obvious.[20] Linear models, like input-output models and linear programming models,

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19 Short-run models as most macroeconometric models can serve as a guide for making long-run models (providing data and insights), but are generally not useful for long-run projections of economic development.

20 For instance the assumption on fixed input-output relationship is unrealistically in long-run analysis, because it render impossible any shifts between sectors. In this way the input-output model presents a static picture of the economy.

are best suited for cases with a high degree of central planning, where the planning authority maintains control of the resources. These resources are subject to physical and technological constraints, for which these linear models are appropriate. However, under conditions with increasing market based economies and structural adjustment policies the CGE models give more satisfying possibilities for introducing behavioural aspects such as consumer preferences.

3.4.6 Data collection

The main statistical data source for macroeconomic analysis are normally the national statistical institutions such as the central bureau of statistics or, as is often the case in developing countries, the central bank. These institutions will normally be responsible for national accounts, demographic data, monetary data and foreign exchange. Beyond these institutions additional data on public finance in some cases must be collected from the Department of Budget or Finance. Additionally, information on agriculture and forestry are often housed in the Ministry of Agriculture and Forestry, and related institutions. Technical data on energy, such as reduction options, can be obtained from a number of national and international sources and databases.

3.5 Structure of a national CGE model for modelling the economy-emission interaction

The purpose of the following section is to give a broad overview of the structure of simplified CGE models and furthermore present essential components of CGE models especially aimed at analysing macroeconomic consequences of GHG reduction.

It is not possible to give a complete description of how to build CGE models with special reference to GHG emissions in this section. This is due to methods and availability of data and resources. However, a schematic model of an economy aimed at analysing GHG reduction would normally consist of the following parts, some of which could be more or less elaborated. Furthermore, even though different CGE models include the same aggregated relations it is very likely that specific assumptions and national conditions will lead to different results. It is not an objective to try and implement one uniform general CGE model in several countries – the specific differences between countries are likely to be large. It is in many cases desirable to build on existing data and CGE models even if a model have been developed for another purpose that climate change mitigation studies.

A simplified CGE model consist of the following parts:

1) A block of production and factors.
    - Production function generally based on input-output tables.
    - Demand for factors, both primary and intermediate.
2) Price equations of the economy.
    - Domestic.
    - Imports and exports.
    - Capital.
    - Consumer goods.
3) Income formation.
    - National.
    - Factor.
    - Enterprise.
    - Household.
    - Government.

4) Expenditures.
   - Households.
   - Government.

5) Capital, investment and depreciation.

6) Foreign trade (import and export).

7) The environment – emissions.
   - Most important energy sectors.
   - Other important emitting GHG sectors such as agriculture and forestry.

8) Assumptions about market clearing and closure of the model.

The construction of a CGE model has the advantage of formalising the underlying assumptions. However, the model only represents an *abstraction* of which main purpose, is to highlight some aspects of the interaction between macroeconomic variables and GHG emission. The purpose of a CGE model developed for addressing GHG reduction is *not* to give specific answers such as "If carbon tax is increased by 20% over the next 10 years, then the GDP will fall by 1.3%."

The CGE model consists of a number of relations or equations. The equations are often in a matrix formulation due to the multisectorial format of the model. An important distinction between the equations is whether they are:

- Identities. The identities define given relations between variables, e.g., that consumption plus savings equals production.
- Endogenous equations. The equations are determined within the model.
- Exogenous equations. The variables are determined outside the model and inputted into the model. Therefore, there are no feedback effects from this kind of variables within the model.

3.5.1 Production and factors of the economy

To make a reasonable realistically CGE model it is necessary to include several production sectors. These sectors correspond to the aggregation level of the input-output table. In Table 8 an example of the sectors of a small input-output table is shown. The specific conditions of a country will always influence the concrete input-output table. For a country relying heavily on for instance coffee production it would be relevant to include several different sectors of the coffee production process.

Table 8 Example of sectors of the input-output table of a CGE model.

Sectors	
Primary	Agriculture Forestry
Secondary	Industry Construction Transport
Tertiary	Services
Energy	Coal Oil Electricity Fuelwoods

The sectors in Table 8 are very aggregated and as already mentioned, a disaggregation of sectors other than the energy sector could be relevant.

3.5.2 GHG emissions: the linkage between the economy, emissions coefficients and emissions

Almost all models have until now have focused on CO_2 emission. The reason for this is obvious because of the importance of CO_2. On the other hand, non-CO_2 emissions constitute an important share of the emissions. In principle, the non-CO_2 emitting sectors (for instance land-use) should be included in an assessment. However, it is probably unrealistic to expect that a detailed modelling of non-CO_2 emissions can be done in most developing countries.

Often GDP growth and emissions are related, but not in a proportional way. This is other called the possibility of “decoupling” energy consumption (and thereby emissions) from economic growth. The relation between growth and emission is typically divided in two: one part where energy is related to the economy through prices and income, and one part where energy is autonomous from the economy. This latter is called autonomous energy efficiency improvements (AEEI). Through this an efficiency increase decoupled from the economy can be incorporated in the model framework. One problem is that few empirical estimated of the AEEI have been made.

Finding the emissions from different sources in for instance the energy system involves assessing emissions factors for different technologies. With these factors, the real energy consumption is translated into physical emission. In this way it is possible to assess the emission at a given consumption level. The next step is normally to formulate a relation with a carbon tax. The carbon tax makes it possible to assess impacts on consumption, investment, employment, etc. of different levels of taxation. Depending on model formulation, the revenue from the carbon tax is, or is not, transferred back. Often it is assumed that the revenue is used for reducing inefficiencies in the tax system in general.

3.6 Some alternatives to formalised economic modelling

The primary reasons for not performing a comprehensive macroeconomic analysis based on a formalised model are, as already mentioned, the lack of useful data and the required resources compared with the pay-off of the analysis.

A viable alternative to modelling is to make a broad and more descriptive assessment of important development trends of the economy. The first step is to identify the most important macroeconomic variables as listed in Table 5 followed by a projection of development trends. This should be linked with data on emission sectors. Through combining economic development with emissions and assumptions on energy efficiency improvements and future energy demand, at least a qualitative assessment of different development paths can be undertaken.

3.7 Macroeconomic assessment: different assessment levels

The purpose of this section is to present and discuss advantages and drawbacks of macroeconomic assessment of GHG limitation in developing countries. Furthermore, a procedure for making a so-called simplified macroeconomic analysis of GHG (SMAG) is presented. In connection to this procedure the numerous problems connected with SMAG are highlighted. The main purpose of SMAG is to make a *general* framework for macroeconomic assessment of GHG limitation in individual developing countries. Because of the big differences between developing countries it is necessary to introduce different levels of assessment. The three main levels of analysis are shown in Table 9.

Table 9 Different macroeconomic assessments of GHG limitations.

Assessment approach and level	Output of the assessment
1. **Descriptive** Quantified assessment of most important economic background parameters.	1. Input to baseline and reduction scenario. 2. Identification of most important sectors of the economy in relation to GHG limitation.
2. **SMAG** Simplified assessment using existing statistics and possibly models. Minimal objective is to ensure internal consistency in projections of economic growth.	1. Baseline and reduction scenarios. 2. Quantification of changes in the most important sectors in the economy in relation to GHG limitation. 3. Development of a data base and model frame for further development of macroeconomic assessment.
3. **Modelling** Macroeconomic modelling. Typically CGE modelling expanding already existing data and models.	1. Baseline and reduction scenarios based on consistent economic projection. 2. Quantified macroeconomic impacts of different reduction targets and measures. 3. CGE model with special attention to GHG limitation.

Each of the above listed levels of analysis should be seen as additive: performing step 1 will make it easier to later perform a further assessment as described in step 2 and so on. For many developing countries with insufficient data and resources to carry out a more in-depth assessment such as the SMAG the descriptive level of assessment is the most reasonable approach. On the other hand, a number of developing countries with relatively good statistics and development plans have the possibilities to improve the decision framework in relation to the economics of GHG limitations by making a SMAG. Taking the analysis a step further by making a specific CGE modelling effort places great demands on data and especially on resources with regard to labour.

3.8 Simplified macroeconomic assessment of GHG limitation (SMAG)

The primary aim of SMAG is to establish a coherent framework for constructing GHG limitation scenarios in developing countries. These scenarios should, as far as possible, use already existing official data on economic development such as national statistics, national development plans and structural adjustment plans. Furthermore, the scenarios, depending on the specific country, should include influence from the international economy as such (international growth, prices and trade patterns).

The following is a general outline of how a simplified macroeconomic assessment of GHG limitation (SMAG) can be performed in different developing countries. The main restrictions on SMAG are availability of data / models and labour. A further problem is the difference between developing countries; this makes it more difficult to generalise the framework. Above anything else a common sense approach to the problem is important: it is essential to relate the different aspects of GHG limitation to the macroeconomic development trends.

3.9 Elements of SMAG

This section describes – in broad terms – the method or procedure when performing a SMAG. It is important to stress that *no* uniform procedure exists. The common elements and suggestions must be related to the specific conditions of each particular developing country. Above all, it is essential to start any SMAG with a thorough collection, presentation and analysis of socio-economic data in relation to GHG limitation in the country.

In the following, the different steps of the SMAG are listed and elaborated:

1. **Overview of published material on the subject in the country.**
   This preliminary step is more or less the same as the first step in the general guidelines of the *Economics of GHG limitations* project. This step aims to clarify the existing national study capacity by identifying for instance prior studies on the same subject this step should facilitate the SMAG. Above all the step should focus on building an overview of material of relevance to the economy.[21]

2. **Data and possible models.**
   In this step essential data should be identified. Scanning of possible models or capacity of relevant modelling effort should be investigated. Application of already available national or possibly generic models should be considered.

3. **National development plans and other economic data.**
   This should include all available material on future economic development, including for instance structural adjustment programmes to be implemented in the future. National account data (SNA) on a fairly detailed level should be collected; preferably obtaining an input-out table, possibly a social accounting matrix (SAM). Longer time series on SNA generally improve the reliability of projections.

4. **Collection of sectoral data (energy, agriculture, forestry, etc.).**
   This step includes both specific information such as statistics on energy, agricultural sector and forestry and adaptation of data specific to GHG limitations. This step can, depending on the ambition level and availability of data, be very time consuming. Linking economic activity to GHG emission is likely to entail the biggest problem.

5. **International background.**
   The importance of this step depends on the specific country's economic openness. International assumptions on energy prices should here be included in addition to assumptions on possible future trade patterns for the most important tradable goods with relationship to the national GHG emissions.

6. **Establishment of the baseline scenario.**
   This part includes establishing a consistent projection for the different sectors in the country. It is essential to ensure that obviously conflicting projections of different sectors, for instance forestry and agriculture, are eliminated or as a minimum lessened. Establishing a consistent baseline scenario is probably the *most* important and time-consuming step in the SMAG.

7. **Assessment of different reduction options.**
   This includes technical options, both supply- and demand-side options, as well as administrative and economic measures such as taxes and regulation. This step makes it possible to simulate different reduction scenarios.

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[21] The step can also include an identification of possible collaborating institutions, for example the central statistical bureau or the central bank, either, of which often have the best knowledge of the countries national accounts.

3.10 Concluding remarks

Performing a macroeconomic assessment of GHG reduction is often a time consuming project. Therefore, a sensible first step is to complete a survey of available data and models. The next step would be to estimate the time necessary for the different levels of macroeconomic assessment. Finally, when these steps have been concluded, the assessment itself should be done.

No matter at which level a macroeconomic analysis is carried out it entails two related and considerable “secondary benefits”. The first is the fact that collection of data for the model will generate a database on energy, emissions, and economic statistics, which are potentially useful in other applications. The second benefit is that the modelling effort may uncover a shortage of important official statistics on the economy and environment. Therefore, even if the actual modelling effort is only at a general level, it is likely that it will create additional benefits.

The simplified approach, as outlined above, provides a feasible framework for most developing countries because it consists of individual and almost independent steps. In this respect the simplified approach enables a coherent assessment framework, while at the same time allowing for different levels of analyses.

Sectoral Assessment

1 The energy sector

The current section outlines the main definitions and analytical steps in the energy sector assessment. Furthermore, an overview of main tools and technical assumptions to be used in the assessment is given. The aim of the section is to put existing energy sector methodologies into the specific context of climate change mitigation assessment and to refer to further readings and data sources.

1.1 System boundaries

The energy sector is defined according to IEA standards and includes the following categories (IEA energy statistics):

- production of primary fuels.
- import and exports.
- transformation.
- energy sector consumption.
- distribution losses.
- final consumption (industry, transport, other sectors and non-energy use).

Final consumption includes all energy end-use sectors such as industry, transport, agriculture and services, and non-energy use of energy sources. Thus, it should be noted that the energy sector assessment considers the full fuel chain from extraction to final transformation of net energy into useful energy.

There can be some overlap between assessments for the energy sector and for other sectors, for example in cases where the energy sector consumes biomass produced by agriculture and forestry. This means that an inter-sectoral consistency check on demand projections and resource availability must be carried out across the sectors.

National baseline projections should be closely linked to greenhouse gas emission statistics. The baseline projections should not be developed as projections from one statistical point in time, but already established national GHG emission statistics should be used as the starting point for national baseline projections. The physical emissions sources should therefore be linked to the main categories of the energy sector baseline scenario. An example of such a link is further shown in the baseline section.

1.2 GHG emission inventories

GHG emission inventories and projections established as part of the mitigation assessment should be based on the IPCC / OECD methodology (IPCC, 1997). The GHG accountings should include the most important present and future greenhouse gas emission sources and sinks, but do not need to include a detailed assessment for all sub-categories defined by the IPCC / OECD methodology.

The basic principle of the IPCC / OECD methodology is that all emissions are to be counted in relation to the physical emission sources. Examples of such physical emission sources are coal mines, oil and gas extraction, power plants, burners, furnaces, cooking stoves, and vehicles. The emission accounting methodology is further illustrated by a number of examples:

- Coal mines: GHG emissions to be counted are CH_4 emissions from the coal bed, *but* not CO_2 emissions from coal combustion. The latter should be counted in relation to the physical combustion process.
- Electricity export and import: emissions should be counted at the power plant for all electricity produced in the country. However, annual fluctuations in electricity trade can give an unrealistic impression of national development trends in GHG emissions. It can therefore be appropriate to calculate average emission trends by smoothing for longer time periods or applying correction factors for electricity trade.[22]
- Industrial process emissions such as CO_2 emissions from cement production should be counted at the cement plant and *not* where the cement is finally used.
- Conservation: emission reductions achieved through end use savings should be calculated in relation to the saved emissions by the specific reduced energy supply.

The main direct GHG emissions from the energy sector are according to these accounting principles listed in Table 10.

Table 10 Main categories of GHG emissions from energy sector sources.

	CO_2	N_2O	CH_4
Coal mining			X
Oil and gas exploitation	X		X
Gas pipeline leakages			X
Fossil fuel combustion	X	X	X

The measurement of CO_2 emissions related to fuelwood use is a complicated cross-sectoral issue. The IPCC / OECD methodology recommends that CO_2 emissions from fuelwood should be counted as zero in the energy sector, but the national emission inventory at the same time should measure net emissions connected to land use change. Fuelwood use that implies a decrease in standing biomass will then show up as decreased CO_2 sequestration of forested land. This accounting rule does not consider the final use of the biomass products in time and space.

The advantage of counting emissions in relation to physical emission sources is that the direct control potential inside national borders and the emissions sources coincide. The focus on national physical sources in some cases, however, can lead to sub-optimal control policies because imports of very CO_2 intensive energy forms will "look attractive" compared with less intensive national sources.

The importance of different system boundaries has been investigated in a Dutch energy sector mitigation study. The study concluded that the inclusion of national emissions as well as emissions outside the national boarders, but related to national energy consumption, only causes modest changes in the cost effectiveness of different energy technologies compared with a narrow national case. Only renewable technologies had a tendency to show up more beneficial as mitigation options, when emissions related to energy imports were included in the analysis compared with the closed national analysis (Ybema & Okken, 1993).

[22] Different correction factors can be applied. For example, Denmark has in a European context argued for using a correction factor for GHG emissions related to imported electricity that is calculated as the average GHG emissions by electricity produced in Europe.

An alternative to the focus on physical sources and sinks is to measure all emissions related to final consumption using an input-output approach. This implies that GHG emissions should be assigned to different final energy forms and industrial products etc. This necessitates a distinction between domestically produced goods and imports and exports. Such GHG emission estimates for import and export goods require a very detailed accounting system for GHG emissions produced for all internationally traded goods relating to different production processes in the countries of origin.

The input-output related emissions accounting system needs a transformation to physical emission sources before it can be used to evaluate technical emission reduction projects.

1.3 Analytical steps

The energy sector assessment basically should include the same analytical steps as specific for the country studies in general in section 1).

These steps are:

1. Construction of baseline scenario including energy demand and supply projections.
2. Identification of mitigation options.
3. Assessment of mitigation potential and costs of the options.
4. Construction of mitigation scenarios that integrate multiple mitigation options.
5. Assessment of broader social, environmental and economic impacts.

The specific detail and coverage of these steps will vary from country to country depending on data availability, modelling tools, and already established capacity in energy sector assessment. All studies, however, should use the key uniform concepts and country study assumptions summarised in section 1 of this guideline document. Some examples on how the analytical steps can be conducted are provided in Annex E2.

The last step – Assessment of broader social, environmental and economic impacts – is not specifically described in this energy sector framework, but is considered in general terms in section 1.5 Assessment of broader social and environmental impacts of mitigation policies.

The assessment of mitigation potential and costs of the options should be done according to the general concepts outlined in section Cost Assessment. Basically, energy consumption, GHG emissions, and cost of specific technical options should be assessed in relation to a baseline scenario.

1.3.1 Step 1: construction of baseline scenario

The baseline scenario for the energy sector includes projections of future energy demand and supply system structure. Energy demand projections can either be closely linked to macroeconomic activity projections or can be based on detailed inventories of energy consuming technologies. The supply system projections are closely linked to different energy modelling approaches. The main distinction here should be made between energy optimisation models that project future technologies as the least cost future technology choice and simulation models that project future supply technologies as a development trend from present system structure. The MARKAL model is an example of an energy optimisation model, while the LEAP model is an example of an energy simulation model. An extensive discussion of energy modelling issues and the consequences for mitigation cost assessment is presented in IPCC, 1996b, ch. 8 & 9.

The baseline scenario can either be defined at the detailed individual technology level, or for the whole energy demand and supply system as such. The mitigation options are in the first case assessed in relation to the specific options that are substituted, while in the latter case, the mitigation options are assessed in a total system context.

1.3.2 Step 2: identification of mitigation options

A very large number of energy technologies can in principle be assessed as part of a mitigation scenario, but only a limited number of these options will be important in the specific national context. Data collection is very time consuming, especially for developing countries, and a critical screening should therefore be carried out to select those options which will undergo close-examination.

The choice of options for the more detailed assessment should be evaluated in relation to the following criteria:

- present and future importance of the specific GHG emission source.
- magnitude of the mitigation potential that can be captured by the option.
- implementation policies.
- development of efficiency and cost over time of the option (learning curves).

It is not the purpose of the current methodological framework for country studies to cover a full menu of technical options in the sectors. It is instead recommended to select a portfolio of options that for the energy sector will include:

- *short-term GHG reduction options* related to end-use energy demand and efficiency improvements, small-scale renewable technologies, efficiency improvements in conventional power supply etc.
- *long-term GHG reduction options* as for example power supply technologies, and advanced renewable technologies.
- *large scale investment projects* as well as *demand side regulation efforts*.

The following list shows possible economically attractive technology options for reducing greenhouse gas emissions in the energy sector. The list is not intended to be exhaustive, but shows some categories of options that will be relevant for inclusion in most country studies.

End-Use

Lighting:

- Commercial facilities: replacement of standard fluorescent tubes with lamps with electronic ballasts and reflectors.
- Residential: replacement of incandescent bulbs with efficient fluorescent and compact bulbs.

Motors:

- Use of high-efficiency motors and adjustable-speed drives in industrial facilities.

Refrigeration:

- Residential: replacement of old home refrigerators (e.g., 1000+ kWh / yr in the USA) with new high efficiency models (e.g., as low as 300 kWh / yr in the USA).
- Commercial: replacement of standard compressors with high-efficiency compressors or multiplex compressors.

Industrial Processes:

- Encouraging cogeneration for provision of electricity and process heat. Waste products from industrial processes (wood waste, bagasse, etc.) could also be usable for combustion in a cogeneration process.
- Industrial processes often have very high cost-effective energy efficiency potential, but their process-specific nature often precludes generic programs. Industrial audits are necessary to identify the most appropriate measures, and a financing mechanism should then perhaps be put in place to encourage actual equipment retrofits following audits.

Cooking:

- Use of improved woodstoves and other more efficient cooking devices.
- Substitution of wood fuels in cookstoves in institutions such as rural schools, hospitals, and other centres.

Water Heating:

- Replacement or reduction in use of electric resistance heating. Greater use of natural gas or simple solar systems. Heat pumps may be applicable in commercial and industrial facilities.

Space Heating:

- Refurbishing of district heating systems: improved controls, maintenance, metering.
- Use of heat pumps.

Space Conditioning:

- Many air-conditioning options are available, in particular district cooling in tropical countries.

Other appliances:

- Reduction of standby devices.

Supply Side

- Combined-cycle natural gas and high-efficiency simple cycle gas turbine operations to replace coal- and oil-fired boilers for electricity generation.
- Combined heat and power production systems.
- Hydropower: large-scale systems have significant environmental impacts. Smaller-scale run-of-river systems may often be attractive..
- Wind power in places with favourable climate.
- Small-scale photovoltaics can be competitive especially in remote areas with no grid access. In general, small-scale renewables in rural areas can be cost-effective and also reduce deforestation by reducing reliance on local biomass. Options include solar cooking stoves, biogas plants, small-scale wind systems, and small run-of-river hydro installations. Large-scale photovoltaics are not yet competitive against traditional generation in areas with a developed transmission grid.
- Biomass-based electric generation systems using agricultural wastes or forest plantations show significant potential, especially as gasification systems mature and allow biomass combustion in gas turbines.
- New coal-based electric generation such as integrated gasification combined cycle (IGCC) and pressurised fluidised bed combustion (PFBC) systems are both now well-demonstrated technologies that have been successful in significantly raising the efficiency of coal-based systems to total efficiencies of up to 45%.
- Fuel substitution.
- Establishment of infrastructure: power transmission, natural gas pipelines.
- Deployment of decentralised options for infrastructure development (photovoltaics, wind, photovoltaic/wind hybrid systems) and renewables for

grid support and energy management. A distributed utility in which net metering and a form of performance-based rate making allow distributed generation, storage, and DSM to play an important role, could support the implementation of rural solutions.

1.3.3 Step 3: assessment of mitigation potential and costs of the options

In this step the technical potential for GHG reductions and the related cost are assessed for the individual options. This step will require collection of detailed data, and the following section 1.5 Data sources and 1.6 Sample data for energy end-use and supply technologies gives an overview of sources for technical information and sample data for energy end-use and supply technologies.

The cost calculation should use the basic cost concepts defined in section 1.2 Cost Assessment. A number of case examples included in the Annex 3.4.

1.3.4 Step 4: construction of mitigation scenarios

A mitigation scenario is a combination of individual mitigation options such as power supply technologies and energy efficiency options for different end-use sectors. The mitigation potential and cost of such options can sometimes be interdependent due to technical interdependencies in the energy system or general equilibrium effects of project implementation. Only the technical interdependencies will be considered in the current section – see the section on cost and benefit concepts for a discussion on general equilibrium effects.

A “classical” example of technical interdependencies between energy sector projects is when an electricity saving project and a power production project are combined. The costs and GHG emission reduction of the electricity saving project depend on the power system. The “outcome” of implementing an electricity saving project as part of a comprehensive mitigation strategy will then depend on what is assumed about the implementation of power supply changes.

Technical interdependencies in the energy system can be addressed in different ways either using advanced energy system models or by scenario analysis, where mitigation costs and GHG emission reduction are assessed for different “packages” of options.

Such scenario assessments can be represented in cost curves (see section 1.5). A cost curve can show more or less sophisticated study results either as a ranking of individual options or as the result of an integrated energy system analysis.

A case example of a cost curve construction for Zimbabwe is shown in Annex 3.2 below.

1.4 Methodological issues

1.4.1 Energy demand projections

Several methods can be used in energy demand projections. A main distinction can be made between projections that are driven by aggregate macroeconomic activity forecasts and those that are based on detailed assessments of energy end-use and supply technologies. The following section explains the main differences between simplified versions of these two approaches.

Projections based on aggregate macroeconomic activity start with a link between economic development measured as total GDP or divided into various demand and production sectors and GHG emission sources and sinks. The activity forecast can be generated by macroeconometric models of various types or by simpler statistical surveys. In the simplest case, the relationship can be formulated as:

$$E = AY^{\alpha} P^{\beta}$$

where:

E is the energy demand

A is a (positive) constant (which, for example, can represent a technological trend factor)

Y is the income (total GDP or a vector of sectoral outputs)

P is the energy price

α is the energy-income elasticity (or a vector of sectoral elasticities); this elasticity is *positive*, implying that higher income entails higher energy demand.

β is the energy-price elasticity; this elasticity is *negative*, implying that higher energy prices entail reduced energy demand.

It should be recognised that this energy demand equation is based on a highly schematic functional relationship, but it illustrates how econometric estimates of historical trends can be used to establish a macroeconomic activity link to energy demand forecasts. Such an approach should be distinguished from behavioural relations, where energy demand is expressed as a function of prices, quantities, and substitutability.

This framework has its advantage in establishing a consistent relationship between macroeconomic activity and energy demand. The demand projections should preferably be divided into the main energy categories and demand sectors. In developing countries, however, it can be very difficult to obtain the appropriate statistical data for a time series that is long enough to make a valid econometric energy demand forecast. Many studies in these countries have therefore used some sort of generic international data to substitute for the lack of national data. Such an approach will, of course, decrease the quality of the forecasts.

Econometric energy demand forecasts are especially valid for short-term projections, because they basically project what will happen if existing historical trends continue in the future. Structural changes in energy demand or major technological changes are not reflected in the simplified representation of the demand forecast shown above. Such information, however, can be integrated into the assessment, for example, through the use of exogenous input on sectoral changes in energy demand. This limits the application of econometric forecasts in longer-term projections.

Some macroeconomic energy models include a so-called AEEI (Autonomous Energy Efficiency Improvement) parameter that reflects long-term technological changes, which are not induced by structural economic output changes or relative price changes. The AEEI parameter is exogenously determined, which, of course, is not a very satisfactory solution. It is difficult to estimate the AEEI factor, and many studies have therefore used expert judgements in its determination. The AEEI value applied in macroeconomic energy models typically varies between 0.5% and 1.5% annually (EMF, 1993). As an alternative to the use of an exogenous AEEI factor, one can estimate a technological progress factor and include it in a production function.

An alternative energy demand projection methodology is the technology-driven end-use approach (Januzzi, Swisher, and Redlinger, 1997). The end-use approach projects future energy demand as the product of two factors: the energy service level and the energy intensity. The energy service level is, as with econometric projections, related to economic output, income, and population projections. The energy services are then linked afterwards to detailed end-use technology data in order to project the quantity of energy that will be needed to satisfy a given energy service. The energy demand is calculated according to the following formula:

$$E = \sum_{i=1}^{n} Q_i \cdot I_i$$

where:

E is the energy demand

Q_i is the quantity of energy service *i*

I_i is the intensity of energy use for energy service *i*

The idea of the end-use methodology is that the various energy services and technologies represented by I_i can be considered separately, thus making it possible to assess the impact of introducing options relating to the different parameters. Lighting could be an example of such an energy service. The I_i would in this case be represented by the energy intensity of the light bulb, and the point would be to investigate the technical possibilities of keeping a constant energy service level whilst saving primary energy through efficiency improvements in lighting technology.

The energy service demand is, by nature, a rather detailed projection of energy requirements related to subcategories such as process heat, lighting, space heating, and air conditioning, The quantity of energy services Q_i can, for example, be projected on the basis of the following parameters (Januzzi, Swisher, and Redlinger, 1997):

- number of customers eligible for end use i.
- penetration of end-use service i (units/customer).
- magnitude or extent of use of end-use service i (e.g., number of hours in use).

The energy intensity parameter I_i is related to the end-use technologies and reflects the efficiency of these technologies. This efficiency level will change over time, based on the expected turnover rate of the existing stock of appliances.

The advantage of the end-use approach is that it can reflect developments in appliance technology. Future energy demand is primarily projected on the basis of today’s known energy services and technologies, and the approach will therefore be most appropriate for the short to medium term. New energy service needs related to economic activity changes, or new future end-use technologies, can be difficult to forecast on the basis of the detailed technology information contained in end-use models. The best energy demand forecasting approach may therefore be a combination of the end-use and the econometric approach.

1.4.2 Supply system projections

The energy supply system includes power production technologies and heat production technologies. These technologies can be large centralised plants or decentralised in relation to specific production processes, heating and cooling systems, cooking devices, vehicles etc.

Supply projections can basically vary around the following parameters: fuel mix, technologies, and final energy forms (electricity / heat / cooling). Different sorts of supply scenarios can be constructed varying these parameters.

The fuel mix can include both imported and domestic resources. Supply technologies are in most cases linked directly to the fuel mix, but a number of variations is possible, where different fuels can be used in the same combustion process – or with small technical modifications.

A major scenario parameter is the assumed technological development. This assumption relates to already implemented and traditional technologies as well as to technologies that in the future would be cost-effective to implement given improved efficiency or decreased costs.

Changes in final energy demands in the form of substituting one energy form with another are closely linked to the detailed data on end-use technologies described in the section on energy demand forecasts.

Energy system models often contain databases with background information for establishing supply system projections. Optimisation models generate, by definition the supply system as the least cost case (subject to certain constraints), while energy simulation models allow more freedom in the criteria applied for scenario construction. Different types of possible supply system scenarios in these latter simulation models include:

- Frozen efficiency scenario, which assumes constant technological efficiency in the scenario period.
- Continuation of current trends scenario, which assumes a continuation of current technological development trends. The fuel mix is in the same way assumed to change according to current trends.
- Business-as-usual scenario, assuming that the supply system will follow already decided official energy plans.
- Least-cost scenario, assuming implementation of all technologies with the lowest cost.

It can be recommended to include a business-as-usual scenario based on official energy plans in all studies, because such a scenario is a very important source of information about national priorities in future energy system development. The official energy scenarios should however, as far as possible, be supplemented with a number of alternative scenarios in order to assess the importance of different assumptions.

1.4.3 Interpretation of the results of various energy models

National and international mitigation studies for the energy sector have been carried out with a variety of models. In recent years, extensive scientific discussion has surrounded the review and comparison of results from these different modelling exercises (IPCC, 1996b, Chapters 8 and 9). The models include technology assessment models, integrated energy system models, partial equilibrium models, macroeconomic models, and others. Despite differences in their focus and coverage, all of the models recognise a number of key input assumptions as being of major importance for the assessed mitigation potential and related costs.

The following identity shows, at the aggregate level, why energy baselines and mitigation assessments differ (Kaya, 1989):

The growth rate in CO_2 ≡ the GDP growth rate
– the rate of decline of energy use per unit of output
– the rate of decline of CO_2 emissions per unit of energy use

This identity can be developed further by adding extra arguments that reflect:

- The ratio of emissions to primary energy use.
- The ratio of primary energy use to secondary energy use.
- GDP per capita.
- Population growth rate.
- Structural changes in GDP.

Energy models will, in most cases, include more detailed information than the parameters reflected in the Kaya identity. Energy consumption, for example, will be represented in an energy system model by detailed fuel and final energy subcategories. The growth of energy consumption will subsequently depend on the development in energy service demand and technological development of end-use and combustion technologies. The CO_2 intensity of energy consumption is likewise related to the detailed background information on the energy system. The three arguments of the Kaya identity are therefore primarily of interest as comparative aggregate statistical indicators of energy modelling output.

International reviews of mitigation costing studies for the energy sector have assessed the implication of key input assumptions on mitigation cost assessments (IPCC, 1996b; Haites and Rose, 1996). Table 4.1 shows the implications of a number of key input assumptions.

Table 11 Main input assumptions in energy models.

Input assumptions	Meaning and relevance
Population	High growth will, if all other things are held equal, increase GHG emissions
Economic growth	Increased economic growth increases energy-using activities, and also through increased investments increases the turnover of energy-using equipment.
Energy demand	
- structural change	Different sectors have different energy-intensity; structural change will therefore have a major impact on overall energy use.
- technological change	This "energy-efficiency" variable influences the primary energy requirements to satisfy given energy services.
Energy supply	
- Technology availability and cost	Potential for fuel and technology substitution.
- Backstop technology	The cost at which an infinite alternative supply of energy becomes available. Upper bound of cost estimates.
Price and income elasticities of energy demand	Relative change in energy demand due to change in price or income respectively. Higher elasticities cause larger changes in energy use.
Existing tax systems and tax recycling	Recycling of carbon taxes. Substitution of distortionary taxes decreases costs.
Implementation	
- Instruments	Economic instruments versus regulation.
- Barriers	Cost of overcoming barriers either in the form of transaction costs or improvements of markets (incl. capacity building and institutional reforms). Behavioural assumptions.

Source: IPCC, 1996b table 8.3 p. 286

International reviews of mitigation costing studies for the energy sector have concluded that differences in study results can be explained to a large extent by differences in key input assumptions (IPCC, 1996b; Haites & Rose, 1996). Table 11 shows the implications of a number of key input assumptions.

A recent and somewhat comparable assessment of country study results in the UNEP phase two project showed that the energy sector study results were especially influenced by the following assumptions:

- energy intensity of economic development.
- carbon intensity of energy consumption and production.
- assumptions on technological development in baseline- and mitigation scenarios.
- assumptions on technology penetration in the baseline and mitigation scenarios.

The country studies in the UNEP phase two project showed large variations in these assumptions. Some studies assumed high energy and carbon intensity in the baseline case implying a relatively high projected future GHG emission growth. These assumptions were in some cases combined with rather pessimistic assumptions on technological development in the mitigation scenario which all together implied that the assessed mitigation potential ended up as being rather small and expensive. The country studies of Thailand and Brazil were such study examples. In contrast, the Egypt study assumed low energy intensity of economic development in the baseline case and had optimistic assumptions on technological development, and related costs and penetration rates in the baseline and mitigation scenarios. In combination, these assumptions implied relatively low projected future GHG emissions but a large and relatively inexpensive mitigation potential.

1.5 Data sources

One common difficulty in conducting climate change mitigation analyses is the shortage of data characterising different technologies and their costs and performance. While it must be emphasised that nothing can truly substitute for local country-specific data, there are several data sources containing "generic data" which can provide a useful starting point for analyses. Some of these data sources are described below.

A number of international databases offer information about energy technologies. Some of the most important sources are briefly described in the following. More details and full source reference to the databases can be found in the Annex.

IIASA CO_2 Data Bank. The CO_2 Data Bank (CO2DB) was developed by the International Institute for Applied Systems Analysis (IIASA) in Austria. It contains approximately 1500 entries describing a wide range of technologies including energy supply- and demand-side technologies, fuel extraction and conveyance, and passenger transportation.

IPCC Inventory of Technologies, Methods, and Practices for Reducing Emissions of Greenhouse Gases. The Intergovernmental Panel on Climate Change has produced this database as a technical appendix to the Climate Change 1995 Working Group II Second Assessment Report. The IPCC Inventory contains approximately 100 technologies, including energy supply, end-use, fuel extraction, and passenger transportation.

Environmental Management for Power Development (EM Model). The EM Model is a computer software package and database developed by the German aid agency GTZ, the Oeko-Institut, and the World Bank. The software contains generic data on a wide range of technologies and processes including costs and detailed pollutant emissions.

CEC Energy Technology Status Report. The Energy Technology Status Report (ETSR), published by the California Energy Commission (CEC), is a multi-volume document describing a very wide variety of supply-side and end-use energy technologies and processes including coal, oil, and gas combustion, nuclear, geothermal, hydroelectric, biomass, municipal solid waste, cogeneration, wind, solar thermal, photovoltaics, ocean energy, fuel cells, storage systems, pollution control, water heating, space heating, space cooling, lighting, appliances, boilers, motors, load management, and transmission technologies. The coverage includes qualitative descriptions of the technologies, barriers to implementation, and quantitative economic analysis.

E Source. E Source is a membership-based commercial organisation providing energy efficiency technology information to consulting firms, utilities, governments, and research institutions. E Source is perhaps the most complete source of end-use technology data and publishes, among other things, five comprehensive technology atlases (or "encyclopaedias") covering lighting, drive power, space cooling & air handling, space heating, and residential appliances. These five atlases are over 1700 pages in total length and include theory, design tips, and performance and cost information.

ACEEE. The American Council for an Energy-Efficient Economy (ACEEE) is a non-profit organisation that publishes a variety of books and reports and organises conferences related to energy efficiency. ACEEE publications include useful energy efficiency design guidance through books and reports such as “Energy-Efficient Motor Systems,” “Financing Energy Conservation,” “Improving Energy Efficiency in Apartment Buildings,” and “Energy Efficiency and the Pulp and Paper Industry.”

EPRI TAG. The Electric Power Research Institute (EPRI) is a research organisation jointly financed by U.S. investor-owned electric utilities. EPRI publishes a set of useful Technical Assessment Guides commonly known as TAG. The TAG reports provide information on electric supply-side and demand-side technologies, assessment methods, and data.

GREENTIE. GREENTIE is a project of the IEA to provide information about energy technologies. Though GREENTIE does provide some technology information, its main function at this time is as a directory of companies and organisations working with the various technologies.

The international databases are a valuable starting point for national data collection, but the data applied must always be critically examined in relation to the specific national context, because actual consumption behaviour and management of the technologies varies in different cultural and institutional settings.

1.6 Sample data for energy end-use and supply technologies

The current section shows some data for energy end-use and supply technologies that have been used in climate change mitigation studies.

Household appliances are among the end-use technologies where energy consumption varies significantly from country to country due to different sizes, consumer behaviour and efficiency standards. It is therefore important to use specific national data for these technologies. Table 12 below shows the values used for Danish household appliances in the Danish energy plan “Energy 21”. It should be noted that the Danish values for refrigerators are much lower than for example, in the USA where refrigerators are larger.

Table 12 Expected electricity consumption for Danish household appliances used in recent Danish energy planning.

kWh/year	1995	2005-10	2020-30
Dishwashers	445	375	325
Washing machine	410	350	300
Tumbler dryers	600	400	300
Electric Stove	161	140	130
Electric Hotplate	529	400	350
Microwave stove	75	50	50
Colour TV	175	130	115
Video	95	50	35
Refrigerator	329	264	239
Refrigerator/freezer	600	500	450
Freezer	566	339	313
Oil burner	198	186	174
Natural gas burner	98	88	75
Circulation pumps	372	288	225
Water beds	850	500	400
Computers	85	80	65

Efficiency improvements in electricity generating fossil fuel technologies offer a large CO_2 reduction potential. It is at present possible to increase the efficiency of such plants from the current 30% in many developing countries up to about 50%. Combined cycle plants may in the future reach up to 60% electricity production efficiency.

The following Table 13 gives an overview of electricity production efficiencies and related CO_2 emissions of traditional fossil fuel power production technologies.

Table 13 Electricity production efficiencies and related CO_2 emissions (default values).

	Electricity efficiency	g CO_2/kWh
Average Global steam turbine (coal)	0.30	1140
Average Global steam turbine (oil)	0.31	859
Best available steam turbine (coal)	0.45	760
Gas turbine (gas) + Steam turbine (coal)	0.47	613
Best available steam turbine (gas)	0.47	436
Best available combined cycle (gas)	0.54	379
Future combined cycle in 2015 (gas)	0.61	336

Table 14 gives an overview of the cost of some of the major categories of fossil fuel and renewable power production technologies for 1995 and the expected development trend for the period up to 2020/30.

Table 14 Cost and efficiency data for selected power production technologies.

$/kW	1995	2005/10	2020/30
Photovoltaics	4500	2000	1000
Solar thermal electric	3500	2000	1000
Wind turbines	1200	1000	900
Steam coal	1500	1350	1200
Natural gas combined cycle	800	640	480

Sources: STAP/GEF, 1996; Danish Energy Agency, 1995 and IPCC, 1995a.

Table 14 shows a large expected decrease in costs of the renewable technologies, especially solar thermal technologies and photovoltaics. This decrease is in particular a consequence of decreasing capital cost rather than increased efficiency.

The cost and effectiveness of new advanced renewable technologies can be assumed to follow a so-called learning curve, where the learning curve is estimated as the percentage reduction in cost expected to develop over time with increasing number of plants implemented.

The module price of solar photovoltaics has in this way followed a learning curve with an 82% progress ratio since 1976 (i.e. the installed cost has declined 18% for each cumulative doubling of the total production). The average PV module price in 1994 was $4.5/W, and a cumulative additional world-wide sales volume of 23,000 MW will therefore be needed to bring the module price down to $1.5/W, where the technology would be cost-effective in major on-grid applications (UNDP, 1996).

2 The transport sector

The transportation sector is a sub-sector of the energy sector, and the general methodologies developed for the energy sector are widely applicable to the transportation sub-sector. However, because of the importance of the transportation sub-sector as a source of greenhouse gas emissions, and because the mitigation options are, in some cases, different than for the energy sector, this section specifically outlines the major mitigation options for the transportation sector.

The transportation sector is a source of number of GHGs, including principally, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and CFC-11 and CFC-2. Globally, the transportation sector is estimated by the International Energy Agency (IEA) to have been responsible for about 25% of world primary energy use and 20-25% of global CO_2 emissions in 1990 (IEA, 1993a, b; Argonne National Laboratory, 1993; IPCC 1995c). In many developed countries, this fraction is substantially higher. In the US, for example, according to the U.S. Climate Action Report (1994), CO_2 emissions from the transportation sector constitute about a third of total CO_2 emissions from all sources. While CO_2 emissions from the transport sector are a smaller fraction of total emissions in the developing countries, transportation emissions in these countries are growing rapidly as a result of increases in the number of vehicles and vehicle miles travelled (VMT). This growth is due to a combination of factors, principally increasing vehicle ownership and use for a wide variety of purposes and longer travel distances associated with urban sprawl. Against this backdrop, efforts to reduce GHG emissions from the transportation sector will have potentially large impacts on Global GHG emissions.

2.1 System boundaries

For emissions calculation purposes, the transportation sector includes emissions from all types of vehicles, motorised and non-motorised[23] that convey people or freight from one point to another. It also includes GHG emissions from leaks in pipeline transportation, ground activities in airports and harbours, and on-road and off-road mobile source activities.

The transportation sector is closely tied to a number of other sectors, including vehicle, ferrous and non-ferrous metals, chemical, rubber, and cement manufacturing, as well as to the electricity, construction, communications, and many other sectors. These sectors lie outside the boundary of the transportation sector, but not the inter-industry flow of goods and services that affects the transportation sector. Consequently, mitigation actions that affect the transportation sector have the potential to effect the level of economic activity and GHG emissions in linked sectors.

Because of the highly inter-connected nature of the transportation sector with other industries and sectors, a comprehensive assessment of the emissions reductions and incremental costs of mitigation options in the transport sector will often require a full accounting of these emissions impacts and costs outside the transportation sector, and outside the larger energy sector. However, caution needs to be exercised to avoid double counting of emissions reductions and costs.

For example, increasing the stock of battery-powered electric vehicles will influence the electric power industry by increasing the demand for electricity and this will result

[23] Non-motorised vehicles are emission-free, but trip substitution from motorised vehicles to this type of vehicle reduces emissions.

in higher GHG emissions. These additional emissions from the electricity sector and the costs associated with the additional capacity and operation required to generate this electricity should not be included as a part of transportation emissions. Nevertheless, to ensure a full accounting of all cost and emissions impacts associated with this option, these emissions and costs outside the transportation should be accounted for under the electricity sector.

2.2 Factors contributing to GHG emissions from the transportation sector

GHG emissions from transportation vehicles can be decomposed in a variety of different ways to illustrate the potential for mitigation options in the transport sector. The most basic and general of these is:

$$E = Trip_N \cdot Trip_{Dis} \cdot Fuel_{Int} \cdot E_{coefficient}$$

where total emissions, *E*, are decomposed into:

$Trip_N$ the number of trips taken by individuals or by freight carriers,

$Trip_{Dis}$ the average distance of each trip,

$Fuel_{Int}$ the average fuel intensity (fuel use per each unit of distance), which is the inverse of fuel efficiency, and

$E_{coefficient}$ the emissions coefficient, which represents the GHG emissions per unit of fuel.

The first factor, the number of trips, can further be decomposed to account for increases in the number of vehicles, as:

$$Trip_{number} = Vehicles \cdot \frac{Persons}{Vehicle} \cdot \frac{Trips}{Persons}$$, or for freight travel

$$Trip_{number} = Vehicles \cdot \frac{Tons}{Vehicle} \cdot \frac{Trips}{Tons}$$

The decomposition of emissions in the way shown above makes it possible to divide GHG mitigation options, broadly, into the following categories:

1. Reducing the number of trips taken or the amount of freight hauled by:
    - reducing the number of personal or freight vehicles.
    - more fully utilising the capacity of vehicles.
    - reducing the number of trips required per person or ton of freight.
2. Decreasing the distance of trips.
3. Reducing the amount of fuel used per unit of distance reducing GHG emissions per unit of fuel consumed.

2.3 Overview of transportation mitigation options

2.3.1 Trip reduction

As suggested above, reducing the number of trips taken by individuals or the amount of freight transported one must target mitigation options at several sources: 1) reducing the number of vehicles, 2) increasing the capacity utilisation of vehicles, 3) reducing the number of trips per person or ton of freight.

Reducing the number of vehicles. This can be accomplished in the short- and medium-run by a variety of instruments, such as vehicle sales taxes, fuel taxes, and road charges. These instruments either reduce the demand for vehicles or make the price of trips more expensive, thereby creating incentives for individuals to place less reliance on personal vehicles and switch the mode of: travel on some trips from private to less costly alternatives and public transportation and to non-motorised means of travel and higher capacity forms of freight vehicles, and to optimise trip planning. In the long run, better urban redesign and development of inter- and intra-city mass transit systems can also reduce the demand for private vehicles.

Increasing capacity utilisation. This can be accomplished by better route planning for public transportation, by instruments to stimulate car pooling, through economic instruments (i.e., taxes and charges on vehicles and fuel) to create incentives for individuals to more fully utilise available transportation, and by subsidies to public transportation, where and when needed, to reduce the price of public transportation relative to personal vehicle travel.

Reducing the number of trips per person. This can be accomplished, in the short- and medium-run, through better route planning by individuals and firms, by combing trips for multiple purposes. In the long-run, better urban planning can lower the number of trips people take by personal vehicles through spatial arrangements that make it easier to combine trips, and, as will be seen, reduce the distance of trips from home to work.

2.3.2 Distance reduction

Reducing the distances people travel and the distances that goods need to be shipped is a function of the spatial patterns in economic activity and settlement that evolve through the economic development process. These patterns can be changed through urban planning. A good example of such a change involves journeys to work. In many industrialised countries, the processes of "urban sprawl" and "suburbanisation" have greatly increased the distance which individuals must travel from home to work. This increases the amount of fuel used to meet this particular transportation demand and results in higher emissions of GHGs and other pollutants from mobile sources, holding other factors constant. A different pattern of spatial organisation, such as "compact cities" in which residences are located closer to the work place and other essential services, would not only shorten the distances which people travel to and from work, but also would indirectly increase the demand for less polluting forms of transport by making it easier to walk or cycle or to and from home and the work place.

Unfortunately, these kinds of changes are hard to orchestrate in the face of market forces that have been responsible for both urban sprawl and suburbanisation: To implement them effectively requires not only a high degree of centralised planning but also the absence of pre-existing patterns of urban sprawl and suburbanisation, as in areas that are just beginning to urbanise.

2.3.3 Increase fuel efficiency

The options available for increasing fuel efficiency include:

Changes in technology to incorporate fuel savings features in new vehicles. Technical measures for new vehicles include: reduction in vehicle weight, drag, or rolling resistance, improvements in engine, transmission and drive-train performance. For some types of vehicles another option involves switching fuels (e.g., heavy trucks from gasoline to diesel).

Shifting the mix of new vehicles toward more efficient models. This includes options for improving the technical efficiency of vehicles that are produced or assembled domestically, or imported. Vehicle-producing countries can influence fuel efficiency by fuel efficiency standards and fuel taxes. At present, most developing countries do not exercise direct control over the design of the vehicles they import or assemble. However, they can influence the mix of vehicles that they import through trade regulations, tariffs aimed at fuel efficiency, domestic fuel taxes, and they can negotiate with suppliers of vehicle components or vehicle designs assembled domestically to increase the fuel economy of the final product.

Changes in existing fleet efficiency. Changes in existing fleet efficiency improves the fuel efficiency of all vehicles in operation through proper maintenance. This include:

1. Better engine maintenance, and driver training.
2. Changes in road surfaces.
3. Better tires / tire maintenance.
4. Changes in traffic flow through improve traffic signal timing, limiting the mix of vehicles or access on some routes or other measures to reduce congestion or increase average speed and load.
5. Increasing vehicle load factor by ride sharing, changing routes or schedules, or increased backhauling, and improve operating training and performance.

2.4 Reduction of emissions from vehicles

Mitigation options falling under this category include:

Switching to fuel systems with lower emissions. This includes advanced engine designs such as fuel cells, which may also increase fuel efficiency, fuel switching to fuels derived from renewable resources, such as ethanol, and to electricity, all with lower emissions per unit of service (vehicle-kilometre travelled, tonne-kilometre of freight lifted). Specific actions may also include measures to ensure production and distribution of fuel, measures to ensure availability of vehicles to use the fuels, and measures to maintain the vehicles and fuel systems, with the specifics depending on the type of fuel and degree of market penetration sought. Some types of fuel switching, such as to battery power, will reduce emissions from vehicle tail pipes, but may have high enough emissions in the production and distribution stages that total emissions for the fuel cycle will offset these reductions partially or totally. In particular the impact of switching to electric vehicles is strongly dependent on the electricity generation resource mix. Fuel switching may also be applicable for railroads, which may consider switching from coal to diesel or electric locomotives, or switching from diesel to electric.

Encourage shifts towards modes with lower emissions. This includes measures to promote walking, bicycling, public transportation, and railroad freight relative to automobile and truck traffic; measures to avoid creating barriers to modes with lower emissions when developing, managing, or operating infrastructure for motor vehicles, measures to increase infrastructure devoted to low emissions modes; increase the cost of using motor vehicles relative to modes with lower emissions; increase licensing requirements for motor vehicles; promote modes with lower emissions via public information campaigns or improvements in the quality of service (e.g., dedicated rights-of-way for buses, increased frequency of service).

3 The forestry sector

3.1 Introduction

Many developing countries have large areas of land that are being deforested, either to provide fuelwood for their rapidly growing populations or for agricultural development. As this process takes place, carbon sinks in these countries are decreasing, while net global emissions are on the rise. By one estimate, net carbon emissions from tropical land use changes in 1980 around was around 1-1.6 $PgCyr^{-1}$ (1 PgC = 1015 g) (Houghton, Jenkins, & Ephtamus, 1990 and Houghton, 1996). This compares with carbon emissions from fossil fuels hat are on the order of 5-6 $PgCyr^{-1}$. At the same time, many of these countries are located close to the equator, where forest resources may be extremely vulnerable to climate change (Haxeltine, 1996) because of already dry conditions.

In some countries, net emissions of carbon are due almost entirely to forest clearing and subsequent wood energy use. For example, in Tanzania over 95% of CO_2 emissions are associated with fuelwood use. Moreover, around 95% of all roundwood harvests in Tanzania are specifically for fuelwood purposes. Over all, 70% of the deforestation in Tanzania is related, directly or indirectly, to fuelwood provision (Makundi & Okiting'ati, 1995). The picture is the same, or has been in the past, in number of other African, Latin American, and Asian countries.

The significance of deforestation in the global carbon budget, the fact that emissions associated with land use changes dominate the carbon budgets in some countries, and the vulnerability of many tropical countries with large forest areas to climate change are all factors that underscore the importance of mitigating climate change through the manipulation of carbon sinks by land use changes.

However, evaluating the impacts of land use and forestry sector mitigation options on net emissions and calculating the incremental costs of these options involves the use of somewhat different accounting concepts and estimation methods than are used to evaluate mitigation options in other sectors, particularly the energy sector. As such, the purpose of this chapter is to supplement other information in the guidelines and provide more specific guidance about how to identify and evaluate land use and forestry sector mitigation options.

The chapter is organised as follows. After the introduction, Section 3.2 discusses the topic of system boundaries. Section 3.3 identifies the different types of mitigation options that can be evaluated. Section 3.4 identifies the analysis steps that are required to estimate the changes in net emissions and the incremental costs of land use and forestry sector mitigation options. It includes discussions of the unique features of carbon accounting and cost estimation in the analysis of land use and forestry sector mitigation options. Section 3.5 identifies several sector-specific issues that need to be addressed in the context of the evaluation. Finally, Section 3.6 identifies, in fairly broad terms, the types of methods that are available for evaluating these mitigation options.

3.2 System boundaries

The forest and land use sectors are here defined to include activities which affect GHG emissions or carbon storage on forested land, as well as the conversion of land from (or to) forests from (or to) other land uses. This includes activities that both effect the stock of carbon in forests and the demand for wood products, including energy and substitute wood products. There is one exception: the growing of short-rotation biomass crops on agricultural land is covered in the chapter on non-energy agriculture. Soil carbon storage, specifically on agricultural lands, is also dealt with in that chapter.

There are many potential inter-linkages between forest and land use activities, agriculture and the energy sector and the boundaries between these two sectors therefore must be carefully defined. The following two examples illustrate that.

First, take the case of a country where most of the primary fuel that is consumed comes from cutting down natural forests and using the wood for cooking and, perhaps, lighting. The land that is cleared is used for subsistence agriculture. Energy sector policies to promote electrification would probably reduce the pressure on deforestation, provided that the dominant end use was correctly targeted. Another example is the classic case where more efficient wood stoves to reduce wood fuel use are subsidised. Such programs have had mixed results. In some cases, the wood stoves were sold to raise cash. In others, people tended to increase wood fuel use because the implicit price of the end use activity had fallen, making cooking cheaper.

In the same setting, policies instituted to increase output per unit area on agricultural lands could have a number of different effects on the use of forested land. Such policies might, for example, reduce the pressure on forests by reducing the land required to produce a given amount of food. However, this does not take into account the fact that such measures would also improve the profitability of agricultural activities and make them a more desirable alternative for land use than previously. In that event, deforestation might actually increase.

Implicit in all of these examples are the impacts of policies in one sector on the price of wood fuel, the implicit price of the end use activities associated with that (or some other, substitute) end use, and the marginal value of forest land in relation to other uses. These types of substitution effects are largely unavoidable. In terms of analysing mitigation options, the potential presence of these effects imply that studies of forest, agriculture and energy sector must be closely co-ordinated. The system boundaries for the forest and land use sectors should according to that be set with regard to the following factors:

- major land uses that compete with forests should be included.
- energy and non-energy markets that compete directly with forest product markets should be included.
- markets where consumer demand will be influenced by mitigation policies in the land use and forestry sector.

3.3 Mitigation options

There a number of different ways to classify mitigation options in the land use and forest sector. The one used here is a combination of the classification schemes developed by Houghton (1996), Sathaye et al. (1995) and Richards (1994). The types of mitigation options that are listed below should not be considered definitive. On the other hand, if one of the options that one selects does not contain similarities to any of those enumerated below, then there may be some cause for concern, and that option should be reviewed carefully to determine if it is indeed feasible. We identify the following broad types of measures.

- Reduce the rate of deforestation.
- Increase forested area (afforestation).
- Increase of stocks of carbon in existing forests.
- Increase in wood use and efficiency.

- Substitute wood for fossil fuels.

Reducing the rate of deforestation

This category of measures includes options designed, specifically, to reduce the source of the demands that lead to deforestation, primarily the demand for fuelwood and agricultural products. In the 1980s, the rate of deforestation was approximately 15.4 million ha, or about 1% of the forested area of the globe. Over the period, 1980-1990, the net release of carbon from deforestation averaged about 1.2 PgC yr^{-1}, all of it concentrated in the tropics (Houghton, 1996). This process could be slowed down by a variety of measures. These include:

1. **Switching to sustainable energy resources**. The primary use of forests in many developing countries is for wood fuels. Programs that can reduce end use demands for wood fuel, through substitution to other so called “sustainable” fuels, such as biomass, solar and wind energy, have the potential to reduce both the clearing of forests and net carbon fluxes. Measures to promote conversion to conventional fossil fuels can reduce deforestation, but they will almost invariably increase net GHG emissions, and so are not considered here.

2. **Increasing the efficiency of wood fuel use**. In many developing countries, wood is burned as a cooking fuel in open hearths. Energy losses are substantial. Increasing the efficiency of wood use in satisfying end use demands, again, has the potential to reduce both the clearing of forests and net carbon fluxes.

3. **Measures to increase agricultural productivity**. Much of the land that is deforested in developing countries is subsequently used for agricultural purposes. In the long run, dramatic increases in global agricultural productivity have helped developed countries to reduce rates of deforestation. There is also a growing body of evidence showing that these increases in global agricultural productivity have helped to slow down rates of deforestation in developing countries in recent decades, particularly in Latin America. By reducing the demand for agricultural land, increases in agricultural productivity can help to slow deforestation. But this type of measure can have counter productive results, for example, if it makes a country a low cost producer in an international export market. In that case, increases in productivity will actually fuel higher land demands from agriculture**.**

4. **Other measures to reduce conversion of forest to agricultural land**. Forest land is converted to agricultural land because the net return from agriculture is higher than in alternative forest uses. There are a variety of ways to affect the relative profitability of land. These include:

    - Regulations to promote environmental quality, such as requiring replanting after harvesting, which effectively make it more expensive to convert land to agricultural purposes.
    - Changes in land tenure practices which take into account environmental values.
    - Taxes on land conversion.
    - Export regulations.
    - Other market mechanisms.

Increasing the area of existing forests

Afforestation in developing countries is a relatively new phenomenon. Plantation forests are one of the legacies of colonialism. Increases in the area of plantation forests in the tropics were relatively modest in the 1980s. However, beginning in the late 1980s, increasing attention has been focused on planting forests in developing countries for environmental purposes, often to satisfy environmental regulations in developing countries which allowed certain industries to offset GHG emissions by actions taken elsewhere.

Increasing stocks of carbon in existing forests

A third approach to increasing carbon storage through land use changes is to enhance the storage of carbon in existing forests. This includes projects that either maintain or expand the existing pool of carbon in soils and vegetation. Technically, afforestation falls into this latter category. These measures also include:

1. **Forest protection and conservation**. These measures can preserve the carbon and other GHGs in both the vegetation and soil. However, increasing the area of protected forest, whether through legislation, land purchases by NGOs, and by other market methods, increases the cost of access to these resources and, as such, creates the potential for carbon leakages. This is because these types of programs increase the scarcity of land, often causing other substitute lands to be brought into agricultural cultivation. Such measures are often included in projects which are devoted to non-carbon resource management purposes, such as wildlife protection, soil conservation, water catchment, and recreational reserves. Other “no regrets” measures include improvements in wildfire protection and reduced forest losses from insects and diseases.

2. **Timber stand improvement**. This includes measures to increase the intensity of management on existing stands and encompasses a wide range of measures from reforestation of existing forest land to simply increasing the intensity of management on existing stands. It should be recognised that not all such measures result in increases in the carbon pool. Birdsey (1992a) examines the case where conversion of natural stands to planted pine plantations would result in a net loss in carbon storage, although it would increase merchantable timber supplies. Other measures include:

    - Hardwood controls.
    - Precommercial thinning.
    - Firewood harvests.
    - Fertilisation.
    - Pest and disease protection.
    - Mechanical site preparation.
    - Site preparation burning.
    - Chemical site preparation.

3. **Agroforestry**. One set of measures that has received much attention in developed countries involve intercropping and the planting of windbreaks and shelter belts. These measures may also be cost-effectiveness in developing countries.

4. **Increasing carbon in agricultural soils**. Conversion of forest to agricultural land generally results in losses of carbon. However, these losses can be reduced by methods to increase carbon storage in soils, by selectively planting crops and adopting tillage methods that increase soil carbon. However, there are limited data about the effects of management on carbon in soils in developing countries to support such analyses and the resultant gains may be quite small. Also advanced

tillage systems, such as low till and no till systems are extremely capital intensive and cost-effective only for commercial agriculture.

5. **Urban and community forestry**. Forest management, practised in large contiguous blocks generally to produce wood products, is a rural activity. Development of community-based forestry systems can increase carbon storage if the systems are sustainable. However, community based forestry must be targeted at developing countries with dispersed populations. When forestry is practised in an urban setting, it provides an entirely different set of benefits. Urban forestry can influence greenhouse gas emissions by modifying the urban environment in two ways. Trees can directly reduce summer temperatures in their immediate surroundings. They can also reduce the electricity consumed for heating and air conditioning when placed at strategic locations around buildings. In addition, tree growth can capture carbon dioxide from the air in the form of woody biomass.

Increase efficiency of wood use and enhanced utilisation of wood

Options that fall under this category involve increasing the ratio of biomass (i.e., carbon) in wood products to biomass harvested. This can be accomplished in two different ways, as follows:

- Increasing the technical efficiency of wood recovery through improved harvesting and milling techniques that reduce the amount of waste.
- Increasing the merchantable uses of wood from existing harvests.

The intent of these options is to turn wastes from current harvest and milling practices into longer-lived products. However, policy makers must be cautious in how they implement these options because they may well increase the profitability of harvesting natural forests. In that case, deforestation may actually increase (due to higher harvest levels) although the source of the demand for this increase would shift from agricultural products to forest products. These options, like many others, look attractive when they are evaluated from the standpoint of engineering calculations and direct cost outlays, but may have unintended consequences due to wider, market effects.

Substitution of wood for fossil fuels

There are two means of substitution. The first involves the direct substitution of biomass fuels from plantations for fossil fuels. Biomass energy plantations occupy an intermediate position between forestry and annual agriculture. With woody biomass crops, harvesting occurs approximately every 5-12 years, and regeneration is accomplished by coppice methods that rely on regrowth of new stands from the root stock of the harvested stand. The harvested material can be used directly as a boiler fuel; it can be converted into biofuels, such as ethanol and methanol; or it can be gasified. The second includes indirect substitution, whereby new wood products replace other products that are more energy intensive, such as steel. Creation of large biomass plantations for fuel and feedstock purpose has been identified as among the most cost-effectiveness methods of mitigating GHG emissions in developing countries.

3.4 Analytical steps

The analysis of mitigation measures in the land use and forest sector involves the following five steps:

1. Development of baseline scenario.
2. Identification of mitigation options.

3. Assessment of mitigation potential and costs of the options.
4. Construction of mitigation scenarios that integrate multiple options.

3.4.1 Step 1: construction of baseline scenario

This step explicitly involves projecting land use changes over time and the carbon flows associated with these changes. The baseline scenario has two components. First it describes a general scenario of land use development and evolution of carbon sinks that would occur in the absence of specific measures to mitigate climate change. Second, it describes the physical parameters of the land use and forest sector activities that will be displaced by the mitigation option, the carbon flows and stocks associated with these activities, and their cost components.

Once the baseline scenario is established, it serves as the basis for evaluating the effects of the mitigation options. In simple terms, the carbon flow reduction is defined in absolute terms by the carbon flows for the baseline minus the carbon flows for the project case

3.4.2 Step 2: identification of mitigation options

Mitigation options will generally have to be identified in areas with an expected significant mitigation potential that seems to be possible to implement. This step therefore involves a comparative assessment of technical details of potential mitigation projects and the baseline scenario. Potential policy obstacles to technically feasible projects should be included here.

Specific criteria for selecting forestry mitigation options may include: conformity with existing forest management plans, equity and co-benefit issues, feasibility and / or ease of implementation, and ecological soundness of the option. The following are two examples of screening criteria (Sathaye & Meyers, 1995):

- Biophysical factors which may include site characteristics, e.g., climate, soil, drainage, and altitude. For example, large increases in productivity in a dry area through short rotation forestry in an area without the possibility of irrigation can be screened out at this stage.
- Institutional factors, such as options which may infringe on the sovereignty of a country or might tend to cause political instability. For example, a measure which requires physical removal of large numbers of forest dwellers for re-settlement may be politically infeasible and socially unwise.

3.4.3 Step 3: assessment of mitigation potential and costs of the options

This step involves estimating the carbon reduction potential and costs of the different mitigation options with reference to the baseline scenario.

3.4.4 Estimating the carbon reduction potential

Carbon accounting in forest ecosystems involves entirely different components than in energy accounting. Carbon is stored in the trunks of trees, but it is also stored in other components of the forest. Birdsey (1992b) identifies the following carbon components:

1. *Trees*: All above- and below-ground portions of all live and dead trees, including the merchantable stem; limbs, tops, and cull sections; stump; foliage; bark and root bark; and coarse tree roots (greater than 2 mm in diameter).
2. *Soil*: All organic carbon in mineral horizons to a depth of 1m, excluding coarse tree roots.

3. *Forest Floor*: All dead organic matter above the mineral soil horizons, including litter, humus, and other woody debris.
4. *Understory vegetation*: All live vegetation except that defined as live trees. This is sometimes counted together with soil carbon.

Other sources of carbon fluxes that should be included in the analysis are:

1. *Carbon losses at harvest*, which depend on the species and the harvesting method.
2. *Woody debris* (or decomposing matter), which accumulates due to natural process and at harvest and then decays slowly over time.
3. *Fate of carbon after harvest*, which can be divided into the following categories:
   - wood in use in products.
   - wood burned.
   - wood in dumps and landfills.
   - residual (decay).

Calculation of carbon flows and stocks over time for the baseline scenario and for mitigation options varies with the type of program, and there is, unfortunately, no single recipe for estimating carbon stocks and emissions that will hold in all cases. However, one calculation that is widely required for the baseline and many mitigation options is an estimate of dry biomass density. This can be estimated as (Sathaye & Meyers, 1995):

$$Dry\ Biomass\ Density\ (t/ha) = SV \cdot AS \cdot TA \cdot DW \cdot WD \qquad \textit{Eq. 8}$$

where:

SV	Stemwood volume (m^3/ha)
AS	Above-ground biomass over Stemwood volume ratio
TA	Total biomass (above plus below-ground) to above-ground ratio
DW	Dry to wet biomass ratio
WD	Wood density (t/m^3)

Eq. 8 may be most useful in computing the carbon stock in standing biomass in the baseline and forest protection measures which do not involve harvesting. For project analysis purposes, a fuller accounting is given in Sathaye & Meyers (1995) for a reforestation option. Assuming an infinite sequence of forest rotations with a fixed rotation age, the steady state carbon storage can be estimated as:

Total carbon stored = Land carbon + Product carbon

Land Carbon = Vegetation {(including understory) +
soil (including forest floor) +
decomposing matter} carbon

The computation of each term in the above formula for stored carbon is summarised in Eq. 9 below.

$$Carbon\ Stored\ per\ ha = cv \cdot \frac{T}{2} + cs \cdot \frac{T}{2} + cf \cdot T + cu \cdot \frac{T}{2} + cd \cdot \frac{t}{2} + \sum_i cp_i \cdot \frac{n_i}{2} \qquad Eq.\ 9$$

where:

Vegetation Carbon stored/ha:	$cv \cdot T/2$
cv	Average annual net carbon sequestered per hectare.
T	Rotation period.
Soil Carbon stored/ha	$cs \cdot T/2$
cs	Increase in soil carbon per hectare.
T	Rotation period.
Forest floor carbon stored/ha	$cf \cdot T/2$
cf	Increase in forest floor carbon per hectare.
T	Rotation period.
Understory carbon stored/ha	$cu \cdot T/2$
cu	Increase in understory carbon per hectare.
T	Rotation period.
Decomposing Matter stored/ha	$cd \cdot t/2$
cd	Average annual carbon left to decompose per hectare.
t	Decomposition period.
Product Carbon stored/ha	$\sum_i cp_i \cdot n_i/2$
cp_i	Amount of carbon stored per ha in product i.
n_i	Life of product i.

Eq. 9 is illustrative only and is associated with a specific set of assumptions about growth and regeneration. It also is based on the idea of a steady state carbon stock. Annual carbon storage for these components can also be calculated and tracked by a simple adjustment to Eq. 9 by removing the "/2". terms. More generally, using Eq. 8,

$$\begin{aligned} &Carbon\ Stock\ in\ year\ t = S_t = \\ &Forest\ Area_t \cdot (SV_t \cdot AS \cdot TA \cdot DW \cdot WD + \\ &\frac{Soil\ Carbon_t}{ha} + \frac{Forest\ Floor\ Carbon_t}{ha} + \frac{Understored\ Carbon_t}{ha}) + \\ &\sum_t Carbon\ in\ Products_t + \sum_t Fossil\ Fuel\ Displaced_t - \sum_t Carbon\ Leakages_t \end{aligned} \qquad Eq.\ 10$$

$$\begin{aligned} &The\ corresponding\ annual\ carbon\ flow\ in\ year\ t = \\ &C_t = S_{t+1} - S_t - E_t - L_t \end{aligned} \qquad Eq.\ 11$$

where:

S_{t+1}	Stock of carbon (tons) in period *t+1* (*t*=1,..,N).
S_t	Stock of carbon in period t.
E_t	Net additional emissions from fossil fuel used in program.
L_t	Market leakages.

The inventory of stored carbon and associated fluxes (changes in stock) can be tracked annually using Eqs. 10 and 11, but one must be careful about some of the terms, especially at harvest, if the stand is rotated. At harvest, a number of things happen to reduce the carbon stock and it is important to account for these, as follows:

- Biomass Carbon - At harvest, this is divided into merchantable and non-merchantable biomass. The ratio between the two can vary widely depending upon the method of harvest, the species, and the use of the merchantable portion after harvest
- Merchantable Biomass Carbon - At the mill, after harvest, some portion of this is burned to displace fossil fuels (and, thus, is not emitted) and some portion is turned into wood and paper products, which decay over time as emissions.
- Non-Merchantable Biomass Carbon - The non-merchantable portion of biomass can further be divided into two pools, depending upon management practice: i) the portion which is burned on site and is lost as emissions, and ii) the portion which remains on the stand and decays over time.
- Soil and Forest Floor Carbon - Very little is known about the effects of management on soil and forest floor carbon. At harvest, soil carbon is released as emissions, depending on the harvesting method and type of soil, and then, when the stand is re-established begins to build up again.
- Understory Carbon - At harvest, the understory vegetation is disturbed and, depending on the type of management, some portion is lost as emissions, while the remaining portion continues to grow. The dynamics of understory growth is very complicated, since the climax species in the newly regenerated stand competes with the understory vegetation for available light and soil nutrients. Thus, following harvest, the understory vegetation may increase very rapidly, and then, later on, as the climax species dominate, biomass in the understory grows more slowly and may actually decline.

Finally, the treatment of post-harvest carbon in wood products is very important, since this potentially represents the most long-lived portion of the carbon stock. Over repeated rotations on a single stand, the cumulative stock of carbon from a single stand can continue to increase, as product carbon from additional harvests is added to the stock. However, this cumulative stock of carbon will eventually achieve a steady state cycle, once the stock of carbon from the first rotation has been entirely released to the atmosphere. Thus, converting the merchantable portion of a forest into long-lived wood products or into fuel provides a way to continue the build-up of carbon associated with a single stand, well after the harvesting of the wood. In the case of wood that is burned to displace conventional fuels, a positive carbon flux from the stand can be maintained indefinitely.

Associated with this carbon stock and associated carbon flows, one can calculate both the average annual carbon flow and the annualised carbon flows as follows:

$$\textit{Average annual carbon flow for years 0 to } t = \frac{C_N - C_0}{N} \qquad \textit{Eq. 12}$$

where C_N is the carbon stock by the end of the period and C_0 is the carbon stock in the beginning of the period.

3.4.5 Assessment of costs and benefits

The accounting of costs and benefits associated with the land use and forest sector is somewhat different than in other sectors. While the type of benefits and costs included in the analysis will vary across the different types of mitigation options, those that should generally be included are as follows:

- Land conversion and establishment costs.

- Maintenance costs.
- Harvest costs.
- Harvest revenues.
- Opportunity cost of land.

However, for many different types of mitigation options the net private benefits, relative to the baseline, can be computed as follows:[24]

$$Net\,Present\,Value\,of\;Benefit = NPV = \sum \frac{P_t Q_t - (Ch_t + Cm_t + Cl_t + Cr_{0t})}{(1+r)^{-t}} \quad Eq.\ 13$$

where:

P_t	the market price of stumpage from thinnings and harvests on project lands.
Q_t	the harvested quantity of stumpage from thinnings and harvest.
Ch_t	harvesting cost.
Cm_t	maintenance and tending costs.
Cl_t	the annual rental rate of the displaced agricultural activities on the land.
Cr_{0t}	the land conversion costs at the start of the program, plus subsequent regeneration costs after harvests.
r	discount rate.
	t=1,…,N is an index of time.

Eq. 13 is a measure of the private benefits to land owners from switching their land from agriculture to forests, after all economic adjustments have taken place. This measure does not include: 1) benefits to consumers, or 2) non-market environmental benefits and costs. Both of these components are legitimate to include in cost benefit calculations, and can best be estimated using a sector model.

The rental rate term in Eq. 13, Cl_t is important and can not be ignored. In the afforestation example, it represents the net present value (annualised) of the agricultural activity that is displaced directly or indirectly as a result of the afforestation program. In a broader context, the rental rate expresses the annualised value of the land in its highest alternative use. If the net present value of the rental rates (i.e., the land rent) exceeds the net present value of the profits from the project, this suggests that, from a market perspective (only), the land owner would be better off by selling his land, or converting it to the best alternative use. This is, then, a measure of the value of the land in the baseline and is included as a cost in Eq. 13. Thus, as seen here, Eq. 13 measures the difference in the net benefits flowing from the land in the mitigation scenario as opposed to the baseline.

Measuring land opportunity costs with respect to the "best alternative use" is especially important for mitigation options that may be in direct economic competition with market alternatives. To understand this, consider a case where the mitigation option involves restoring abandoned agricultural land to natural ecosystems. In this situation it might be tempting to assume that the land will remain idle, and that the rental rate on this land is very low. On the other hand, reforesting the land in timber plantations might return a positive net gain, but below the rate of return from harvesting existing natural forests. Under these conditions, the appropriate land rent is

[24] The expression can easily be converted into an annualised cost estimate (AC) following $AC = \left[1-(1+r)^{N}\right] \cdot NPV / r$.

actually the higher value. Use of this higher rental rate will make the incremental cost of the option higher, and thus less attractive, from a mitigation perspective.

But this is not the entire story. The use of arbitrarily low rental rates for land use sector projects can have the indirect effect of promoting "leakage" prone projects, whereby a forestry project that is economically feasible on land targeted for a mitigation project simply moves to other land and the carbon gain from the mitigation project is offset, partially or entirely, by the resulting leakage. Under these conditions, the environment is actually better served by promoting land use projects that can compete more directly with market uses of the land. The incremental costs of such projects may be higher, but the leakage is smaller.

For many mitigation programs, incorporating the rental rate of the land into the net present value calculations completely takes care of the valuation of the activities in the baseline. However, whether this is true or not in every case depends on the type of mitigation measure being investigated. Needless to say, every mitigation option that is evaluated needs to be strictly scrutinised to determine what baseline activities are impacted or displaced and how these impacts are to be measured in monetary terms with reference to the mitigation scenario.

3.4.6 Step 4: construction of mitigation scenarios that integrate multiple mitigation options

The objective of this step is to calculate the cost effectiveness of the different mitigation options and to integrate this information into mitigation scenarios.

The way this is done depends upon the methods that are employed, and many of the issues associated with measuring and displaying incremental costs and cost effectiveness in this sector are identical to those in the energy sector.

The traditional approach for calculating cost effectiveness ratios for mitigation options involves dividing the present value of the incremental cost associated with an option by the change in the carbon stock achieved by the program, or:

$$CER = \frac{PVC}{\sum_t \Delta E_t} \qquad \textit{Eq. 14}$$

where:

PVC the present value of the direct costs associated with the mitigation option.
ΔE_t the emissions flow (flux) in period t.

For the approach that employs discounting, the CER is characterised by:

$$CER = \frac{\left(\frac{PVC \cdot r}{1-(1+r)^{-N}}\right)}{\left(\frac{PVE \cdot r}{1-(1+r)^{-N}}\right)} \qquad \textit{Eq. 15}$$

where:

PVE the present value of the carbon flows associated with the mitigation option.

The numerator is the annualised value of the incremental cost of the option. However, the denominator represents the annualised value of the emissions / carbon flow generated by the mitigation alternative (relative to the baseline case, of course).

Notice that, in the case of a continuous emissions flow, the CER in the discounting case reduces to the ratio of the PVC to PVE, both of which are annualised. However, if the emissions flows are discontinuous, or if a different discount rate is used to discount costs and benefits, then the expression is conceptually the same. The point is that both benefits and costs are discounted from the point in which they occur back to a reference year. This is done, as previously indicated, to account for the fact that a ton of CO_2 emissions reduced (or stored) today may not have the same benefit as a ton of CO_2 emissions reduced (or stored) at some other point in time

3.5 Sector specific issues

3.5.1 Flows or stocks

Traditional carbon accounting practices in the energy sector, and the carbon cycle in general, focus on annual flows, or fluxes, of greenhouse gases (GHGs). These flows are similar in conceptual accounting terms to emissions from the energy sector, except that carbon sequestration fluxes represent negative emissions. However, it is important to keep in mind that mitigation options that influence the carbon stored in ecosystems can be accounted for, simultaneously, by means of changes in carbon fluxes over a given unit of time ***and*** carbon stocks, where the latter is simply the accumulated carbon fluxes up to a specific point in time. Used correctly, both measures are valid indicators of the performance of a mitigation option: the net annual carbon flux of a mitigation measure is a correct measure of the net annual emissions that are sequestered in an ecosystem and its products and the net stock of carbon in a given year measures the sum of the net annual emissions sequestered up to that point in time.

In displaying the performance of a mitigation option in reducing net emissions it is useful to show the following information:

- profile of net annual carbon fluxes over time (relative to the baseline)
- profile of net carbon stocks over time (relative to the baseline)
- an indicator of the “average” performance of the mitigation option over the relevant time period (relative to the baseline).

The last bullet raises two critical, and closely-related issues associated with comparing the performance of land use and forestry sector mitigation options in relation to each other and those in other sectors, namely:

- what is the appropriate “average” measure.
- what is the appropriate time period, or life-time of the mitigation option.

Defining a measure of the “average” carbon flux associated with a mitigation option in the forest sector is an issue for three reasons. First, trees grow at different rates over time. Second, changes in the stock of carbon are discontinuous at certain stages in the life-cycle of a tree and its resultant products. Third, over a long enough period of time, the annual flux of virtually all types of forest mitigation options approaches zero or becomes negative (as carbon stocks decline). More specifically, some mitigation options will result in only temporary increases in carbon stocks. As a result, mitigation options that have temporary carbon benefits, say over 30 years, may have zero benefits in 31 years or 100 years.

Three assumptions are generally made that get around the two issues raised above. These assumptions are:

- annual emissions do not vary over time,
- project life time is fixed,
- projects can be sequenced perfectly with no interruption in emissions.

There are, broadly speaking, two different approaches one can take in dealing with the issue of indicators of average performance and project life time:

1. Use a measure of net average annual carbon flux over a specific period of time that is comparable to that used in the energy sector. This takes care of the accounting issue, but it avoids the issue of how to compare carbon flows at different points in time.
2. Discount the carbon flows, as recommended in section 1 Cost concepts in relation to GHG mitigation, thereby giving temporary carbon storage more value than it would otherwise receive.

3.6 Dynamic and life cycle issues

Carbon sequestration is a complex process. Initially, carbon dioxide is withdrawn from the atmosphere and stored in organic materials over a period of time. Trees accumulate carbon at different rates, depending upon their species, soils and climate, and the intensity of management that is applied. The sequestration process in an unmanaged forest ends when the carbon is released back into the atmosphere, principally as carbon dioxide, through combustion and decay.

However, in forests that are subject to any degree of management, including harvesting of natural forests, the process is not the same. When trees are harvested, some of the material may be burned, and some of it may be left to decay slowly on the site. The rest is taken and used to produce products and to provide co-generated heat. Wood products do not decay immediately, and decay rates vary widely among different types of products. In addition, the fate of these products is not an easy matter to keep track of. For example, recycled fibers, which are being ever more widely used, prolong the life of sequestered carbon. Some products may be deposited in land fills where they may be long-lived, although not being used. Finally, some products may end their life cycle by being burnt or just being left to decay.

The point is that the accounting of carbon in forests is not the same as accounting for emissions from fossil fuels from many other sources. The most important of these differences must be integrated into the analysis of mitigation options. This can easily be done in the framework of all the methods discussed in the next section. Even very simple spreadsheet models can incorporate the factors discussed here, as long as these models keep the carbon mass balance over time, allowing for establishment, management, growth, mortality and harvesting in each period.

3.6.1 Focus on net growth effects on biomass

When assessing the effects of mitigation activities on sequestered carbon, it is important to focus, not on the gross effects of these measures, but on their net effects on biomass and sequestered carbon. For example, increasing the intensification of management in an existing forest can result in large gains in the merchantable portion of trees. This might give the misleading effect that this gain was, in fact, the net effect of the program. However, the types of intensification that have the largest impact on merchantable biomass generally involve reducing competition for resources (minerals, water and sunlight) with other plants. The increase in merchantable biomass may be greater than the loss in other forms of biomass, but that is not the point. The net effect includes both components and will invariably be smaller than the gross effects on merchantable biomass. Defining the net effects of mitigation options on carbon sequestration also involves accounting for harvest losses and differential rates of decay associated with different products over time.

3.6.2 Leakages of carbon

We have seen how policies in one sector can influence those in an another sector. An important reason for looking at the cross sectoral impacts of mitigation options is to account for the impacts on net emissions in the other sector. This is because the net change in emissions may be lower or higher when the inter-sectoral impacts are accounted for.

Leakages of emissions within the forest sector as a result of implementing a mitigation option are probably more common than cross-sectoral leakages. There are two kinds of these leakages:

- static leakages when one activity simply displaces another activity in space.
- dynamic leakages when one activity causes this displacement to occur over time.

An example of a static leakage is a case where a given amount of land is afforested and set aside as a permanent nature reserve. While it may be tempting to measure the performance of this option in terms of the steady state increase in carbon stocks associated with a new forest, it may also be true that more land is deforested elsewhere. Why would this happen? Increasing the scarcity of land on which timber can be grown by reserving land, generally will make it more profitable to invest in timberland, increase harvests and sell the wood. Induced changes in the profitability of some land uses relative to others changes land prices and can cause land shifts to take place. If, for example, the land that was reserved would have shifted into agriculture in the baseline scenario, then, in the mitigation scenario, agricultural prices would rise, providing an incentive for timber land owners convert their lands to crops. In this case, the additional harvesting losses would offset to some extent the carbon sequestration gains of the program.

These leakages can also have a much more dynamic (i.e., intertemporal) quality to them. For example, some programs to increase the intensity of forest management may simply be paying farmers to do what they would do anyway when future stumpage prices became high enough to justify that management. In that case, there would be no increase in sequestered carbon because the mitigation option would have been adopted anyway. This is a case of not defining the baseline scenario well enough.

3.7 Methods

This section identifies, in fairly broad terms, the types of methods that can be used to estimate the carbon flows and costs associated with mitigation options in the land use and forest sector, and it evaluates the strengths and weaknesses of these various approaches, with specific reference to modelling issues in developing countries. This section may be helpful for researchers to identify the kinds of approaches that might work in their countries. However, the final selection of methods should involve a more detailed assessment and comparison on individual models by the country study teams.

3.7.1 *Tools for project assessment*

As for energy sector bottom-up models, the project assessment tools are built around a parametric representation of individual mitigation options. The models are typically rich in detail about land and forest project-specific issues while costs and benefits are treated in a more aggregate form. Market prices of final goods and production factors are typically exogenous or assumed constant, because the projects are assumed to be marginal. In this way the models focus on the supply side and have no representation of demand.

Many project assessment models include a consistent accounting system of the total available land in various categories. They calculate the carbon accounts on these lands over time, and show how different types of mitigation options affect carbon flows and stocks.

The earliest types of project assessment tools were static. That is to say, they kept carbon accounts for a specific period of time, such as the rotation length of an even-aged forest, and calculated carbon flows on an average annual basis for that period. Annual tree growth over time and the associated carbon flows were not estimated. Perhaps the best known of these first-generation models is the one used by Moulton & Richards (1990) to estimate the costs of carbon sequestration programs in the United States. Spread sheet models now in use are dynamic. They track the growth of trees over time and keep carbon accounts on an annual basis. More advanced models, such as COPATH (Makundi, Sathaye, & Ketoff, 1991), not only track carbon over time, but also contain assumptions about biological process and management which they build into the calculations for carbon balances.

The key advantages of project assessment tools are:

- They are relatively simple to construct and use.
- They can be organised around existing data.
- They are adaptable to different countries and land-use systems.
- They can be used to generate carbon sequestration supply curves.
- Existing models are available which are widely applicable.
- The results they generate are transparent.
- All of the carbon flow, stock and cost calculations can be made internally consistent because the format is so flexible.

The tools have a number of limitations that are especially important when larger mitigation activities or combined strategies are to be assessed. The major disadvantages are that the behaviour of landowners, land markets, and final product markets are not integrated, and it is therefore not possible to assess indirect economic impacts and the structural impacts of larger mitigation programmes. Furthermore, the missing demand representation makes it difficult to model the impacts of using economic instruments such as taxes and subsidies.

3.7.2 *Sector models*

Sector models are, generally speaking, economic models that are used to simulate various kinds of economic activity in different product markets that are organised as a sector. For example, a model of the agricultural sector in a country would include markets for many different types of crops and livestock. Sector models can be either mathematical programming models, or econometric models, or a combination of the two. These models can represent market processes related to the production of goods and services in a sector (i.e., supply side only), or they can simulate *both* the production and consumption of goods and services in a sector (supply and demand sides are integrated). This is an important distinction.

Supply side models. The purpose of a supply side sector models is to generate supply curves for goods and services in that sector of the economy. These supply curves show how the minimum additional (i.e., marginal) cost of producing a good or service varies with the level of production. The models do not solve for market prices, although given an exogenous vector of prices, they can solve for the associated levels of output for the goods and services included in the model.

Supply and demand side (price-endogenous) models. Sector models can include consumer behaviour along with producer behaviour. This is usually done by including final demand equations in the model to show how consumer purchases of goods and services vary with the prices paid for these items. By integrating the demand and supply curves for goods and services in many different markets simultaneously, sector models are able to solve for their associated market clearing output levels and prices. Hence, they are referred to as "price endogenous" models. Often it is possible to take an existing supply side sector model and integrate it with a corresponding set of demand equations to produce such a model.

In the land-use and forestry sector, the most relevant sector models are forestry sector models, agricultural sector models, and models that combine the two sectors.

Static agricultural sector models. Agricultural sector models can be modified to develop supply curves for afforestation. Given an existing integrated model of the agricultural sector this can be done by including activities for growing trees to sequester carbon (Adams et al, 1993, Callaway & McCarl, 1996). The model can then be used to simulate the competition between agricultural products and these tree growing activities for crop and pasture land.

This type of approach can also be used in developing countries where there are existing agricultural sector models. Many such models do exist, and modifying them is not difficult. Mitigation costs associated with fermentation from rice paddies can also be estimated this way. The two biggest advantages of the approach are, firstly, that it allows fairly detailed representations of mitigation options, both from a technological and management perspective. Secondly, these models take into account a number of different economic adjustments that may occur in markets when existing activities are displaced. As a consequence, they can capture some of the spillovers and leakage effects that project assessment tools cannot capture. However, the approach has its drawbacks. It requires the use of an existing model or the development of a new model, which is fairly data and labour intensive and requires substantial analytical capacity. The models are largely limited to examining afforestation programs and so to examine forest mitigation options requires a model of forest land use.

Forestry sector models. Forestry sector models generally have two basic components: 1) an inventory projection model to simulate the evolution of trees on forest land over time, and, associated with it, 2) an economic component that determines the optimal level of management associated with these forests, including harvest levels over time, regeneration of new forests after harvest, and investment. The demand for forest products is exogenous in forestry sector models, so that over time harvest levels, timber prices, regeneration and investment are determined as a part of the model solution. These models are usually multi-regional, taking into account spatial variations in important factors influencing supply and demand for wood products. They are usually national in scope, although at least one international model, the

Global Trade Model (GTM), exists. The development of these models has been limited primarily to developed countries.

Once they are constructed, forestry sector models can be modified easily to perform carbon accounting of forests. The advantages and disadvantages of developing such models for use in mitigation assessments of the forestry sector are essentially the same as those for developing agricultural sector models. They are also of limited use in that they can only be used to examine forest mitigation options. In addition, data required to model natural forests is often very limited. Therefore when considering whether to use this approach one needs to weigh the analytical advantages of these models against their limitations. That such models are not widely available for developing countries, and that they require significant technical capacity to build and use and have limited application are all factors which need to be taken into account when evaluating their use.

Land-use models. Land-use sector models combine the agricultural and forestry sectors and simulate the competition within and between these two sectors for land.

There is at least one example of a “systems” model that has been built for developing country applications. This is the LUCS model (Faeth, Cort & Livernash, 1994), which was designed to evaluate land-use mitigation options and has been applied in several instances.

4 The agricultural sector

4.1 Overview

The agricultural sector includes both activities that emit greenhouse gases and sequester carbon. Table 1 indicates the major sources and sinks of GHG emissions in the agricultural sector. Except for land clearing operations, the non-energy agricultural sector is not an important source of global carbon dioxide emissions[25]. However, in many developing countries, the agricultural sector is the largest source of methane emissions, from rice paddies, from enteric fermentation on ruminant livestock, and anaerobic fermentation of livestock wastes. Numerous measures for mitigating these emissions exist, but many of those associated with livestock are not practicable given the organisation of the livestock industry. The agricultural sector can also be an important source of nitrous oxide emissions; however, the impact of agricultural practices on the release of nitrous oxide from soils is not well understood, making these options difficult to evaluate. Table 1 identifies the major sources and sinks of greenhouse gases in the non-energy agricultural sector.

Table 15 Main sources and sinks of greenhouse gases in the agricultural sector.

Sources			Sinks
Carbon Dioxide	Methane	Nitrous Oxide	Carbon
1. Land Clearing 2. Agricultural soils	1. Anaerobic fermentation from rice paddies 2. Enteric fermentation from livestock 3. Anaerobic fermentation from livestock 4. Savannah burning and burning of agricultural residue 5. Soil cultivation	1. Manure management 2. Soil cultivation 3. Savannah burning and burning of agricultural residues	1. Agricultural soils 2. Short-rotation biomass crops 3. Windbreaks and shelter-belts

In the context of the earth's carbon cycle, carbon sequestering is the capture and storage of carbon. Carbon sequestration is reversible, depending upon agricultural management. It is a two-step process; carbon dioxide is first withdrawn from the atmosphere through the photosynthetic process, then stored in organic materials and perhaps underground over a period of time. The sequestration process ends when the carbon is released back into the atmosphere, principally as carbon dioxide and other carbon compounds, because of either combustion or decay. In this sense, carbon sequestration is defined by flows of carbon among the atmosphere, plants, animals, and soil. Carbon sequestration in agriculture is increased when the amount of carbon flow from the atmosphere to plants exceeds the flow from plants to the atmosphere.

The complexities of agricultural systems may present challenges to knowledgeable reporters when assessing specific effects of individual conservation or agronomic

[25] According to IPCC, 1997, biomass burning and loss of soil carbon associated with the conversion of native ecosystems to agricultural use are the largest non-fossil fuel use source of CO_2 emissions to the atmosphere.

applications. Even more important will be understanding the integration of these efforts in the context of ecosystems-based management as well as impacts upon the atmospheric natural resource.

4.2 System boundaries

Where to draw the system boundaries for conducting a mitigation analysis is always an important issue, and this is particularly important in dealing with the agricultural sector. For the purposes of these guidelines we have divided the agricultural sector into three segments, as follows:

1. Agricultural sector (including the growing of biomass crops) - which is treated in this section,
2. Energy-use in agriculture - which is treated under the section on the energy sector, and
3. Deforestation of land for agricultural use and afforestation - which is treated under the section on the forestry and land use.

The boundary between the agricultural sector, the energy sector and the forest sector is particularly important to set because of the “spillovers” that occur in the form of substitution effects between sectors. What we mean by this is that actions taken in one sector that have an impact on greenhouse gas emissions (GHG) can also effect GHG emissions in one of the other sectors. These spillovers are perhaps most obvious in the case of growing biomass crops and in the recovery of methane from manure to produce energy, as a substitute for existing fossil fuels. For example, conversion of existing agricultural land, or degraded lands that previously were under agricultural production, to grow energy fuel crops affects the supply of land available for alternative uses and, thus, has the potential to change land rents in the agricultural and forestry sectors. It also affects the competition for fuel in the energy sector and may lead to changes in the relative prices of different fuels. Any resulting changes in the price of land or fuels used in the energy sector can cause land use and fuel use substitution that affect net GHG emissions.

Implicit in this example are the impacts that policies in one sector have on the price of fuels, and the implicit price of the end use activities associated with that (or some other, substitute) end use, and the marginal value of forest land in relation to other uses. These types of substitution effects are largely unavoidable. In terms of analysing mitigation options, the potential presence of these effects has two important implications. First, studies of mitigation options and policies in these three sectors (forests, agriculture, and energy) need to be closely co-ordinated in defining system boundaries. Second, the analysis of mitigation options in these three sectors should try to take into account the spillovers that occur between sectors as a result of mitigation policies and options taken in one sector.

It is generally not possible to avoid missing some spill over effects in setting system boundaries. Because the production and consumption of goods and services of every sector are linked by the inter-industry flow of goods and services, mitigation studies will always be somewhat arbitrary and incomplete with respect to the inclusion of spillovers. Nevertheless, some guidance can be given with regard to including spill over effects in mitigation analyses, once system boundaries are established. In cases where mitigation projects affect the competition for land between the forest and agricultural sectors, one needs to look at the possibility that this will affect GHG producing or sequestering activities on other lands.

4.3 Overview of mitigation options

There are many different sources of GHG emissions from agricultural activities. These sources and their contribution to GHG emissions are discussed in detail in IPCC (1990, 1996) and U.S. Country Studies Programs (Sathaye & Meyers, 1995). This section focuses on mitigating GHG emissions associated with four general forms of agricultural activity:

1) Rice production (CH_4). Rice production results in methane emissions from the decay of organic material in ponds.

2) Animal husbandry (CH_4). Animal husbandry results in CH_4 emissions from two sources:

   - enteric fermentation by ruminant livestock, and
   - anaerobic fermentation associated with the decay of manure from livestock operations.

3) Carbon storage on existing agricultural lands (CO_2). Carbon fluxes from agricultural land can be increased by several methods:

   - cropland and grazing land management to conserve soil carbon,
   - use of biomass crops as fuels that displace existing CO_2 emissions from existing fossil fuels in a sustainable way, and
   - creation of windbreaks and shelter belts.

4) Fertiliser application (N_2O). The application of organic and inorganic fertilisers to soils influences nitrous oxide emissions.

4.3.1 Rice production

Methane is produced in the soil by the anaerobic decomposition of organic substances, promoted by the action of bacteria (methanogenics) that require highly reduced conditions for their development, such as the ones found in flooded rice paddy soils. Flooded rice paddies are one of the most important anthropogenic sources of methane (CH_4). The global emission rate of this gas in irrigated rice fields was estimated at 20 to 150 Tg per year, which corresponds to 5-20 per cent of the total emissions from all sources (IPCC, 1996c). Among the factors influencing methane from cultivated rice paddies that can be manipulated through mitigation options are: Cultivated area, period of flooding, variety of plant, plant nutrients.

Reduction in cultivated rice area

Perhaps the most obvious way to reduce domestic methane emissions from rice paddies is to reduce the area of cultivated production in a country. This will result in a proportional reduction in methane emissions in the country. However, there are two key issues in the assessment of this option. The first regards “leakages” of methane emissions. Rice is a staple crop in the developing world, and the global demand for rice is not very sensitive to changes in rice prices because of this. In addition, the cost of replacing the lost production is quite low and the global rice market is highly competitive. Thus, a reduction in rice output in one country will stimulate production elsewhere to offset this loss, and total methane emissions, globally, will not be much affected. On these grounds, alone, reducing rice production in one country is not a very realistically option. The second issue involves estimating the incremental cost of this measure. If land use in the sector is dominated by market forces, and the area reduction is small, then land that can not be used to produce rice will revert to its highest alternative use, and the incremental cost of the measure is the difference between the Net Present Value (NPV) of the profits from the land in its alternative use less the sum of the land conversion costs and the NPV of the profits from producing rice. However, estimating the difference in profits from alternative uses can be difficult if markets are distorted by government agricultural policies, or if the project is so large that it causes measurable changes in food prices and land rents that lead to changes in the crop mix on other lands and to different food consumption patterns.

Reduction in period of flooding

Another, more effective and less costly, way to reduce methane emissions is through intermittent flooding and drainage of rice paddies, or by increasing the percolation rate of the soils. For example, a recent study on China (Kern et al., 1995) estimated that introducing intermittent drainage on 33% of the poorly drained soils used for rice production would reduce methane emissions by roughly 10%. Although intermittent drainage has been shown to reduce methane emissions, this option is limited by several practical factors, including the area of rice that is relatively easy to drain and re- flood and the need for secure and controllable water supplies. The need for controlled flooding and drainage is particularly important for avoiding yield losses due to under-irrigation. Further, it is important to keep in mind the fact that the controlling factor is the reduction in the period of time anaerobic conditions exist in the field. If drainage is poor, then the reduction in irrigation inputs may have a smaller impact on methane emissions than under good drainage conditions.

Introduction of new plant varieties

Another way of effectively reducing methane emissions is by adopting plant varieties that mature more quickly and so require less flooding. Newer varieties of paddy rice mature from 10% to 15% more rapidly than traditional varieties in some parts of the world, without sacrificing yields. While these varieties were developed to conserve water, their adoption can also lead to reduced methane emissions at relatively low cost.

Nutrient management

In many parts of the world, rice is grown using abundant organic fertilisers and straw. A number of studies have shown that methane production in rice paddies is heavily influenced by the amount of green manure (Lauren et al., 1994) and straw (Neue et al. 1994 and Nouchi et al.,1994) that are added to provide plant nutrients. Substituting inorganic fertilisers for organic nutrients can slow the rate of anaerobic decomposition. A study in the USA by Lindau (1994) indicated that methane emissions could be reduced by as much as 50% by substituting commercial fertilisers for organic fertilisers. However, these types of reductions are highly dependant on soil conditions, water regime, and other biogeochemical factors. Moreover, the introduction of sizeable quantities of commercial fertilisers may also be quite costly in some developing countries and could also lead to increases in N_2O emissions.

4.3.2 Animal husbandry

Enteric fermentation

Methane is produced in herbivores as a by-product of enteric fermentation, a digestion process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption in the bloodstream. Both ruminant animals (like cattle and sheep) and some non-ruminants like pigs produce methane. The amount of released methane depends on the type, age and weight of the animal, the quality and quantity of the feed and the energy expenditure of the animal.

Methane emissions per animal can vary widely – from 50 l / day to 500 l / day – depending on the above factors. However, under a wide variety of every day conditions, these emissions are a relatively constant fraction of the diet consumed, about 6% of diet energy or 2% of the diet by weight. Most of the options used to reduce methane emissions from ruminant livestock focus on decreasing the feed intake required per unit of product – milk, meat and work – by means of simultaneous improvements in diet quality and animal productivity. The effectiveness of this strategy is based on shifting feed intake from maintenance to production. The feed required to maintain livestock is approximately the same for a low producer as for a high producer. However, when productivity is increased, the proportion of feed going to maintenance is reduced, and methane emissions per unit of product decrease. For example, for a 400 kg dairy cow an increase in productivity from 2.2 to 4.4 kg / day can reduce methane emissions by 40% per kg of milk. This means that one can produce the same amounts of milk, meat and work as in the baseline scenario from fewer animals. By cutting the herd size, while maintaining production at baseline scenario levels, methane emissions are reduced.

The range of options available for reducing methane emissions from enteric fermentation in ruminant animals include:

1. Mechanical and chemical feed processing. These measures generally involve chemical treatment of straw, using alkali / ammonia and chopping of low quality straw. Assuming that feed digestibility is increased by 5%, methane emissions per unit of product may decrease around 10 to 25% depending on management practices.
2. Strategic supplementation. These options include using molasses / urea supplements, rumen bypass product, bioengineering of rumen microbiota, and mineral supplements. Using these methods can reduce methane emissions by 25 to 75% per unit of product.
3. Enhancing agents. Methane emissions per unit of product can be reduced substantially by using bovine somatotropin, anabolic steroids, and other agents.
4. Genetic improvement. Crossbreeding and upgrading (especially in developing countries), as well as genetic improvements in the stock and genetic engineering are among the methods that can be used to increase animal productivity.
5. Reproductive improvement. Methods that improve animal productivity indirectly reduce the numbers of animals needed to produce offspring, and this leads to reduced methane emissions However, there are direct measures which can achieve the same result, including twining, embryo transplants, artificial insemination, and estrus synchronisation.

Anaerobic fermentation

Methane is also produced from the decomposition of organic components in animal waste due to anaerobic fermentation. The amount of released methane depends on the quantity of waste produced and the portion of the waste that decomposes anaerobically. When the animal waste is stored or treated as a liquid (as in lagoons and pits) it tends to decompose anaerobically and methane can be produced. This means that the principal sources of methane emissions from this process are liquid / slurry storage facilities (pits and tanks) and anaerobic lagoons. When the waste is handled as a solid (as in stacked piles) or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. This has important implications for developing countries in which manure is managed as a solid, either as a fertiliser or a fuel. In these cases, mitigating methane emissions will not be very cost-effective, because the reduction in methane emissions will be quite low and the cost of replacement fertiliser may be high. However, dry manure that is deposited on fields may be associated with N_2O emissions from the nitrogen cycle.

The options for reducing this type of methane emissions all involve recovering the methane from anaerobic fermentation and using it as a gas. The recovered methane gas can be used directly on the farm to supply various energy end uses, or can be collected and sold, or it can be used to fuel boilers that provide the energy to generate electricity. The remaining by-products of anaerobic decomposition, contained in the slurry or liquid effluent, can be used as crop fertiliser, animal feed, and as supplements for aquaculture.

The main mitigation options include:

1. Small scale digesters. Digesters are basically containers into which manure and water are placed. They maintain suitable conditions for bacteria to digest the biologically active component of the manure resulting in the production of biogas which is 60-80% methane. Small scale digesters are appropriate for small and medium sized rural farms. Typical fixed dome small-scale digester sizes range from a 4-5 m^3 total capacity design suitable for small farms, to 75-100 m^3 total capacity designs. For a family of 6 in the developing world, digester systems of size 4-6 m^3 can meet daily biogas requirements, estimated at 2.9 m^3, for all local residential and agricultural uses. Efficient digesters with gas recovery systems may reduce methane emissions up to 70%, with larger reductions achievable at longer retention times.
2. Large scale digesters. Large scale digesters operate on the same principle as small scale digesters, but are considerably larger and are appropriate for relatively large, intensively managed farms. Such systems are capable of handling the manure output of operations with a few hundred to several thousand, or more, head of cattle or swine, or roughly 0.5 million poultry. Gas recovery rates depend on ambient temperatures throughout the year and vary depending on the farm's geographic location. A typical digester will produce 0.25-0.6 m^3 biogas per kg of volatile solids, operating at 30 to 35 ^0C. Efficient digesters with gas recovery systems may reduce methane emissions by 70%, or greater in cases of longer retention times.
3. Covered lagoons. Methane from lagoons can be captured by placing a floating, impermeable cover over the lagoon, sealed at the edges to prevent influx of air. Gas recovery rates depend on ambient temperatures and the farm's geographic location. Average gas recovery at US dairy farms range from 187-375 m^3 biogas / 1,000 kg of volatile solids handled. Assuming 10 kg of volatile solids produced daily by an average US dairy cow and a 60% methane content in biogas, daily recovery rates at dairy farms handling 100% of the manure produced can range from 112-225 m^3 methane / 100 head.

4.3.3 Carbon storage on existing agricultural land (CO_2)

Crop and grazing land management to conserve soil carbon

Intensive soil cultivation and over-grazing of range lands deplete soil carbon and, under some conditions, so depletes the soils of nutrients that production of any kind can no longer be maintained and the lands have to be abandoned. Re-establishment of native species and the resultant succession may or may not occur. Particularly in dry regions, once productive lands that are abandoned do not re-establish themselves naturally and are often invaded by non-native species. Better cropland soil management practices and various range land management strategies may result in increases in soil carbon. However, information needed to assess the impacts of specific mitigation measures on soil carbon is not widely available. Moreover, these impacts vary widely depending on the type of soil, climate and past management practices. Consequently, the transfer of available information from existing studies to different locations introduces large uncertainties into the analysis.

Mitigation options that may be considered include:

1. Adoption of no-till, low till cultivation practices on cropland. Reduced tillage practices – low- till and no-till – appear to increase the amount of organic carbon in the top 4 to 6 inches of the soil profile. Limited research on conservation tillage indicates that this system maintains the existing organic matter equilibrium. Although conventional tillage has been shown in long-term plots to reach an equilibrium, smaller losses have been noted after the initial decline (Kern & Johnson, 1993). However, different soil types (with different texture, drainage, and erosion status) will respond differently to the same management regimes. These systems are generally applicable only to commercial farming due to machinery requirements and the need for additional N fertiliser and herbicides.
2. Range land rehabilitation. Apart from reforestation and afforestation, which are treated in the Section on Forestry, the major option involves re-establishment (by planting or natural regeneration) of grass and shrubs to enhance soil carbon storage. Sites where hardy, non-native species have invaded may be candidates for replanting due to high site preparation costs.
3. Reducing livestock numbers. Overgrazing is the primary cause for the degradation of range lands. Reducing livestock numbers on lands that have not been severely degraded can improve soil carbon and has also been shown to reduce emissions of N_2O from soils and CH_4 from manure (Howden, 1991).

Use of biomass crops to produce fuel

Biomass is currently being used to produce liquid fuels such as ethanol, methanol, and biodiesel as well as a fuel to produce electricity. Biomass crops can be woody (short rotation woody biomass), herbaceous perennial (for example, switch grass), or herbaceous annual (such as corn or sorghum). These crops are grown under intensive management, generally with high nitrogen requirements, and are most suited for developing countries that have a developed, commercial agricultural sector. These crops can be substituted for existing crops to reduce CO_2 emissions.

The production of biomass has an impact on carbon emissions in three different ways. First, it can substitute for fossil fuels. The conversion of biomass to energy releases CO_2 into the atmosphere. The photosynthesis process recycles CO_2 from the air and converts it into biomass. Therefore, any quantity of biomass substituted for fossils fuels will reduce the net increase of CO_2 in the atmosphere that would occur from combustion of the fossil fuel. Second, the difference in fuel and agricultural chemical requirements to produce biomass versus other crops will have an impact on carbon emissions to the atmosphere. The third impact of producing biomass is the sequestration of carbon in the soil. On the average, there is less soil disturbance in the production and harvesting of biomass crops than for annual crops. This should reduce oxidation and release of carbon to the atmosphere and help sequester carbon in the soil (except if the biomass crop is an annual such as energy sorghum).

Planting of windbreaks and shelter belts

Windbreaks are composed of rows of progressively taller vegetation established perpendicular to the predominate wind flow. The lowest vegetation is on the windward side and the tallest on the downstream, leeward, side of the flow. This vegetation is a mixture of low- to mid-level brush and low- to tall-growing trees. As these plantings mature, they offer significant resistance to wind flow and reduce net CO_2 emissions by sequestering carbon in wood and the soil. Windbreaks and shelterbelts are grown mostly to slow winds during the growing season, thus stopping wind erosion and plant desiccation. They can also be used to shelter the farmstead, thus reducing fuel required to heat and cool the buildings, thus reducing the energy requirements for heating and cooling farm dwellings.

4.3.4 Fertiliser application N_2O

Nitrous oxide is produced naturally in soils by the microbial processes of nitrification- the oxidation of ammonia to nitrate (NO_3)-and denitrification- the reduction of nitrates or nitrites (NO_2) to gaseous nitrogen. The application of commercial nitrogen fertilisers provides an additional source of nitrogen that can enhance natural nitrous oxide emissions from the soil. In well-aerated conditions, where soil moisture content does not limit aeration, nitrous oxide emissions from the nitrification of ammonium-based fertilisers can be substantial. The nitrogen cycle is subject to considerable variability from a wide variety of sources, and the impacts of management practices on denitrification vary widely, as a result. Unless a great deal of information is available from field studies on this topic, the assessment of mitigation options should be considered highly preliminary. Nevertheless, there are number of potential “no regrets” management options which, if adopted, can promote sustainable agriculture while at the same time leading to potential reductions in N_2O emissions.

The basis for mitigating N_2O emissions as a no regrets option is that high-yield production agriculture can be sustainable agriculture. They are not mutually exclusive. As conservation and agronomic practices are adapted, nutrient use efficiency increases, erosion is slowed, the potential for non-point source water pollution drops, and crop yields go up. The efficiency of nutrient use in agriculture can be greatly improved as a result of farmer implementation of science-based technologies, including conservation tillage practices to reduce erosion, hold more nutrients in the soil, and improve infiltration. Some of the ways farmers can ensure that applied nutrients are used more efficiently include:

- testing and plant analysis to determine N needs,
- use of precise application equipment to ensure optimal timing and placement of nutrients in order to match nutrient levels to crop needs,
- encapsulating fertiliser to slow the release of nitrogen and using nitrification inhibitors to reduce nitrous oxide emissions, and
- better irrigation water management to reduce leaching of N into the groundwater where it is lost as a source of plant nutrients.

Adding nitrogen to the soil results in some nitrous oxide emissions, a very effective greenhouse gas. But how much is emitted depends upon many factors, including the quantity, the acreage, the form in which nitrogen is added, the manner of application, and the frequency of application. Nutrient contents of manures are low compared to commercial fertilisers, so large quantities of manure must be applied to each acre. In commercial agricultural settings, this requires significant amounts of fuel and is usually labour intensive. While all forms of nitrogen added to the soil result in the formation of nitrous oxide, the efficient application of commercially available sources of N can have two potential effects on greenhouse gas emissions:

- direct reductions in the amount of N_2O produced per unit product, so that less cropland is needed relative to the baseline scenario to meet food demands, and
- indirect increases in carbon sequestered in native ecosystems, which do not have to be converted into crop, pasture, or grazing lands to meet food demands in the baseline.

4.4 Analytical steps

The analysis of mitigation measures in the land use and forest sector involves the following five steps:

1. Development of baseline scenario
2. Identification of mitigation options.
3. Assessment of mitigation potential and costs of the options.
4. Construction of mitigation cost curves.

4.4.1 Step 1: development of baseline scenario

In the agricultural sector, this step explicitly involves projecting, over time, the agricultural activities that will be affected by potential mitigation options. The baseline scenario has two components. First it describes a general scenario of agricultural sector development and the GHG emissions that would occur from various sources in the absence of specific measures to mitigate climate change. This scenario of agricultural development should be closely tied to general macro-economic trends projected for the country, as well as national development plans related to agriculture. Second, it describes the physical parameters of the agricultural sector activities that will be displaced by the mitigation option, the GHG emissions and carbon sequestration fluxes associated with these activities, and their cost components. Once the baseline scenario is established, it serves as the basis for evaluating the effects of the mitigation options.

Once projections of the relevant future agricultural activities have been projected, such as number of livestock, irrigated rice area, fertiliser use, etc., these estimates can be used as inputs for estimating the associated annual GHG emissions and soil carbon fluxes. Estimation methods for calculating GHG fluxes in the agricultural sector are available in the IPCC guidelines for estimating emissions (IPCC, 1997). This, important step involves in almost every case, determining three key elements:

- the future demand for the agricultural products that are associated with specific types of GHG emissions,
- the levels of output and area allocated to the production of these products,
- the production systems / management methods associated with producing these crops,
- the input use for resources that will be affected by the mitigation measure, directly or indirectly, and
- the demand for fuel that will compete with mitigation options that produce a substitute fuel.

In addition, information is needed about the costs and benefits associated with the production activities that will be displaced or affected by the mitigation options. This includes information about direct fixed and variable costs associated with different production systems for each product, the revenues from production, and the net returns per unit area (or per unit product). Where the mitigation option involves substitution / displacement of nutrient sources or alternative fuels, this type of information needs to be supplemented with additional information about fertiliser and fuel demand and input prices in order to determine the cost effectiveness of the proposed measures with reference to the baseline.

Constructing the baseline scenario for the agricultural sector will depend on the mitigation measures that will be selected in Step 3: identification of mitigation options.

4.4.2 Step 2: identification of mitigation options

Mitigation options should generally have to be identified on the basis of factors like potential GHG reduction, expected cost, consistency with national goals, ease of implementation, and others. There are additionally some criteria, which are specific to the agricultural sector. These criteria may include: conformity with existing agricultural development or management plans, environmental regulations or considerations, applicability to the agronomic conditions and practices within the country, and whether the organisation an structure of the agricultural sector are consistent with the measure.

The last criteria can be very important in an agricultural sector context, as the following two examples suggest. In the case of reducing methane emissions from livestock due to enteric fermentation, most strategies focus on increasing the productivity of livestock which reduces methane emissions per unit of product. In this manner substantial reductions in methane can be achieved by reducing herd sizes. However, if the dominant pattern of livestock ownership involves owning one, or at most two animals, to support a single family on a small farm, it may not be possible to cut the herd size without economically disadvantaging the owner and his family. Finally, consider the case of reducing methane emissions to anaerobic fermentation in livestock. Typically, anaerobic conditions require that the manure from livestock be put in pits, slurry’s or lagoons. But this practice requires the concentration of livestock in feed lots, or at the very least disposal of manure from large herds. This may work against the feasibility of this option in many developing countries in which herd sizes are small and the manure is used as a fertiliser on dry soils where anaerobic conditions do not dominate.

4.4.3 Step 3: assessment of mitigation potential and costs of the options

This step involves estimation of the GHG fluxes of the mitigation options and a cost assessment. The current section focus on the cost assessment and a detailed overview of the estimation of GHG fluxes for the sub-categories of mitigation options listed above, are given in the Annex.

The incremental cost of a mitigation measure in the agricultural sector is the value of the societal benefits which producers and consumers give up, relative to the baseline scenario, as a result of implementing a mitigation measure to reduce or offset GHG emissions. In most cases, this will involve changes in production practices that will cost more to implement than existing production practices, and this will show up as a cost to the society.

In theory, one should measure the incremental cost of a mitigation measure in terms of the change in the net benefits to both consumers and producers. For example, there may be cases when the implementation of a mitigation measure results in market adjustments that cause the prices of some agricultural commodities to increase, making consumers worse off than in the baseline, because consumers will have to pay more money than before to consume some agricultural products. However, to measure the costs of mitigation measures to consumers requires the use of economic market or sectoral models, which is beyond the current capability of many developing countries.

Fortunately, for analytical purposes, the need to measure price changes in consumer benefits as a part of calculating costs, only arises if the implementation of the mitigation measure causes a change in the market price of one or more agricultural commodities. If the mitigation measure has only a small effect on domestic production relative to total production in the market for the product as a whole, then it probably will not affect the price of the commodity in the larger market. If this is the case, then one can safely ignore the impact of the measure on consumer welfare, at least in terms of calculating mitigation costs.

In this case, the appropriate measure of the cost of a mitigation measure in the agricultural sector is the change in producer surplus. Producer surplus is a measure of the benefits farmers receive from producing goods, less their variable costs. This can be approximated, for a single period, by the net income, or profit, which is expressed generally as:

$$\Pi = TR - TC \qquad \textit{Eq. 16}$$

where Π is profit, TR is total revenue and TC is total cost. The total revenue is equal to the price of each good times the amount of the good produced, summed over all goods, and total cost is equal to the price paid for each input to production (land, labour, fertiliser, water, etc.) times the amount of the input used, summed over all inputs.

The more formal way to express profits on an annual basis is:

$$\Pi = \sum_i P_i \cdot Q_i - \sum_j c_j \cdot X_j \qquad \textit{Eq. 17}$$

and

$$Q_i = f_i(X_{i1},..., X_{im}) \qquad \textit{Eq. 18}$$

and other restrictions on the availability of inputs, such as total land available, as applicable.

where:

P	= the price of an agricultural commodity
Q	= the amount of an agricultural commodity that is produced
i	= 1,…, n an index denoting the commodities that are produced
c	= the price of an input used in agricultural production
X	= the amount of an input used in agricultural production
j	= 1,…, m an index denoting the inputs that are used
$f_i(\cdot)$	= the production function for agricultural commodities.

The function, $Q_i = f_i(X_{i1},..., X_{im})$ is the production function for a single agricultural commodity (i) which characterises how various inputs (such as land, labour fertiliser, pesticides, water, etc.,) are combined in producing that commodity. It is important to understand this function because mitigation policies are almost always targeted at changing either the level or kind of inputs to production, or the production process itself embodied in the function, or both. For example, reducing methane from enteric fermentation in livestock involves changing the feed mix for cattle to improve productivity. The feed constitutes one or more of the inputs (X) to production and the change in productivity is embodied in the change in the amount output (Q) produced by livestock, in terms of milk, meat, and work.

The mitigation costs, *MiC*, are measured in terms of the difference in profits between two scenarios – a baseline case and a mitigation scenario. This is expressed for a single period in the future as:

$$MiC = (TR_m - TC_m) - (TR_b - TC_b) \qquad \textit{Eq. 19}$$

where the subscript, *m*, indicates the mitigation scenario and, *b*, indicates the baseline case.

Profit can also be expressed in long run in terms of land rents. This is related to profit in the following way: the land rent is equal to the net present value of the expected profit from the most profitable use of a piece of land, over an infinite time horizon. This is equivalent to:

$$LR = \sum_t^{\infty} E(\Pi_t) \cdot (1 + r)^{-t} \qquad \textit{Eq. 20}$$

where:

LR = Land rent
$E(\Pi_t)$ = the expected profit
r = the annual real discount rate (adjusted for inflation)
t = 1,…, ∞ an index denoting time (years).

This term can be expressed on an annual basis, using a large value for T, t = 1,…,T, as:

$$ALR = r \cdot LR \cdot (1 - (1 + r)^{-T})^{-1} \qquad \textit{Eq. 21}$$

where *ALR* is the annualised land rent. To capture the annual flow of expected benefits from a piece of land. This expression reflects the annual value of land when an analysis is done to compare the value of land in its current use with alternative uses over time. In fact, annualised (i.e., levelised) land rent is, theoretically, the appropriate measure of the opportunity cost of land, and not its profit. However, if the land is expected to stay in its current use for the foreseeable future, the calculation of annualised profits and annualised land rent will be the same, and are often used interchangeably.

The corresponding measure for the annual mitigation cost is, then:

$$MiC = ALR_m - ALR_b \qquad \textit{Eq. 22}$$

It is important to note, once more, that the change in profit as a measure of the cost of a mitigation measure is a good one, only in situations where the prices of agricultural commodities are not affected by a mitigation measure. The analyst must determine this before the cost calculations are undertaken. In situations, where the mitigation measure will affect a measurable share of production in the total market for the commodity, then the change in consumer welfare should also be accounted for.

If a market or sector model is not available to estimate the change in price, there are two choices. First, if there is information about the price elasticity of demand for the product, then once the change in output has been determined, this information can be used to estimate both the price response to that change and the change in revenue. Second, if this information is not available, then one can approximate, very roughly, the change in consumer benefits by the change in revenue. In this, second case, the measure of mitigation costs reduces to the change in total cost.

The accuracy of this second approximation depends on how inelastic the price elasticity of demand for the commodity is. The more inelastic the demand, the better the approximation. As a general rule, the demand for food products is quite inelastic relative to other goods and services, and the demand for staple and subsistence foods is more inelastic than the demand for "convenience" items.

4.4.4 Step 4: construction of mitigation cost curves

The cost curve for the mitigation options in this sector represents an effective way of ranking the cost-effectiveness of various sectoral mitigation options from lowest to highest cost. The underlying economic rationale behind this construct and concepts on which it is based are presented in Section 2.4.

Construction of the supply curve for agricultural mitigation options involves the following steps:

Step 1

Convert the reduction in GHG emissions associated with the measure in period t into its CO_2 equivalent using the appropriate global warming potential coefficient (GWP) for the gas, or gasses reduced by the option.

Step 2

Estimate the cost effectiveness of each option for the time period under consideration. We recommend constructing two mitigation supply curves, one for a near term period (2010) to reflect short term cost-effectiveness and one for to represent the cost-effectiveness of mitigation options, further off in the future (2030, or 2040). The cost effectiveness ratio (CER) of a single option for a period in the future (t) is expressed as:

$$CER_t = MiC_t / \Delta E(CO_2 equivalents)_t \qquad \textit{Eq. 23}$$

where the mitigation cost (*MiC*) is estimated from Eqs. 21 through 23 and the total change in emissions associated with the mitigation option is expressed in terms of its CO_2 equivalent emission reduction.

Step 3

Arrange the options, based on their CER calculation, from lowest to highest cost and plot the CER (vertical axis) vs. the CO_2 equivalent emissions reduction (horizontal axis) for each mitigation option. This procedure is used to generate two supply curves for two specific periods in the future, as previously mentioned

4.5 Models and methods

There are several different broad approaches for estimating the reduction in GHG emissions that will occur as a result of a mitigation option. However, because of the large degree of variability associated with agricultural production, due to soils, climate, technology, etc., models or calculations that are made for a specific country are very often hard to transfer to another country without introducing considerable uncertainty. Resources that can be used to estimate GHG emissions reductions associated with selected mitigation measures are as follows:

IPCC Guidelines/Default factors. The IPCC (1997) has published a manual for estimating GHG emissions from the main sources and sinks in each sector, including agriculture.

This resource also contains methodologies for estimating GHG emissions from these sources and sinks. In many cases, it includes "default" factors for key emissions-related factors. For many developing countries, it will be easiest to adapt these calculations and factors to suit local conditions, although considerable expert judgement is required to do so and produce accurate results. Unfortunately, very few default factors exist for agricultural activities, since, as was previously mentioned, emissions from any activity depend upon specific characteristics such as type and condition of the site, management practices, and weather. Field measurements or site-specific estimates are almost always preferred to default factors. As the scientific understanding of atmospheric greenhouse gases increases, more default factors will become available for use in specific situations. These default factors may make it possible to report projects easily, but they will be less precise than data from actual field measurements.

Field measurements. When appropriately designed and executed, site-specific field studies will provide the highest quality data and thus the highest credibility to the national report. Unfortunately, estimation of GHG emissions from agricultural activities is a relatively new endeavour, and field measurements that are helpful for estimating the GHG emissions associated with a specific mitigation option rarely exist.

Models. Many of the estimation techniques discussed in this document for specific sectors rely on the use of models. A further discussion of some different modelling approaches is contained in Section 5. One should carefully consider the suitability of any model that is to be used to calculate GHG emissions associated with specific mitigation measures. For example, some models are designed for farm-scale use; to apply them on a district-wide basis may reduce their accuracy. Moreover, many of the models that are in use in the non-energy agricultural sector for estimating GHG were originally developed for different purposes than estimating greenhouse gas emissions and, therefore, may not adequately address issues of many effects, integrated effects, or multiple gases. Finally, the model that is otherwise suitable for a particular situation may not provide a credible reference case, since the agricultural techniques currently in use are not accommodated in many of these models.

Finally, it is important to include the effects of projects on all GHG emissions, directly or indirectly associated with the mitigation option. In some cases, the adoption of a GHG mitigation measure will result in a direct reduction in GHG emissions at the source, but an indirect increase in emissions some place else. These indirect increases are known as "leakages" and they occur because a change in agricultural production or practice in one place creates incentives for production or practices to change in another place.

In the agricultural sector, mathematical, computer models can be used to obtain the most accurate estimates of the effects of mitigation on emissions, soil and tree carbon and crop yields. Some of the models that can be used to perform these functions are "generic" in the sense that there structure is general and they can be used in a variety of different agronomic and meteorological conditions, by changing key model parameters to fit local conditions. This may sound easy, but often the data needed to drive these models is not available in developing countries, and resources have to be expended to collect the data or conduct experiments to obtain it. Other types of models – particularly economic models – are not so easy to adapt because the structure of the model is developed for a specific crop, or country or region. Applying such a model in a different structural setting is almost impossible to accomplish, without developing a new model.

Thus, in selecting what types of models and methods to use to conduct a mitigation assessment in the agricultural sector, one needs to balance the need for greater accuracy against the availability of data and the costs of adapting existing models, or developing new ones, as well as the human capital available and the access to resources to develop new capacity. In some, and perhaps many cases, a mitigation assessment that relies primarily upon simple arithmetic calculations within a spreadsheet format will be the most sensible approach, after weighing these factors.

4.5.1 Models of GHG emissions/carbon uptake on agricultural lands

In the case of many different forms of economic activity and greenhouse gases, its is possible to use a parametric approach for estimating emissions, whereby one multiplies a key activity variable, such as fuel input, or energy output by an emissions coefficient relevant to that input or output. This approach is commonly used in other sectors, especially the energy sector, and is highlighted for the agricultural sector by the calculations shown for step 3 of an mitigation assessment in the agricultural sector. This "bottom" up approach to estimating GHG emissions is the basis for almost all of the GHG inventories developed to date, based on the IPCC guidelines for calculating emissions inventories (1997).

One specific area where models can be helpful to calculate GHG emissions in the agricultural sector involves the effects of fertiliser management on nitrous oxide emissions. The NLEAP (Nitrogen Leaching and Economic Analysis Package (Shaffer et al., 1991) is a process oriented predictive simulation model. It uses basic information concerning onfarm management practices, soils, and climate to project N budgets and nitrate leaching indices. NLEAP calculates potential nitrate leaching below the root zone and to ground water supplies. The NLEAP model has been extended to predict N_2O emissions from agricultural soils under a range of management and weather conditions. Field testing of the model in Colorado showed that simulated N_2O losses are consistent with measured values. The model was designed as a field-scale model, however, it can be used in a larger spatial context. The model is "transferable", but is not well-suited for organic soils. It requires information on soils, climate and management practices.

A variety of "transferable" models are available to calculate carbon uptake for plant and forest ecosystems. Two models that have been used specifically to estimate carbon uptake as a result of mitigation options are Century and Spurr.

Century (Parton et al., 1992) is a simulation and process model used to understand grassland and agroecosystem dynamics. Other versions exist for savannahs and forests. The purpose of the model is to analyse soil organic matter dynamics in response to changes in management and climate. The model uses monthly time steps for simulations of up to several thousand years to examine the flows of carbon, nitrogen and phosphorus. Data required for input include: monthly mean maximum and minimum temperatures; mean precipitation; soil texture and soils depth; vegetation types and CO_2 levels, and management type. The model has been recently extended to estimate carbon uptake in forest biomes, as well. The output contains information on carbon and nitrogen fluxes, net primary production and soil organic matter. The spatial extent of the model is regional with most executions at the 1 m^2 resolution.

SPUR (Simulating Production and Utilisation of Range Land) is a simulation and process model for managed and unmanaged grasslands. Its purpose is to determine and analyse management scenarios as they affect rangeland sustainability and to forecast the effects of climate change on rangelands (Hanson et al., 1992). The model is a multipoint model, designed to allow for direct competition between several species for water and nitrogen. It estimates carbon uptake and allocation, and, as such, can be used to assess the effects of management practices on soil carbon on grasslands. Driving variables for the model include daily precipitation, maximum and minimum temperature, solar radiation and wind speeds. SPUR I has been validated by several researchers (Hanson et al., 1992).

4.5.2 Crop yield models

A number of the mitigation options, described here, involve changes in N fertiliser, water, and tillage regimes to reduce GHG emissions. Changes in inputs and management practices can affect crop yields, which in turn influences the revenue received by farmers. If these changes in crop yields are large enough, and the area affected is large enough, this can also affect domestic and perhaps global commodity prices. It is often assumed that the changes in inputs and management techniques are introduced without affecting crop yields. While this assumption may simplify the economic analysis, it is not always the case. There are several different modelling approaches available to estimate the effects of mitigation options on crop yields.

1. Statistical Methods. If data are available on inputs, management and yields associated with the mitigation measure, as is sometimes the case, then it is possible to estimate the parameters of statistical (i.e., multivariate regression) models. Such models may already be available. The advantage of this approach is that it is relatively easy to execute, provided that data are available. The main drawback is that the estimated regression parameters only apply to the specific conditions and crops for which data are available. Thus, these models are not easily transferable.
2. Process Models. Process models differ from statistical models in that they include the structure for important crop growth and development processes. The extent of the structure varies quite widely. Some crop-specific process models are extremely complicated, while others are highly parameterised. A number of models are available, specifically, for estimating rice yields. These include the CERES rice model (Singh et al., 1993), EPIC (Williams et al. 1983) and ORYZA_W (Bouman, 1993).

4.5.3 Economic models

Economic models are useful for calculating the costs of mitigation measures. These models include mathematical representations (directly or indirectly) of the demand and supply function of specific commodities in a country or region. The models simulate the effects of changes in exogenous variables that influence supply and demand on commodity production, prices, and the allocation of some inputs, usually land, labour and fertiliser. There are two important sets of distinctions with regard to these models:

1. market level vs. producer level.
2. multi-commodity (sector) vs. single commodity.

The first distinction relates to the ability of the model to simulate changes in commodity prices. Market level models solve for market-clearing commodity prices, an important feature if the mitigation measure is expected to have an impact on output prices. Producer level models assume that commodity and input pries are fixed and represent a model input. In addition, economic models may focus on a specific market, or they may focus on multiple markets, usually the entire sector. In the agricultural sector, land and other resources are easily substitutable between crops. As a result, if a mitigation measure affects the relative profitability of a single crop or the price or use of a single input, such as water, producers may find it economical to make adjustments to their crop mix in general. As a result, a mitigation measure which substantially effects the production of one crop may influence the allocation of land to many different crops.

Agricultural sector models combine multiple commodity markets with the ability to estimate market clearing prices for different supply and demand regions. These models can be particularly valuable in conjunction with estimating the costs of some mitigation measures. To do this requires limited modifications, usually involving just the addition of emissions coefficients, to simulate emissions from different crops and management systems.

Adams et al. (1992) modified an existing, price-endogenous sector model of US agriculture to evaluate the economic effects and costs of reducing methane emissions rice production and enteric fermentation. The rice analysis showed that reducing crop area, especially if the crop is highly profitable, can result in changes in crop mix at the regional and national level, and also to high mitigation costs relative to other options. Reducing enteric fermentation was also an expensive option in the US, because livestock productivity is already very high and mitigation measures are not as effective as in developing countries, where productivity is much higher. Consequently, cutting herd sizes to reduce methane emissions increased product prices and stimulated imports of some products.

Price endogenous agricultural sector models are available for many of the more advanced developed countries with large agricultural sectors. Some of these models can be adapted for use mitigation assessments, along the lines of Adams et al. (1992). For example, the Egyptian agricultural sector model has a detailed description of rice production, and could be modified relatively easily to look at a number of the rice methane mitigation options in this country.

For countries that do not already have agricultural sector models, the task of developing such models is fairly substantial and this approach is probably not practicable, or warranted if the country’s agricultural sector is small or poorly developed. Since agricultural sector models calculate commodity production and price levels using the principle of economic efficiency, these models are not well-suited for simulating subsistence agriculture.

5 Waste management

The following section outlines the main definitions and analytical steps involved in waste sector assessment. The aims of the section are to describe the specific methodological framework for assessing GHG emission sources in the sector and to examine the key steps in cost assessment of mitigation options via practical examples. The analytical steps are identical in all sectors: a) the construction of a baseline, and b) the identification of mitigation options followed by an assessment of their potential and costs.

With the exception of small amounts of nitrous oxide (N_2O) from human sewage and waste incineration, GHG emissions from the waste sector are mainly methane (CH_4), and these account for 15-50% of the total global methane emissions of approximately 375 Mt (IPCC, 1997). Options for mitigating emissions from livestock manure are discussed in section 4 The agricultural sector.

These guidelines define the system boundaries for the waste sector according to IPCC (1997). The GHG emission inventory includes the following three areas, with the last being the smallest source:

- Solid waste disposal on land.
- Wastewater handling (industrial and domestic wastewater).
- Waste incineration of fossil-based products such as plastics.

5.1 Solid waste disposals on land

Methane emitted from landfills results from the anaerobic decomposition of organic wastes. The methane migrates through the waste, eventually escaping to the atmosphere. Estimates suggest that landfills are a global source of 20-70 Mt (=Tg) CH_4 (IPCC, 1997). There are large uncertainties in these estimates due to a lack of information about the amount of organic material actually disposed in landfills or open dumps, the waste management practices employed, the portion of the organic wastes that decomposes anaerobically and the extent to which the waste will ultimately decompose.

5.2 Solid waste baseline

When constructing the solid waste baseline, a time-series of the total amount of landfilled waste has to be established as far back into the past as possible, since old landfills continue to emit methane. Assuming that half of the waste decomposes after 10 years, 12.5% is left to decompose after 30 years.

If no statistics are available for the amount of waste contained in landfills, it can be calculated on the basis of the amount of solid waste generated per capita, using the default values in IPCC (1997). The future amount of landfill waste can be estimated in the same way, taking the national waste management policy into account. In countries where no organised waste collection or disposal takes place in rural areas, only urban areas should be considered.

The amount of methane produced depends on the management of the disposed municipal solid waste and the depth of the site in question. Methane Correction Factors (MCF) reflect the effect on methane generation. IPCC (1997) recommends multiplication of the amount of disposed waste with the MCFs in Table 16.

Table 16 Methane Correction factors

Type of site	MCF values
Managed	1.0
Unmanaged - deep (>5m waste)	0.8
Unmanaged - shallow (<5m waste)	0.4
Default value - not categorised	0.6

If possible the amount of landfilled waste (in tons) should be disaggregated according to sector origin (see Table 17). Since the carbon content of the waste varies from fraction to fraction an emission factor should be calculated for each.

Table 17 Composition of landfilled waste (Denmark 1985)

Material fractions in:	Waste food	Paper & cardb.	Wet paper & cardb.	Plastics	Other combus-tibles	Glass	Metal	Other Non-combus-tibles	**Total**
Household refuse	0.38	0.15	0.26	0.07	0.03	0.02	0.05	0.05	1.00
Bulky refuse		0.31		0.05	0.46	0.09	0.09	0.02	1.00
Garden refuse					0.76			0.24	1.00
Service refuse	0.25	0.35	0.11	0.05	0.10	0.05	0.05	0.05	1.00
Industrial refuse	0.06	0.09	0.01	0.01	0.06	0.04	0.18	0.54	1.00
Construction refuse					0.07			0.93	1.00
Sludge					0.83			0.17	1.00
Ash & slag								1.00	1.00
% DOC content	20	40	20	85	15-40	0	0	0	
Emission factor kgCH_4/ton waste	60	120	60	255	45-120	0	0	0	

The total CH_4 emission from one ton of landfilled waste is calculated in the bottom row of Table 17. The emissions depend on the content of degradable organic carbon (DOC) in the waste, and this DOC content depends on the composition of the landfilled waste as shown in Table 17 (default values can be found in IPCC (1997), where an emission factor is calculated for each fraction). The values will of course vary from country to country and change over time. Calculation of the emission factors in kg CH_4/ton waste (results shown in the bottom line of Table 17) is performed according to IPCC (1997):

$$\text{Em-factor} = \text{MCF} \cdot \%\text{DOC} \cdot \text{Fraction of DOC converted to } CH_4 \cdot \text{Fraction of } CH_4 \text{ in landfill gas} \cdot \text{Fraction of } CH_4 \text{ oxidised} \cdot 16/12.$$

The default value for the fraction of DOC converted to CH_4 has been reduced to 50% according to the revised IPCC Guidelines. The fraction of CH_4 in landfill gas is 0.5. The fraction of CH_4 oxidised in the upper layers of the landfill is not well known, and a value of 10% was used in Table 16. The last factor of 16/12 is just the relative weight of a methane molecule compared to a carbon atom.

The time series for the baseline for emissions from the landfilled waste can now be calculated in several ways. The simplest approach is to calculate the emissions in a specified year as the amount of waste landfilled that year multiplied by the above CH_4 emission factors. However, this assumes that all the waste is decomposed in one year, which is incorrect. A more precise method is to use a kinetic approach, assuming that the waste sent to landfill in a given year decomposes following an exponential curve, which can be described as:

Amount of waste landfilled in year zero not yet decomposed in year t = exp(-k·t)

The half-life of the waste is the time taken for half of the waste to decompose. With exp(-k·half-life)=1/2 the degradation rate constant k is

k = ln(2)/half-life.

Values for k can vary considerably, but assuming a half-life of 10 years gives k = 0.069

The emissions of CH_4 in year t from the waste landfilled in year zero is then the emission factor calculated according to the formula above, multiplied with the waste decomposed in the last year, or more specifically:

em-factor · (exp(-k(t-1))-exp(-kt)) · total amount of waste (in tons)

The total emission in a given year is then the sum of all the emissions from each of the preceding years, calculated according to the same method.

5.3 Solid waste mitigation options

There are two approaches to reducing the methane emissions from landfills: (1) the resultant methane can be recovered and then either flared or used to produce energy, or (2) the quantity of landfilled waste can be reduced through source reduction, recycling or other waste management practices.

In addition to reducing methane emissions to the atmosphere, the recovery of landfill gas creates other benefits, such as:

- Improved landfill safety. In recent years several accidents have resulted from explosions of methane in houses situated close to landfills.
- Reduced emissions of other Volatile Organic Compounds (VOC).
- Reduced odour problems.

5.3.1 Recovery of methane from landfills

The recovery of methane from landfills has been attempted since the mid 1970s, when the first plants were built in the US. More than 400 plants have since been constructed world-wide, with more than 100 of these in the US. In the UK, plants of this kind have been one of the successful technologies under the NFFO (Non-Fossil Fuel Obligation), and 60 plants totalling more than 80 MW have been constructed.

The landfill gas is extracted through a series of wells drilled into the landfill. The well shafts, typically 1-3 feet (30-90 cm) in diameter, are drilled from the surface to within a few feet of the bottom. A narrow, perforated plastic pipe is then inserted into the well. The shaft is backfilled with gravel or a similar permeable material and the top is sealed to prevent the inflow of air. Finally the pipehead is connected to the collection system, where the gas is processed and purified to remove water, particulates, halogen compounds and hydrogen sulphide (H_2S). The purified landfill gas is typically a 50:50 mixture of methane and carbon dioxide with a calorific value of 18 MJ/m^3. A plant of this kind can extract 30-40% of the methane generated.

The gas recovery can be improved by covering the landfill with a membrane such as a layer of clay, or a thick layer of soil, possibly incorporating a plastic layer. Well-designed systems have achieved recovery efficiencies of 70-80%. The annual amount of gas collected from the landfill can then be calculated by multiplying the recovery rate with the amount of gas produced. The gas production is then calculated as the number of tons in the landfill multiplied with an average CH_4 emission factor based on the material fractions in the landfilled waste (see Table 17).

An example of a GHG-mitigation calculation for a landfill is shown in Table 18. The calculation was performed with the greenhouse gas costing model (GACMO), which has been used in Denmark, Zimbabwe, Zambia, Botswana and Peru. The GACMO model, developed at the UNEP Centre, is a simple spreadsheet model, which contains each mitigation scenario in one workbook. All mitigation options are treated in a standardised fashion. The mitigation costs for all options are combined in one worksheet where the size of each option is entered and a graph of the cost curve is drawn automatically. The price projections for the fuels used in the options are made on a separate worksheet. All other common assumptions such as country name, currency name, discount rate, exchange rate, emission factors, and global warming potentials are made on one worksheet, in order to easily update the cost curve.

In the standard format for an option (shown in Table 18), the first column contains the calculation for the reduction option and is compared to a reference option (from the baseline scenario) in column two.

The upper part of Table 18 calculates the increase in the annual costs of the reduction option (the landfill gas recovery plants) compared to the reference option (no gas recovery, natural gas used instead). The investments are levelised with the project lifetime in the second row and the discount rate shown below the table in order to add it to the annual O&M costs and the annual fuel costs.

The lower part of Table 18 calculates the reduction in the annual emissions of the reduction option compared with the reference option. The emissions of CO_2 (zero for landfill gas), CH_4 and N_2O are calculated with the IPCC default values and the Global Warming Potentials to calculate the total emission in tons of CO_2 equivalents. A separate row adds non-combustion emission (the CH_4 leaking from the landfill). The cost of reducing GHG emissions for the option is calculated at the bottom of the table. All specific inputs for the reduction option and the reference option are documented on the spreadsheet in order to make the calculation more transparent.

The landfill in the example is covered by a clay / bentonite membrane (230 kUS$ / ha) and the CH_4 recovery rate is assumed to be 70%. The collected landfill gas, with a methane content of 50%, is used in a small scale gas motor combined heat and power plant where 35% of the energy is converted to electricity and 54% to heat. The plant is compared with a reference case where no methane is collected from the landfill and the output of the plant replaces the output from a gas motor power plant using natural gas with the same efficiency, C_m value and capacity factor. The calculation is for a site containing more than 200,000 tons of waste. For older or smaller landfills it may be more cost efficient to flare the recovered landfill gas with a torch instead of using it for energy purposes.

Table 18 Large landfill gas plant with 70% recovery

Costs in kUS$	**Reduction option**	**Reference option**	**Increase (Red.-Ref.)**
Total investment	6,848		
Project lifetime (years)	10	20	
Annual Levelised Investment	887	46	841
Annual O&M	63	59	4
Annual Fuel cost		226	-226
Total annual cost	950	331	**619**
Annual emissions in tons:			
Fuel CO_2 emission	0.0	2,827.4	2,827.4
Fuel CH_4 emission	0.050	0.050	0.000
Fuel N_2O emission	0.005	0.005	0.000
Leaking CH_4 emission	0.0	1,005.2	1,005.2
Total CO_2 equiv.	2.6	23,939.3	**23,936.6**
US$/ton CO_2 equivalent			**25.87**

General inputs:	
1 Ton CH_4 =	21 Ton CO_2
1 Ton N_2O =	310 Ton CO_2
Discount rate	5.0%
Fuel type for reference option: Natural gas	
Ref. CO_2 emission factor:	56.1 $kgCO_2/GJ$
Ref. CH_4 emission factor:	0.0010 $kgCH_4/GJ$
Ref. N_2O emission factor:	0.0001 kgN_2O/GJ
Fuel type for reduction option: Landfill gas	
Red. CO_2 emission factor:	0 $kgCO_2/GJ$
Red. CH_4 emission factor:	0.0010 $kgCH_4/GJ$
Red. N_2O emission factor:	0.0001 kgN_2O/GJ
Reduction option:	
Annual landfill gas collected:	2.8 mio.m^3
Plant capacity:	675 kW
Specific cost of plant (excluding membrane):	3077 US$kW
Cost of membrane:	4769 kUS$
Cost of plant:	6848 kUS$
Annual O&M of plant:	6% of investment
Total annual O&M:	63 kUS$
CH_4 content in landfill gas:	50%
Annual CH_4 collected:	1.40 million m^3
CH_4 calorific value:	36 MJ/m3
Annual fuel collected:	50,400 GJ
Generator elec. Efficiency:	39%
Capacity factor:	0.92
Electricity produced:	5460 MWh
Reference option:	
Annual CH_4 emitted:	1.40 mio.m3
CH_4 density:	0.718 kg/m3
Annual fuel used:	50,400 GJ
Ref. power plant O&M:	0.01 US$/kWh
Investment in ref. power plant:	0.85 kUS$/kW

5.3.2 Wastewater handling

When wastewater is treated anaerobically methane is emitted. Anaerobic methods are used to treat wastewater from municipal sewage and from food processing and other industrial facilities, particularly in developing countries. In contrast, developed countries typically use aerobic processes for municipal wastewater treatment and anaerobic processes in closed systems, where CH_4 is recovered and utilised.

Uncertainty regarding these estimates results from a lack of characterisation of wastewater management practices. In IPCC (1997) the total emissions from wastewater is estimated to be 26-40 Mt CH_4, with industrial sources as the major contributor. Domestic emissions are estimated at approximately 2 Mt CH_4 (IPCC, 1997).

5.3.3 Waste water baseline

The method for estimating CH_4 emissions from wastewater handling involves five basic steps (IPCC, 1997):

1. Determine the total amount of degradable organic component (DC) in the wastewater for each wastewater handling system. For municipal wastewater this is measured as kg BOD (Biochemical Oxygen Demand) and for industrial wastewater as kg COD (Chemical Oxygen Demand). The future amount of municipal and industrial wastewater can be projected as proportional to the urban population and the economic activity in the industrial sector, respectively.
2. Estimate the methane production capacity for each wastewater handling system. This is the maximum amount of CH_4 that can be produced by a given quantity of wastewater or sludge. The default values are 0.25 kgCH_4 / kg BOD for municipal wastewater and 0.25 kgCH_4 / kg COD for industrial wastewater.
3. Estimate the Methane Conversion Factor (MCF) for each wastewater system. MCF defines the portion of the methane production capacity that is achieved in reality. The MCF varies between 0.0 for a complete aerobic system to 1.0 for a complete anaerobic system.
4. For each wastewater handling system, multiply the total amount of DC in the wastewater (from step 1) by the methane production capacity (from step 2) and then by the MCF (from step 3), and sum across the wastewater systems to estimate total CH_4 emissions.
5. Project future emissions by projecting the urban population and the industrial production in tons.

The availability of necessary waste management data may be limited. Chapter 6.3.6 in the IPCC Reference Manual (IPCC, 1997) contains some area-specific default values, i.e., the production in kg BOD / cap / day for municipal wastewater and the production in m^3 wastewater / tons of product and kgCOD / m^3 for each type of industrial wastewater. Only some MCF's are given – IPCC research is ongoing in order to provide MCFs for more countries and regions.

5.3.4 Wastewater mitigation options

The largest potential for methane emission reduction from wastewater exists in developing countries, where wastewater streams are often unmanaged or maintained under uncontrolled anaerobic conditions. The untreated waste and sludge is often flushed into waste lagoons, rivers and oceans. The wastewater GHG mitigation options also reduce the health risks associated with the pathogens, heavy metals, and toxic compounds it contains.

Detailed descriptions of the options for reducing methane emissions from wastewater and sludge management are not included in these guidelines. In USEPA (1993) a characterisation of the technologies is given for the main options listed below.

Prevent CH_4 production during wastewater treatment:

- Aerobic primary treatment. Sufficient oxygen levels are maintained by using proper organic loading techniques (controlling waste levels and organic concentrations) or by provision of oxygen to the wastes through mechanical aeration.
- Aerobic secondary treatment. Oxidation is accomplished through prolonged exposure of wastewater to aerobic micro-organisms which are either floating or attached to fixed or rotating media.
- Land treatment. Applying raw or partially stabilised wastewater to soils (not appropriate for wastes containing heavy metals). In this way the organic constituents in the wastewater are broken down without methane production.

Recovery and utilisation / flaring of methane from anaerobic digestion of wastewater or sludge:

- Methane utilisation.
- Methane flaring. An alternative to preventing methane production in wastewater and sludge is to encourage anaerobic conditions in the wastes through anaerobic treatment. The resulting production of methane is recovered and utilised as an energy source or flared.

Minimising emissions from sludge

Just as methane emissions can be avoided during wastewater treatment, methane production can be minimised during sludge stabilisation. These stabilisation and disposal options include:

- Aerobic digestion.
- Land application (as for wastewater).
- Chemical stabilisation with lime or kiln dust / fly ash.
- Incineration.
- Landfilling / methane recovery.
- Aerobic composting.

5.4 Waste incineration of fossil fuel based products

If the heat produced in the waste incineration plant is used for district heating or for electricity production, it is part of the energy system and should therefore be considered with the energy sector. However in many countries this is not the case.

Only combustion of the fossil fuel based fractions, such as plastics, creates net emissions of CO_2. The largest fraction of the carbon in the combusted waste (e.g., paper, food waste) is derived from biomass that is replaced by regrowth on an annual basis. The combustion of this fraction creates only a small net emission of CH_4 and N_2O.

5.4.1 Waste incineration baseline and mitigation options

It is not an easy task to project the amount of fossil fuel-based products that will be incinerated in the future. Data is needed to estimate the present amount of plastics and other materials that are incinerated. If no data are available on how the composition of the solid waste will develop in the future the fractions can be kept constant. The future amount of incinerated waste in the baseline must be consistent with the environmental policy of the country concerned and reflect the priority given to different solid waste disposal options: recycling, waste use in power plants, landfills and incineration. The main mitigation options are: to reduce the amount of waste or to separate the plastics from the waste and either recycle the plastics or landfill the plastics with recovery of the methane.

Policy Instruments

1 Policy instruments

1.1 Introduction

The topic of policy instruments is seldom addressed in connection with mitigation guidelines. This is because mitigation guidelines tend to treat mitigation options as projects, without addressing the issue of how the incentives to undertake these projects will be created. When policy instruments are discussed in mitigation studies, they are typically treated as mitigation options. For example, it is typical to view carbon taxes as a mitigation option on the same level as a demand side management (DSM) option, such as installing high efficiency light bulbs. However, there is a fundamental difference between policy instruments, such as carbon taxes, and mitigation options, such as DSM programs and planting trees to sequester carbon. The important difference, that we wish to emphasise in these guidelines, is that policy instruments are not an end in themselves, as are mitigation options. Rather, policy instruments are a means of *inducing, or causing,* mitigation options to occur by changing either the economic incentives that individuals, governments and firms have to undertake mitigation options or the regulatory environment affecting mitigation options, or both.

Viewed from that perspective, the purpose of this section of the guidelines are to:

- to identify and describe in fairly broad terms the types of policy instruments that are available to induce mitigation options,
- to critically evaluate these options, specially from a developing country perspective.

No single policy instrument is appropriate for every country to address its GHG reduction needs. The choice of appropriate instruments will depend upon the mix of GHGs in the emissions inventory of a country, the mitigation options that it has in its disposal, the structure of energy markets, and the experience and capacity the country has developed in conducting environmental policy and controlling emissions.

This chapter outlines and evaluates some of the more important policy instruments that have been proposed, or are available, for reducing GHG emissions. The policy instruments to be reviewed in this section include:

- Command and Control (CAC) approach to regulate GHG emissions.
- Market Approach (also referred as Economic Instruments, EI), broadly consisting of following:
  - market restructuring policies in energy markets.
  - taxes on primary fuels, energy, and emissions including carbon taxes.
  - cost-based market mechanisms, such as emissions trading.

1.1.1 Regulation of GHG emissions through command and control

Environmental regulations have been used with success to achieve substantial, but not complete, improvements in air and water quality in many nations. In addition, the regulation of GHGs at the global level lies very much at the heart of all the policies proposed by the Kyoto Protocol to the FCCC. Thus, it would seem worthwhile to look at how GHG regulations can be used to induce mitigation options.

Command and control systems (CAC) that can be used to reduce GHG emissions include:

- direct regulation of GHG emissions,

- regulation of the chemical contents of fuels,
- standards to regulate energy efficiency in buildings and energy-using durable goods in the industrial, residential, commercial, and agricultural sectors,
- regulations to mandate carbon conserving forest practices (forest practice laws), and
- automobile fuel efficiency standards.

A regulatory policy consists of the three following ingredients:

1. Selecting the types of regulation appropriate for different sectors and sources.
2. Selecting the emissions targets, efficiency levels, and practice levels.
3. Development of an effective and efficient set of mechanisms and protocols for monitoring emissions and practices, verifying regulatory compliance, and enforcement.

Selecting appropriate types of regulations is a particularly important part of this process in the use of CAC to regulate GHG emissions, because these sources vary widely from country to country, depending on the level of economic development, the sectoral structure of the economy, the availability of various fuels, etc. Direct regulation of GHG emissions from combustion sources may not always be the most effective means of reducing emissions. For example, in a country dependent upon the use of wood fuels, a combination of energy efficiency standards and forest practice laws will be more effective then regulation of power plant stack emissions.

Eliminating pollution entirely is, in most cases, either technologically infeasible, or too costly in terms of foregone economic development opportunities. Thus, emissions, energy efficiency and practice "targets" can be based both on environmental quality and ancillary objectives, and economic efficiency, costs, and equity. The appropriate balance of these objectives will differ from case to case. To achieve this balance requires not only selecting the appropriate mix of objectives, but also the ability to measure the performance of alternative regulations and targets in achieving these objectives in quantitative terms.

Experience suggests that regulations must be backed up by mechanisms to monitor and verify pollution levels, to create disincentives for non-attainment and the enforcement mechanisms to carry them out. Direct regulation of GHG emissions raises some important issues. A good deal of the successful experience in regulating air pollutants has involved the regulation of so called "criteria" air pollutants, such as SO_2, NO_x, and particulates, from large sources in developed countries. These emissions are relatively easy, but can be expensive, to monitor, verify and enforce. However, GHG emissions come from a wide variety of sources, and these sources differ a great deal depending on a country's natural endowments and its stage of economic development.

In addition, it is extremely hard to attribute some kinds of GHG reductions to specific sources. This is the case with GHG reductions due to energy efficiency improvements and to land use policies to slow down deforestation. Since emission reductions or offsets from these sources can not be monitored directly (as stack gases), they must be estimated by other, less reliable means. However, alternative regulations that specifically target energy efficiency levels, forest area and practices, etc., can be enforced using other attainment criteria that are more suited to the specific type of regulation and are easier to measure. While estimates of GHG emission reductions due to these alternative types of regulations are needed to determine their effectiveness and for accounting purposes under the FCCC, verification and enforcement problems are reduced.

The use of command and control systems to directly regulate GHG emissions is problematic because the technology to remove CO_2, directly from the emission stream, is quite costly compared to other indirect means such as fuel switching, conservation and use of renewables, improving transmission and distribution efficiency, etc. In addition, many of the measures that can be used to mitigate GHG emissions involve even more indirect actions, such as planting trees, switching production to less GHG intensive goods and services, and a host other types of actions that are really not very amenable to direct regulation. This is why most plans to reduce GHG emissions envision a mixed system of regulation and economic incentives. If a strict regulatory system is used to control GHGs, it must be designed to allow regulated sources to reduce their emissions through whatever means is possible.

At the same time, the effectiveness and efficiency of command and control systems depends greatly on how concentrated the emissions sources are in institutional terms and in physical terms. If the major "polluters" are in a single industry, or if the number of sources is small or spatially concentrated, CAC can be quite effective. Thus, the regulation of many criteria air pollutants has been relatively successful because it has been possible to target a single industry, the electric power industry. However, if energy supply systems are decentralised, or if important opportunities for reducing GHG emissions exist outside the energy sector, regulations better suited to these opportunities are appropriate.

Most of the other critiques of CAC focus on their weaknesses from a developed country perspective, not from a developing country perspective. Viewed from the former perspective, CAC are seen both as very expensive, requiring large bureaucracies to implement and enforce the regulations and very inefficient from an economic perspective, providing no built in mechanisms for ensuring that pollution levels are "optimal", or that emissions reductions are achieved at the lowest possible cost[26]. Developing countries experience with CAC is also not satisfactory, but due to different reasons; lack of capacity and institutions, and monitoring and enforcement problems. However, the use of market mechanisms, especially emissions trading, to address environmental quality problems has not worked as smoothly in practice as many economists suggested would be the case, based on economic theory. In the case of the US SO_2 market, the initial auction established a permit price that turned out to be higher than the avoided cost of mitigating these emissions, due to decreases in coal transportation rates and scrubber prices. Thus the debate about the use of CAC versus market mechanisms to achieve environmental quality in developed countries is a bit cloudier than it once was.

1.1.2 Market restructuring policies

By market restructuring we are referring to a broad range of policies that involve removing government intervention in energy markets. These policies aim broadly at bringing the prices at which primary fuels and energy are bought and sold into line with the prices that would prevail in competitive markets. The justification for doing this is simply that, by creating competition in energy markets, the total welfare of buyers and sellers in these markets will increase.

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[26] The term economic efficiency is often used loosely in connection with policy instruments. By "optimal" pollution levels we refer to those that are socially optimal. This means that the marginal cost of abating the last unit of emissions is equal to the marginal social benefit of doing so. This is sometimes confused with cost efficiency, whereby a regulation is met at the least possible cost to private firms. Cost efficiency does not take into consideration changes in social benefits as a result of reducing pollution damage.

Market reform, or "liberalisation", policies as they are sometimes referred to, are not *per se* focused on environmental quality objectives, generally, or reducing GHGs, specifically. While, environmental quality is recognised as an important goal, the theory that underlies these policies is based on the concept of private, not social economic efficiency. As such, this theory does not take into account the presence of environmental externalities that exist in energy markets when access to some pollutant media, such as the air and water, is hard to define in terms of private property rights, whether for institutional reasons or technological reasons. However, it is important to ask if market reform policies create incentives for the adoption of cost-effective mitigation options.

The argument is made that primary fuel and energy markets are inefficient in many countries and that more competitive energy markets will foster greater energy efficiency and energy conservation. Advances in these areas will, in turn, result in reduced energy use and lower emissions of GHGs and other air pollutants.

While "getting the prices right" may directly stimulate resource conservation and indirectly stimulate improved environmental quality, it is also the case that market prices will not, in most cases, reflect social value of the damages caused by pollution. Therefore, many multi-lateral and bilateral funding agencies have adopted policies to finance the additional cost of pollution-reducing and pollution-prevention activities to achieve higher environmental quality standards. In the context of the FCCC, the Global Environmental Facility (GEF) is one such body that was created specifically to provide funding for developing countries to study, plan, and eventually implement mitigation measures that would reduce GHG emissions and stocks.

1.2 Taxes, pollution charges, and externality "adders"

There is a direct relationship between an emissions regulation and an emissions tax[27]. Provided the regulation is achieved at minimum cost, the cost to society of reducing the last unit of emissions is equivalent to the emissions tax that would achieve the same emissions reduction.

The theoretical purpose of a pollution tax is to internalise the social costs created by air and water pollution, at the margin, into the price of market goods and services. This approach is justified on the basis of economic theory which states that the "optimal" level of output for a good is achieved when the marginal social benefits associated with the consumption of a good equals the marginal social cost of producing it. If too much pollution is taking place as a result of energy production, then the marginal private cost of producing energy (or fuel) does not include the marginal value of the damages caused by pollution in energy markets. In that case, the traditional theory runs, government intervention in the market is justified to restore the balance between social costs and benefits by levying a tax that is equal to the marginal value of the "damages" caused by a pollutant.

The idea of "optimal" taxation is just that: an idea. In practice, the argument for a pollution tax is that, no matter what tax level is selected, it is a less costly approach for achieving emissions reductions than emissions regulations. Calculating the "optimal" carbon tax that perfectly internalises all of the externalities associated with energy fuel cycles is difficult and requires information about the marginal costs and benefits of

[27] We have chosen not to focus on subsidies in this section, for two reasons. First, subsidies to reduce pollution create mixed incentives in the sense that, while they may lead to less pollution per unit of output, they also encourage higher production in order to receive the subsidy (Baumol & Oates, 1988). Subsidies also create a fiscal burden that most governments are unwilling to bear.

reducing pollution. A number of studies (Hohmeyer, 1988, Pearce et al. 1992, ExternE 1995 and Rowe et al. 1996) have estimated the marginal benefits of reducing some forms of pollution in some developed countries. However, none of these studies have arrived at a defensible estimate of the value of the damages caused by GHG emissions. Therefore, most carbon tax studies (Richels & Edmonds, 1994; Jorgenson & Wilcoxen 1992; Hamilton & Cameron, 1994) have focused on the value of the carbon tax required to achieve specific reductions in atmospheric CO_2 and the impact of this tax on GNP/GDP.

Externalities can be internalised through taxes on energy, on primary fuels, or on pollutants themselves, through charges on pollutants, and by externality “adders” on energy which reflect the marginal value of pollution damage. From now on, we will refer to all of these instruments simply as taxes, for the sake of simplicity. Taxes on energy, primary fuels and pollutants are closely related. This is because the relationship between the three are determined by the technology of the firm and the level of inputs, including primary fuels and also other inputs, some of which may go into pollution abatement. For example, a direct carbon tax on an electrical utility is a tax on the carbon content in the energy output of the firm. The same carbon tax can be expressed in terms of the carbon content of the output ($/tonne C/yr), or it could be expressed in equivalent terms with respect to energy output ($/kWh), or it could be expressed in terms of the indirect carbon content of the primary fuel ($/tonne coal/yr).

There are some reasons for preferring direct carbon taxes, as opposed to indirect carbon taxes on energy and primary fuel. This is because taxes on energy and primary fuels allow firms to substitute inputs which can lead, potentially, to increases in CO_2. For example, a tax on oil would reduce the use of oil, but much of the reduction could be negated as energy users switch over to coal and natural gas, which also emit carbon dioxide. Also energy efficiency standards and other regulatory alternatives, which do not raise the price of emitting carbon, do not discourage energy use nor do they provide electricity generators with incentives to move away from carbon-intensive fuels. A carbon tax, on the other hand, would give all users of fossil fuels the same incentive to reduce carbon emissions.

Carbon taxes (in the broadest sense) can also be defined so as to account for the effects of GHGs on climate. To be most effective in limiting GHGs, taxes on different fuels or energy should reflect the relative long-term global warming potential of the various GHGs embodied in those goods. Thus, a simple BTU tax on coal, for example, would not be as effective as a tax that was weighted sum of the GHG warming potential of each GHG that was emitted from the use of coal as a fuel in a specific use. This is because the BTU tax does not reflect the externalities from the burning of coal as well as does the weighted tax.

Finally, the use of carbon taxes has important fiscal implications. The less responsive energy consumption is to increases in the price of energy, the larger the tax required to achieve a reduction in both energy consumption and GHG emissions. Since energy consumption is relatively inelastic, most pollution taxes have the potential to raise substantial government revenues. In theory, the revenues from a carbon tax need to be rebated in lump sum form to ensure that energy consumers have the same income after the tax as before it. In fact, governments often use tax revenues from pollution taxes to support all forms of government spending. This raises the issue of what to do with the revenues from a carbon tax, whether to rebate them to consumers, use them to reduce government deficits, or to recycle the revenues into environmental programs, possibly creating a “double dividend” (Oates, 1995 and Goulder, 1995).

1.3 Cost-based market mechanisms

As we have observed, both CAC and tax systems have a number of shortcomings in limiting emissions. In the US, these problems have combined to focus attention on the use of mixed regulatory mechanisms that use market mechanisms to increase the flexibility of firms in meeting regulations and, thereby, reducing the costs of regulation. Under the topic of cost-based market mechanisms, we group a wide range of "mixed" options which combine the CAC approach with various market mechanisms to achieve a least cost regulatory solution. Instruments that are included in this category can be referred to in very broad terms under the single heading of "emissions trading". However, there are number of different, specific instruments – all with slight variations – that involve emissions trading. These include:

- tradable emission instruments:
  - allowances.
  - permits.
  - quotas.
- emissions (CO_2) offsets.
- joint implementation.

All of these instruments share in common the following characteristics:

1. A regulation that fixes pollution (emissions) levels for some group of sources.
2. Provisions that allow the regulated sources to pay other sources, regulated and unregulated, to reduce their emissions, if the other sources can do so less expensively than the regulated source seeking the reduction.

1.3.1 Tradable emission instruments

The theory underlying emissions trading instruments is well-documented in standard text books on environmental economics (Tietenberg, 1996). Emissions trading allows regulated emissions sources facing different abatement costs to shift from their own emissions abatement marginal cost curve to an aggregate emissions abatement supply curve.

The mechanics of each type of emissions trading mechanism differs somewhat. Perhaps the easiest to explain in practical terms is an emissions permit trading system. Under this type of system, a government must start by deciding how many tons of a particular gas may be emitted each year. It then divides this quantity up into a number of tradable emissions entitlements - measured, perhaps, in CO_2-equivalent tons - and allocates them to individual firms. The method of the initial allocation is flexible and does not effect the final trading outcome, although it does affect the distribution of wealth. The two most popular methods for initially allocating permits are: 1) an auction, 2) a quota system, based on historic emissions ("grand fathering"), or projected (base line) emissions, or some other principle. This initial allocation of permits gives each firm a quota of greenhouse gases that it can emit over a specified interval of time. Then the market takes over. Sources basically have three options:

1. Hold the allowances and emit that level of GHGs.
2. Sell some of their allowances to other firms, which requires the seller to reduce their own pollution and allows the buyer to increase their emissions accordingly.
3. Buy additional allowances in order to increase GHG emissions, while the seller reduces their emissions by a like amount.

In addition, individual buyers, such as NGOs, can effectively lower emissions, as a whole, by purchasing allowances and retiring them. If these allowances are exchanged in a competitive market, the marginal emissions reductions cost will be the same across all firms and the total emissions reduction is achieved at least-cost. To do this a market must be created, to bring buyers and sellers together and facilitate low cost exchanges.

1.3.2 Emissions offsets

Emissions trading works best when the sources of regulated emissions are easily identified and regulated, and when the main options for reducing emissions can be controlled by the sources (firms or individuals). In the case of some pollutants, like SO_2, both of these conditions are satisfied because the major sources are power plants, and the major options for controlling emissions involve either direct investments in new generating or scrubbing technologies to reduce emissions, or else reducing electricity consumption through conservation programs. In the case of CO_2 and other GHGs, however, sources are more diffuse and the opportunities for reducing GHGs are much more numerous and not under the direct control of the sources. The primary reason for this is, of course, that there is no cost-effective technology for eliminating CO_2 from stack gasses, as in the case of SO_2, although measures like fuel switching, re-powering, and conservation programs remain viable options for reducing GHGs.

One method for increasing the effectiveness of emissions trading in the GHG context is through the use of “emissions offsets”. This systems allows both regulated and unregulated entities to trade emissions reductions with regulated entities. For example, it is quite possible that all firms on which emissions limits are imposed may have very high control costs, relative to some other options, for example planting trees to sequester carbon. The offset system would allow either the utility itself (in this example) or another firm, NGO, or individual that was not regulated to “create” an emission offset through a tree planting program. This requires that there be an “approved” methodology for calculating the size of the offsets from carbon sequestration and other approved activities (offsets from a baseline scenario level of emissions) for accreditation purposes; it requires an instrument for exchanging these credits that does not allow both parties to inflate the quantity of the offsets; and a method for monitoring and verifying the offsets is necessary to ensure compliance.

Once this system was established, the regulated sources could essentially “go shopping” for offsets and negotiate, directly, with second parties (the offset sellers) or, indirectly, through a third party (perhaps a clearing house or trading exchange) to obtain offsets in exchange for compensation. Regulated sources have an incentive to buy and unregulated sources have an incentive to sell offsets, as long as the marginal cost of reducing emissions to the buyers of the offset is higher than the marginal cost of the seller to create the offset.

Thus, offset systems help to reduce some of the inherent weaknesses of command control systems when dealing with GHGs. On the other hand, offset systems are more costly than trading of emissions permits, allowances, quotas, etc. This is because offset systems require the intervention of third parties to calculate and verify offsets, to act as a clearing house or trade exchange, to ensure that buyers and sellers have access to the same information, and to remove other incentives to misrepresent offset quantities. Another important limitation of offset systems is that the emissions reductions associated with many activities, such as energy efficiency, energy conservation and carbon sequestration projects are extremely difficult to calculate and verify in the same way as direct source GHG emissions. As a result, potential buyers of these offsets may find them less attractive than offsets associated with direct source GHG emissions reductions, and may require a premium to buy them, unless there are mechanisms in place to reduce the risks associated with verification and accreditation. Both of these problems apply to Joint Implementation, which is taken up in the next section. Whether these additional costs and accounting difficulties are "worth" the additional flexibility afforded by offset programs must be determined in each and every case.

1.3.3 Joint implementation

Joint implementation (JI) is a mechanism which, if implemented through the Climate Convention, would allow nations to meet their obligations to reduce net GHG emissions by trading emissions offsets with other countries. The use of this instrument is based on the expectation that GHG emissions reductions / offset costs vary widely between countries. In reality, JI just extends the concept and practice of an offset program to the international arena. It allows countries with high emissions reductions costs to finance and implement mitigation measures in countries with lower emission reductions costs. The emissions reductions achieved in the "host" country would then be credited to the "donor" country and would count towards the achievement of their FCCC-mandated GHG emissions reduction. The mechanisms required to implement JI and offset systems are identical:

- a method for calculating and accrediting offset quantities (from baseline scenario level emissions) over a wide range of options.
- an instrument that ensures that buyers and sellers do not overstate the quantity of the offsets they negotiate.
- a system to verify the offsets from the options, *and ensure compliance*, once they have been implemented.

Developing countries have raised concerns about the impact of JI on their own economic and social development. These concerns include:

- JI will replace existing aid and development programs.
- it allows developing countries to escape their commitments by using the "cheap" resources of developing countries.
- many of the projects that might be proposed could involve "dumping" of older energy technologies and GHG reduction options in developing countries.
- some options, particularly large scale biomass plantations, may not be consistent with the social and economic development plans and aspirations of developing countries.

Some resistance to JI on the part of developing countries may have been abated by JI projects that have been voluntarily undertaken under the FCCC, through AIJ programs (actions jointly implemented) in the US and several European nations. However, much work remains to be done to break down these barriers, even after the FCCC institutes formal JI.

1.4 Issues in policy implementation

Command and control policies are fairly common and regulatory framework exists in all countries. However, experience with this approach indicates that costs increase sharply as the standards become stricter. For example, pollution control costs in 1980s reached 1.25% to 1.65% of 1980's GNP in several countries, that took stricter environmental measures (Pearce & Turner, 1990). On the other hand, the approach left little incentive for innovation in the pollution control for the polluters as standards were based on a given best or practically achievable technology. Market approaches (also referred as economic instruments) on the other hand offer cost effectiveness, continuous incentive to reduce emissions, flexibility to polluters as well as regulators and opportunities for resource transfer. Several developed countries therefore adopted market approaches to supplement the regulatory approach. However, several issues need to be addressed before a market approach through introduction of economic instruments can be taken.

Distributional impacts: The studies on the distributional impacts of carbon taxes, emission taxes, gasoline taxes, and energy taxes indicate that these are usually regressive (IPCC, 1996b). Distributional impacts of emission permit system have not been studied in detail. The impacts are expected to be same as in case of taxes, if permits are sold. Allocation criteria would determine the impacts in the event of permit allocation.

Distributional impacts is a political issue and requires a compensation mechanism aimed at adversely affected groups (OECD, 1996). This requires identification of vulnerable sectors and populations and an estimate of magnitude of the impact. Compensation can be provided through reduction in other taxes on the target group or through direct transfer payments. In the case of Sweden, the government put a cap on carbon tax payments to ease the burden on certain industries for example. Compensation programmes may however distort the structure of the sectors, for example exemption from taxation of certain types of industries may result in growth of that type of industry, an unintended result. Also, protection to one sector would imply higher burden on the other sectors. Therefore, great care needs to be exercised in formulating compensation policies. As mentioned earlier, revenues from the taxation can also be used to improve environmental quality or tax distortions elsewhere in the economy.

Competitiveness and other side effects: Since economic instruments involve changes in costs of production, unpredictable side effects are possible. These depend on the elasticity of demand for the product and income distribution effects. For example, application of a carbon tax at a national or industry level may make it un-competitive. It may also effect the investment pattern and shift investments to other places. Thus, in case of industries, shifts in geographic location may occur depending on tax rates and old plants may face closure. However, economic instruments motivate firms to improve their resource use efficiency and hence competitiveness may not be an issue. Factors such as availability of capital, skilled labour etc. are more important than such taxes in deciding an industrial location. Since the costs related to environmental management constitute only a small proportion of production costs, these are unlikely to be a major factor determining industrial location (CEPA).

Some empirical studies also confirm that link between competitiveness and environmental policies is generally weak due to low share of environmental costs in the total costs. Competitiveness is nevertheless perceived as a major issue by the industries and it has yet to be studied in the context of GHG limiting policies. In case of energy intensive industries, effect on competitiveness can not be ruled out.

Tax level and tax neutrality: Tax neutrality may be demanded by the affected parties. This may require that carbon tax is introduced as a part of broader ecological tax reform to ensure that imposition of carbon tax results in tax deductions in other areas and thus maintain revenue neutrality for the business (Anon, 1997). This is a political issue. Unfortunately, business sector is likely to have little trust on governments on this issue. Introduction of energy related taxes has been difficult in many countries due to this lack of trust. While imposing environmental taxes, review of existing taxes is needed with a view to reduce taxes on energies that are less harmful to environment.

Developed market requirement: By definition market based instruments require a well developed market, which may be a constraint in several countries, specially in developing countries. Incentives and pricing mechanisms can operate properly only in a well developed market.

The economic instruments can be efficient provided marked are well developed. This means that markets are perfectly competitive and firms have perfect information. But this is not always the case. For example, “in Britain a rise of 400% in sewerage charges failed to change firms’ behaviour, even though it was shown that small investments in pollution control would pay back in under a year (Beder, 1997)”. The information dissemination was not perfect. Thus, in a situation like this, a regulation requiring installation of pollution control equipment would have been more efficient

Administrative and institutional issues: Administrative and transaction costs can be expected to vary and depend on the type of economic instrument, system design and institutional mechanism for its implementation. An efficient system using existing institutional mechanism, for example using existing tax collection machinery to collect carbon taxes, is likely to result in low costs. On the other hand, switch to EIs from the CAC system may also find resistance from players in the existing system; industries as well as bureaucracy on account of threat to their interests. Weak legal and institutional framework may be a serious problem in developing countries (O’Connor, 1996). For example, some EIs may require one or more of the following conditions for successful implementation - assignment and enforcement of property rights, market clearing mechanisms, efficient monitoring system, tax administration and financial markets etc.

Choice of instruments and problems in implementation: This is an important component. A wrong choice of instrument may make the monitoring very expensive, for example, if monitoring involves a large number of small but dispersed pollution sources. Since combination of instruments (including “hybrid”, i.e. a combination of CAC and EI) is one of the alternative, it may be preferable in many circumstances to attain objectives of efficiency, effectiveness and equity (O’Connor, 1996). Thus a tax on fuel in combination with emission standard for automobiles may be an efficient and effective option than merely a tax or an emission standard. On the other hand, a complex instrument may also be difficult to implement. Powerful interest groups, weak legal and institutional framework may also hamper implementation in some cases, as mentioned in the previous paragraph.

Transparency in policy making: Transparency through disclosure of information, public participation (for example through hearings and debate) is needed for an effective and responsive policy making. This helps public acceptance and support to the policy and minimises the chances of sabotage by vested interests. Similarly, informing tax payers of the purpose for which revenue will be used also adds to transparency and greater public support although it may reduce governmental flexibility (O’Connor, 1996).

It may also be necessary to ensure that environmental policies are not in conflict with other policies, for example, a subsidy (or tax exemption) to export oriented units or an environmental tax on a product import. While the former is not consistent with the broader international agenda to reduce emissions, the latter may be inconsistent with the international agreement on taxation on product imports in forums such as WTO.

Market power and transaction costs: There is a possibility that some firms may influence the tradable permit price as a major buyer or seller of the permits, and exercise monopoly power in the product markets through permits. The pollution control costs in these cases may not be optimum. Permit system design, that involves initial allocation, life of the permits etc. may have to address these issues. Similarly, in a non-competitive market, introduction of emissions tax may result in welfare loss due to reduced output, which may be more than the gains due to reduced emissions.

Transaction costs in a tradable permit system is an important component in design of the system. These costs are incurred related to search and information, bargaining and decision making, and monitoring and enforcement. The first two costs may not be significant in a fully developed market. But if market does not develop, innovative approaches may be needed to reduce these costs. The costs of monitoring and enforcement are part of the overall costs of the system but not borne by trading parties. Hence, these are not directly relevant for the trade.

Problem of free riders and leakages: GHG emissions are a global issue and abatement is expected to benefit all the countries. Thus, even if abatement is not done by one country, it stands to benefit from the abatement efforts by other countries. On the other hand, abatement action taken in a country may result in increased emissions from other countries, causing emission leakage, for example, through a shift in the production base of carbon intensive products from a country with strict emissions standards to other countries. Both these issues can be tackled co-operatively by all countries, as action by an individual country may not be sufficient. Thus, an international mechanism is required to address these issues.

Tax harmonisation: Discussions on this issue revolve around the question - "Should the taxes be domestic, international or harmonised domestic taxes?"

In case of an international carbon tax, the marginal cost of reducing CO_2 would tend to be equal to the tax rate across the countries. Theoretically, this provides international cost efficiency in reduction of emissions but allocation of tax revenues is a complicated issue in this case. For a country, a domestic carbon tax is an effective method to reduce emissions to a target level. However, the concerns related to competitiveness, free rider problems, emissions leakages etc. have led to the debate that a harmonised global tax system, that requires each country to impose the same tax rate (for example, a carbon tax), should be considered. It has been suggested that this can be accomplished either by an international agency or through agreement by all the countries to levy domestic taxes accordingly. But such agreements are possible only if there is an agreement on reallocating the revenue collected from the taxes. Further, "due to differences in resource endowments, consumption patterns, climate change impacts, and other factors, this tax rate may not be the most appropriate from a national perspective, thus side-payments are likely to be required to secure broad participation (IPCC, 1996b)". The requirement that countries levy a uniform tax is a difficult task considering different tax systems across countries. Some countries may be currently levying the tax in different form, while the others may have a negative tax (subsidy). For an equitable system to be in place, this will result in transfer of resources from "polluters" to "non-polluters", similar to what one can expect in an international permit trading system.

1.5 Policy instruments and developing countries

Command and control V/S economic instruments: It is clear from the discussions that CAC and EIs are complementary rather than a substitute for environmental protection during various stages of development. Whereas, CACs are more productive during initial stages, EIs become more relevant when costs of CAC become high and conditions for introduction of EIs are ripe. Taylor (1993) even argues that economic and social dislocation, unemployment, and increased environmental degradation may result if developing countries open up to the rigors of a pricing system. However, with wave of liberalisation of economies all over, enough maturity and experience to deal with such changes can be expected. Thus, liberalised economies at an advanced stage of development within developing countries may find that conditions are suitable for introduction of EIs.

Developing countries and economic instruments:

On account of various pre-requisites, one needs to examine preparedness of a developing country before EIs can be introduced. Typically, developing countries may have some of the following barriers to successful operation of EIs:

Availability of technology: Lack of availability of technologies to reduce emissions and inadequate R & D infrastructure to develop technologies are problems that most of the developing countries face. This is compounded by restrictive policies of developed country organisations with advanced technologies due to their reluctance to transfer the technologies. In some cases, the reluctance is due to protective policies of some developing countries, that prevent ownership of companies by outsiders. On the other hand, organisations with advanced technologies may be unwilling to transfer state-of-art technologies without ownership rights for fear of competition. Restrictive policies on the part of governments or at the firm level both may affect such transfers.

Monitoring and enforcement: Monitoring requires a well designed system supported by proper infrastructure including necessary equipment and trained personnel. This can sometimes be a constraint, resulting in a poor monitoring system. In turn, it may be difficult to check the evasion.

Trained personnel are also needed to design and administer a regulatory mechanism based on technical and performance standards. Lack of availability of trained personnel can make the enforcement difficult.

Political unfeasibility: In low income developing countries, it may be politically unfeasible to levy a regressive tax before a compensation mechanism for vulnerable section has been put in place and people convinced. Even in developed countries such as North America, implementation of carbon charges is considered difficult due to "anti tax" mood of the public (Anon, 1997). Identification of vulnerable sections, suitable compensation mechanisms and public awareness all pose significant challenges.

Distributional impacts: These are of utmost importance in the case of developing countries. Who ultimately pays the tax and how much, what is to be done with the revenue from taxes are important issues before a mechanism can be accepted. For example, regressivity of a carbon tax may be greater in developing countries. where the poor rely for cooking and heating on coal while the wealthy prefer gas and oil (O'Connor, 1996).

1.6 Assessment of policy instruments

1.6.1 Command and control

Standards have been extensively used in different countries to control the pollution. Evaluation studies on performance of standards indicate its success in driving polluters to initiate environmental pollution control measures in the initial stages. However, it required detailed measures such as emission standards for large number emission points, evaluation of available technologies, area specific requirements etc. Substantial reduction in pollution was obtained through CC: for example through Clean Air Act Regulations in the US, in the form of 58% reduction in total annual particulate emissions and 25% in sulphur oxides emissions by 1981 (Tietenberg, 1990). However, the costs of this system became prohibitive with increased requirements for control and this resulted in acceptance of economic incentive policy instruments (market instruments). The command and control approach also may lack incentives for technological improvements beyond required standards.

Some experts (Taylor, 1993) argue that command and control methods employing quantitative control are more cost-effective in initial stages of environmental protection, the stage in which developing countries may currently find themselves. It is only at a later stage of development when marginal costs of control exceeds benefits, that market policy may have a role to play. Even within OECD, there is yet no tendency towards replacing the basic command-and-control approach with a purely economic one. "Economic instruments are complements mostly and substitutes only sometimes for other types of approaches" (OECD, 1994). Command and control approach can therefore play an important part in controlling emissions, especially in developing countries.

1.6.2 Economic instruments

Emission charges / taxes: Theoretically emission charges are designed with twin objectives in mind; to achieve a desired ambient standard at the lowest possible cost (i.e. cost effectiveness), and to force the polluter to compensate for damages caused by pollution (Tietenberg, 1990). The cost here consists of control as well as damage costs.

In practice, schemes often do not fit in this framework and the charges are designed to raise revenues to fund environmental schemes besides speeding up achievement of standards set by regulators. For example, water taxes in the FRG and Italy, waste taxes in Belgium and Denmark, and aircraft noise tax in the UK had incentive purposes (Vernon, 1990). An OECD study examined all these charges and concluded that the noise and waste taxes were too low to make any impact and the Italian tax was more in the nature of a penalty. The FRG water tax was linked to emission standards and offered incentives for pollution reduction through tax discounts. It did result in action by polluters to accelerate the process of pollution reduction to avail the 50% discount on taxes (which was offered as incentive for emissions reduction) despite the fact that the tax was merely about 2% of pollution treatment costs (OECD, 1989). The OECD review of incentive product taxes indicates that the tax (on non-returnable containers, and on batteries based on their nickel and cadmium content in Sweden) did not have significant effects as the rates were too low. However, incentive taxes in Finland on non-returnable beverage containers and plastic bags in Italy (five times the cost) are significant and can be expected to have sufficient impact.

Thus taxes have not been used as the theory would suggest for pollution control, and therefore results achieved are predictable. They were able to achieve the limited objectives in line with efforts made and had only marginal effects in cases where regulating authorities put only half-hearted efforts on pollution control and raising revenue.

Market creation: There is limited experience on tradable permit systems. The US programme of emissions trading (under the Clean Air act 1955 and amendments 1970, and 1977) did result in substantial cost reductions in meeting the requirements of the Clean Air Act. Estimated savings were over $ 10 billions (Tietenberg, 1990) besides recurring savings in operating costs. This could be achieved owing to flexibility imparted by the programme to meet the regulatory requirements. But it did not achieve the magnitude of savings that a true market mechanism could have achieved. The market for ERCs did not develop fully due to several reasons such as uncertainties about baselines for allocating ERCs, possible errors in estimates of emissions, future needs of ERCs to meet changing regulations, high transaction and information costs (identification of buyer and seller, bureaucratic demands for approval of trades etc. (Vernon, 1990)). Control costs did come down for sulphur scrubbing. Though air quality improved, it is difficult to identify how much of it was due to the emissions trading scheme. The programme was mainly expected to support the existing regulatory approach. Vernon concludes that cost effectiveness of the programme is not very clear as most of the schemes had a mix of direct regulation and market mechanism approaches.

Experience with lead trading in the US has been of a programme closest to the ideal free market (Hahn, 1989). The programme allowed refiners flexibility in reduction of lead in gasoline. The programme had essential features such as certainty (fixed life from the outset based on agreement), banking, non-discriminatory requirements between new and old sources and no grand-fathering, thus making it closer to the theory. EPA estimated savings of US $ 228 millions (Hahn, 1989). It can be termed as a successful programme. Trading activity was high in the market.

Experience with the application of EIs was limited even in OECD countries until a decade ago. An OECD review in 1989 indicated that of the 100 EIs in use in 15 member countries, very few actually had any incentive effect and policies were still dominated by command-and-control. However, policies after 1989 are slowly relying more on EIs (O'Connor, 1996).

Theoretically, the evaluation of economic instruments should be done on the various grounds of benefits claimed from them. However, in practice, most of the economic instruments applied differed from the criteria laid down in theory. The schemes were a mix of traditional regulations and standards approaches and the economic instruments approach. Therefore, the results of application are also a mix of success and disappointments as they do not necessarily achieve optimal solutions.

EIs have been in use in Central and Eastern Europe (CEE, the economies in transition) also but have due to current economic hardships, had difficulties in getting public acceptance. The political and social support for environmental protection have declined in recent years (Klarer, 1994). There is also a lack of experience and expertise in CEE with designing and implementing market-based environmental protection policies and mechanisms.

EIs such as emission charges and product charges have also been in use in developing countries within an overall regulatory framework. Newly industrialising economies (NIEs) have been taking a lead with Singapore even having a tradable permit scheme. Voluntary agreements and other suasive instruments are also being experimented in some NIEs (O'Connor, 1996).

1.7 Criteria for selection of policy instruments

Given a number of issues surrounding various types of policy instruments, choice of appropriate instrument is very important. It may not be possible for a single instrument to address various issues while inducing emissions reduction. A combination of policies may have to be adopted, where the choice of instruments are based on importance of issues and on policy planners assessment of the extent to which the instruments can address these issues. Developed countries, who have been mandated to reduce emissions by the Kyoto agreement would look for measures that will have least effect on their economic growth. Since economic instruments offer several advantages including cost effectiveness, it may be natural to introduce them in conjunction with CAC measures. On the other hand, although developing countries have currently no obligation to reduce emissions, they are mandated by FCCC to take such appropriate measures to reduce emissions that are consistent with their development priorities. Therefore, they need to look for instruments that meet their development requirements besides reducing emissions. One of the major objective should be to reduce emission intensity of the output without effecting the growth. For example, efficient use of energy and other resources can put developing countries on a lower energy intensive path, thereby reducing emission intensity of the development.

Within developing countries, there is wide disparity in terms of current emissions and economic development. On one end of the spectrum are fairly advanced economies that are close to developed countries, while on the other yet very poor countries. Further, baseline future emissions in some cases may indicate highly emission intensive output growth resulting in high growth of their emissions, while in the others growth may be moderate and emissions well below average emissions. Some poor developing countries are also dependent on bio-fuels to meet a substantial part of their energy requirements, rendering use of some of the instruments meaningless. There is yet another group of developing countries that export energy and hence find any taxation on energy affecting their economic growth. Since emissions are due to consumption of energy, the action for emission reductions therefore may have to be left to energy importing countries.

Developing countries that are close to developed economies in terms of development and emissions may have options to introduce economic instruments without significant adverse impacts on their economies. For other developing countries, the options may be limited in the short term. In the short term, there focus may be on efficient use of energy and other resources, which may help them reducing emissions besides fitting in their development priorities. Therefore policies that would encourage efficient use of energy and other resources, fuel switch to less carbon intensive fuels (wherever desirable), reduction in energy intensity of the output etc. may be desirable. It is important that barriers to this are identified and instruments selected accordingly.

Technical Assumptions

1 Technical input assumptions

1.1 Introduction

The following section reports the technical assumptions that countries have been recommended to use in the project Economics of GHG Limitations.

1.2 Fuel prices

It is recommended to use a common fuel price scenario to be supplemented with specific nationally developed scenarios.

The common fuel price scenario that has been suggested to use is based on the energy scenarios developed by the World Energy Council (WEC, 1992) for the study "Energy for Tomorrow's World". A high- and a low fuel price development scenario is developed. The high fuel price case can be interpreted as applying to a case where the demand for fossil fuels is relatively high because major global climate change mitigation policies are not implemented. The low fuel price case, on the contrary, applies to a case, where the fossil fuel demand is low, because a significant global climate change mitigation policy is implemented.

Table 19 Common fuel price scenarios (prices in US$ 1990).

	1995	2005/10	2030/40
High case			
Crude oil price ($/bbl)	18	24	28
International coal ($/tce)	50	53	55
Low case			
Crude oil price ($/bbl)	18	21	23
International coal ($/bbl)	50	49	48

Note: Coal prices are for high grade coal (29 GJ/tonne).

No global natural gas prices are suggested. It is assumed that the oil price will continue to act as the leading price and therefore gas prices will more or less follow trends in oil price, depending on the developments in gas supply and demand as described in the WEC scenarios (WEC, 1992).

It is recognised that there can be many alternative views of fuel-price development over such a long period as the one we are dealing with. The behaviour of the oil price over the past 20 years clearly illustrates this. However, in the interests of comparability it is valuable to include a case where studies use a uniform fuel price scenario.

1.3 Prices of oil products

Prices of oil products may be calculated from the above crude oil prices using the set of distillate ratios shown below in Table 20. The ratios are the result of a study (Caminus, 1993) of spot prices and distillate prices since 1980, comprising the Rotterdam, Singapore and US markets, and four distillates: fuel oil, gasoil, premium gasoline and jet kerosene. The distillate prices are specifically related to Arab-Light-34 crude oil.

Table 20 Distillate to Arab-Light-34 ratios.

Distillate	Rotterdam	Singapore	US market
Fuel oil	0.9	0.8	1.0
Gasoil	1.3	1.3	1.3
Premium gasoline	1.5	1.6	1.6
Jet kerosene	1.4	1.4	1.4

Sources: 1980-1985 “Spot Oil, Netback and Petroleum Futures”. EIU (1986). 1986-1992 “OPEC Bulletin”.

Fuel oils are 1% sulphur for the US and Rotterdam markets and 0.3% sulphur for the Singapore market.

US gasoline prices are for premium unleaded gasoline. The others are for premium gasoline.

In the Singapore market from October 1989 0.15 g/l gasoline replaced 0.4 g/l gasoline. The Singapore gasoline ratio is based on 0.15 g/l prices only.

1.4 Energy units

The international energy unit, the joule, with appropriate prefixes, should be used as far as possible. Conversion factors are shown below.

Conversion factors for the most commonly used units are shown below. National teams are requested to supply information on energy content of local fuels, preferably in terms of net heating value. This information should be included in the full country reports.

1 kilocalorie (kcal)	=	4.1868 kj (kilojoule)
1 British Thermal Unit (Btu)	=	1.055 kj
1 quad	=	10^{15} Btu = 1.055 E = 10^{10} therms
1 terawatt-hour (Twh)	=	3.5 Pj
1 tonne oil equivalent (toe)	=	10.0 Gcal = 41.9 GJ NHV
1 barrel oil	=	0.136 tonnes
1000 m^3 natural gas equivalent	=	8.6 Gcal = 36 GJ = 0.86 toe NHV
1 tonne coal equivalent	=	7.0 Gcal = 29.3 GJ = 0.70 toe NHV

1.5 GHG emission data

A standard for emission inventories has been defined by OECD/IPCC (IPCC, 1995b). Relevant GHG sources are listed below:

- CO_2 from fossil fuel combustion
- CO_2 from decrease of biomass stock
- CO_2 from cement and lime
- CH_4 from combustion
- CH_4 from oil and gas
- CH_4 from coal mining
- CH_4 from enteric fermentation
- CH_4 from animal waste
- CH_4 from landfill/sewage treatment
- CH_4 from rice production
- CH_4 from forest and savannah burning
- N_2O from combustion
- N_2O from agricultural soils

GHG emissions should primarily be reported in mass units of CO_2, CH_4 and N_2O. This will allow subsequent conversion into other units. GHG emissions can also be converted into CO_2 equivalents. IPCC has defined the following standard Global Warming Potentials of the gasses (IPCC, 1995a, b).

Table 21 Global Warming Potentials (100 years time horizon).

Species	Chemical formula	100 years GWP
Methane	CH_4	21
Nitrous oxide	N_2O	310
Perflouromethane	CF_4	6,500
Perflouroethane	C_2F_6	9,200
Perflourobutane	C_4F_{10}	7,000
Sulphur hexaflouride	SF_6	23,900
HFC-23	CHF_3	11,700
HFC-32	CH_2F_2	650
HFC-43-10	$C_5H_2F_{10}$	1,300
HFC-125	C_2HF_5	2,800
HFC-134a	CH_2FCF_3	1,300
HFC-143a	$C_2H_3F_3$	3,800
HFC-152a	$C_2H_4F_2$	140
HFC-227ea	C_3HF_7	2,900
HFC-236fa	$C_3H_2F_6$	6,300
HFC-245ca	$C_3H_3F_5$	560

1.6 Emission factors

If more appropriate specific national data are not available, national teams may use the following IPCC default CO_2 emissions factors shown in Table 22. Note that if the standing stock of biomass is in balance, the emission factor for CO_2 from biomass combustion should be zero due to recirculation.

Table 22 Default CO_2 emission factors.

Fuel type	Emission factor (kg CO_2/GJ)
Coal	94.6
Lignite	95.7
Sub-bituminous coal	101.2
Peat	106.0
Coke	108.2
Gasoline	69.3
Kerosene	71.3
Jet fuel	73.3
Diesel oil	74.1
Fuel oil	77.4
LPG	63.1
Naphtha	73.3
Bitumen	80.7
Petroleum coke	100.5
Natural gas	56.1

2 Reporting forms

1 Fuel price assumptions

Country: X

Table 1.1 basic assumptions Reporting year	Base year	2005/10	2020/30
International (CIF) price of crude oil, US$/bbl			
International (CIF) price of coal, US$/ton			
Local price of fueloil, local currency/GJ			
Local price of gasoil/diesel, local currency/GJ			
Local price of natural gas, local currency/GJ			
Local price of gasoline, local currency/GJ			
Local price of coal, local currency/GJ			
Local price of fuel1, local currency/GJ			
Local price of fuel2, local currency/GJ			

Table 1.2 sensitivity case (s) Reporting year	Base year	2005/10	2020/30
International (CIF) price of crude oil, US$/bbl			
International (CIF) price of coal, US$/ton			
Local price of fueloil, local currency/GJ			
Local price of gasoil/diesel, local currency/GJ			
Local price of natural gas, local currency/GJ			
Local price of gasoline, local currency/GJ			
Local price of coal, local currency/GJ			
Local price of fuel1, local currency/GJ			
Local price of fuel2, local currency/GJ			

2 Key national indicators

Country: X

Table 2.1 GDP	Reporting year	Base year	2005/10	2020/30
Total (fixed local prices)				
Primary	Agriculture			
	Forestry			
	Mining			
Secondary	Industry			
	Construction			
	Transport			
Tertiary	Services			

Table 2.2 National indicators Reporting year	Base year	2005/10	2020/30
Population (millions)			
Urban population (%)			
Land cover (1000 km^2)			
Forest land (%) in baseline			
Agricultural land (%) in baseline			

3 Macroeconomic statistics

Country: X

Table 3.1 GDP	Reporting year	Base year
Consumption	Households	
	Government	
Investment		
Foreign trade	Exports	
	Imports	

Table 3.2 Labour force (thousands)	Reporting year	Base year
Primary	Agriculture	
	Forestry	
	Mining	
Secondary	Industry	
	Construction	
	Transport	
Tertiary	Services	
Unemployment		

Table 3.3 Exchange rate	
Exchange rate of to (name of local currency)	1 US$ =
1990	
1991	
1992	
1993	
1994	
1995	
1996	

Table 3.4 Inflation rate	%
1990	
1991	
1992	
1993	
1994	
1995	
1996	

4 Energy sector (Baseline scenario)

Country: X

Table 4.1 (a) Total energy requirement (PJ) Reporting year	Base year	2005/10	2020/30
Reference scenario total			
Oil products			
Natural gas			
Coal products			
Hydropower			
Nuclear			
Fuelwood			
Other renewables 1			
Other renewables 2			

Table 4.2 (a) Total final energy by sector (PJ) Reporting year	Base year	2005/10	2020/30
Reference scenario total			
Industry			
Agriculture			
Service			
Residential			
Transport			

Table 4.3 (a) Electricity supply (GWh) Reporting year	Base year	2005/10	2020/30
Reference scenario total			
Oil			
Natural gas			
Coal			
Hydro			
Nuclear			
Renewables (incl. geothermal)			
Net import			

4 Energy sector (Mitigation scenario)

Country: X

Table 4.1 (a) Total energy requirement (PJ) Reporting year	Base year	2005/10	2020/30
Mitigation scenario total			
Oil products			
Natural gas			
Coal products			
Hydropower			
Nuclear			
Fuelwood			
Other renewables 1			
Other renewables 2			

Table 4.2 (a) Total final energy by sector (PJ) Reporting year	Base year	2005/10	2020/30
Mitigation scenario total			
Industry			
Agriculture			
Service			
Residential			
Transport			

Table 4.3 (a) Electricity supply (GWh) Reporting year	Base year	2005/10	2020/30
Mitigation scenario total			
Oil			
Natural gas			
Coal			
Hydro			
Nuclear			
Renewables (incl. geothermal)			
Net import			

5 GHG emissions (million tonnes)

Country: X

Table 5.1 (a) Baseline scenario emissions Reporting year	Base year	2005/10	2020/30
Baseline scenario total CO_2			
CO_2 from fossil fuels			
CO_2 from decrease of biomass stock			
CO_2 from cement & lime			
Baseline scenario total CH_4			
CH_4 from combustion			
CH_4 from oil and gas sector			
CH_4 from coal mining			
CH_4 from enteric fermentation			
CH_4 from landfills/sewage treatment			
CH_4 from rice production			
CH_4 from forest and savannah burning			
Baseline scenario total N_2O			
N_2O from combustion			
N_2O from agricultural soils			

Table 5.1 (b) Mitigation scenario emissions Reporting year	Base year	2005/10	2020/30
Mitigation scenario total CO_2			
CO_2 from fossil fuels			
CO_2 from decrease of biomass stock			
CO_2 from cement & lime			
Mitigation scenario total CH_4			
CH_4 from combustion			
CH_4 from oil and gas sector			
CH_4 from coal mining			
CH_4 from enteric fermentation			
CH_4 from landfills/sewage treatment			
CH_4 from rice production			
CH_4 from forest and savannah burning			
Mitigation scenario total N_2O			
N_2O from combustion			
N_2O from agricultural soils			

6 Cost curve data

Country: X

Table 6.1 Short term cost curve. End year:___	GHG reduction (1000 tonnes GHG)			Local currency/ton-CO_2 equivalent	US$/ton-$CO_2$ equivalent
CO_2 mitigation options	CO_2	CH_4	N_2O		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
...					
Total reduction					
Total reference scenario emissions					

Table 6.2 Long term cost curve. End year:___	GHG reduction (1000 tonnes GHG)			Local currency/ton-CO_2 equivalent	US$/ton-$CO_2$ equivalent
CO_2 mitigation options	CO_2	CH_4	N_2O		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
...					
Total reduction					
Total reference scenario emissions					

Please list the options according to increasing marginal cost and remember reporting years!

7 Individual option data

Country: X

Option number and name

Costs in local currency	Mitigation option	Baseline option
Electricity consumption		
Capacity of unit		
Efficiency		
Fuel type		
Fuel consumption		
Annual fuel cost		
Investment		
Lifetime (years)		
Discount rate		
Levelised investment		
Annual O&M		
Total annual cost		
CO_2 emission		
N_2O emission		
CH_4 emission		
Total CO_2 equivalent		
Number of installed units		

Local currency/ton CO_2 eq.	

Please give a short description of the options including other important assumptions

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Annexes

1 Estimates of damages from industrialised countries

A great deal of work has now been undertaken to value the damages from the major pollutants associated with fossil fuels: SO_2, NO_x (and associated ozone) and particulates. Studies include ExternE (1995) for the EU, Rowe et al. (1995) for the US (New York), Thayer et al. (1994) for the US (California), CSERGE (1993) for the UK. The estimates of damages can be reported in terms of ECU / kWh or in terms of ECU / tonne of emissions. Both values are, of course, site dependent; the closer a source is to population, the greater will be the damages. The ExternE work has, however, noted the importance of long distance impacts of most pollutants, so that, for most sources, less than 20% of the total effect is picked up in the impacts over the nearest 50 km (ExternE, 1995). This implies that the total damages will be less site dependent than was originally envisaged.

Table 23 provides a summary of damages in ECU / tonne from the ExternE, CSERGE Thayer et al. and Rowe et al. studies[28]. All figures are in 1996 prices. For all damages the ranges are very wide. For NO_x the estimates are also highly dependent on the source and on local conditions It should be noted that work is ongoing in these areas and some adjustment to the estimates can be expected over the next year or two.

Table 23 Estimates of Damages from EU and US Studies

Study And Year	Study Area	Pollutant	Damage ECU/Tonne (1996 Prices) Low	Central	High
CSERGE (1993)	UK	SO_2		1,993	
Rowe et al. (1995)	New York	SO_2	620	842	1,063
ExternE (1997)	UK/Germany	SO_2	7,884		22,913
Thayer et al. (1994)	California	SO_2		816	
CSERGE (1993)	UK	NO_x		1,005	
ExternE (1997)	UK/Germany	NO_x	17,864		47,003
Rowe et al. (1995)	New York	NO_x	-992	-98	797
Thayer et al. (1994)	California	NO_x		14,241	
CSERGE (1993)	UK	Particulates		12,240	
Rowe et al. (1995)	New York	Particulates		20,534	
ExternE (1997)	UK/Germany	Particulates	22,046		60,439
Thayer et al. (1994)	California	Particulates		46,825	

Notes:

1. All values are converted into ECU using exchange rates of: 1 ECU = $1.269 and 1 ECU = £1.23. Adjustment to studies in earlier years was made using changes in the Consumer Price Index (CPI).
2. Differences in the Rowe et al. study emerge from different sites in New York.
3. Differences in ExternE are from one study each in the UK and Germany. The 1995 ExternE figures have been revised in forthcoming update of that study and it is the latest figures that are being used here. The NO_x damages include damages from associated ozone for ExternE.
4. Differences in NO_x arise partly because of different sources. Rowe et al. argue that damages are negative because of ozone “scavenging”. However, their study only looks at local impacts. Much of the damage from NO_x arises over a wider area, and this has been assessed in the ExternE study.

In addition to the above some estimates have been made, and are being made for damages from the above pollutants in developing countries or economies in transition. These include the following:

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28 IPCC (1996) quotes some studies with damages in $ / tonne. These are all rather older studies and the state of the art has advanced since they were done. Hence in this report only the most recent studies are taken.

- Krupnick et al. (1996) have made estimates for particulate damage for Bulgaria and Hungary, and come up with figures of ECU 3,390 to ECU 4,467 per tonne. These values were derived from US studies of the type described above, with damage estimates scaled using an "elasticity" of damages with respect to real *per capita* GDP of one.
- Florig (1993) provided estimates for the Tianjin province of China of health damages from particulate pollution based on US damage values. These were revised by Pearce (1996), using an elasticity of one for damages with respect real GDP. Unfortunately there is no data on emissions from the different sources for which damages could be reported in terms of ECU / tonne.
- There is ongoing work by the World Bank and others, to derive damage estimates for developing countries, by carrying out primary studies in these countries. To date these studies have not been published and the information is not available.

In view of the shortage of direct developing country studies it is proposed that estimates of damages be developed based on the EU / US studies, but adjusting the figures on the basis of differences in real *per capita* GDP. The elasticities used there were 1 and 0.35. Given the ranges of values for the damages per tonne, it is important to do the calculations for a range of values. From Table 23, the following values are proposed:

SO_2 Damages

The range of values is from 620 ECU / tonne to nearly 23,000 ECU / tonne. The ExternE studies, which give the higher values are, however, more comprehensive and include more impacts and cover much wider areas. The Rowe et al. study, for example has too restricted a range to pick up all the impacts. Hence, it is proposed that damages in the EU be taken in the range ECU 7,884 to ECU 22,913 / tonne emitted.

NO_x Damages

The NO_x damages are clearly dependent on how the secondary species of nitrate aerosols and ozone etc. are treated. The CSERGE study did not pick up the full range of such impacts, nor did the Rowe et al. study. From the other two studies it is proposed that the range of value of damages be taken in the range ECU 14,241-47,003 / tonne. These values are assumed to apply at a *per capita* GDP which is the average of that of the US and the EU. The EU figure is ECU 17,764 and the US figure is ECU 20,394 (at an exchange rate of $1.269 = 1 ECU). Hence the average *per capita* income is ECU 19,079.

Particulate Damage[29]

Particulate damage is particularly controversial, particularly the magnitude of the chronic health mortality effects and the valuation of the acute health effects. These are the values most likely to change in the near future. Hence, it is proposed that a range based on Table 23 (ECU 12,240-60,439 / tonne) be taken for the study. These values will be assume to apply at a *per capita* GDP equal to the average of the US and the EU, namely ECU 19,079.

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[29] Particulate damage refers to damages from PM_{10}. Not all studies measure this particle size, and conversions have to be made if estimates are for other sizes or related pollutants (e.g. total suspended particulates of "black smoke"). Approximate conversion figures are available for this purpose.

In some cases, only partial local data will be available. For example a local study may be available for health benefits of reducing particulate pollution (as in the case of China). While no general prescription is available for incorporating such information, it may be useful to note the “shares” of damages associated with each of the impacts (health agriculture etc.). The range of damages in the ExternE study for the three pollutants listed above is given in Table 23. Hence if a study is available for health benefits and gives damages from particulate pollution as ECU X per tonne, total damages may be computed noting that of the *valued* damages, health damages are the dominant ones, accounting for over 98 percent of the total[30].

[30] For example, particulate pollution has some identified impacts on materials. It is just that these have not been quantified and valued.

2 Sustainability indicators

Table 24 Sustainability Indicators for GHG Limitation Projects

Policy Intervention	**Sustainability Indicators**		
	Sustainable Use of Renewable Resources	**Key Natural Capital**	**Other**
Switches in fossil energy use	Period for which new regime of fossil fuel use will be economically feasible		Cost/unit of energy from renewable energy source at end of period when fossil fuel will be economically feasible
Renewable energy Energy Conservation Market Based Instruments	Change in share of total energy from renewable sources at beginning and at end of planning period	Any impacts on key biodiversity or other natural assets of developing renewable sources	
Forestry	Change in share of total energy from renewable sources at beginning and at end of planning period Will programme include replanting at end of each cutting period?	Any impacts on key biodiversity or other natural assets of forestry resource development	
Transport	Change in share of total energy from renewable sources at beginning and at end of planning period		Impact of policies on share of total land for urban/suburban use
Land Use/Agriculture	Change in share of total energy from renewable sources at beginning and at end of planning period	Any impacts on key biodiversity or other natural assets of developing renewable sources	Change in yields from land devoted to biomass etc. at end of planning period

A key indicator of sustainability in Table 24 is the impact the project or policy has for the share of total energy that will come from renewable sources at the beginning and at the end of the planning period. This applies to almost all interventions that are likely to be considered, and could, in fact, be reported for *all* interventions, even those that will not impact on the use of renewable resources.

For fossil fuel policies it is important to look at how long such policies will last. This is not mainly a physical consideration, but an economic one. At some time the fossil energy source may be so depleted that the costs of extraction will rise above those of the renewable source. That is the point at which the fossil fuel is effectively depleted. An idea of when that is likely to happen will provide useful information on the length of time for which the present project (and its successors) can last.

For projects that impact on the natural resource base directly -- forestry and biomass production -- an assessment of the impacts on key forms of natural capital, particularly biodiversity related, should be provided. This information will probably not be quantitative, but rather a qualitative description of what impacts are expected. In some cases, however, it is possible that quantitative data on species impacts or increased measures of eco-system stress may be available.

For biomass projects it is important to monitor how agricultural land use will affect yields in the medium to long term. Placing a reporting requirement on this will ensure that estimates are prepared. A range will typically need to be reported to allow for the uncertainty arising from the estimation procedures.

Finally, some projects involving transport will have impacts on urbanisation and on land available for agriculture. One sustainability concern is that the trends in land use are not sustainable; that as more and more land is taken into urban and suburban use, there is a loss of amenity and of biodiversity. A proxy for that is the change in the percentage of urban / suburban land. Polices in the transport sector that reduce energy use could reverse present trends and cause a fall in the areas or suburban land (or at least arrest the rate of growth of such land).

The above measures of sustainability are useful complements to the monetary measures of the costs of GHG limitation projects. The section 1.7.2 Quantitative non-monetary information discusses how the two kinds of information may be integrated into a framework for decision-making.

3 Case examples: mixed energy supply and demand options

The following example illustrates how one might assess the emissions reductions and incremental costs for a mixture of supply and demand side options in the energy sector. The options include the installation of compact fluorescent lighting in residential households and the replacement of coal-fired electric generation with combined cycle gas and hydro-electric generation. The example is purely hypothetical and the analysis assumptions are purposely made fairly simple so the reader can better understand the steps in the methodology. The impact of these simplifying assumptions on the analysis, as well as several “complicating factors” that one might have to deal with in actual situations, are discussed at the conclusion of the example.

3.1 Step 1: project baseline scenario emissions

In order to be able to project emissions in the baseline, one needs to know the following:

- projected energy demand by sector
- emissions associated with these level of demands over time.

3.1.1 Calculating energy demand

In this example energy demand is projected, by sector and fuel, using demand equations for the different sectors. In most cases, the demand for different fuels in different sectors will be affected by different factors, and the demand equations that will need to be estimated will vary over both. However, for simplifying purposes, only two demand equations are used in this example.

The demand growth rate equation for coal, petroleum products, natural gas, and electricity in all sectors, except for electricity demand in the residential sector is used in this example:

$$\ln \dot{E}^{Demand} = 0.8 \cdot \ln Pop_t + 1.1 \cdot \ln(GDP/Capita)_t - 0.5 \cdot \ln P^{Oil} \qquad \textit{Eq. 24}$$

where,

$\dot{E}^{Demand}$	Growth rate of energy demand.
Pop_t	Population at *t*.
$(GDP/Capita)_t$	GDP / capita at *t*.
P^{Oil}	Price of oil.

The demand growth rate for the different energy types in the various sectors is then projected by substituting the values for the independent variables (population, GDP per capita, and oil price) in each period into the demand equation. In this example, the following assumptions (Table 25) were used to project the trends in these independent variables over time:

Table 25 Energy demand projections

Independent Variable	Base Period Value (1993)	Projected Annual Growth Rate (%)
Population	$59 million	2.00
GDP	$107 billion	3.50
GDP per Capita	$1.814 per capita	1.47
Oil Price	$20 per barrel	1.0
Projected Energy demand growth Rate		2.73

To calculate the projected energy demand divided in fuels and sectors, one needs to know the distribution of energy use by sector and fuel in a base year (1993). This is shown below in Table 26. Energy demand in each sector can then be projected on a year by year basis, as

$$\dot{E}_t^{Demand} = (1 + Growth_t) \cdot (X \ Base\,Period\,Energy\,Demand) \qquad Eq.\ 25$$

Table 26 Energy distribution by sector and fuel in 1993

Sector	Coal	Petroleum Products	Gas	Electricity	Total
Industry	106,027	148,154	12,828	77,883	344,892
Transport	0	596,033	0	0	596,033
Residential	0	45,485	0	42,973	88,459
Commercial	0	0	0	79,131	79,131
Agriculture	0	68,178	0	477	68,655
Other	0	0	0	2,177	2,177
Total Final Demand	**106,027**	**857,850**	**12,828**	**202,641**	**1,179,346**

A slightly different approach is used in the residential electricity sector. The assumptions used in this sector are as follows (Table 27):

Table 27 Electricity projection for the residential sector

Variable	Assumed value
1993 Residential electricity consumption	11,938 GWh
Average number of persons per household	5.2
Rate of growth of households	2.2% per annum

For this sector, a demand equation is used to project the Penetration growth rate of different appliances. Normally, different appliances will have different demand function; however, in this example just one equation is used for all appliances. The equation is:

$$\ln(Penetration\,Growth\,Rate)_t = 1.3 \cdot \ln\left(GDP/Capita\right)_t \qquad Eq.\ 26$$

To forecast the penetration of various appliances in the residential sector by year, one uses the same approach as for the other sectors. First, the penetration growth rate for each appliance is projected over time by inserting the projected values for GDP per capita into the penetration growth rate equation. Then, using the observed penetration rate of appliances in the base period (1993) as a starting point, one can use the estimated penetration rate to calculate appliance penetration in each period, as

$$Penetration_t = (1 + (Penetration\ Growth\,Rate)_t) \cdot X\ Penetration_t \qquad Eq.\ 27$$

Finally, given estimates of the number of households in each period and the amount of electricity consumed by each appliance, residential electricity demand can be estimated using the following equation:

$$Electricity\ Demand = Household_t \cdot \sum_t Penetration_{it} \cdot Use_{it} \qquad Eq.\ 28$$

where

Electricity Demand	Total electricity consumption
Households	Number of households
Penetration	Appliance penetration
Use	Average electricity use per appliance
t	An index denoting time
i	An index denoting appliance type

By following the steps outlined above, one can construct a forecast for energy demand in the baseline scenario for the various fuels and sectors. An example of the output of these calculations for 2010 is shown in Table 28) below.

Table 28 Country X energy demand projection for 2010

Sector	Coal	Petroleum products	Gas	Electricity	Total
Industry	167,574	234,156	20,275	123,093	545,098
Transport	0	942,024	0	0	942,024
Residential	0	71,889	0	74,943	146,832
Commercial	0	0	0	125,065	125,065
Agriculture	0	107,754	0	754	108,509
Other	0	0	0	3,441	3,441
Total final demand	**167,574**	**1,355,824**	**20,275**	**327,297**	**1,870,970**

3.1.2 Calculating emissions

Once the levels of energy demand, over time, are determined for the baseline scenario, one needs to translate these into emissions. This is done by calculating emissions factors for each type of fuel in the non-electricity sector. These emissions factors are shown below. To calculate the emissions factor associated with electricity generation, one needs to know:

- the average generating efficiency for each type of generating technology
- the mix of generation technologies over time
- and the emissions factor for each type of fuel used.

This information is also shown below. In calculating a weighted emissions factor for the electricity sector, it is assumed for simplicity, that the mix of generating technologies remains constant, over time, following the pattern in 1993. Normally, this mix can be expected to change over time, as a part of the development process and in response to environmental regulations, not related to GHG reduction. The weighted average emissions factors for the electricity sector can be calculated as:

$$Emission\ Factor_t = \sum_j \frac{1}{Generation\ Efficiency_j} \cdot \sum_j \frac{1}{Emission\ Factor_j \cdot Input\ Fuel_{jt}} \qquad Eq.\ 29$$

Emissions Factor (1993) = 253.629 kg CO_2 per TJ of electricity consumed. Note that losses in distribution and transmission systems here are assumed included in the generation efficiency.

The resulting emission factors are shown in Table 29.

Table 29 Calculated emission factors.

Emission Factors (kg CO_2 per TJ) - Non Electricity Sectors			
Coal	94.600		
Petroleum Products	73.080		
Natural Gas	56.100		
Hydroelectric	0		
Emissions Factor Input Information for Electricity Sector			
Average Generation Efficiency			
Existing Coal	32%		
Existing Oil	24%		
Existing Natural Gas CT	24%		
New Natural Gas Combined Cycle	44%		
Hydroelectric	100%		
1993 Electricity Generation by Fuel	(GWh)	(TJ)	Percent
Coal	13.504	48.614	21,30%
Petroleum Products	18.247	65.689	28,78%
Gas	27.953	100.631	44,08%
Hydro	3.705	13.338	5,84%
TOTAL	63.409	228.272	100,00%
Weighted Average Electricity Emission Factor (1993) 253.629 kg CO_2 per TJ of electricity consumed			

The resulting pattern of emissions calculated using these emissions factors is shown in the Figure 1.

3.2 Step 2: estimating emissions reductions and incremental costs of the mitigation options

Mitigation costs are calculated by comparing the costs and emissions of the mitigation option against the cost and emissions of the baseline scenario. In the energy sector, CO_2 emission reductions can be achieved through options which address energy supply or which reduce energy demand through improved end-use efficiency. The following tables provide an example of how to calculate mitigation costs of a demand-side program in which standard incandescent light bulbs are replaced with compact fluorescent (CFL) bulbs.

The table below describes the essential characteristics of both the baseline (incandescent) and mitigation (CFL) technologies. These include capital costs, equipment life, energy consumption, annual usage, etc. The marginal electricity cost, which defines the value of the saved energy, and the discount rate are also provided.

Figure 14 Estimated CO_2 emission for baseline scenario.

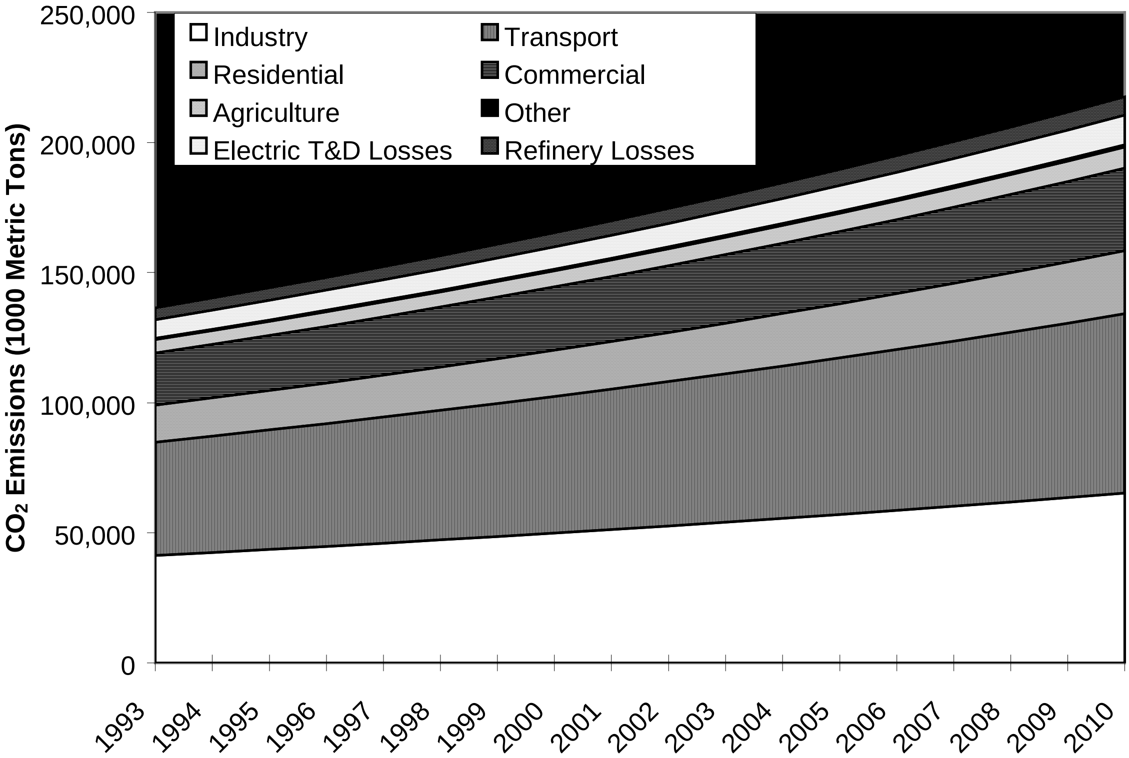


Table 30 Replacement of incandescent bulbs with compact fluorescent bulbs in residential sector.

All costs in 1990 $	Incandescent	Compact fluorescent
Capital cost per bulb ($)	$1.00	$13.00
Life of bulb (hours of operation)	1,000	10,000
Energy consumption (W)	60	13
Annual hours of operation (hours)	912.5	912.5
Actual life of bulb (years)	1	11
Marginal electricity cost ($/kWh)	$0.05	$0.05
Annual electricity consumption per bulb (kWh/yr)	54.75	11.86
Annual electricity cost ($)	$2.74	$0.59
Annual bulb replacement cost ($) (for 11 eleven years of CFL life)	$1.00	$0.00

Discount rate (real)	3.0%

The hypothetical CFL promotion program is implemented over the course of four years, starting in 1997 and finishing in 2000. With CFLs having a lifetime of 11 years, the benefits of the program are expected to accrue through the year 2010. The following table provides a summary of year-by-year benefits and costs resulting from the program. The right-most column, "Cumulative Cash Flow," is calculated by subtracting the incremental capital cost and administrative cost from the annual cost savings. The cash flows is negative in the first four years due to the high capital costs of the CFLs, but net benefits then accrue until 2010.

Table 31 Compact fluorescent lightbulb (CFL) promotion program.

Year	Number of bulbs installed	Electricity savings (kWh/yr)	Annual cost savings	Incremental capital cost	Administrative cost	Cumulative cash flow
1997	500,000	21,443,750	$1,572,188	$6,000,000	$500,000	($4,927,813)
1998	750,000	53,609,375	$3,930,469	$9,000,000	$500,000	($5,569,531)
1999	1,000,000	96,496,875	$7,074,844	$12,000,000	$500,000	($5,425,156)
2000	1,000,000	139,384,375	$10,219,219	$12,000,000	$500,000	($2,280,781)
2001		139,384,375	$10,219,219			$10,219,219
2002		139,384,375	$10,219,219			$10,219,219
2003		139,384,375	$10,219,219			$10,219,219
2004		139,384,375	$10,219,219			$10,219,219
2005		139,384,375	$10,219,219			$10,219,219
2006		139,384,375	$10,219,219			$10,219,219
2007		139,384,375	$10,219,219			$10,219,219
2008		117,940,625	$8,647,031			$8,647,031
2009		85,775,000	$6,288,750			$6,288,750
2010		42,887,500	$3,144,375			$3,144,375
2011		0	$0			$0

Calculations of the program's cost-effectiveness are next illustrated using two different techniques: "average emission reductions" and "levelised emission reductions."

Table 32 Cost-effectiveness.

Average annual emission reduction option		
Cumulative electricity savings due to program: 1997 - 2010	1,533.23	GWh
Average annual CO_2 emission reductions over 11 Years	127.27	thousand tons CO_2, w/ baseline elec. mix.
Net present value of program in 1997 (1990 $)	$51,969,404	
Levelised cost of CFLs ($/yr)	($5,616,721)	
CO_2 emissions reduction cost	**-44.13**	**$/ton CO_2**
Levelised emission reduction option		
Cumulative electricity savings due to program: 1997 - 2010	1,533.23	GWh
Net present value in 1997 of cumulative electricity savings	1,224.55	GWh
Net present value in 1997 of CO_2 emission reductions	1,118	thousand tons CO2, w/ baseline elec. mix.
Levelised annual CO_2 emission reductions (levelis. over 11 yrs)	121	thousand tons CO2, w/ baseline elec. mix.
Net present value of program in 1997 (1990 $)	$51,969,404	
Levelised cost of CFLs ($/yr)	($5,616,721)	
CO_2 emissions reduction cost	**-46.48**	**$/ton CO_2**

In the Average Annual Emission Reduction option, cumulative electricity savings over the 14 year period 1997-2010 are averaged over 11 years. The savings are averaged over 11 years because each CFL's lifetime is 11 years (the total savings accumulate for 14 years because the CFL installations are spread out over 4 years). The average annual electricity savings are converted into CO_2 emission reductions using the emission factor of 253,629 kg CO_2 per TJ of electricity derived earlier, to provide an average annual CO_2 emission reduction of 127.27 thousand tons. The Cumulative Cash Flow is levelised (over 11 years) to provide an annualised net economic cost of -$5,617 million per year. In other words, the net negative cost indicates that the CFL promotion program provides net economic benefits. By dividing the levelised cost of -$5,617 million per year by the average CO_2 reduction of 127.27 thousand tons per year, we obtain the overall CO_2 emission reduction cost effectiveness of -$44.13 per ton.

In the Levelised Emission Reduction option, in addition to levelising the cash flow, the CO_2 emission reductions are also levelised over 11 years at the same discount rate as the cash flow. Whether or not to discount CO_2 is a controversial issue which has not been resolved and is related to the nature of the CO_2 emissions' damage function. For mitigation projects, not discounting CO_2 tends to provide an incentive to delay implementation of mitigation projects until as far in the future as possible.

For energy supply options, a similar procedure could be followed in comparing a mitigation option against a baseline option. Table 33 presents the example of a combined cycle natural gas power plant mitigation option replacing a baseline scenario coal-fired power plant.

Table 33 Combined cycle natural gas power plant mitigation option.

	BASELINE SCENARIO		MITIGATION SCENARIO	
Variables	Coal-Fired power plant		Combined cycle natural gas plant	
Base year total plant cost	$1,293	/kW	$506	/kW
Fixed charge rate (real)	6.3%		6.1%	
Capacity factor	75%		75%	
Base year fuel cost	$1.95	/MBtu	$2.43	/MBtu
Fuel escalation (real)	1.81%	/year	2.38%	/year
Base year fixed O&M	$18.75	/kW-yr	$17.10	/kW-yr
Base year variable O&M	$0.00054	/kWh	$0.0022	/kWh
O&M escalation rate (real)	1.00%	/year	1.00%	/year
Discount rate (real)	3.00%	/year	3.00%	/year
Heat rate	9,800	Btu/kWh	8,022	Btu/kWh
Plant life	30	years	30	years
Plant Capacity	500	MW	400	MW

Based on the above characteristics, levelised costs can be calculated for the capital cost, operations & maintenance (O&M) cost, and fuel cost components of each plant. The total levelised costs of the two plants can then be compared to obtain the net cost of the mitigation option. Dividing the net levelised mitigation cost by the emission reduction provides the cost effectiveness ratio. Again, in the example in Table 34, the combined cycle natural gas plant is cheaper than the coal plant, resulting in a net negative cost.

Table 34 Negative costs example; combined cycle natural gas plant vs. coal plant.

	Coal-Fired power plant	Combined cycle natural gas plant
Levelised capital cost	1.24 cents/kWh	0.47 cents/kWh
Levelised fuel cost	2.46 cents/kWh	2.72 cents/kWh
Levelised O&M cost	0.39 cents/kWh	0.55 cents/kWh
Total levelised cost	**4.08 cents/kWh**	**3.74 cents/kWh**
Levelised cost savings:	0.34 cents/kWh	
Electricity generated in 2010	2,628 GWh	
CO_2 emission reductions in 2010	1,591 thousand metric tons of CO_2	
CO_2 emissions reduction cost	**-5.66 \$/ton CO_2**	

Carrying out a similar calculation for a hypothetical hydroelectric plant replacing the same coal-fired plant is shown in Table 35.

Table 35 Positive costs example; hydroelectric plant vs. coal plant.

	Coal-Fired power plant	Hydro-Electric plant
Levelised capital cost	1.24 cents/kWh	3.14 cents/kWh
Fuel levelisation factor	1.28	1.00
Levelised fuel cost	2.46 cents/kWh	0.00 cents/kWh
O&M levelisation factor	1.15	1.23
Levelised O&M cost	0.39 cents/kWh	1.91 cents/kWh
Total levelised cost	**4.08 cents/kWh**	**5.05 cents/kWh**
Levelised cost savings:	-0.97 cents/kWh	
Electricity generated in 2010	701 GWh	
CO_2 emission reductions in 2010	746 thousand metric tons of CO_2	
CO_2 emissions reduction cost	**9.09 \$/ton CO_2**	

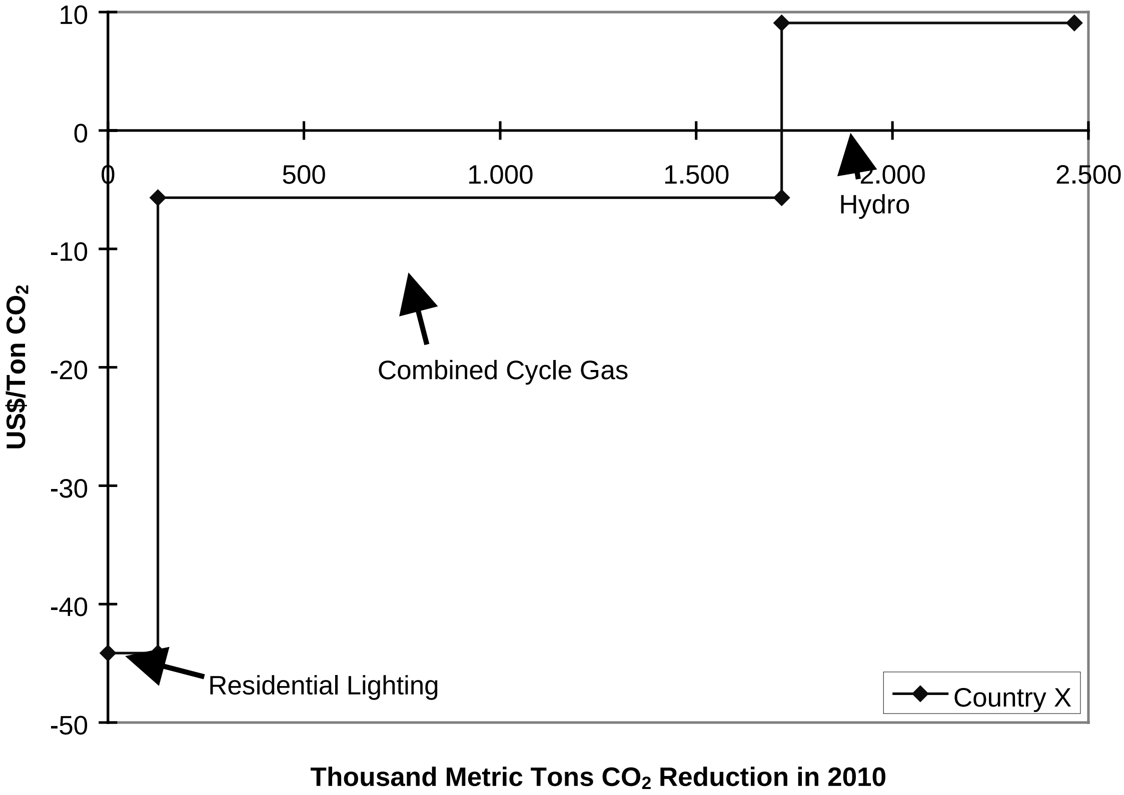
In this case, with the hydro plant being more expensive than the baseline scenario coal plant, the CO_2 emissions reduction cost is positive.

Note, the analysis of the above supply-side options is highly simplified in that with both the combined cycle gas plant and the hydroelectric plant, these mitigation options are assumed to displace a coal-fired plant. In reality, the nature of the baseline scenario emissions being displaced will be dependent on the mix of power plants assumed in the baseline scenario and is likely to be composed of several fuel types. In cases where the baseline scenario is composed primarily of hydro or nuclear electricity, the combined cycle gas plant could result in a net increase in emissions rather than a decrease as shown above.

3.3 Step 3: calculating supply curves for the options

The supply curves for the three options are calculating by plotting the emissions reductions for each option, relative to the baseline scenario, on the horizontal axis against the associated incremental cost on the vertical axis. The supply curves are shown in Figure 15, below.

Figure 15 CO_2 abatement cost curve



3.4 Case example: assessment of energy sector mitigation options in Zimbabwe

An example of an assessment of the efficient lighting as a mitigation option applied for Zimbabwe is shown in the following.

The lighting option analysed is a replacement of incandescent lamps with compact fluorescent lamps. The mitigation lighting options is as shown in Table 36 compared with a traditional incandescent lamp. The two options differ according to cost, lifetime and electricity consumption. The lighting options is assumed implemented in a coal based power plant system with an average efficiency of 35% and 12 % transmission losses. The cost of the incandescent lamp is 140 Zim$ compared with 3 Zim$ for the reference lamp.

The main technical and economic assumptions used in the calculation of CO_2 reduction costs are shown in the following Table 36.

Table 36 Basic assumptions applied in the assessment of a lighting mitigation option for Zimbabwe.

Discount rate	10%	
Fuel CO_2 emission factor	95	kg CO_2/GJ coal
Fuel CH_4 emission factor	0.0015	kg CH_4/GJ coal
Fuel N_2O emission factor	0.003	kg N_2O/GJ coal
Invest. in coal power plant	12,300	Z$/kW
Life time of power plant	35	years
Capacity factor	7,884	hours
Coal to elec. efficiency	0.35	
Electricity transfer losses	0.12	
O&M	2%	
Reduction option:		
O&M (lamp change)	1.50	Z$
Activity	1,000	locations
Cost of eff. lamp	140	Z$
Lamp lifetime	8,000	hrs
Lamp wattage	7	W
Daily usage	4	hrs
Annual electricity used	36.8	GJ
Reference option:		
O&M	1.50	Z$
Activity	1,000	locations
Cost of incand. lamp	3	Z$
Lamp lifetime	1,000	hours
Lamp wattage	40	W
Daily usage	4	hrs
Annual electricity used	210.2	GJ

The abatement costs are calculated with the GACMO-model that has been used for country studies in Denmark and a number of African countries. The model is a simple spreadsheet model, structured with each mitigation option in a worksheet. The project assumes an implementation of 1000 incandescent lamps. The total project costs are calculated as the costs of saved electricity at a reference coal fired power plant. The costs turns out to be negative, namely – 29,355 Zim$. The project saves in total 54.1 tonne CO_2 equivalents per year, and the reduction cost of the lighting options can therefore be calculated to be 54.1 t CO_2 eq. / -29,355 Zim$ = -543 Zim$ / tonne CO_2 equivalent Table 37 below shows the cost calculation carried out for the lighting option in the GACMO model.

Table 37 Abatement cost calculation for a lighting option applied in Zimbabwe.

Costs in Z$	**Reduction Option**	**Reference Option**	**Increase (Red.-Ref.)**
Total investment	140,000	24,000	
Project life	5.5	5.5	
Levelised investment	34,414	5,899	28,514
Levelised investment in power plant	10,145	57,972	-47,827
Ref. Power plant O&M	1,468	8,386	-6,919
Annual O&M	369	2,197	-1,828
Levelised fuel cost	275	1,569	-1,295
Total annual cost	46,670	76,024	**-29,355**

Annual emissions	Tonne.	Tonne.	Reduction
Fuel CO_2 emission	11.3	64.8	53.5
Fuel N_2O emission	0	0.002	0.002
Fuel CH_4 emission	0	0.001	0.001
Total CO_2 equiv.	11.5	65.5	**54.1**
Z$/ton CO_2 equivalent			**-543.00**

Note: 1 US $ = 8.2 Zim$

The UNEP country study for Zimbabwe calculated a cost curve where a similar worksheet as applied for the lighting option was used for all individual mitigation options. The information for the options were combined in a common worksheet in order to calculate mitigation potential and costs of the individual options. The options were finally ranked according to cost-effectiveness as a last step in constructing a cost curve. The resulting cost curve data for Zimbabwe for the lighting option and other mitigation options are shown in Table 38.

As can be seen in Table 38 the Zimbabwe study included in total 20 options. The mitigation costs and GHG reduction potential were calculated individually for all of these options with the procedure reported in detail for the lighting option. Technical interdependencies between the 20 options considered were expected to be small. This assumption seems reasonable because the options typically represent marginal changes. This is, for example, the case for electricity saving options which in total represent a small fraction of total electricity demand in Zimbabwe. The same is the case for the hydro power mitigation option that will only generate a small marginal change in the total coal dominated power supply system of Zimbabwe.

Table 38 Cost curve data for Zimbabwean mitigation options.

		Common assumptions					Short run			
	Reduction option	Z$/ CO_2	Unit size	Unit Type	Energy Type Saved	Emission reduction $tonCO_2$/unit	Units penetrating in 2010	Reduction in 2010 mill ton/year	Reduction in 2010 %	Energy Saved 2010
1	Tillage	-1046.3	1	tractors	diesel	18.5	1227	0,02	0,1	0,31
2	Efficient lighting	-543,0	1000	Bulbs	el-coal	54,1	1000	0,08	0,1	0,57
3	Geyser timeswitches	-171,9		units	el-coal	1,3	61000	0,15	0,5	0,82
4	Coalbed ammonia	-159,9	83	MW	coal	808131,3	1	0,96	2,9	8,51
5	Methane from sewage	-135,9	1	plant	el-coal	1203,8	10	0,97	3,0	0,13
6	Prepayment meters	-107,3	200	units	el-coal	1,9	3000	0,98	3,0	0,06
7	Cokeoven gas for Hwankie	-104,5	15000000	l diesel eq.	diesel	43941,9	1	1,02	3,1	0,59
8	Efficient motors	-99,3	1000	kW	el-coal	4,3	14000	1,09	3,3	0,64
9	Efficient boilers	-23,0	100	tonnes	coal	1051,4	635	1,75	5,4	0,00
10	Savings in industry	-14,0			in-split			1,75	5,4	0,00
11	Efficient tobacco barns	0,1	1	barn	coal	639,7	320	1,96	6,0	2,15
12	Pine afforestation	9,9	1	ha	wood	29,4	50000	3,43	10,5	13,37
13	Efficient furnaces	47,5	2	MW	coal	7241,7	115	4,26	13,0	8,77
14	Biogas from landfills	24,4	1	Landfill	el-coal	447828,5	1	4,71	14,4	4,71
15	Biogas for rural households	48,0	1	digesters	wood	9,1	7500	4,78	14,6	0,62
16	Hydro power	65,1	0	kW	coal	8,2	0	4,78	14,6	0,00
17	Solar geysers	238,2		units	el-coal	2,9	61000	4,95	15,1	1,84
18	Central PV electricity	564,4	1	kW	coal	2,1	0	4,95	15,1	0,00
19	Power factor correction	6687,0	1	MVAR	el-coal	778,5	234	5,13	15,7	1,92
20	Solar PV water pumps	27566,3	3,5	kW		0,2	1500	5,14	15,7	0,00
	Totals	**-1407,4**				**1310170,1**				**45,01**
	Total emission:							**32,70**		
	% reduction of total CO_2 emission:							**15,7%**		

		Long run				Short run		Long run	
	Reduction option	Units penetrating in 2030	Reduction in 2030 mill. ton/yr	Reduct. in 2030 %	Energy Saved 2030	Total cost 2010 mill z$	Av. cost 2010 Z$/ton	Total cost 2030 mill z$	Av. cost 2030 Z$/ton
1	Tillage	1227	0,02	0,0	0,31	-24	-1046,3	-24	-1046,3
2	Efficient lighting	5000	0,29	0,5	2,85	-53	-691,9	-171	-582,0
3	Geyser timeswitches	91000	0,41	0,7	1,22	-66	-430,0	-190	-465,6
4	Coalbed ammonia	1	1,22	2,1	8,51	-196	-203,3	-320	-262,6
5	Methane from sewage	20	1,24	2,2	0,25	-197	-202,5	-323	-260,2
6	Prepayment meters	3000	1,25	2,2	0,06	-198	-201,9	-324	-259,5
7	Cokeoven gas for Hwankie	1	1,29	2,2	0,59	-203	-197,7	-328	-254,2
8	Efficient motors	61200	1,56	2,7	2,80	-209	-192,2	-355	-227,8
9	Efficient boilers	2000	3,66	6,4	22,14	-224	-127,8	-403	-110,1
10	Savings in industry		6,16	10,7	10,18	-224	-127,8	-438	-71,1
11	Efficient tobacco barns	660	6,58	11,5	4,44	-224	-114,4	-438	-66,5
12	Pine afforestation	100000	9,53	16,6	26,75	-209	-61,0	-409	-42,9
13	Efficient furnaces	115	10,36	18,0	8,77	-170	-39,8	-369	-35,6
14	Biogas from landfills	1	10,81	18,8	4,71	-159	-33,7	-358	-33,1
15	Biogas for rural households	10500	10,90	19,0	1,00	-156	-32,6	-354	-32,4
16	Hydro power	450000	14,60	25,4	38,92	-156	-32,6	-113	-7,7
17	Solar geysers	91000	14,86	25,9	2,75	-114	-23,0	-51	-3,4
18	Central PV electricity	200000	15,27	26,6	4,37	-114	-23,0	183	12,0
19	Power factor correction	854	15,94	27,8	7,00	1104	215,0	4629	290,4
20	Solar PV water pumps	1500	15,94	27,8	0,00	1112	216,6	4637	290,9
	Totals				**147,61**				
	Total emission:		**57,40**						
	% reduction of total CO_2 emission:			**27,8%**					

Note: Savings in Industry from Touche Ross (CIDA) Scenario II 14.2% savings

4 Estimation of GHG fluxes in the agricultural sector

Rice production: area reduction

Calculating the annual change in methane emissions in some future period by reducing the area of planted rice involves calculating two effects: 1) the direct effect of the area reduction in the source country, and 2) the leakage due to increases in rice area elsewhere. The direct effect is equal to:

$$\Delta DM = EF \cdot \Delta A \cdot 10^{-12} \qquad \textit{Eq. 30}$$

where:

- ΔDM The annual change in domestic rice methane emissions in Tg / yr due to the direct reduction in area.
- EF Methane emission factor integrated over cropping season in g / m^2
- ΔA The change in area planted in m^2.

This should be integrated over various factors that effect methane emissions, including rice variety, soil type, fertiliser, and management regime, as suits the country, and as data permits. In many cases, the indirect leakage will be close to 100%, meaning that all of the emissions reductions will be cancelled out by increased production in other countries.

Rice production: intermittent flooding

The key to this mitigation option lies in the effect which intermittent flooding of fields will have on the period of time during which anaerobic conditions are present. In many studies, it has simply been assumed that the reduction in methane emissions will be proportional on a 1:1 basis to the number of days the field is flooded. Lacking field data, another approach is to use the scaling factors supplied by the IPCC (1997) in the Revised Guidelines for National Greenhouse Gas Inventories. Using either of these approaches, the annual reduction in methane emissions for some future year can be estimated using a modification of Eq. 30 as:

$$\Delta DM = EF \cdot SC \cdot \Delta A \cdot 10^{-12} \qquad \textit{Eq. 31}$$

where:

- ΔDM The annual change in domestic rice methane emissions in Tg / yr due to the direct reduction in area.
- EF Methane emission factor integrated over cropping season in g / m^2.
- SC Scaling factor to represent the proportional reduction in flooding days in the crop year.

Rice production: changing plant varieties

It may be possible to switch plant varieties that mature more quickly, with a subsequent shortening of the period under which anaerobic conditions are present. In that case, the reduction in methane emissions can be estimated using Eq. 30 where the emissions factors are adjusted downward to reflect the emissions from the new varieties. Leakages may take place as a result of this option, if the new varieties are more (or less) profitable than those in the baseline scenario. However, these leakages can probably be ignored for practical purposes.

Rice production: nutrient management

Replacing organic with inorganic fertiliser and reducing the amount of organic material introduced with the manure can reduce methane emissions. However, the impact on methane emissions from this option has not been well researched, and so researchers will probably have to comb the secondary literature on this subject in order to adjust the methane emissions factors in Eq. 30 to reflect the change in practice. The substitution of inorganic for organic fertiliser implies an increase in fertiliser production, causing additional greenhouse gas emissions. Thus, the decrease in methane emissions will be offset somewhat by these emissions. It is important that these additional emissions be included in the analysis, either under calculations for the energy sector, or else by using global warming potential factors to convert these additional emissions into methane emissions. These converted methane emissions should then be deducted from the emissions reduction achieved through the mitigation option.

Animal husbandry: enteric fermentation

The procedures for quantifying the methane reductions from livestock associated with enteric fermentation can be quite complicated because emissions reductions are best accomplished, indirectly, by reducing methane emissions per unit of product and then decreasing animal numbers required to meet baseline scenario levels of production.

The first step in this analysis is to identify the livestock that can be targeted for specific mitigation options. This requires breaking down the animal population into animal and feeding categories. Not all animals will have access to all mitigation options. For example, animals that graze year round on pasture are poor candidates for most options. Animals who are fed hay for part of the year on pasture are candidates for a limited number of options, primarily adding inorganic N to feed and chopping it. For animals to have access to production enhancing treatments, they must be contained in barns or feedlots. In ever case, experts who are conducting the mitigation studies need to talk with livestock experts to determine what mitigation measures are applicable to livestock in their country, and base their breakdowns on this information. It may be that only a small portion of the total animal population can benefit from this approach.

Second, since most of the measures, here, rely on indirect productivity increases to reduce methane emissions, it is important to determine the extent to which this option is feasible on farms with one or two animals. Cutting animal numbers on these small holdings may not be an option. In that case, the only possible means of reducing methane emissions is to improve the digestibility of feed, primarily by chopping hay and add liquid nitrogen, holding animal numbers constant.

One of the options in this category involves adding inorganic N to feeds in order to improve digestibility. This option may require the production of additional additives, and this process, in turn, produces additional emissions of greenhouse gases, primarily CO_2. It is important to include these additional emissions in calculating the net effect of this mitigation option. This can be accomplished by increasing the additional emissions in the appropriate energy sector budget for chemical production, or by converting the additional CO_2 emissions into methane emissions by using the ratio of the global warming potential factors for methane and CO_2.

IPCC (1997) presents two approaches for estimating methane emissions from enteric fermentation in livestock. The first is straightforward, and involves multiplying the number of head of livestock in each animal category by an emissions factor:

$$M = EF \cdot N / 10^6 \quad \textit{Eq. 32}$$

where:

M	Annual methane emissions in Gg / yr.
EF	Methane emission factor in kg / head / yr.
N	The number of head of livestock in the category

Following this approach, the change in the annual average methane emissions for each animal category would be:

$$\Delta M = EF_m \cdot N_m / 10^6 - EF_b \cdot N_b / 10^6 \quad \textit{Eq. 33}$$

where:

ΔM	The annual change in methane emissions in Gg / yr.
i	*m* and *b* denotes baseline and mitigation.

This approach can be modified slightly as shown in the U.S. Country Studies Mitigation Guidebook (Sathaye & Meyers 1995) guidance for mitigation projects as:

$$\Delta M = EF_m^{'} \cdot Q_m \cdot N_m / 10^6 - EF_b \cdot Q_b \cdot N / 10^6 \quad \textit{Eq. 34}$$

where:

$EF^{'}$	The methane mitigation factor expressed in terms of methane emissions per unit of production (kg / Gg / yr.)
Q	Production per head of livestock in kg / yr.

This approach explicitly recognises that the methane mitigation options will result in an increase in both *EF'* and *Q*. However, because *Q* will generally increase at a faster rate than *EF'* for a given option, total methane emissions will fall when production is held constant, such that $P_m \cdot N_m = P_b \cdot N_b$.

The problem with the approach shown in Eqs. 33 and 34 is that it is difficult to relate changes in specific dietary practices to *EF'* and *Q*, without making intermediate calculations. Both IPCC (1997) and Gibbs & Johnson (1994) present a more detailed approach that allows one to estimate the effects of changes in diet on both factors separately. Default factors and the calculations required to use this method are provided for various subregions and animal categories in IPCC (1997). This approach is too complicated to show here, but involves the following steps:

1. Divide the livestock population into animal and feeding practice categories. (This is also needed in the approach shown above, because not all animals will be able to have access to the most advanced measures). These distributions could be affected by the mitigation option.
2. Estimate feed digestibility (the proportion of energy in feed that is not excreted). This factor can be influenced by mitigation options.
3. Calculate the net energy requirements (NE) for maintenance, feeding, growth, lactation, work (drafting power), and reproduction associated with these functions. NE is a function of how the animal is fed (i.e., feed lot, pasture, range land), and the amount of production desired. Both of these factors can be affected by mitigation options.

4. Calculate the gross energy intake using information from step 3 (feed intake), step 2 (feed digestibility) and from step 1 (net energy).
5. Estimate the methane conversion rate (per cent of feed energy converted to methane). This can be affected somewhat by mitigation options, but is held constant in most studies.
6. Estimate the emissions factor in Eq. 32 as a function of gross energy intake and the methane conversion rate.
7. Use this information to evaluate Eq. 34.
8. Adjust the calculation of net emissions to account for increased emissions of CO_2 associated with the production of the inorganic N that is added to feeds to improve digestibility (if this option is utilised).

An example of this methodology is presented in USEPA (1995) in which a spreadsheet was utilised to calculate the reduction in methane from ruminant livestock in the Ukraine for a suite of mitigation options. This study showed that methane emissions could be reduced by about 35% by tripling the productivity of the livestock sector, using various mitigation options. While methane emissions per head actually rose by about 42%, animal numbers were reduced by about 50%, leading to a net reduction in methane emissions.

Animal husbandry: anaerobic fermentation

It is important to understand that the applicability of this mitigation option is limited to mitigating emissions from manure that is subject to anaerobic conditions. This means, primarily, manure that is collected and concentrated in lagoons or slurry / pit storage. Manure that is used on flooded rice paddies is subject to anaerobic conditions; however, this is integrated into the analysis on rice methane mitigation options. Manure that is deposited directly on fields has very low methane emissions. For example, according to IPCC (1997), manure that is managed as a liquid in Asia has a methane emission factor that ranges from 7 to 27kg / head / yr while the emission factor for manure used on fields runs from 1 to 3kg / head / yr. In Africa, where almost all manure is deposited directly on fields, the emissions factors are in the range of 0 to 2 kg / head / yr.

Thus, if the primary system of manure management in a country's baseline scenario involves spreading manure on fields, it may not be feasible to include this mitigation option, unless one also includes large changes in livestock management as a part of this mitigation option. These kinds of changes may not be feasible, if the distribution of livestock holdings is concentrated on small farms on which manure is the primary source of fertiliser. In this case, manure management can be associated with mitigation options to reduce nitrous oxide, but probably not methane mitigation.

A second caution regards the use of methane as a substitute fuel. Methane that is collected in digesters can be used to displace emissions from existing fuel. In the developed countries, the displaced fuel is usually a conventional fossil fuel, and the emissions that are displaced are primarily CO_2 emissions. However, in many cases in developing countries, and particularly on small farms, the substitute fuel is either wood or manure, mixed with straw. In the latter case, this manure comes directly from the livestock owned by the farmer that would have otherwise been deposited on the field. The emissions that are displaced, in this case, may be primarily nitrous oxide emissions, and not methane. Furthermore, the use of methane may involve the substitution of a cook stove for a conventional oven. However, it may be the case that the cook stove will not be a perfect substitute for the conventional oven, for example if it can not be used to bake bread in a traditional manner. If so, then there may be resistance to the adoption and diffusion of this technology, and the displacement of emissions would be incomplete. These considerations need to be factored into the analysis.

Finally, the substitution of inorganic fertiliser for manure fertiliser implies an increase in fertiliser production, causing additional greenhouse gas emissions. Thus, the decrease in methane emissions will be offset somewhat by these emissions. It is important that these additional emissions be included in the analysis, either under calculations for the energy sector, or else by using global warming potential factors to convert these additional emissions into methane emissions. These converted methane emissions should then be deducted from the emissions reduction achieved through the mitigation option.

Both IPCC (1997) and USEPA (1995) outline two approaches for estimating methane reductions from anaerobic decomposition of manure. For both methods, the first step involves identifying and categorising the livestock populations based on animal type and relevant manure management characteristics (manure deposited on fields, or collected in lagoons or in pit / slurry storage.

Using the simpler of the two approaches, the change in methane emissions in each category can be estimated as in Eq. 32. A more detailed procedure takes into account the variability in manure excretion rates, as outlined in IPCC (1997) and USEPA (1995) and involves the following general steps:

1. Estimate excretion rates as a function of estimated daily average feed intake, the percent of feed digested, and the ash content of the manure.
2. Estimate the annual emission factor in Eq. 32 as a function of daily average excretion rate, the maximum methane producing capacity of each animal type, the methane conversion factor for each type of manure management system, and the fraction of manure handled by each management system.
3. Use this information to evaluate Eq. 34.
4. Adjust the calculation of net emissions to account for increases in CO_2 emissions due to additional production of inorganic N.

Carbon storage on existing agricultural land: changing tillage practices

Estimating the effects of management on soil carbon is difficult for two reasons. First, there is very little literature and experimental data on this subject which can be easily transferred to developing countries. Second, because there are so many “local” factors that effect soil carbon, there is also bound to be fairly large variability in the response of soil carbon to a given management measure, depending on soil type, climate, crop, etc.

Where possible, it is recommended that models be used to estimate emissions reductions associated with various tillage options. Such models, which can be adapted to developing country use (for commercial agriculture) include EPIC (Williams et al., 1983, Jones et al. 1984, Sharpley & Williams 1990) and Century (Parton et al. 1992). For example, EPIC, can be used in conjunction with a two-equation model (Kern & Johnson, 1993) to estimate the effects of different tillage practices on soil carbon. EPIC is a multi-year simulation with daily time-step accounting that considers weather, soils, cropping rotations, planting dates, cultivation dates, fertility dates, herbicide applications, all types of tillage and management practices, and natural wind or water erosion process. It monitors soil fertility, soil organic content, soil moisture, and soil erosion, and has the capability to provide very accurate accounting of "before and after" sequestered soil carbon.

However, it is also possible to use simpler "parametric" calculations to model mitigation options in this category, and these are discussed below. The approach used by IPCC (1997) can be adapted for use in mitigation assessments of the impact of changes in tillage practices on CO_2 stored in soils. This involves four steps, as follows:

1. Identify those lands targeted for changes in tillage practices and subdivided them by soil type and tillage practice in the baseline scenario.
2. Estimate soil carbon in the baseline scenario on these lands, using experimental data, available soil maps / data, or using models like Century or EPIC.
3. Identify the tillage practices that will be modified and relate each change in tillage practice to the soils / land area identified in the baseline scenario.
4. Estimate the change in soil carbon stocks in each soil category as:

$$\Delta SC = (SC_m \cdot TF_m \cdot IF_m - SC_b \cdot TF_b \cdot IF_b) \cdot A \qquad \textit{Eq. 35}$$

where:

ΔSC	Change in the stock of carbon in soils.
SC	Soil carbon in t C / ha.
TF	Tillage factors which scale soil carbon, proportionally, to account for different tillage systems (no tillage, reduced tillage, full tillage) .
IF	Like tillage factors for different input systems (low, medium, high, manure fallow, shortened fallow).
A	Area in the soil category in ha.

Tillage and input factors are provided in IPCC (1997) for developing countries. However, these can be replaced with factors that are better suited for local conditions from published sources, or by use of expert judgement.

Carbon storage on existing agricultural lands: use of biomass crops as fuels that displace carbon dioxide emissions

Cropland can be used to grow biomass crops for producing fuel, and it can also be used to grow short rotation woody crops that can be used to produce fuel or which can be used directly in a boiler associated with electricity generation. The emissions from these fuels can be used to displace emissions from conventional fossil fuels, resulting in a net reduction in CO_2 emissions. For crops, the calculations may be performed using the following procedure:

1. Identify the lands on which biofuel crops will be grown.
2. Estimate the average annual yield for each type of crop in terms of kg / ha and multiply this by the harvested area to estimate total yield for each biomass crop.
3. Translate the total annual crop yield into an equivalent quantity of biofuel.
4. Estimate (a) the rate at which the biofuel can be substituted for the conventional fossil fuel to be displaced, and (b) the carbon content of the conventional fossil fuel
5. Estimate total annual displaced CO_2 emissions for the crop as:

$$\Delta CO2 = Fuel_m \cdot SF_m \cdot CC_m + \Delta CE_m \qquad \textit{Eq. 36}$$

where:

$\Delta CO2$	The annual displaced CO_2 emissions from the crop
$Fuel_m$	The amount of fuel produced by the crop in the mitigation case.
SF_m	The substitution rate at which the biofuel can be substituted for the fossil fuel
CC_m	The carbon content of the conventional fossil fuel in tC in the mitigation case.
ΔCE_m	The additional (or decreased) CO_2 emissions associated with biofuel production, including transportation, relative to the baseline.

For short woody rotation crops, the procedure in step 2, above, has to be modified slightly to account for the fact that the trees are not harvested annually, but every 3-8 years, or so. Since the rotation periods are fairly short, the best way to account for this is to simply estimate the total useable biomass yield at harvest and divide this by the rotation age to estimate average annual yield. The average annual yield is then multiplied by the total harvested area to obtain an estimate of total annual average useable biomass.

The conversion of wood biomass into displaced CO_2 emissions will depend on the nature of the technology used. To give an example, we assume that the harvested biomass can be used directly in a boiler to generate electricity. For these systems one can obtain information about the kWh produced per unit of dry biomass and use this factor to convert the biomass production into the average number of kWh hours displaced by the fuel. This can be converted into kW of generating capacity by multiplying by the total number of hours in a year and multiplying that by the capacity factor for the technology. Finally, the displaced capacity can be translated into total annual average displaced CO_2 emissions by multiplying the estimate of displaced capacity by the relevant emissions coefficient for the conventional fossil fuel that is being displaced, and by subtracting from this an estimate of the additional (or decreased) CO_2 emissions associated with the production of the woody biomass, including transportation, relative to the baseline scenario.

Carbon storage on existing agricultural lands: increasing carbon storage by planting windbreaks and shelter belts

The approach for measuring the change in carbon stocks as a result of planting windbreaks and shelter belts is based on methods used to estimate carbon stocks for many forest and land use mitigation. This will involve the following calculations:

1. Estimate the number of ha of trees of each variety that will planted that will be planted.
2. Calculate the annual carbon fluxes associated with each species, using tree growth models, or growth and yield tables and the associated carbon conversion coefficients (see Section 3 on Forestry) to create a time path estimate for carbon storage and fluxes from planting until maturity. The calculations should account for storage and fluxes in all parts of the ecosystem (bole, branches, roots, soil, understory, and forest floor).
3. Calculate the annual average flux and storage over the relevant time period for each species.

5 Technology database references

One common difficulty in conducting climate change mitigation analyses is the shortage of data characterising different technologies and their costs and performance. While it must be emphasised that nothing can truly substitute for local country-specific data, there are several data sources containing “generic data” which can provide a useful starting point for analyses. Some of these data sources are described below.

IIASA CO_2 Data Bank. The CO_2 Data Bank (CO2DB) was developed by the International Institute for Applied Systems Analysis (IIASA) in Austria. It contains approximately 1500 entries describing a wide range of technologies including energy supply- and demand-side technologies, fuel extraction and conveyance, and passenger transportation. The entries contain, with varying degrees of detail, information on energy consumption, capital costs, operations & maintenance costs, pollutant emissions, and source references. The CO2DB contains significant amounts of both European and North American data as well as a limited amount of data from developing countries. The CO2DB is provided as an electronic database through an interactive software program.

The CO2DB is distributed free of charge to non-profit-making organisations and can be obtained by sending a written request to the IIASA project leader at the following location:

Dr. N. Nakicenovic
Environmentally Compatible Energy Strategies
IIASA
Schlossplatz 1
A-2361 Laxenburg
Austria

IPCC Inventory of Technologies, Methods, and Practices for Reducing Emissions of Greenhouse Gases. The Intergovernmental Panel on Climate Change has produced this database as a technical appendix to the Climate Change 1995 Working Group II Second Assessment Report. The IPCC Inventory contains approximately 100 technologies, including energy supply, end-use, fuel extraction, and passenger transportation. The data is concentrated on U.S. technologies and processes.

The IPCC Inventory can be accessed through the World Wide Web at the following address:

http://www.energyanalysis.anl.gov/1-vol1.htm

Printed copies may be available in limited quantities through Argonne National Laboratory in the U.S. by contacting the following:

Dr. David G. Streets, Ph.D.
Director
Policy and Economic Analysis Group
Decision and Information Sciences Division
Argonne National Laboratory
9700 South Cass Avenue, DIS/900
Argonne, IL 60439-4832
USA
Tel. +1-708-252-3448
Fax. +1-708-252-3206
email: streetsd@smtplink.dis.anl.gov

Environmental Management for Power Development (EM Model). The EM Model is a computer software package and database developed by the German aid agency GTZ, the Oeko-Institut, and the World Bank. The software performs environmental analysis of energy supply technologies by analysing the full fuel chain, including fuel extraction, transportation, combustion, and conversion. The software contains generic data on a wide range of technologies and processes including costs and detailed pollutant emissions.

The EM Model is available free-of-charge from the World Bank on the World Wide Web at the following address:

http://www.worldbank.org/html/fpd/em/emhome.htm

Further information can be obtained by contacting:

Joseph Gilling, The World Bank, Industry & Energy Division, Washington D.C., USA; Phone +1-202-473-3230, Fax +1-202-477-0558

or

Tilman C. Herberg, GTZ Energy & Transport Division, Eschborn, Germany; Phone +49-6196-79-1619, Fax +49-6196-79-7144

CEC Energy Technology Status Report. The Energy Technology Status Report (ETSR), published by the California Energy Commission (CEC), is a multi-volume document describing a very wide variety of supply-side and end-use energy technologies and processes including coal, oil, and gas combustion, nuclear, geothermal, hydroelectric, biomass, municipal solid waste, cogeneration, wind, solar thermal, photovoltaics, ocean energy, fuel cells, storage systems, pollution control, water heating, space heating, space cooling, lighting, appliances, boilers, motors, load management, and transmission technologies. The coverage includes qualitative descriptions of the technologies, barriers to implementation, and quantitative economic analysis.

The last ETSR was published in 1991, but a new edition is expected to be available by the end of 1996. There is a charge for this large document, but the price is very reasonable compared to other commercially available data.

The CEC's World Wide Web site can be accessed at:

http://www.energy.ca.gov/

The ETSR can be ordered through the CEC's publications department at the following telephone number: +1-916-654-5200.

Technical information regarding the ETSR can be obtained by contacting:

Mr. Pramod Kulkarni
Energy Technology Development Division
California Energy Commission
1516 Ninth Street
Sacramento, CA 95814
USA
Telephone: +1-916-654-4637
Fax: +1-916-653-6010

E Source. E Source is a membership-based commercial organisation providing energy efficiency technology information to consulting firms, utilities, governments, and research institutions. E Source is perhaps the most complete source of end-use technology data and publishes, among other things, five comprehensive technology atlases (or "encyclopaedias") covering lighting, drivepower, space cooling & air handling, space heating, and residential appliances. These five atlases are over 1700 pages in total length and include theory, design tips, and performance and cost information. E Source also publishes a variety of reports on a regular basis including recent technology developments, product reviews, application issues, case studies, and newsletters.

Organisations must become members of E Source in order to access the various reports. Membership fees depend on the size and type of organisation but tend to be US$5000 and up per year.

E Source's World Wide Web site can be accessed at:

http://www.esource.com/

Further information can also be obtained by contacting:

Tony Foster
E Source
1033 Walnut Street
Boulder, Colorado 80302-5114
USA
Telephone: +1-303-440-8500
Fax: +1-303-440-8502
email: esource@esource.com

ACEEE. The American Council for an Energy-Efficient Economy (ACEEE) is a non-profit organisation dedicated to advancing energy efficiency as a means of promoting both economic prosperity and environmental protection. Among other things, ACEEE publishes a variety of books and reports and organises conferences related to energy efficiency.

ACEEE publications include useful energy efficiency design guidance through books and reports such as "Energy-Efficient Motor Systems," "Financing Energy Conservation," "Improving Energy Efficiency in Apartment Buildings," and "Energy Efficiency and the Pulp and Paper Industry."

A list of available publications and other information about ACEEE can be accessed through their World Wide Web site at:

http://solstice.crest.org/efficiency/aceee/index.htm

ACEEE publications are modestly priced (US$5 - 30) and can be ordered through:

American Council for an Energy-Efficient Economy
2140 Sciatic Avenue, Suite 202
Berkeley, CA 94704
Fax: +1-510-549-9984
Telephone: +1-510-549-9914
email: ace3-pubs%ace3-hq@ccmail.pnl.gov

EPRI TAG. The Electric Power Research Institute (EPRI) is a research organisation jointly financed by U.S. investor-owned electric utilities. EPRI publishes a set of useful Technical Assessment Guides commonly known as TAG. The TAG reports provide information on electric supply-side and demand-side technologies, assessment methods, and data. Each report costs US$1000 to non-U.S. organisations. EPRI reports can be ordered through:

EPRI Distribution Center
207 Coggins Drive
P.O. Box 23205
Pleasant Hill, CA 94523
USA
Telephone: +1-510-934-4212

GREENTIE. GREENTIE is a project of the IEA to provide information about energy technologies. Though GREENTIE does provide some technology information, its main function at this time is as a directory of companies and organisations working with the various technologies. The GREENTIE database could be useful for countries that are contemplating developing a particular technology option and are looking for technical expertise and partners in the particular technology.

GREENTIE can be reached at the following:

GREENTIE
Swentiboldstraat 21
P.O. Box 17
6130 AA Sittard
The Netherlands
Tel. +31-46-420-2203
Fax. +31-46-451-0839
email: nlnovbas@ibmmail.com
web: http://www.greentie.com