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Guidelines For Climate Change Global Overlays

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Guidelines For Climate Change Global Overlays

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Contents

1 Purpose Of This Guidelines Document

A key objective of these guidelines is to enable Bank staff and client country counterparts to extend their sector work by including GHG emission impacts and possible GHG mitigation options in their analyses. This document also provides guidance for including GHG externalities in economic analyses when (a) payments related to the project are made under international agreement, or (b) project and project components are financed by the Global Environment Facility (GEF) (OP 10.04). Furthermore, these guidelines have been developed within the context of Parties' obligations under the Framework Convention on Climate Change (FCCC), recognizing that country communications on GHG emission inventories and mitigation programs are under development and/or have been prepared.

The global overlay tool is intended as a modest extension of current sector work and relies primarily on much of the data, tools, and models currently used in the Bank's work. Given the broad diversity of the work conducted by the Bank (in terms of scope, resources, data, tools, and models) the framework presented here is necessarily flexible to allow application to a broad range of circumstances. The framework is also designed to be compatible with the GEF operational strategy in climate change (Exhibit 1-1).

These guidelines on global overlays have been developed for two main sectors - the energy sector and the forestry sector. For each of these areas, we also address how to evaluate the macroeconomic implications of GHG mitigation options. Exhibit 1-2 illustrates the structure of the global overlays and their relationship to existing data, tools, and models. Currently, the Bank's sector work relies on macroeconomic forecasts and technology and emissions data, combined with sectoral models of the region or country to develop a Reference Scenario. Incorporating the Bank's policies and interventions with these tools and data produces a Reform Scenario.

The global overlay adds to this framework a process for assessing the emissions implications of the Reference and Reform Scenarios, screening GHG mitigation options, ranking and selecting a number of these options based on multiple criteria to form a GHG Mitigation Scenario, and for assessing the emissions and cost implications of the Mitigation Scenario. Evaluation of the macroeconomic impacts accompany both analytic frameworks. There are five steps to conducting a global overlay: (1) developing GHG emissions estimates under a Reference Scenario, (2) developing emissions estimates under a Reform Scenario, (3) identifying mitigation options and screening on the basis of cost-effectiveness and other criteria, (4) formulating a GHG Mitigation Scenario, and (5) comparing these results with the Reform Scenario. These are described in Exhibit 1-3.

EXHIBIT 1-1. GEF OPERATIONAL STRATEGY

The overall strategic thrust of GEF-financed climate change activities is to support sustainable measures that minimize climate change damage by reducing the risk, or the adverse effects, of climate change. The operational criteria for these GEF activities will be developed in accordance with this strategy and with GEF policies. The initial focus of GEF activities is on enabling activities that specifically support national communications. However, as the GEF builds on this foundation, the emphasis will switch to long-term measures, which will constitute the largest share of the GEF climate change portfolio, with enabling activities and short-term mitigation projects constituting only a small share of the portfolio.

In line with the recommendations of the GEF's Scientific and Technical Advisory Panel (STAP), *long-term* programs will be developed to expand, facilitate, and aggregate the markets for the needed technologies and improve their management and utilization, resulting in accelerated adoption and diffusion. The emphasis will be three-pronged:

- *Removal of barriers* to implementation of climate-friendly, commercially viable *energy-efficient technologies and energy conservation measures*
- *Removal of barriers and reducing implementation costs* of commercial and near-commercial *renewable energy technologies*
- *Reduction of the cost* of prospective technologies that are not yet commercially viable, to enhance their commercial viability

The following considerations will guide appraisals for *short-term* projects:

- *Cost-effectiveness.* Cost-effective projects are those that mitigate a specified amount of greenhouse gas emissions for a given cost, typically a low unit abatement cost (approximately less than or equal to $US10 per ton of carbon).
- *Likelihood of success.* When a project's funding is seen to be justified primarily in terms of the expected carbon abatement resulting from the project itself, it must have a high probability of success.
- *Country-driven.* Proposed short-term projects must be country driven and have the country's highest priority for funding.

Exhibit 1-2. Current Bank Sector Work

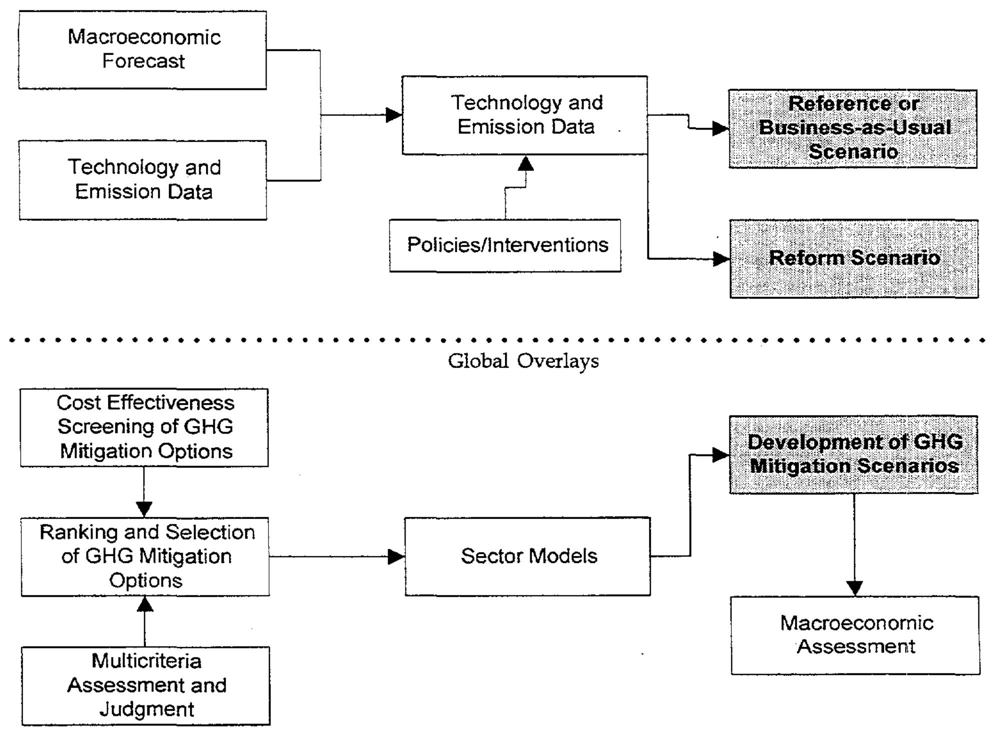


Exhibit 1-3. Methodological Framework for Global Overlays

Step 1: Develop estimates of GHG emissions under the Reference or Business-as-Usual Scenario. These emissions levels would be expected to occur in the country or region with no involvement from the Bank on issues of broad sector policy or reform, or in the specific area of GHG emissions. These estimates would reflect expectations for macroeconomy, structural and technological change for consumption, and production technologies.

Step 2: Develop emissions estimates under the Bank Reform Scenario to assess how the pricing, policies, and other interventions that comprise this scenario are expected to affect economic activities and, consequently, GHG emissions. These estimates should not only focus on emissions within a given country, but should also factor in any emission changes that may occur globally as a result of the policies adopted. The differences between the Reference and Reform Scenarios indicate the emissions and cost impacts of the Reform Scenario.

Step 3: Identify, evaluate, and screen (on the basis of cost-effectiveness or other criteria) a range of GHG mitigation options. These options may collectively comprise a broad sectoral strategy and encompass many individual projects. For example, they may represent a range of specific projects with the goal of increasing the use of domestic natural gas reserves. Alternatively, they may focus on increased end-use efficiency (over any level included in the Reform Scenario) through pricing policies and specific demand-side management activities.

Step 4: Formulate alternative Mitigation Scenarios comprised of mitigation options and/or policies and estimate the GHG impacts of each scenario.

Step 5: Compare the Mitigation Scenario developed in Step 4 with the Reform Scenario. The differences in costs and emissions between the two scenarios indicates the cost and cost-effectiveness of GHG emissions reductions.

2 Use Of This Guidelines Document

To use this document as an extension to the Bank's economic and sector work, readers can select those portions of the document most directly relevant to the work being conducted. All readers are encouraged to review Chapter 3 for an understanding of the basic concepts used throughout this document. After reviewing this chapter, one can choose which substantive area is of most interest to integrate global climate change externalities into the Bank's economic and sector work. The three major areas for consideration are:

- *Chapter 4: The Energy Sector.* This chapter reviews the GHG implications of the various energy supply and demand options that may be considered in the Bank's work, and how to incorporate these impacts into the Bank's work.
- *Chapter 5: The Forest Sector.* This chapter discusses the processes of carbon storage and emissions from forestry and land-use policies, and how to factor these considerations into the Bank's work.
- *Chapter 6: Macroeconomic Analysis.* This chapter discusses how to evaluate the relationship between GHG emissions and macroeconomic activity, particularly as it relates to traditional Bank-supported actions and additional actions the Bank could support to reduce GHG emissions.

Each of these chapters is designed as an extension to the Bank's economic and sector work so that the reader can use the information as an overlay onto this existing work. In all cases the use of climate change global overlays is intended to augment, not replace, existing Bank work. Use of global overlays can also assist countries in meeting various requirements under the FCCC, as described in Exhibit 2-1.

Exhibit 2-1. Meeting Commitments Under the Framework Convention on Climate Change (FCCC)

Article 12 of the FCCC describes the commitments of Parties to communicate information related to implementation of the Convention. Under terms of this Article, each Party agrees to provide: (1) a national inventory of anthropogenic sources and sinks of all GHGs not covered by the Montreal Protocol; (2) a general description of steps taken or envisaged by the Party to implement the Convention; and (3) any other information considered relevant to achieving the objective of the Convention. Annex 1 countries (which includes Eastern Europe and the former Soviet Union) also agree to provide a detailed description of the policies and measures adopted to implement commitments under Article 4 and to estimate the effect of these policies and measures on GHG emissions from both sources and sinks. Furthermore, developing country Parties may propose projects for financing that include, if possible, an estimate of all incremental costs, reductions in emissions and removals of GHGs, and consequent benefits from the project. Given these commitments, climate change global overlays can assist countries in meeting their commitments under the FCCC since GHG impacts of possible investment actions need to be estimated.

3 Basic Concepts

3.1 What is a Reference or Business-as-Usual Scenario?

The Reference, or Business-as-Usual Scenario typically developed in Bank sector work reflects those actions expected to be taken by the country (or region) under study without any specific Bank-supported policies, actions, or interventions. This scenario essentially provides a base case of future actions or investments that the country (or region) would expect to occur using the most accurate assessment of likely future economic and social conditions in the absence of participation by the Bank. For example, if a country's energy development plans call for the installation of 1000 megawatts of conventional coal-fired electric generating capacity each year for the next 20 years as part of the electric utility industry's standard investment strategy, then these coal-fired investments would be considered part of the Reference Scenario. Similarly, the GHG emission estimates associated with these investments would reflect the GHG emissions levels associated with a continuation of the current path of energy production and usage. As its name suggests, the Reference Scenario acts as the point of reference in analyzing the potential impacts of Bank-recommended policies on the country.

3.2 What is a Bank Reform or Economic Efficient Scenario?

The Bank Reform, or Economic Efficient, Scenario represents changes to the Reference Scenario due explicitly to any Bank-assisted actions to move towards economic efficiency. That is, as the Bank finances various investments, these investments influence the future economic trajectory of the country.

To be acceptable on economic grounds, a Bank-financed project must meet two conditions: (a) the expected net present value of the project must not be negative, and (b) the expected net present value of the project must be higher than or equal to the expected net present value of mutually acceptable project alternatives. For other projects, physical indicators of achievement in relation to costs (cost-effectiveness) are appropriate. In other cases, such as institutional reform, , a qualitative account of the expected net development impact might have to suffice. In all cases, however, the economic analysis should give a persuasive rationale for why the benefits of the project or policy are expected to outweigh its costs — in other words, why the net development impact of the project or policy is expected to be positive. The revised trajectory resulting from the Bank's actions is the Reform Scenario.

By comparing different attributes of the Reform Scenario - such as investment and employment impacts - to the Reference Scenario, one can define the specific accomplishments of Bank-supported actions. For instance, in the example cited earlier, a Reform Scenario could include any Bank-supported actions that caused the country to modify its initial investment plans to increase the total efficiency of the combustion process and minimize local environmental problems - such as installing state-of-the-art coal combustion technology. One difference between the two scenarios would be any differences in GHG emissions, with the GHG emissions of the Reform Scenario reflecting the GHG implications of a country adopting Bank reform policies. The global overlay process presented in these guidelines can be used to measure these GHG emission impacts.

3.3 *What is a Mitigation or Lower Carbon Scenario?*

In addition to using the concept of global overlays to evaluate the GHG emission impacts of scenarios defined in standard Bank economic and sector work, it can also be used to establish a Mitigation, or Lower Carbon, Scenario. This scenario identifies the action(s) that would result in lower emissions of GHGs compared to the Reform Scenario. That is, it specifically evaluates changes to more traditional Bank investment practices by identifying the potential for and costs of GHG emission reduction options. The Mitigation Scenario could include specific project impacts - such as changing the type of technology to be used for a given project to a lower carbon-emitting technology, or it could include broader sectoral actions - such as policies designed to alter pricing patterns (e.g., a carbon or energy tax). In the example cited above, the Mitigation Scenario could involve the installation of integrated coal gasification/combined cycle technology for generating the electricity. The differences in costs and emissions between the Mitigation Scenario and the Reform Scenario using the global overlay concept would define the advantages or disadvantages of adopting the actions reflected in the Mitigation Scenario.

3.4 *Estimating Emission Impacts for a Global Overlay*

The emission impacts of Bank-supported actions can be estimated using the GHG emission inventory guidelines developed by the IPCC. These guidelines were devised to assist countries when developing national inventories for reporting under the FCCC (See Exhibit 3-1). This information is a useful starting point for developing emissions estimates for the Bank's Reference and Reform Scenarios, and can also be applied to the Mitigation Scenario. The discussions on emission estimation presented in these guidelines for conducting global overlays rely on the conceptual framework developed and presented in the IPCC guidelines.

Exhibit 3-1. The Intergovernmental Panel on Climate Change Guidelines for National GHG Inventories

Signature of the U.N. Framework Convention on Climate Change (FCCC) by over 150 countries in June 1992 indicated widespread recognition that climate change is potentially a major threat to the world's environmental and economic development. A key objective of the Convention is the stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. As a step toward this goal, the Parties to the Convention agreed to develop and periodically update their national inventories of anthropogenic emissions by source and removals by sinks of all GHG not controlled by the Montreal Protocol. The IPCC has developed guidelines for National Greenhouse Gas Inventories approved by the Scientific Assessment Working Group of the IPCC and adopted at its 10th session in Nairobi. The Guidelines represent substantial progress towards the understanding of GHG emission inventories, and provide a common methodology to be used by signatory countries in developing their inventories.

Source: UNEP/OECD/IEA/IPCC. 1995. IPCC Guidelines for National GHG Inventories Volume 3: GHG Inventory Reference Manual. IPCC: Bracknell, United Kingdom.

It is important to note that, while these guidelines rely in part on the IPCC Inventory Guidelines for its analytic framework, there are differences in objectives between the two documents. The World Bank emissions assessments do not share the same goal as the IPCC inventory (i.e., a complete inventory of GHG emissions in the country or region). Instead, these guidelines provide a framework for quantifying *changes* in emissions from the Reference to the Reform Scenario and the potential for, and costs of, GHG emissions reductions in a Mitigation Scenario. Therefore, the *differences* in emissions and costs are important. Since *differences* in costs and emissions between scenarios are important, the analysis should emphasise those sources that are expected to be affected in the Reform and/or Mitigation Scenarios. For example, if emissions from coal mining are not expected to change between the Reference and Reform Scenarios, it is not necessary to include these calculations in the emissions baseline. On the other hand, you may want to include these emissions if they are an increasingly important source of emissions and a potential source of emissions reductions in the Mitigation Scenario, or if the sector affects the macro-economic results. In general, there is no need to quantify emissions for those sectors that are not expected to contribute significant GHG emissions, are not expected to change significantly over time, or are not expected to be affected by Bank-assisted actions, programs, or policies. For example, the IPCC includes among its category of activities to be included the emissions associated with bunker fuels used for international marine or aviation purposes. If it is the case that no changes are expected in bunker fuels, then it is not necessary to estimate the carbon emissions associated with their use. Similarly, development of inventories requires an assessment of net increases or decreases in fuel stocks. If policies and actions under the Bank's Reform or Mitigation Scenarios are not likely to affect fuel stocks substantially, there is no need to calculate these emissions.

In the course of evaluating possible mitigation actions that could be undertaken to minimize GHG emissions, one must be able to compare impacts across a wide variety of different types of actions. This is true not only because GHG-emitting activities occur in virtually all Bank economic and sector work, but these activities also produce a variety of GHGs, including CO_2, CH_4, and N_2O. To compare the effects of different GHGs, the concept of Global Warming Potential (GWP) has been constructed to allow one to express all GHGs on a common basis. See Exhibit 3-2 for further discussion.

Integrating global concerns into the Bank's regular economic and sector work will require on-going awareness of the latest scientific and technical information. The global overlay guidelines presented here are an important first step reflecting the most recent information available. There will continue to be a need, however, to stay up-to-date on the latest developments. While no single source of information can meet all needs, one excellent United Nations-supported effort to increase access to the latest information is discussed in greater detail in Exhibit 3-3.

Exhibit 3-2. Selected GHG Characteristics

Expressing reductions of different GHGs (e.g., CO_2, CH_4, N_2O) on a common basis makes comparison of very different GHG mitigation options possible. Gases can contribute to climate change in two ways: directly and indirectly. Direct radiative forcing occurs when the gas is itself a GHG, while indirect forcing occurs when chemical transformation of the original gas produces GHGs, or influences the atmospheric lifetimes of other GHGs. The contribution of a gas to the greenhouse effect primarily depends on its atmospheric concentration and the wavelength at which it absorbs infrared radiation.

The concept of the Global Warming Potential (GWP) has been developed to compare the ability of each GHG to trap heat in the atmosphere relative to another gas. Because it is the most prevalent anthropogenic GHG, carbon dioxide is often chosen as the reference gas against which to measure the impacts of these other gases.

The GWP of a GHG is the ratio of global warming, or radiative forcing (both direct and indirect), which results from one kilogram of a GHG relative to one kilogram of carbon dioxide over a specified period of time. The IPCC has developed GWPs for the direct effects of a variety of gases for 20, 100, and 500 year timeframes, as shown below . The indirect effects are highly uncertain and cannot readily be quantified at this time. Only the direction of the indirect effect is indicated in the table. The IPCC recommends using a timeframe of 100 years as a basis in analysis.

Direct Global Warming Potentials (GWP) of Gases

Species	Chemical Formula	Atmospheric Lifetime	Direct Effect for Time Horizons of 20 years	100 years	500 years	Sign of "Indirect" Effect
Carbon Dioxide	CO_2	a	1	1	1	none
Methane[b]	CH_4	14.5±2.5[c]	62	24.5	7.5	positive
Nitrous Oxide	N_2O	120	290	320	180	uncertain
CFC-11	$CFCl_3$	50±5	5,000	4000	1,400	negative
CFC-12	CF_2Cl_2	102	7,900	8,500	4,200	negative
HCFC-22	CF_2HCl	13.3	4,300	1,700	520	negative
HFC-134	CHF_2CHF_2	11.9	3,100	1,200	370	none
HFC-152a	$C_2H_4F_2$	1.5	460	140	44	none
Carbon-Tetrachloride	CCl_4	42	2,000	1,400	500	negative
Carbon Monoxide	CO	months	-	-	-	positive
Non-Methane Hydrocarbons	NMHCs	days to months	-	-	-	positive
Nitrogen Oxides	NO_x	years	-	-	-	positive

aDecay of CO_2 is a complex function of the carbon cycle. Its effective atmospheric residence time is on the order of 75-150 years.
bIncludes the direct effect and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of carbon dioxide is not included.
cThe adjustment time is given rather than the lifetime.

Source: Referenced to the absolute GWP for the Bern carbon cycle model CO_2 decay response and future CO_2 atmospheric concentrations held constant at current levels (based on IPCC 1994 Draft and WMO 1994) as cited in the Guidelines, p. E.3. Updated to reflect IPCC 1995

Exhibit 3-3. Staying Abreast of the Latest Climate Change Developments.

One international source for recent information on climate change is CC:INFO. CC:INFO is the Climate Convention Information Exchange Programme created in 1993 jointly by the interim secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Environment Programme (UNEP). The main objective of CC:INFO is to improve the exchange of information (1) among organizations that are supporting climate change activities, (2) between these organizations and countries, and (3) within countries themselves. Ultimately, CC:INFO facilitates the process of implementation of the Climate Convention. CC:INFO does not itself provide resources, only information about their availability.

CC:INFO is implemented under the umbrella of CC:COPE, an acronym used to describe the activities undertaken by the secretariat in the field of technical cooperation. At this stage, CC:COPE consists of the following main elements: CC:INFO, CC:FORUM (an informal consultative mechanism to exchange experiences on the implementation of projects), CC:TRAIN (the Climate Convention Training Programme operated jointly with the United Nations Institute for Training and Research [UNITAR]), and a number of information, coordination, and advisory activities. The secretariat provides assistance to countries for enabling activities and for national communications, including advice to the secretariat of the Global Environment Facility (GEF). CC:INFO can be reached via the Internet at http://www.unfccc.de

4 Energy Sector

4.1 Introduction

The World Bank energy-related and economic and sector work (ESW) analyzes demand and supply conditions, government institutions and policies, investment priorities, development programs, policies, and constraints and environmental issues associated with the energy sector in borrowing countries around the world. Energy sector work encompasses studies of the electric power market, fuel options, energy conservation opportunities, and institutional and market reform. ESW analyses are the foundation of the Bank's assistance to its borrowers and provide the framework for the Bank's lending program and policy advice.

Global overlays for climate change provide a framework for incorporating global environmental considerations - specifically emissions of greenhouse gases (GHGs) - into the analyses currently conducted by the Bank. Global overlays have particular relevance to the energy sector because this sector is responsible for a significant share of greenhouse gas (GHG) emissions worldwide and also because many mitigation options exist to reduce emissions from the sector.

4.1.1 "Top-Down" and "Bottom-Up" Approaches

The Bank's sector studies are conducted using alternative methodological approaches that can be classified into two broad categories: "top-down" approaches and "bottom-up" approaches. Top-down approaches comprise short-run macroeconomic and long-run general equilibrium models that look at the overall impact of policies on the economy (e.g., imposition of a carbon tax or introduction of price reforms). These models treat energy as a production input and associate any restrictions on energy consumption with a positive cost, assuming production is efficient.

Top-down models have limited applicability to modeling GHG mitigation options because they do not contain sufficient technological detail to evaluate the effect of specific investments. Also, because the models assume that energy is used efficiently, they may overstate the costs of GHG mitigation options. To the extent that energy is used inefficiently (e.g., because of lack of information, unfavorable institutional arrangements, and price distortions), GHGs could be abated at a low, or even a negative, cost.

Top-down models are typically used to evaluate the effects on GHG emissions and costs of broad, sector-wide interventions and policies, such as pricing reform. They are required to capture the links and feedbacks between the energy sector and the rest of the economy and focus less on the detailed operation of the energy sector.

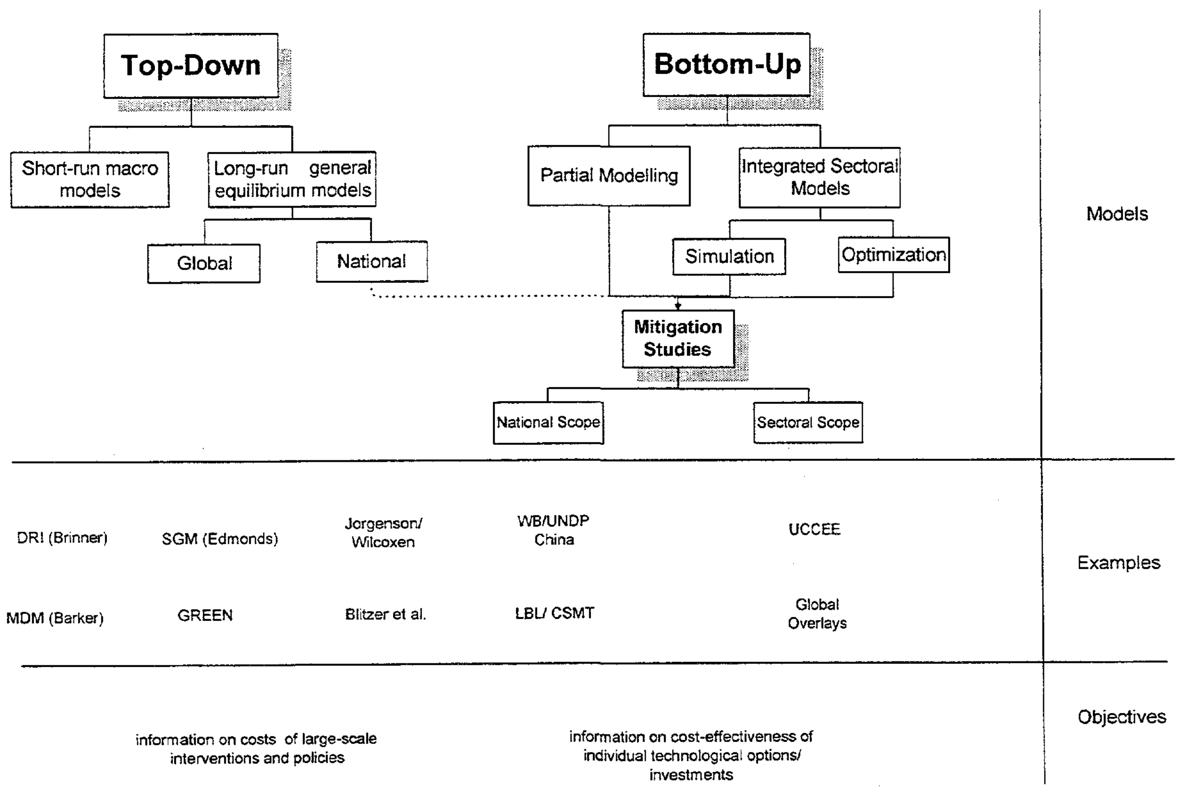
Bottom-up approaches include partial and full energy system models (often based upon linear programming techniques). These models are based on least-cost planning approaches that integrate supply- and demand-side aspects of energy planning. These models use engineering estimates of costs for individual options and combinations of measures.

Because they contain detailed information on the cost-effectiveness of specific technologies, bottom-up models are used to evaluate individual mitigation options in the energy sector. However, unlike the top-down approach the bottom-up approach generally ignores the feedback effects that may occur between the energy sector and the rest of the economy.

Exhibit 4-1 shows that the difference in methodology and professional orientation between top-down and bottom-up approaches is matched by a difference in objectives. It also indicates that mitigation studies may combine a bottom-up approach on a partial modelling basis or sectoral integration basis with a macro-economic assessment component that is derived with a top-down approach.

Despite its limitations, the bottom-up approach is more appropriate for evaluating specific GHG reduction measures and it is often the approach used in mitigation studies. These studies often combine the bottom-up approach with some form of macroeconomic analysis (see Chapter 6), which helps partially overcome the approach's shortcomings. These Guidelines generally describe an approach to evaluating GHG mitigation options using a bottom-up approach. In addition, discussions of the Mitigation Scenario assume that bottom-up approaches are used in the sector work.

Exhibit 4-1: Typology Of Greenhouse Gas Abatement Cost Studies



4.1.2 *Scope of the Guidelines*

This chapter discusses GHG mitigation options in the main energy production and consumption sectors within an economy, including the electric power sector, natural gas production, coal mining, and the residential, commercial, and industrial end-use sectors. Further, emissions from all the major GHG-generating energy sources and fuels are relevant to the discussion in this chapter, including electricity, coal, natural gas, petroleum products, and biomass.

To allow for a careful accounting of all emission sources, emissions inventories for the Reference, Reform and Mitigation Scenarios should be estimated for all activities which fall within the scope of the sector work to which the global overlay is being applied. Similarly, when evaluating GHG emissions mitigation options, all sectors should be included. Exhibit 4-2 summarizes the following potential sources by GHG.

Exhibit 4-2: Anthropogenic Sources of GHG Emissions

CO_2 Emissions
- Fossil Fuel Combustion
- Cement Production
- Gas Flaring

CH_4 Emissions
- Coal Mining
- Natural Gas and Petroleum Production
- Biomass Burning

N_2O Emissions
- Biomass Burning
- Stationary Combustion

- **Combustion emissions from burning fossil and biomass fuels** for all sectors being considered, including direct combustion of fossil fuels and biomass by end-use sectors and direct combustion of these same fuels for electricity generation (including associated parasitic loads, such as power plant loads, compression stations, and pollution control equipment). Predominant emissions from these sources include CO_2 and N_2O.

- **Emissions from coal mining and handling activities.** The most significant emissions that occur during these activities are emissions of CH_4, although other gases may be emitted from accidental coal mine fires and burning of coal in waste piles.

- **Fugitive emissions from oil and natural gas activities,** including production, processing, and transport, and from non-productive combustion of oil and gas. Here again, the most significant emissions that occur are CH_4 emissions.

The scope of these guidelines is currently limited to emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) because these are the most abundant GHGs globally. In addition, options in the energy sector offer the greatest potential to reduce these gases. The Bank's work currently considers the value of reductions (or increases) in certain other emissions, including SO_2 and NO_x, so these are not discussed here. However, this chapter discusses evaluating the ancillary impacts of GHG reduction option activities on these emissions. The remainder of this chapter is organized into the following four sub-chapters.

- *Chapter 4.2* develops an approach to estimating the GHG emissions inventory associated with these two scenarios which are typically developed as part of the Bank's energy sector work, as well as considerations in developing projections of future years' emissions. Carbon dioxide emissions associated with fuel combustion, coal mining, and oil and gas production are evaluated using a top-down approach. This chapter also discusses the bottom-up approach to estimating CO_2, N_2O, and CH_4 emissions.

- *Chapter 4.3* discusses the methodological and conceptual issues which must be addressed when evaluating classes of GHG emission reduction activities and strategies. In addition, it provides a specific discussion for each class of options.

- *Chapter 4.4* describes how to select a portfolio of options to include in a Mitigation Scenario designed to achieve some specified reduction in GHG emissions. This chapter also discusses how one would go about ranking and selecting from a broad range of options to develop scenarios which achieve certain reductions in emissions. Important considerations in evaluating these Mitigation Scenarios are also reviewed.

- *Chapter 4.5* describes how to use the information developed in screening analysis of GHG mitigation options to develop GHG Mitigation Scenarios.

4.2 Developing Emissions Estimates for the Reference (or Business-As-Usual) and Reform Scenarios

This chapter provides instructions on estimating the GHG emissions associated with the Reference and Reform Scenarios. The Reference, or Business-as-Usual Scenario, reflects the GHG emissions levels associated with a continuation of the current path of energy production and usage. The GHG emissions inventory of the Reform Scenario reflects the GHG implications of a country adopting Bank reform policies that affect energy production and use, and associated emissions, either directly or indirectly through other sectors of the economy.

Developing an emissions inventory under the Reference and Reform Scenarios requires that an emissions profile for the base year (typically an historical year) be developed using data on energy production, transformation, handling, and consumption. Base year emissions would be the same for both scenarios. This chapter describes estimating emissions associated with these scenarios for a base year.

The energy production, transformation, handling and consumption profile for the base year should then be extended to future years based on macroeconomic forecasts of variables such as economic growth and fuel prices. Emissions estimates for these future years should be developed consistent with the base year. As discussed in Chapter 4.2.4, future years' emissions can be developed in a similar way or by using simpler approaches.

4.2.1 Emissions from Fuel Combustion

The first step in estimating the CO_2 emissions associated with the Reference and Reform Scenarios is to develop an emissions inventory for the base year. The base year may be an historical year or a future year for which projections have been developed. As discussed later, developing a base year emissions inventory provides a basis for projecting future years' emissions.

4.2.1.1 Scope of the Assessment

The emissions inventory should be estimated for both indigenous and imported fuels to account for global externalities associated with emissions of GHGs. This is particularly important if, over time, the balance of imported and domestic fuels is expected to change in the Reference or Reform Scenarios. Ignoring emissions from the production of imported fuels could potentially misstate total emissions and the benefits of mitigation options. Also, as discussed earlier, it is important to note that while these guidelines rely in part on the IPCC Inventory Guidelines for its analytic framework, World Bank emissions assessments do not share the same goal as the IPCC inventory, i.e., a complete inventory of GHG emissions in the country or region. Most significantly, since *differences* in cost and emissions between scenarios are important for the World Bank's work, it is only necessary to include in the emissions calculations those sources which are expected to be affected in the Reform and/or Mitigation Scenarios. As a result, it is not necessary to quantify emissions for those sectors which are not expected to contribute significant GHG emissions, are not expected to change significantly over time, or are not expected to be affected by World Bank proposed actions, programs, or policies.

4.2.1.2 "Top-Down" Approach to Estimating CO_2 Emissions from Fuel Combustion

CO_2 emissions from fuel combustion can be estimated using a "top-down" or "bottom-up" approach. The top-down approach is so called because it works from the highest level of energy data - accounting only for the total quantities of fuels consumed, without regard for how they are ultimately consumed. This contrasts with the bottom-up approach, which relies on estimates of energy consumption at the technology and end-use level.

The approach used to estimate fuel consumption for GHG emissions depends on the scope of the sector work and the information available. Some sector work encompasses a review of a country's entire energy sector, while others focus on only a province or state within a country. Still others focus on a subsector of the energy economy, such as the power sector, industrial energy use, or a subsector of industry, such as the iron and steel industry. The level of information and the sources used will vary depending on the scope of the analysis. For example, when developing emissions for a country's total energy sector, consumption can be estimated based on the total quantities of fuel produced indigenously, and the total quantity flowing into and out of the country or region.

For studies of subsectors within the energy economy, the top-down approach is based on estimates of total fuel consumption within the sector.[1] For example, a top-down approach could be applied in the power sector, where total fuel consumption is readily available for the industry, if information on emissions by unit or plant type is not critical.

These top-down approaches are comprised of six general steps as outlined below. Each is reviewed in more detail in this chapter. The next chapter reviews the bottom-up approach in greater detail.

- *Step 1: Estimate Total Fuel Consumption.* Estimate total consumption of fuels by fuel product type for the sector or subsector (e.g., power sector, industry) and geographic area (i.e., the nation, state, or province) under study for the base year and for each year of the analysis. For a full energy sector analysis, this requires estimating total primary fuels produced within the region, plus imports, minus exports. For a subsector analysis, this requires information on total fuel consumed by type (e.g., total fuel consumed in electric generation, total fuel consumed by industry).

- *Step 2: Convert To Common Units.* Some or all consumption data may be expressed in physical units (e.g., million metric tons of coal, billion cubic meters of natural gas), or a mix of physical and thermal units. In order to calculate energy emissions, it is necessary to convert all data into common energy units, such as terajoules (TJ).

- *Step 3: Calculate Total Carbon Content of Fuels Consumed.* Next, an appropriate carbon emission factor (in kg of carbon per TJ) for each fuel product type is applied to fuel consumption to derive the total carbon content of the fuels.

- *Step 4: Estimate Carbon Stored in Products.* Some fuels are used to make products in which carbon is permanently stored. The total carbon stored should be removed from the total carbon content of the fuels.

- *Step 5: Estimate Carbon Oxidized During Fuel Use.* Not all fuel is oxidized during combustion. This step removes carbon stored permanently in ash or soot.

- *Step 6: Convert from Carbon to Carbon Dioxide.* Net carbon emissions can be expressed as carbon dioxide by multiplying the total oxidized carbon by the molecular weight ratio of carbon dioxide (CO_2) to carbon (C).

Step 1: Estimate Total Fuel Consumption. When evaluating the GHG emissions of a country's entire energy sector, the simplest approach to estimating GHGs is to use information on total "apparent" fuel consumption. Exhibit 4-3 summarizes this relationship. Total apparent fuel consumption is the sum of total primary fuel production in the region, plus imported fuel, minus exported fuels. In some instances, changes in fuel stocks may be an important consideration.

Exhibit 4-3: Total Apparent Fuel Consumption

Total Apparent Consumption =	Production of Primary Fuels + Imports of Primary and Secondary Fuels - Exports of Primary and Secondary Fuels - Stock Change

A distinction is made between *primary* fuels - those found in nature such as coal, crude oil and natural gas - and *secondary fuels*, which are derived from primary fuels, such as diesel fuel. In calculating emissions from total fuel consumption data, it is necessary to exclude data on the production of secondary fuels since their carbon is accounted for in the primary fuel calculation. However, consumption of imported secondary fuels should be included in the calculations. Exhibit 4-4 illustrates the range of fuels to be considered and the nature of the complete calculations. Since carbon content varies considerably by fuel type, data should be reported on the basis of detailed fuel categories. The table illustrates the top-down approach generally recommended by the IPCC for developing national level emissions inventories.[2]

Exhibit 4-4: Entries and Calculations for Estimating Total Apparent Fuel Consumption

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fuel	**Units**	**(Production)**	**+ (Imports)**	**- (Exports)**	**-(Stock Change)**	**=Consumption**	**Conver-sion Factor**	**Consumption (TJ)**
Primary Fuels		input	input	input	input	calc	input	calc
Crude Oil								
Natural Gas (Dry)								
N. Gas Liquids								
Anthracite								
Coking Coal								
Other Bituminous Coal								
Sub-bit. Coal								
Lignite								
Peat								
Biomass, Solid								
Liquid Biomass								
Gas Biomass								
Secondary Fuels								
Gasoline								
Jet Kerosene								
Other Kerosene								
Gas/Diesel Oil								
Residual Fuel Oil								
LPG								
Ethane								
Naphtha								
Bitumen								
Lubricants								
Petroleum Coke								
Refinery Feedstocks								
Other Oil								
Coke								

The level of detail included in these calculations depends on the scope of the sector work. For studies of a province or region within a country and depending on the level of data collection, estimates of fuel consumption may need to be constructed for each sector, and totaled to the regional level. For some countries, reasonable data will be collected for each province, including imports from other regions of the country and out of country, and regional fuel production. In a more limited sectoral analysis of the power sector, the calculation of GHG emissions could be based on the total estimated fuel consumption in the sector, without regard for whether the fuels are domestically produced or imported. These estimates are readily derived from information typically developed by borrowing countries and gathered in these studies.

In those instances when a limited sectoral analysis is conducted, fuel consumption data may need to be estimated on an end-use basis using a bottom-up approach. For example, in addition to estimating the GHG emissions associated with direct combustion of fossil fuels by the power sector, it will be necessary to estimate the direct combustion of fossil fuels used in the generation of electricity to serve the sector.

This may require that assumptions be developed regarding the efficiency of electricity generation and the fuel mix and carbon characteristics of the fuel used in electricity generation. This is discussed in greater detail in Chapter 4.2.1.3.

Step 2: Convert To Common Units. Some or all consumption data may be expressed in physical units (e.g., million metric tons of coal, billion cubic meters of natural gas), or a mix of physical and thermal units. In order to calculate energy emissions, it is necessary to convert all data into common energy units, such as terajoules (TJ). To convert consumption data to an energy basis, assumptions regarding the heat content, or calorific value of the fuel (e.g., joules per metric ton of coal), is required. The IPCC recommends using net calorific values (NCV) in these calculations.[3] Default NCVs are provided in the IPCC guidelines for a number of countries based on IEA energy data. Selected values are shown in Exhibit 4-5. Data on the NCV for local fuels are likely to be available and these should be used in place of the national average values where available.

Exhibit 4-5. Illustrative Country-Specific Net Calorific Values (1990)

Fuel	Unit	China	Czech	India	Kazakhstan
Crude Oil	Terajoule per kilotonne	42.62	41.78	42.79	42.08
Hard Coal (Domestic)	Terajoule per kilotonne	20.52	24.4	19.98	18.58
Lignite/Sub-bit (domestic)	Terajoule per kilotonne	-	12.26	9.80	14.65

Source: OECD/IEA, *Energy Statistics and Balances of Non-OECD Countries: 1990-1991.* International Energy Agency, OECD, Paris, France, 1992.

Step 3: Calculate Total Carbon Content of Fuels Consumed. Emissions estimates need to consider the carbon content per unit of energy (an emission factor) for each fuel. These values vary considerably across fuels, therefore, local data should be used when available. An appropriate carbon emission factor (in kg of carbon per TJ) for each fuel product type is applied to fuel consumption to derive the total carbon content of the fuels.

For coal, carbon emissions per metric ton vary considerably depending on the coal's composition of carbon, hydrogen, sulfur, ash, oxygen, and nitrogen. While coals vary considerably on a mass basis (i.e., per metric ton), they vary considerably less on an energy basis (i.e., per Terajoule). Lower ranked coals such as lignite have slightly more carbon per unit of useful energy than higher ranked coals (anthracite is the exception). The values shown in Exhibit 4-6 are based on those reported in the IPCC Inventory Manual.[4]

Exhibit 4-6. Carbon Content of Fuels

Fuel	(7) Consumption (TJ)	(8) Carbon Emission Factor (metric tons of Carbon/TJ)	Total Carbon Emissions
Primary Fuels	**Calculate**	**Input**	**Calculate**
Crude Oil		20.0	
Natural Gas (Dry)		15.3	
N. Gas Liquids		15.2	
Anthracite		26.8	
Coking Coal		25.8	
Other Bituminous Coal		25.8	
Sub-bit. Coal		26.2	
Lignite		27.6	
Peat		28.9	
Secondary Fuels			
Gasoline		18.9	
Jet Kerosene		19.5	
Other Kerosene		19.6	
Gas/Diesel Oil		20.2	
Residual Fuel Oil		21.1	
LPG		17.2	
Ethane		16.8	
Naphtha		(20.0)	
Bitumen		22.0	
Lubricants		(20.0)	
Petroleum Coke		27.5	
Refinery Feedstocks		(20.0)	
Other Oil		(20.0)	
Coke		29.5	

Note: Values in parentheses are default values. The IPCC did not have access to specific carbon content values of these fuel types.

The IPCC methodology for inventories assumes that net CO_2 emissions from the burning of biomass for energy purposes is zero. This assumption is made for convenience since it is difficult to attribute changes in biomass stocks solely to the energy sector since many factors can influence a country's forests. In cases where biomass fuels are sustainably produced, net emissions are actually zero. In cases where these fuels are extracted in an unsustainable manner from existing biomass stocks (e.g., forests), there will be net emissions. Net CO_2 emissions from depletion of biomass stocks contained in forests are addressed in the forestry chapter (Chapter 5) of this guidance document.

To estimate emissions of CO_2 from biomass, the mass of fuel burned (measured as dry matter) is required. For traditional biomass fuel use (i.e., small scale use of fuels in cooking stoves and open fires) direct consumption statistics are often unavailable since these transactions take place outside of normal commercial markets. Some countries have developed surveys of household and small commercial usage patterns that may be useful in developing consumption estimates.

Step 4: Estimate Carbon Stored in Products. Not all of the carbon stored in the fuels consumed is combusted and therefore not all of the carbon is released to the atmosphere immediately. For example, natural gas is used for ammonia production, LPGs are used in the production of solvents and rubber, crude oil is used to derive a variety of non-combustion products, and coal is used to produce coke, which produces oils and tar byproducts used in the chemical industry. The carbon in some of these fuels is oxidized relatively quickly while some is stored (or sequestered) in products for a longer period of time.

The *IPCC Guidelines* summarize a variety of approaches for estimating the portion of carbon stored in products.[5] Typical fractions of stored carbon are shown in Exhibit 4-7. These fractions are applied to the total carbon stored in a fuel and subtracted from the total emissions for the sector under analysis.

Exhibit 4-7. Carbon Stored in Fuel Products

Product/Fuel	Fraction Carbon Stored
Lubricants	0.50
Coking Coal Products	0.75
Natural Gas as Feedstock	0.33
LPG as Feedstock	0.80

Source: UNEP/OECD/IEA/IPCC (1995).

Step 5: Estimate Carbon Oxidized During Fuel Use. Not all carbon in the fuel is oxidized during combustion. A small fraction of the total carbon remains unoxidized in the form of soot in the stack or burner, or in the ash in the case of coal and other solid fuels. Typically, about one percent of the fuel remains unoxidized; however, this varies by fuel and technology. Typical fuel-specific values are shown in Exhibit 4-8.

Exhibit 4-8. Fraction of Carbon Oxidized

Fuel	Fraction Carbon Oxidized
Coal[a]	0.98
Oil and Oil Products	0.99
Natural Gas	0.995
Peat for Electricity Generation	0.99

[a] This varies by coal type and can be as low as 0.91 or lower.
Source: UNEP/OECD/IEA/IPCC (1995).

Step 6: Convert from Carbon to Carbon Dioxide. The final step in estimating CO_2 emissions from fuel combustion is to express the net carbon emissions as carbon dioxide. This is done by multiplying the total oxidized carbon by the molecular weight ratio of CO_2 to C (44/12).

4.2.1.3 The "Bottom-Up" Approach to Estimating Non-CO_2 Emissions from Fuel Combustion

This chapter describes estimating GHG emissions based on a "bottom-up" approach. The bottom-up approach to estimating non-CO_2 emissions uses the same basic steps as the top-down approach. However, the level of aggregation differs. This approach may be most appropriate for certain types of Bank sector studies focusing on a specific end-use sector of the energy economy, where aggregate fuel consumption data are not available. In addition, emissions of non-CO_2 GHGs, including CH_4 and N_2O, depend on fuel characteristics as well as on technology type and pollution control policies. Therefore, a bottom-up, technology-specific approach is required to estimate emissions of these gases.

This approach uses detailed technology-based calculations that provide information on emissions by technology. Such calculations require considerable data on energy consumption patterns in each sector of a country's or region's economy including data on energy consumed by technology and fuel type for the major end-uses (e.g., gas-fired furnaces in the residential sector). Emissions estimates by fuel and technology are summed across all end-uses to obtain total emissions of CH_4 and N_2O from the combustion of fuels. The methodology can also be used to develop estimates of CO_2 emissions, although top-down approaches will be simpler to implement.

The advantage of the bottom-up approach is that it provides a sectoral distribution of emissions (e.g., emissions attributable to biomass-fueled residential cook stoves), which can be useful in evaluating policy options for reducing GHG emissions because such options generally pertain to specific end-uses rather than aggregate fuel use. This approach is, however, extremely data-intensive and the feasibility of using it will depend on the availability of data. Moreover, much of the data required for the bottom-up approach is often needed for other aspects of the Bank's sector or economic work since detailed energy impacts, investment needs, technology requirements, or other elements are often required for conducting its analyses. The equation below summarizes the approach for detailed, bottom-up calculations.

$$Emissions = \sum (EF_{abc} * Activity_{abc})$$

where,

EF = Emission Factor (kG/TJ);
Activity = Energy Input (TJ);
a = Fuel type;
b = Sector-activity; and
c = Technology type.

Total emissions for a country are essentially the sum of individual emission estimates across all activities, technologies, and fuel types. The steps involved for calculating non-CO_2 emissions from fuel combustion activities using this approach are:

- *Step 1:* Obtain energy activity data from national, regional, or subsector sources. This would include energy consumption by technology, fuel, and end-use for each sector under study.

- *Step 2:* Determine the main categories of emission factors. For example, in the end-use sector, emissions factors for each end-use technology and fuel combination is required. For non-CO_2 gases, emissions factors for each technology type are required.

- *Step 3*: Compile emission factor data for the country. This data should ideally be based on national sources. If no national sources are available, the IPCC Guidelines provide emission factor data for non-CO_2 gases that can be used as a starting point for the analysis. The IPCC Guidelines also provide references from which emission factor data can be obtained for individual gases. Emission factors should represent the average emission performance of similar technologies. For non-CO_2 emissions these may vary according to fuel, technology, operating conditions, and maintenance and vintage of technology.

- *Step 4:* Identify the technology categories to be used to link national energy balances and emission factors. The technology categories should be compatible with the form of selected emission factors since the emission factors tend to be technology-specific.

- *Step 5:* Using the technology categories, develop CO_2, CH_4 and N_2O emissions estimates for each energy activity. To accomplish this step, national data on technology shares, or the relative share of technologies in each of the main energy activities, are required. Such data will have to be developed for given countries because no complete international sources of data exist.

- *Step 6:* Sum the emissions estimates for individual energy activities within the sector under study to obtain the total emissions for each gas.

Exhibit 4-9 provides representative emission factors for CH_4 and N_2O for power generating technologies as developed by the IPCC and reported in the Guidelines. Emission factors for these GHGs will vary with the vintage of the equipment and the regulations affecting that unit. Better data may be available for specific countries, particularly for N_2O emissions. These emissions can be incorporated into the option evaluation using carbon-equivalency factors discussed in Chapter 3. Corresponding factors for industrial boilers, and residential and commercial sources are given in the IPCC Manual.[6]

Stored carbon is calculated in the same manner as in the top-down approach. Fuel quantities from which carbon may be stored are estimated, converted to TJ, and multiplied by the carbon emission factor to determine the carbon content of the fuel, and then multiplied by the fraction of carbon stored to determine the carbon stored for each fuel. Estimates done on a technology-based level may account for non-fuel uses at a more detailed level of products and processes; thus, estimates of carbon stored may be improved.

The amount of carbon remaining un-oxidized from combustion activities may vary by fuel and combustion technology, age of equipment and operation and maintenance practices. Therefore, when estimating emissions using a bottom-up approach, it is possible to develop more precise estimates of unburned carbon, depending on data availability. In the absence of technology-based-data, the fuel-specific fractions of un-oxidized carbon discussed earlier may be used.

Exhibit 4-9. Representative Emission Factors for CH_4 and N_2O from Utility Boilers		
Fuel/Technology Type	**Emission Factors[a]** **Kg/TJ energy input**	
	CH_4	**N_2O**
Natural Gas — Boilers	0.1	N/A
Gas Turbine Combined Cycle	6.1	N/A
Gas Turbine Simple Cycle	5.9	N/A
Residual Oil Boilers	0.7	N/A
Distillate Oil Boilers	0.03	N/A
Shale Oil Boilers	0.7	N/A
MSW — Mass Feed[b]	N/A	N/A
Coal — Spreader Stoker	0.7	0.8
Coal — Fluidized Bed Combined Cycle	0.6	N/A
Coal — Fluidized Bed	0.6	N/A
Coal — Pulverized Coal	0.6	0.8
Coal — Tangentially Fired	0.6	0.8
Coal — Pulverized Coal Wall-Fired	0.6	0.8
Wood — Fired Boilers	18	N/A

[a]Values were originally based on gross caloric value; they were converted to net caloric value by assuming that net caloric values were 5 percent lower than gross caloric values for coal and oil, and 10 percent lower for natural gas. These percentage adjustments are the OECD/IEA assumptions on how to convert from gross to net caloric values.
[b]Emissions factors were adjusted to NCV, assuming a 5 percent difference in energy content between net and gross caloric value.
Source: Radian (1990), UNEP/OECD/IEA/IPCC 1995, as reported in the IPCC Inventory Workbook, 1995, P. 1.39.

4.2.2 Emissions from Coal Mining Activities

An important source of GHG emissions is fugitive emissions from production, processing, and handling of coal. These include releases of gases such as methane in mining, as well as emissions from inadvertent combustion of coal in mine fires.

CO_2 emissions from burning coal deposits and waste piles are generally an insignificant percent of total emissions from coal combustion. Nonetheless, these emissions can be estimated by multiplying the quantity of coal burned in coal deposits and waste piles by the emission factor.

The most important component of these emissions is the release of CH_4 from the mining and handling of coal. The process of coal formation inherently generates methane. The methane will remain in the coal until the pressure on the coal is reduced, either through mining or erosion of the overlying strata. The amount of CH_4 generated during coal mining is a function of coal rank and depth, gas content, and mining methods, among other factors. In most underground mining, methane is removed by ventilating large quantities of air through the mine and exhausting a mixture that is about 1 percent methane into the atmosphere.

Alternatively, advanced recovery systems can be used to recover a highly concentrated product, ranging from 35 to 95 percent methane. In underground mines, methane production results from the coal mined as well as the surrounding strata exposed during the mining process. For underground mines the rate of methane production is estimated to range from 10 to 25 cubic meters (m^3) per metric ton of coal mined.[7]

In surface mines, exposed coal faces are believed to be the major source of methane. Emissions per metric ton of coal mined are generally much lower for surface mines because this coal is much lower rank and not buried very deeply. For surface mines, the production of methane is estimated to be about 0.3 to 2.0 m^3/metric tons of coal mined.[8]

The actual rate of methane formation varies with the specific mine. Therefore, depending on the availability of data, one of several methods may be used for estimating methane emissions from coal mining. One approach is to use the global average information on methane emissions from coal mines discussed above. Country-basin-, or mine-specific data may be used in place of global calculations. Emissions are calculated as follows:

$$\text{Emissions (Gg } CH_4\text{)} = CH_4 \text{ Emission Factor (} m^3 CH_4 \text{ / tonne of coal mined)}$$
$$\times \text{ Underground Coal Production (Mt)}$$
$$\times \text{ Conversion Factor (Gg/}10^6 m^3\text{)}$$

where using global data, the CH_4 emission factor is from 10 m^3/tonne to 25 m^3/tonne for underground mines and 0.3 to 2.0 m^3/tonne for surface mines, and the conversion factor is the density of methane at 20°C and 1 atmosphere (equal to 0.67 Gg/$_{106}m^3$), which converts the volume of CH_4 to a weight measure.

The methods discussed above (with the exception of the mine-specific approach) assume that all of the methane will be released to the atmosphere. In many countries, however, some of the methane is used as a fuel. In these cases, the amount of methane used as fuel should be subtracted from the emissions estimates.

In addition to the CH_4 contained in the mine, there are also CH_4 emissions from post-mining activities. Again, global average emission factors combined with production data can be used to estimate these emissions. The formulation is the same as for mining emissions; the emissions factors range from 0.9 to 4.0 m^3/tonne for underground mines and 0 to 0.2 m^3/tonne for surface mines.

4.2.3 Emissions from Oil and Gas Activities

Oil and natural gas production, processing and transport and use of oil and natural gas in non-productive combustion is also a source of emissions which may be important to consider in Bank sector work if policies and programs are expected to significantly affect these activities. Sources include releases during normal operations (e.g., venting and flaring), chronic leaks or discharges from process vents, emissions during maintenance, and emissions from system upsets and accidents. Activities that may produce emissions include:

- **Oil and gas production,** including leaks from gathering lines, and venting and flaring during production.
- **Crude oil transportation and refining,** including leaks or venting of vapors during transport in tankers and pipelines, during refining, and in storage.
- **Natural gas processing transportation and distribution,** primarily from leakage during transport.

Total emissions from these activities can be developed based on production levels. In the case where sector work is addressing a country's entire energy system, useful data on energy production (e.g., the quantity of oil and gas produced, refined and consumed) is likely to be available at the national level. However, when the Bank's work focuses on a specific region or sector, the use of national data is less appropriate and it may be more useful to examine *differences* in national oil and gas production activities as a result of policies implemented at the regional level.

Limited data exist on emission factors from oil and gas production. However, the information available on emissions by activity and emissions source has been summarized in the IPCC Inventory Manual.[9] Global averages and regional estimates are provided.

Other GHG emissions are also emitted from oil and gas activities. Non-methane volatile organic compounds (NMVOC) are the most significant source of emissions after CH_4. The IPCC has not yet addressed the indirect GHGs, including NMVOC, in detail. However, these emissions may be important sources of local and regional air quality programs. Literature is available on these emissions and reported in the IPCC Manual (p. 1.123).

4.2.4 *Projecting Future Years' Emissions Under the Reference and Reform Scenarios*

The previous chapters described methods for estimating a base year's emissions inventory for CO_2 and other GHG emissions. Future years' emissions can be expected to differ from the base year's emissions as calculated in the chapters above. This chapter describes approaches to calculating future years' emissions.

4.2.4.1 Emissions under the Reference Scenario

Future projections of emissions should reflect the macroeconomic forecasts for the Reference Scenario. The macroeconomic forecasts used in the projections should take into consideration factors that could affect future energy usage and thereby affect future GHG emissions. These factors might include:

- Expected rate of economic growth, which would affect the penetration of end-use equipment and its use, industrial output, and other factors;
- Expected population growth;
- Improvements in living conditions;
- Structural changes in industry that may result from the introduction of new technologies, efficiency improvements, and increased specialization;
- Structural changes in other energy-using sectors such as agriculture, transportation, and construction;
- Changes in consumption patterns that may result in a changing product mix and affect the energy intensity of goods produced; and
- Changing fuel supply conditions that may affect the future fuel-mix.

Specific impacts from these actions include changes in end-use demand levels, changes in the fuel mix (direct and in electricity production), changes in end-use efficiency, changes in emissions control systems, changes in the efficiency of the electricity transmission and distribution system, and changes in the efficiency of other energy production, processing and transport processes.

The importance of individual factors depends on country-specific conditions. For example, in countries like China and India where serious power and fuel shortages exist, particularly in rural areas, there is a large potential for growth in per capita energy usage. Another example that illustrates the importance of country-specific conditions is the Ukraine, which currently has a gas-based energy sector with relatively low GHG emissions from the energy sector. The country, however, imports 80 percent of its gas from Russia and is having difficulty meeting its payments for these imports. Consequently, in the future under business-as-usual conditions, the Ukraine may have to switch from gas to domestic coal resources, which could significantly increase its future GHG emissions.

4.2.4.2 Emissions Under a Reform Scenario

Future emissions under the Reform Scenario will reflect the economic and institutional factors that differ from those in the Reference Scenario. Some examples of how Bank reform policies could change energy usage and GHG emissions are provided below.

Policies could include specific action items or institutional changes that may have indirect effects on energy usage and production decisions. Some examples include:

- Increased use of domestic energy resources (e.g., coal or natural gas) and a reduction in reliance on fuel imports.
- Increased use of renewable resources (either centrally located or dispersed), including hydroelectric.
- Institutional reforms including moving tariffs closer to marginal costs of supply.
- Adoption of efficiency measures at the end use or in electricity production.

Bank policies may also have secondary effects that need to be considered in evaluating the GHG implications of reform policies. Some examples include:

- Reform policies could result in a higher rate of economic growth, which in turn could increase energy usage and GHG emissions.
- Pricing reforms could change the mix of fuels demanded and produced.
- Energy price reforms that eliminate energy subsidies to certain sectors within a country's economy could also decrease GHG emissions by providing incentives to improve end-use efficiencies.
- Institutional reforms in a country's power producing sector could make energy production and transmission and distribution more efficient and thereby decrease GHG emissions per unit of energy produced.

Some additional issues may need consideration when evaluating emissions under the Reform Scenario. Changes in imports of fuel into a country not only affect the emissions of the importing country, but of the exporting country as well. Given the global nature of climate change and the need to internalize global externalities associated with emissions when conducting global overlays, it is important to capture such indirect effects.[10]

4.2.4.3 Approaches to Estimating CO_2 Emissions in Future Years

Emissions in future years can be estimated in a number of ways, with varying degrees of detail depending on the level of information available in the sector work. Two approaches are discussed here that can be used to project future GHG emissions under the Reference or Reform Scenario. First, it is possible to develop emissions estimates for each year (or selected years) based on specific fuel consumption data. Either a top-down or bottom-up approach can be used. This is the same approach used in calculating emissions in the base year. All that is required is detailed projections of energy production (or consumption) for future years.

An alternative approach may be necessary when detailed data (e.g., by fuel type and end-use) are not developed for future years as part of the sector work. In this case it may be necessary to project emissions in a simpler manner. For example, in a study of a region's power sector, projections of electricity generation under the Reference or Reform Scenario may be made directly, without any underlying assumptions regarding conversion efficiency and total fuel consumption. Future projections of carbon emissions could then be made by simply extrapolating the base year carbon emissions by the growth in electricity demand. This implicitly assumes a fixed conversion efficiency and T&D loss rate. Alternatively, assumptions may be made regarding changing efficiencies (e.g., percent improvement per year) and fuel mix which can be used to adjust the base year's emissions.

4.2.5 *Data Requirements and Sources*

Whether a top-down or bottom-up approach is used to estimate current and future years' emissions, the development of appropriate data is a relatively time consuming and important task in the development of GHG gas inventories and Mitigation Scenarios. Much of the required data already exists or is collected as part of the Bank's energy sector and economic studies. Typical sources used in the Bank's work include Ministries of Power, Economics, or Finance, State oil and gas agencies, and local utilities and energy producers. Other data exists for specific countries and regions in World Bank project Staff Appraisal Reports, World Bank/UNDP Energy Assessment Reports, and Industry and Energy Department Working Papers. Exhibit 4-10 summarizes the broad types of data that would be required for inventory development and mitigation assessment, specific requirements, and potential sources.

Data requirements fall into these broad categories: (1) energy demand data, (2) energy supply and resources data, and (3) emissions characteristics. Energy demand data consists of historical and projected energy consumption by fuel type and sector. Depending on the framework and scope of the analysis, data requirements may include end-use cost, performance and penetration information, and price and income elasticities. Energy supply data includes the cost and performance of generation technologies, estimates of the resource base (fossil and renewable), and price information. The simplest category of data for which to obtain information is the carbon emissions characteristics, including emission factors per unit of fuel consumed, produced, or transported, and global warming potentials.

The extent of data collection activities will depend on the scope of the analysis (e.g., one sub-sector, all sectors), the methodology being used (e.g., end-use, bottom-up modeling, aggregate, top-down), and the mitigation options being considered. It will always be preferable to use local data whenever feasible, and in some cases, only local data will be meaningful. This may be the case for estimates of end-use and technology penetration or end-use stock by vintage or efficiency level. In some cases, neighboring countries with similar development histories and profiles may prove to be a suitable source for some end-use data. In other cases, data may not be available locally. For example, some advanced generating technologies or options may have limited penetration in the country under study. In many cases, general information can be substituted when performance or costs varies little from installation to installation.

Aside from the country specific and World Bank sources, other data and information sources include energy statistics and publications of the International Energy Agency (IEA), the IPCC (which will provide assistance to signatories to the FCCC), and the U.S. Country Studies Program. Other more general sources include technology cost and performance data developed by industry groups and government agencies, including the Electric Power Research Institute, the Gas Research Institute, Lawrence Berkeley Laboratory, and the National Renewable Energy Laboratory, to name but a few.

4.3 Framework For Screening GHG Reduction Options

The previous chapter described the approach to estimating baseline GHG emissions from fuel combustion and related activities under the Reference and Reform Scenarios. This chapter discusses a number of general issues raised when screening GHG reduction options for reductions and cost-effectiveness. A critical issue that is discussed is the definition of the scope and boundaries of the analysis. While these Guidelines cannot resolve all of these issues, nor address them in great detail, it provides an overview of the most important issues. Additional resources and references are listed at the end of this chapter.

4.3.1 *Identifying Mitigation Options*

The process of identifying appropriate GHG emissions mitigation options will be driven by country-specific, end-use sector, and power system characteristics. For example, in countries where resources are used inefficiently in electricity generation and transmission, options to improve the efficiency of existing facilities could have the potential to cost-effectively reduce GHG emissions. Countries with underutilized, lower carbon indigenous fuel sources (such as natural gas) could potentially use fuel switching options in

Exhibit 4-10. Sample Data Sources for Analysis of Energy

Data Category	Specific Data Requirement	Data Sources
Energy Demand		
Historical Energy Demand Estimates	Energy consumption by type (oil, gas, biomass, electricity)	National energy statistics, UN Energy Statistics Yearbook, local utility. Energy Statistics and Balances for Non-OECD Countries, Energy Balances of OECD Countries, and Energy Statistics of OECD Countries
End -Use Characteristics for Existing Stock	Energy consumption by end-use (e.g., lighting) and technology (fluorescent light): energy use by new vs. existing buildings; energy use by vintage or efficiency levels.	Local energy audits, surveys and studies; in similar countries: general end-use literature.
End -Use Characteristics for New Stock	Effiency levels for new end-use technologies; costs for new end-use technologies	Electric Power Research Institute, LBL, GRI.
Price and Income Response	Sectoral Prices and income elasticities for long and short-term	General economics litature, country specific econometric analyses
Energy Supply Data		
Elictricity Generating Technologies	Costs (capital, fixed and variable O&M); performance characteristics if planned additions, planned purchases and sales, planned retirement	Electric Power Research Institute; experiences in same or similar countries.
Energy Prices	Coal, natural gas, oil, biomass, and electricity unit prices	Local utilities or government; for global markets, see World Energy Council (1992), UNEP (1994), and US DOE Annual Energy Outlook (1996)
Energy Supply Plans	New capacity on-line dates, costs and characteristics of planned additions, planned purchases and sales, planned retirements.	Local utility or government projecctions; projections of other energy producing industries (refineries, coal companies)
Energy Resource Estimates	Proven recoverable reserves for fossil fuels; costs and potential for renewable resources	World Energy Council Survey of Energy Resources (1992)
Programmatic Data for End-Use Options	For effiency investments, administrative costs, incentive requirement, penetration rates, maximum achievable potential), performance contracting	Experience of same or similar countries
Emissions Characteristics		
Emissions Factors	kg of CO_2 or carbon-equivalent per unit of energy consumed, produced, or transported	National greenhouse inventories, IPCC Inventory Guidelines (UNEP/ OECD/IEA/IPCC, 1995), IPCC Technolgy Characterization Inventory (U.S DOE, 1993); U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42); Default Emissions Factors Handbook (EEAFT,1992);Default Emissions Inventory Guidebook (CORINAIR/ EMEP).
Global Warming Potentials (CO_2 equivalents)	Impact on climate measured relatives to CO_2	IPCC.

Sources: This table is based in part on information in *U.S. Support for Country Studies to Address Climate Changes. Guidance for Mitigation Assessments: Version 2*, Lawrence Berkeley Laboratory, March 1995.

all sectors. Depending on the relative emissions characteristics of the displaced fuel and its replacement, overall emissions could be reduced.

Assessment of GHG mitigation options could begin by creating an initial "long list" of measures for screening that are viable given country- or region-specific factors such as existing energy facilities, end-use patterns and efficiencies, and institutional structures. The goal is to eliminate those options that are not feasible, or those that are not likely to yield significant reductions at reasonable costs.

One useful approach to identify viable options is to ask a broad series of questions directed at assessing the attractiveness of a range of options. Perhaps the most important of these is whether the mitigation strategy or option is consistent with national development goals and strategies of the country or region. Other questions may include:

- Is application of the option on a wide scale feasible? Some specific options may be attractive simply because they offer an opportunity to demonstrate a technology or policy which has broad application potential across many regions or countries.

- Are there ancillary local environmental or economic benefits? Reductions in SO_2, NO_x, particulates, or the creation of jobs combined with GHG reductions may make an option attractive despite poor economics.

- Does the option have the potential for large impacts on CO_2 emissions or other GHG emissions? This can be quickly assessed by the relative share of end-use demand, or supply affected, and the relative carbon content of the "before" and "after" fuels, or the potential efficiency improvement planned. Some analyses may consider only those mitigation options with large impacts.

Some more specific questions might include issues related to the country's resource base, its end-use characteristics, and future resource acquisition strategies. For example:

- Is the country planning any electricity generating capacity additions that might be reevaluated with the added criteria of reducing CO_2 emissions?

- Is the institutional structure of the power sector resulting in inefficient power production, delivery and use?

- Are there end-uses that offer the opportunities for energy efficiency improvements?

- Are there industries in the country that are potential candidates for electrotechnologies, which are most promising from an efficiency and carbon perspective?

- Are there available renewable fuel sources (i.e., industrial and agricultural waste products) that could enable low cost GHG reductions?

When developing an initial list of options, it is important to consider the Reform Scenario and what future changes in conditions are projected that may change the outlook for GHG emissions reduction opportunities. For example, if future development of natural gas resources is an integral part of the Reform Scenario, than increased use of natural gas in electricity generation may be a consideration. On the other hand, if the Reform Scenario includes aggressive end-use efficiency measures in industry, incremental reductions may not be available.

These and similar questions can help define those options to be evaluated and can eliminate those that simply are not available or feasible. Caution should be used in this qualitative screening to avoid prematurely eliminating potentially attractive options.

4.3.2 Identifying the Effects of a Mitigation Project or Strategy

A major step in estimating the emission and cost impacts of a GHG mitigation option is to identify all of the potential effects of a project. Most options would have impacts on "direct" emissions - those emissions from sources within the scope of the sector work. There may also be changes in "indirect" emissions - those emissions that occur outside the scope of the sector work, but that are influenced by the sector under study. For example, in an analysis of emissions reductions from the power sector, emissions from the power plant are direct emissions. It also may be important to consider the indirect emissions impacts on coal, oil, and natural gas production and distribution.

In addition to having spillover effects to other sectors of the economy, some greenhouse mitigation options will also frequently affect emissions beyond a country's or region's geographic boundaries. Such international impacts would occur as a direct consequence of international trade in fuels or electricity. Global overlays for climate change require emissions to be viewed from a global perspective. An analysis of a project should in principle consider all project effects, including shifting of activities from one region or sector to another outside the scope of the sector work, outsourcing (purchasing commodities or services formally produced), life cycle emissions shifting (upstream and downstream changes in processes or materials used), and market effects (offsets to achievements caused by residual demand effects). In practice, the scope of the analysis will be limited by practical considerations, such as data availability and costs. Some examples of the range of effects that are possible from GHG mitigation projects are described below.

- Shifts from coal to natural gas in fuel use in the electricity generation sector would affect the direct emissions from the electric power sector. Shifts to natural gas would also change the level of GHG emissions associated with fuel production and transport (i.e., full fuel cycle emissions), in addition to impacts at the point of consumption. The net change in emissions should be considered. Some of these emissions may occur in regions or countries outside the scope of the Bank's work.
- Some energy efficiency measures may affect GHG emissions both in the electricity generation sector and in the residential, commercial, and industrial end-use sectors. For example, switching to electrotechnologies in industry from fossil fueled end-use technologies will increase emissions from electricity generation but have offsetting reductions at the end-use site.
- Industrial cogeneration will increase the industrial customer's costs and emissions. However, these may be offset by reductions in emissions and costs in the power sector.
- If energy usage in a country (or region) falls as a result of mitigation options, it may export surplus fuels or electricity. These fuels may displace fuels that are more or less carbon intensive and have an offsetting effect on the total emissions impacts of the demand reduction. If an option results in emissions being shifted from one country to another, the global benefit is limited to the *net* decrease in emissions.
- Changes in the efficiency of electricity use at an industrial site will reduce electricity production and CO_2 emissions in the power sector. It will also reduce emissions of methane and nitrous oxides. These should be included in the analysis.
- Increased efficiency may have second-order effects that are important to consider. For example, an efficiency lighting program that reduces customers' bills may cause the customer to increase the level of lighting services (hours burned or sockets). These effects are often very difficult to quantify, but, at a minimum, should be acknowledged.
- A mitigation strategy may be to adopt one or several energy efficiency measures through a rebate mechanism. Adopting this strategy may have broader, longer term effects than just the increased efficiency of the particular end-use. Establishing a mechanism for a rebate program may accelerate adoption of additional energy efficiency programs and measures. While these "secondary" market effects are often very difficult to quantify, the potential for these types of effects should be recognized.

4.3.3 *Identifying Cost Components of GHG Reduction Options*

When evaluating the costs of mitigation options, it is important to factor in all costs that may be incurred, including capital; fuel; operation and maintenance (O&M) costs; administrative, monitoring and evaluation costs; and other monetary environmental costs. It is important to note that for a specific option, some of these cost components may in fact be cost reductions. For example, switching from coal to gas in an existing boiler may reduce O&M costs. Key considerations are outlined below:

- **Capital Costs.** Capital costs include those costs incurred to modify existing facilities, to invest in new systems and equipment. Capital costs should reflect any real escalation expected between the time of the estimate and the time the measure is implemented. In addition, they should reflect the appropriate carrying charges (e.g., return to debt holders, taxes, depreciation).

- **Fuel Costs.** Fuel costs will change as a result of a fuel switch or a change in new resource additions. Total fuel costs also may change as a result of changes in utilization of a plant (e.g., after a fuel switch), increased efficiencies, reduced losses, and as a result of using recaptured methane from coal mine or landfill operations in place of fuel purchased from conventional sources. Energy efficiency options will reduce total fuel consumption.

- **Fixed and Variable Operation & Maintenance Costs.** Fixed and variable O&M costs of the power sector may change as a result of fuel switching. Switching from coal to gas will generally lower O&M costs, while co-firing with biomass may raise these costs. Energy efficiency measures would reduce these costs. On the customer side, changes in equipment may lead to changes in O&M costs.

- **Administrative, Monitoring, and Evaluation Costs.** It is important to include all costs associated with GHG options, including any costs required to administer a program (e.g., an energy efficiency rebate program), monitor and evaluate its performance, and verify its results. Administrative costs will vary widely from country to country and option to option.

- **Local Environmental Benefits and Costs.** Some GHG reduction options may have environmental impacts in addition to reduced CO_2 emissions. The most important and readily quantified of these impacts are changes in SO_2, NO_x and particulate emissions. Many mitigation options will result in significant reductions in SO_2 emissions. For example, switching a coal-fired plant to natural gas, or co-firing with natural gas, will result in lower SO_2 emissions from the plant. Similarly, some GHG reduction actions will reduce emissions of NO_x, VOCs, and other pollutants. It is possible to assign them an economic value based on values established by the Bank.

- **Local Economic Benefits and Costs.** The local benefits of GHG mitigation options include improved occupational safety (e.g., in coal mines) and economic benefits (e.g., increased employment, improved trade balance because of lower consumption of imported fuels).

As in all such cost analyses, costs may be measured on a full-cost basis (where the full costs of the GHG mitigation are accounted for under each scenario, and differences examined), or on an incremental cost basis.

The cost analysis must include a determination of the *boundary* of the economic analysis. This is always more complicated when assessing externalities of a project or program, as the boundaries become blurred. The identification of boundaries implies the expansion of the conceptual and physical boundaries of the analysis. The level of this expansion — whether to the sectoral, regional, or macro level — is a matter to be decided on an individual basis.

A decision must also be made about the time horizon of the analysis. For specific projects, if the effects are expected to last beyond the lifetime of the project, the standard prescription is that the time horizon must be extended. This is done by either extending the cash flow analysis a number of years, or by adding to the last year of the project the capitalized value of the part of the environmental impact that extends beyond the project life. Given that the potential future damage caused by increasing GHG concentrations is unknown, it is suggested that the time frame covers the time during which there is a change in the net flow of carbon from the atmosphere.

It is important to ensure that *shadow prices* are clearly explained and integrated in the analysis when deemed necessary. Distortions due to monopoly practices, externalities such as environmental impacts, and interventions in the market process through taxes, import duties, and subsidies all lead to market prices which may be significantly different from their true economic values, or shadow prices. In order to determine optimal investment decisions and policies, it is often necessary to use appropriate shadow prices of project inputs and outputs. However, shadow prices should be used selectively, depending on country circumstances and on the severity and prevalence of distortions.[11]

4.3.4 *Defining a Baseline Against Which a Mitigation Option's Impacts are Measured*

Measuring reductions requires establishing a point of reference or baseline against which the impacts of a GHG reduction action are compared. The baseline, or "but for" case, should reflect what would happen but for the adoption of this mitigation option. The baseline could reflect historical information-for example, the year 1990-or an average of several historical years. This would be appropriate if no changes in the systems affected by the action were expected over time. For example, historical data could be used in analyzing a coal mine methane recovery project if coal production and methane emission rates were expected to remain unchanged over the time frame of the sector work.

However, even in the absence of GHG mitigation actions, the emissions from a source may change over time and differ from a historical year. In this case, a different definition of the baseline case may be required. The impacts of a GHG reduction option could be measured against a projected baseline that reflects the expected emissions over some future time horizon in the absence of actions to reduce GHG emissions. For example, in the case of the coal mine methane recapture project, it is important to consider the impacts of increased coal production and the planned installation of ventilation equipment.

In the case of energy efficiency options, it is important to consider what the expected penetration rates are in the baseline. For example, in the Bank's review of efficiency lighting in Mexico (the ILUMEX compact fluorescent lighting project), it was recognized that the effect of the project was to accelerate the diffusion of efficient lighting technology. The adoption of the technology was likely to have happened eventually. However, the project was expected to accelerate the adoption and diffuse the technology more widely through information effects (a "free driver" effect). The impacts therefore are those which result from adopting these technologies earlier than in the baseline.

The baseline from which the impacts of the Mitigation Scenarios are measured most likely will be the Reform Scenario, although in cases when no such analysis has been performed, the Reference Scenario forecasts developed by the borrowing country are the appropriate baseline.

4.3.5 *Cost-Effectiveness of GHG Reduction Options*

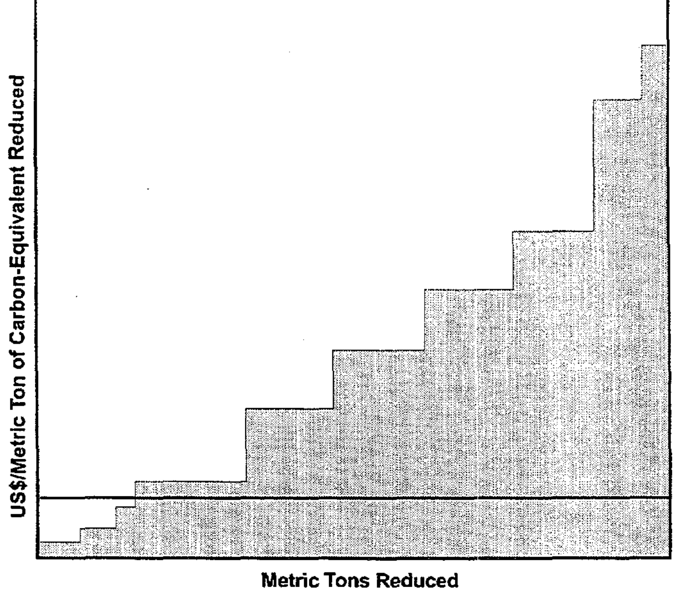
When evaluating the cost and emission effects of GHG reduction options, a common basis is needed to compare their relative *cost-effectiveness*. Cost-effectiveness assessment is a technique commonly used when benefits either do not have a readily accessible market price or are not easily measurable in conventional monetary terms. In the case of GHG emissions mitigation, cost-effectiveness is expressed in terms of dollars per metric ton of carbon-equivalent emissions reduced. This unit measure provides a consistent yardstick for comparing diverse options that result in varied emission reductions. Measuring reductions in terms of carbon-equivalents allows a comparison between options that reduce CO_2 and those that reduce CH_4 or N_2O.

Ranking options on the basis of costs per metric ton of CO_2-equivalent reduced provides a basis for selecting a range of options that meet a target level of reductions over some time frame. However, there may also be other decision criteria that could be considered in evaluating GHG reduction options. The net present value (NPV) , or the internal rate of return (IRR), measures are criteria often used by the Bank in selecting investment projects, and could be used to select among a range of GHG reduction options. The basic data required for IRR calculations are the same as for costs per ton of CO_2 -equivalent, thus they may both be derived based on the framework presented in these guidelines. While both cost-effectiveness selection criteria and NPV/IRR rankings yield valid results, in effect the latter methodology requires adoption of a uniform carbon shadow value.

It may be appropriate to use multi-criteria analysis to allow for more accurate representation of several decision criteria. While traditional cost-benefit analysis focuses on efficiency criteria alone, multi-criteria analysis allows for consideration of social, biophysical and other impacts to be assessed as well. Important criteria may include the total level of reductions achieved, the total capital investment, or the level of local environmental and economic benefits achieved. In fact, multiple decision criteria are likely to be important. Weights would then be assigned to these criteria based on relative importance. This method is discussed in more detail in Chapter 4.5.2.

The results of a simple ranking of GHG reduction options on the basis of US$/metric ton removed produces a curve as illustrated in Exhibit 4-11. After ranking options on the basis of cost-effectiveness (or other criteria or combination of criteria), selecting or eliminate options is quickly done. Some options may be cost-effective without consideration of the GHG reductions (i.e., they produce cost savings). These are illustrated on Exhibit 4-11 as those options falling below the US$0/metric ton line. Examples of options that may fall into this category include certain demand-side management programs, plant efficiency improvements, and T&D improvements. In the process of seeking GHG reductions, some of these options may be identified. The analyst may want to subject these to an internal rate of return (IRR) evaluation.

Exhibit 4-11. GHG Mitigation Option Supply Curve



4.3.5.1 Calculating Cost-Effectiveness

There are many different ways that a cost-effectiveness measure of dollars per metric ton of carbon equivalent might be calculated. It is important that the chosen measure captures differences between GHG reduction options with respect to their emission reductions and costs. Accounting for timing differences is important when options have different lifetimes. Costs are expressed in terms of levelized cost over the lifetime of the measure's reductions, and reductions are measured in terms of levelized reductions over the life of the measure. The calculation of cost-effectiveness is:

$$\frac{\$}{\text{Metric Ton}} = \frac{\text{Levelized Annual Lifetime Net Costs}}{\text{Levelized Annual Lifetime Reductions}}$$

The Levelized Lifetime Net Costs are that stream of equal annual payments over the GHG reduction option's lifetime that have the same present value as the actual stream of net costs to be incurred. This measure allows options with different lifetimes to be appropriately compared.

In each case, the present value of the annual cost stream is developed. This present value is then levelized using an appropriate annuity factor. Cost-effectiveness is calculated by dividing the annual levelized costs by the levelized emission reductions. As discussed in the next chapter, when emissions are not discounted (i.e., the discount rate, *d*, is 0), then levelized emissions reductions are equivalent to annual average emissions reductions.

In the framework used by the Bank in its evaluations, total project costs are often offset by the benefits of the project. These might include the value of the energy provided (as measured by the average rate used as a proxy for the economic benefit).[12] In this case, the numerator would be the net benefits or costs of the project or action. Since different projects provide different levels of economic benefit, this provides a convenient metric for comparing projects of very different types.

Consistent with the approach used in Bank work, the net costs (or benefits) per metric ton of CO_2 emissions may be calculated from three different perspectives: (1) the financial perspective of the project reflecting stated energy and other prices, (2) the economic perspective of the society, based on economic, energy and other prices, and (3) the environmental-economic perspective of society where environmental health benefits are valued and added to the economic accounts previously calculated.

Direct and indirect emissions should be considered. For example, savings result from the direct effects of replacing technologies with more efficient equipment. In this instance, indirect emissions could include the energy use and emissions effects of higher output from new, more efficient technology displacing older technology elsewhere in the sector.

Options can also be evaluated based on their IRR or Net Present Value (NPV).[13] Options that have a positive US$/metric ton removed have a net cost, and have an IRR that is less than the discount rate. Under a criterion of selecting a project meeting minimum IRR, such projects would not be undertaken as investments (except in the case of GEF-funded projects). Some options, however, may have a negative US$/metric ton removed, implying that they produce benefits (i.e., cost savings) exceeding their costs. If such an option requires an investment, it may be useful to further screen the option. In this case, an IRR or NPV calculation is appropriate. In cases where an IRR screening is used, it is important to note that US$/metric ton and IRR estimates of a range of projects may not be directly correlated, since they measure different aspects of a project. Caution must be employed in using the IRR for making decisions, particularly when comparing mutually exclusive alternatives, or minor components of larger projects. Sometimes, projects have more than one IRR, particularly when net benefits change sign during the life of the project. Other important considerations in calculating cost-effectiveness are discussed below.

4.3.5.2 Current (Nominal) vs. Constant (Real) Dollar Analysis

Economic analyses of GHG mitigation options can include the effects of inflation (termed a current dollar or nominal dollar analysis), or exclude the effects of inflation, but include any real price increases (a constant, or real dollar analysis). Economic analysts typically conduct analyses in real terms because this clarifies real cost trends and allows a more intuitive understanding of cost estimates that are closer in value to today's costs. The choice between nominal versus real dollar is, however, left to the analyst. Typically, the Bank's sector work is conducted on a real dollar basis.

4.3.5.3 Dollar Discounting

Cost-benefit analysis typically focuses on costs and benefits that occur over a period of time. Discounting recognizes that a dollar (of costs or benefits) today is worth more than a dollar tomorrow. For economic analysis of projects in developing countries, the Bank typically uses discount rates on the order of 10 to 12 percent, consistent with OCC adopted rates or Bank economic assessment.

4.3.5.4 Emissions Discounting

One principal difficulty in evaluating GHG reduction options arises because costs and benefits accrue at different times, and for many projects, the costs of reducing emissions occur immediately, while the benefits may be realized well into the future. The question arises then whether avoided GHG emissions should be discounted at the same rate as costs.

The specific value of the discount rate that should be applied to project benefits, such as emission reduction benefits of GHG mitigation projects, is the subject of considerable debate. Many studies suggest that an appropriate social rate of discount falls in the range of 0 percent to 4 percent, with a typical value of 2 percent to 3 percent. In some cases these studies rely on estimates of the social rate of time preference and, in others, on the opportunity cost of capital in the public sector. Although some studies contend that a discount rate near zero is most appropriate for discounting benefits that may accrue to future generations many years hence, many studies argue that the appropriate discount rate should be a weighted average of the opportunity cost of capital and the social rate of time preference, with the weights varying depending on the type of project.

In addition, emission reductions are difficult to monetize (convert to dollar values), and considerable debate surrounds the issue of whether discounting procedures that are appropriate for monetized benefits are equally appropriate for non-monetized benefits. Moreover, the actual benefits of emissions reductions, in terms of reduced impacts on agriculture, forests, and coastal resources, occur not at the time of the reduction, but after the full effects of temperature change are realized, which may occur in years or decades after emissions of GHGs into the atmosphere are altered.

Finally, emissions are not strictly proportional to damages. Because different GHGs are characterized by different radiative forcing which depends on the concentration and timing of emissions, changes in emissions do not necessarily imply one-for-one changes in associated benefits.

The U.S. Country Studies Mitigation Guidelines suggest not discounting GHG flows at all.[14] By not discounting, it argues, one assumes that the future economic damage caused by GHG emissions increases at the real rate of discount, an assumption that one could consider reasonable, given that the potential future damage caused by increasing GHG concentrations is unknown. This approach has also been used in much of the Bank's work in this area.

4.3.6 *Incorporating Uncertainty*

Countries face a variety of economic, technical, and political uncertainties. Any analysis of GHG reduction options should include a method for assessing the potential impact of uncertainties on an option's emissions reductions and costs. For many GHG reduction options, the level of emissions reductions are uncertain, and for almost all options, the cost of reductions is uncertain. The key uncertainties that could affect the economics of options and their selection are summarized below.

- **The Availability and Price of Fuels.** Not only are absolute fuel prices important, but relative prices are particularly important (e.g., natural gas price relative to the coal price). One of the options with great potential is fuel switching from coal to natural gas or co-firing with natural gas in electric generation or other applications. The cost of these options is critically dependent on the fuel price differentials. Moreover, if many power facilities in a country switched fuels, the price of natural gas could increase.

- **Future Demand Growth.** Higher-than-projected growth in the demand for power will make it more difficult to achieve large reductions or meet specified goals. On the other hand, lower demand growth could eliminate some options, or increase the cost of others, such as those that depend on the addition of new capacity to achieve lower cost (e.g., repowering, renewables in place of fossil).

- **Future Environmental Requirements.** Future country or Bank requirements related to air pollutants and air toxics could increase the value of GHG reduction options and increase their cost-effectiveness.

- **Technology Cost.** The cost and availability of generation and end use technologies, including renewables, will influence their cost-effectiveness as GHG reduction options.

- **Climate Change Science.** The value of reductions in non-CO_2 gases is uncertain due to uncertainties in the relative global warming potentials (GWPs) of these gases. A change in the GWP could affect the impact and the cost-effectiveness of options to recapture methane or reduce NO_x.

Any exercise to evaluate GHG reduction options and develop a Mitigation Scenario should consider the impacts of uncertainty on estimates of costs, reductions, and cost-effectiveness. One approach is to examine each option under a range of scenarios or sensitivities which reflect uncertainty in key variables. For example, the economics of end-use efficiency could be examined under alternative demand growth forecasts, or under a range of costs for end-use technologies and avoided costs of energy and capacity (consistent with high and low fuel price projections). Key uncertainties for each option can be identified and incorporated into the screening in this manner.

When performing an analysis in this way, it is important to keep the construction of scenarios for uncertainty analysis consistent across options. For example, all options significantly influenced by fuel prices should be evaluated under the same fuel price scenarios. All options that are affected by technology costs should have consistent scenarios constructed. Only in this way can options be ranked and compared fairly and consistently.

4.4 Screening GHG Mitigation Options

GHG emission reductions are available from a broad range of sources. This chapter provides an overview of the basic categories of options in the energy sector. These are summarized in Exhibit 4-12. The remainder of this chapter describes each of these broad types of GHG reduction options, including what conditions make an option suitable to a country or situation and important considerations when evaluating each type of option. Illustrations from various Bank- or GEF-sponsored studies are provided when appropriate and available.

GHG emission reduction options in the power sector may directly affect the fuels used and the efficiency of electricity generation. Options include switching to a lower carbon content fuel; improvements in the conversion, transmission and distribution of electricity; repowering of existing units to more efficient technologies and less carbon intensive fuels; cogeneration; and alternative new capacity choices, including renewable resources. In end-use sectors, GHG emissions reduction options include increased energy efficiency and fuel switching. Finally, methane recapture from landfills, coal mines, and natural gas distribution systems can also be cost-effective GHG emissions reduction options. Each of these options is discussed below.

4.4.1 Electric Generating Unit Repowering

As power plants age the efficiency of their steam production equipment generally declines, even with regular maintenance. Repowering refers to the replacement of aged steam production equipment with new, more efficient equipment. Repowering offers the opportunity to increase efficiency of the steam production process and reduce GHG emissions.

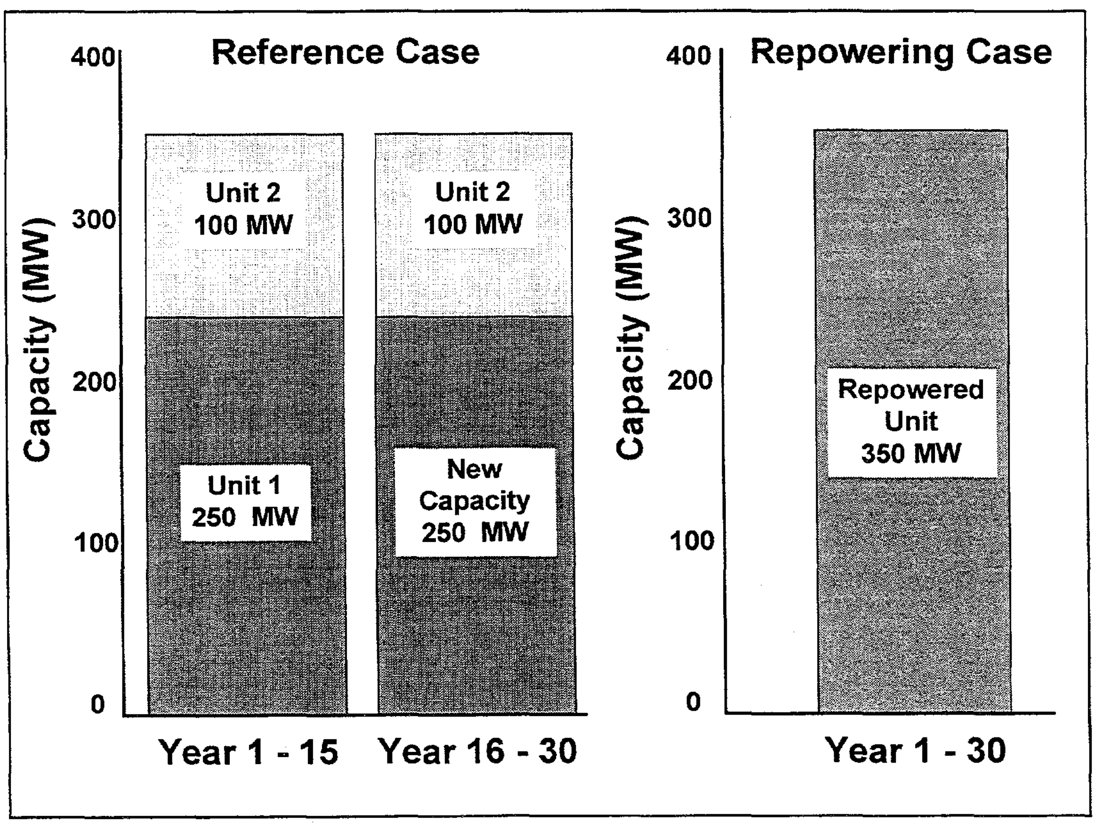
Exhibit 4-12. GHG Reduction	
Energy Supply Options	
Coal Beneficiation	Coal preparation or cleaning can remove impurities to improve the combustion characteristics of the coal.As plant availability factors improve, the entire system is more energy-efficient, thereby marginally reducing system-wide GHG emissions.
Fuel Switching in Electricity Generation	Fuel switching in existing boilers can produce significant GHG emission reductions. The most important factors affecting carbon reductions from fuel switching are the relative carbon contents of the old and new fuels. A switch from coal to natural gas can reduce carbon emissions by about 40 percent. The costs of the options depend on the relative prices of natural gas and coal. Fixed O&M at the units may decrease after the switch as certain fuel handling activities are no longer necessary, and secondary system impacts and interactions may include changes in dispatch.
Electric Conversion Efficiency Improvements	Changes in carbon emissions are based on the difference in heat rates before and after the change. Costs incurred would include capital costs for the improvements and reduced fuel costs. Secondary impacts could include changes in the dispatch of the plant.
Repowering	Repowering can include the advantages of both fuel switching and efficiency improvements. Capital investments for retrofit include any required transportation infrastructure. Fixed and variable O&M may change, and capacity requirements may be reduced or deferred as a result. Secondary system impacts and interactions may include changes in dispatch.
Cogeneration/ Combined Heat and Power	Industrial customers with steam demands may be candidates for cogeneration. The cogenerator is more efficient from an energy use and carbon perspective than the combination of an industrial boiler and utility generation. Cogeneration systems may also be efficient substitutes for heat-only boilers used for district heating.
New Electric Power Capacity including Renewable Resources	This option would involve a change in resource plans to a new capacity addition which (1) either uses a lower carbon content fuel (natural gas in place of coal), or (2) is more efficient and therefore results in lower carbon per kWh generated (combined cycle, IGCC). Costs include the incremental capital, fixed and variable O&M and fuel costs of the selected unit. Secondary impacts may include dispatch changes and changes in the level of reserve required in the case of renewables.
T&D Improvements operation changes.	This option includes more efficient transformers, reconductoring and system
Natural Gas ply Options processing, and transmissio engines.	Options available to the natural gas supply sector include changing out pneumatic Sup- devices, improved inspection and maintenance programs in production and n and distribution, and using turbines in place of reciprocating
Energy Efficiency Options	
Increased End-use Efficiency	Increased end-use efficiency directly reduces carbon emissions from natural gas, oil, or coal used in fossil-fueled end-use applications, or avoids the CO_2 emissions associated with electricity generation. Costs include the capital costs of the technology, incremental fuel costs (or savings), and any required incentives to end-uses.
End Use Fuel Switching	Fuel switching, from fossil fuels to electricity or vice-versa, can have carbon benefits by increasing the total efficiency and emissions of the process.
Recapture Options	
Methane recapture (three types)	Reductions in GHG emissions can be achieved by reducing the leakage of gas from the natural gas distribution system of affiliate gas local distribution companies. Similarly, landfill gas can be recovered and flared, or used as a low Btu gas or for electricity generation on site. Finally, methane can be recaptured from coal mines.

Repowering can be implemented in different ways. The boiler can be replaced with a new steam-producing facility, or repowering can involve a completely new steam production process. Repowering with a natural gas-fired combustion turbine and adding a heat-recovery steam generator improves overall efficiency and reduces CO_2 emissions. In some cases, repowering can significantly increase the capacity of the facility and extend its life. The additional capacity would defer the need for some new capacity in the future. This can lead to significant additional reductions in carbon emissions if more carbon-intensive generation is displaced. Furthermore, repowering with a combustion turbine, integrated gasification combined cycle (IGCC), or coal fluidized-bed combustion (FBC) reduces emissions of SO_2 and particulates, and may result in other environmental benefits.

If the unit is repowered with equipment that uses a less carbon-intensive fuel, GHG emissions will be reduced even further. Repowering of a coal-fired steam unit with a gas-fired combined cycle has the emissions benefits of both fuel switching and efficiency improvements. Thus, the amount of reductions associated with gas repowering are greater than simply fuel switching to natural gas, as less gas is needed to generate the same amount of electricity.

For example, Exhibit 4-13 illustrates the repowering of a unit (Unit 1) which has fifteen years of operations remaining. Repowering adds another 15 years to the life of the unit and defers new capacity that, under the baseline case, would have been built in year 16. In this instance, the avoidance of the new capacity has an economic value which is based on the avoided capacity cost. In the exhibit, repowering also increases the capacity of the unit by 100MW. Increased energy from this capacity displaces generation from existing units (represented by unit 2), which may have a beneficial effect on GHG emissions.

Exhibit 4-13. Repowering Illustration



The most economically attractive units for gas repowering are those that are currently inefficient, and thus have the most to gain from the repowering. Costs may include capital investments for retrofit and any required fuel transportation infrastructure. Fixed and variable O&M may also change as a result, and capacity requirements may be reduced or deferred. The additional generation from the repowered unit could result in changes in system dispatch, depending on the change in the unit's dispatch price as compared to the Reference Case.

4.4.1.1 Evaluating Repowering as a GHG Emission Mitigation Option

In evaluating the cost and reduction potential from repowering of existing electric generating facilities within a country or sector, it is necessary to assess the future conditions for power supply; future growth in demand; the costs of repowering; the impact of repowering on GHG emissions, both within the country and outside the country; and the replicability of the project within the country or region and in other areas. Each of these factors is discussed below.

Energy Demand and Supply. Repowering generally increases the capacity of the generating unit. This increase in capacity is most common with combined cycle repowering, which can triple the original capacity rating depending on the condition and type of the existing equipment. In analyzing repowering options, it is important that the Reference Case be defined appropriately with respect to energy supply and demand.

The first possible scenario is that the additional capacity and energy from repowering increases the service level (i.e., reduces shortages) and does not displace the use of existing generation or the need for new capacity. If a country is growing rapidly and suffers from power shortages, the additional capacity would add to the country's capacity and increase the available electricity to end-users. For such a country, this new capacity and increased generation has an economic value, based on the value of the power to the end-user.

It is important to note that in this case, there may be no reductions in GHG emissions.[15] For this reason, it usually is appropriate to assume for analytic purposes that if the option is undertaken for the purpose of reducing GHG emissions, service levels will remain unchanged with the repowered unit in place. In this case, the incremental energy from the repowered unit displaces some existing generation, and the incremental capacity provided defers some planned capacity addition. Generation from the repowered unit could displace generation from other units that may be older and less efficient. There may be environmental benefits to this displacement and they should be accounted for in the analysis. Exhibit 4-14 illustrates the calculation of carbon benefits when no such shortages exist.

Costs Associated With Repowering. Repowering can be an attractive option when an existing plant has poor reliability and efficiency, or is near the end of its useful life. In the case of the GEF study of a project in Morocco, repowering offered a relatively low cost way to increase the capacity of the system. In addition, it was an opportunity to demonstrate the application of repowering technologies in a developing country. If repowering results in the use of a lower carbon content fuel, carbon emissions can be reduced even further. However, relative fuel prices become an important consideration.

When evaluating repowering options, it is important to define the alternative against which the project will be evaluated. When comparing the cost of repowering with the cost of the alternative option (i.e., continuing to run the unit until retirement and then building a new unit), the latter should include the cost of the unit being repowered, and the cost of deferred capacity and displaced generation. Avoiding or deferring the construction of new capacity has an economic value which is based on the avoided capital and O&M costs associated with any new capacity. Finally, repowering may also result in fuel cost savings because less fuel will be needed to generate the same amount of electricity. The costs that should be considered include:

Exhibit 4-14. Repowering Project in Morocco

Morocco's economy has experienced rapid growth in recent years and the power sector has serious power shortages. Programmed load shedding of up to 17 percent of peak demand has been implemented on industrial customers. A repowering of an existing power plant was identified as a potential project for GEF funding based on the potential to introduce innovative technologies to a growing power sector and reduce greenhouse gas as well as other emissions.

The project would add a new 60 MW new combustion turbine (CT) capable of operating on natural gas and light distillates to an existing 75 MW steam based power generation unit. The turbine will exhaust directly into a new heat recovery steam generator (HRSG) and then the high pressure steam produced in the HRSG will be fully utilized by existing steam turbine.

In analyzing the carbon benefits from this project it is important to define the baseline project. Because the repowering provides additional capacity and generation, it is important to account for energy which would have been generated in the baseline case, and is displaced by the incremental capacity provided by the repowered unit. In other words, the baseline case and the mitigation case should reflect the same level of generation. The result is that the net effect of the repowering on total system generation is zero. The table below illustrates the structure and assumptions underlying the analysis of the repowering option.

Carbon Benefits with No Increase in System Generation

	Fuel	Capacity MW	Output GWh	Efficiency Percent	Efficiency kj/kWh	Fuel Cons. 10^6 kj	Carbon Rate gms/kjoule	CO2 Emissions 10^6 Tons
Reference Scenario								
Original Plant	Oil	71	463	33.8%	10,651	4,931,556	0.077	381,538
Other Energy	Oil	55	355	33.8%	10,651	3,781,215	0.077	292,540
Total		126	818			8,712,771		674,078
Mitigation Options								
Repowered Unit	NG	126	818	39.7%	9,069	7,418,476	0.056	416,177
CO_2 Emissions Savings								257,902

Completion of the repowering project at the plant would increase its output by over 75 percent. From about 463 GWh per year to 818 GWh per year. It is assumed in the illustration that under the Reference Case the original generating unit and the replacement energy source would be oiled-fired. With repowering, natural gas would be used. Repowering also improves the efficiency of the unit by about 15 percent (from 33.8 percent to 39.7 percent). The replacement power in the Reference Case is assumed to have an efficiency similar to the unit targeted for repowering.

As indicated, total fuel consumption from the repowered facility is about 15 percent lower that in the baseline. Because of the switch to a lower carbon fuel, total carbon emissions are reduced even further-by about 38 percent.

Selected information taken from "Morocco Repowering of Power Plant." Project Document. Global Environment Facility (GEF), July 1994

- *Capital Costs*: The capital costs involved with repowering can be significant, particularly if the repowering involves a new turbine and a new heat recovery steam generator (HRSG).
- *Fuel Prices*: Fuel prices are a significant factor in determining the cost of a repowering that involves a change in fuels or increased fuel use.
- *Fixed and Variable Operation and Maintenance Costs*: O&M costs are important considerations. Total O&M costs may change with an increase in capacity; variable O&M costs may change with a fuel switch and attendant changes in handling, inventory and processing requirements.

Benefits may also accrue due to the project. Project benefits may include:

- *Benefits of capacity deferral.* Because repowering can extend the life of equipment, it can also affect the timing of resource additions and capital expenditures. For example, repowering a unit with 15 years of life remaining may extend its life for another 15 years. This life extension may defer the need for new capacity; the cost benefit is the cost savings associated with the deferral of new capacity additions.
- *Local Environmental Benefits.* Some repowering options may decrease emissions of SO_2, NO_x, and other pollutants. These can be valued at the monetary values established by the Bank.

Impact on GHG Emissions. Emissions reductions are measured as the difference between the CO_2 that would be emitted without repowering and the level of emissions with repowering. For the "no repowering case" the emissions depend on three different components: (1) emissions from the existing unit to be repowered, (2) emissions associated with the generation which is displaced by the incremental generation capacity provided by repowering, and (3) emissions from the displaced capacity in the longer term. As discussed above, for screening GHG emission reduction options and for the sake of analytic simplicity, it may be appropriate to assume that generation levels remain constant.

The change in efficiency for the repowered unit will influence the level of GHG emission reductions. Improvements of 30 to 40 percent are possible. The impact on GHG emissions will also depend on how the unit is operated after the repowering relative to how it operated prior to the repowering. An old inefficient unit which is a candidate for repowering may have a relatively low capacity factor. After repowering, the more efficient unit will have a higher capacity factor. For purposes of analysis, generation levels are assumed to remain constant on a system level, and therefore overall capacity factors for the affected plants are assumed to be constant. However, these changes in operation may affect system level emissions. This is discussed further in the next chapter.

The level of emissions reductions will also be influenced by the emissions characteristics of the generation that is displaced by the repowering option (i.e., the marginal generation source). Identifying the marginal impacts of GHG mitigation options is very difficult without detailed system simulations. Therefore, for purposes of this screening analysis, it is best to use an assumption about the marginal fuel source on the system. This is likely to reflect a weighting of the last unit to be dispatched in all hours. The next simplest approach is to use an average carbon emissions rate.

In the example shown in Exhibit 4-14, emissions are reduced as a result of increased efficiency (and reduced fuel consumption), and as a result of the shift from oil to natural gas, a lower carbon content fuel. In the example, had a coal-fired unit been repowered, emissions would have been reduced even further.

Replicability of a Repowering Project. Repowering may offer an opportunity to reduce emissions and defer capacity throughout the power system of a region or country. The analysis should include an evaluation of the potential for the repowering technology to be promoted at other power generating facilities within a country or region. The feasibility of this will depend on the age and condition of the power system and capacity requirements and planned additions.

Other Issues. It should be noted that because the options compared in this example involve different components, each with different lifetimes, a levelized cost analysis is essential. In the example discussed above, the lifetime of the unit once it is repowered is 30 years; otherwise, the existing unit is assumed to have a remaining lifetime of only 15 years. New capacity constructed in year 16 will have a life of thirty years (until year 46). The levelizing of the different streams of costs for the two options enables them to be compared on an annual basis, regardless of their lifetimes.

4.4.2 Cogeneration/Combined Heat and Power Systems

Cogeneration is the simultaneous production of electric energy and useful thermal energy that is inherently more efficient than producing steam and electricity separately. Because of this efficiency gain, cogeneration can be a cost-effective means of reducing emissions. In a typical configuration, an industrial or commercial boiler is replaced by a gas turbine and a heat exchanger, and some of the waste heat is used to make electricity. The entire process is often a more efficient way of making electricity and process heat than a combination of boiler and utility generation, and the overall efficiency gain, as well as a potential fuel shift, can be a cost-effective means of reducing carbon emissions. In addition to using the waste heat in industrial processes, it can be used for district heating. Cogeneration systems can achieve real thermal efficiencies of over 80 percent. Small cogeneration systems may covert about 20 percent of fuel input into power, and 50 to 60 percent of the fuel into useful heat. Larger systems might convert up to 40 percent of the fuel into electric power.

Figure 4-15a illustrates the energy flows through a cogeneration system designed to produce 1 kWh of electricity and associated steam with optimal overall efficiency.[16] In the illustration the cogenerator has an input of 11,000 Btu, produces 4,927 Btu of steam and the equivalent of 3,412 Btu of electricity (1 kWh). Total losses are 2,661 Btu for an overall efficiency of about 76 percent.

Exhibit 4-15a. A Typical Cogeneration System

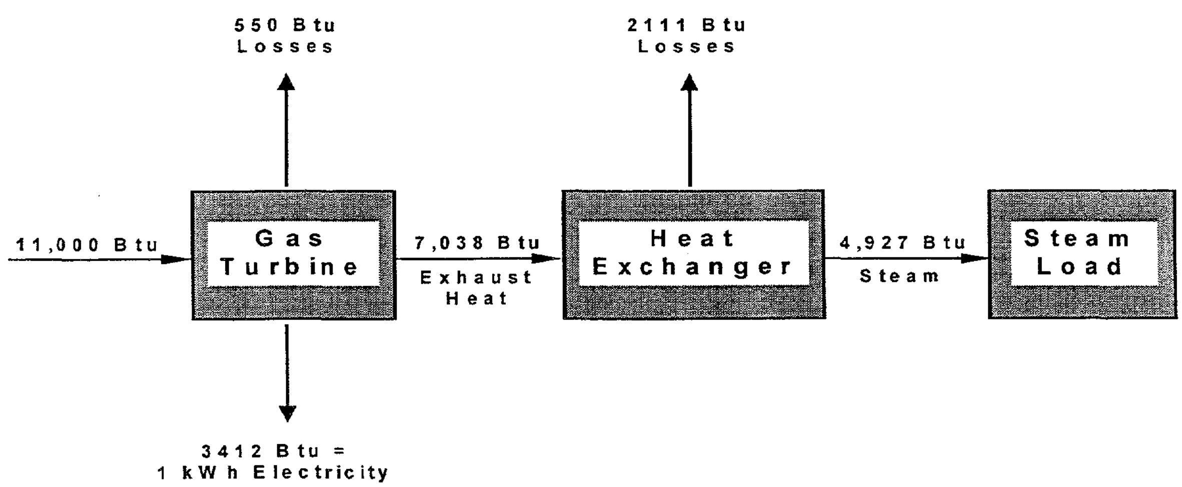
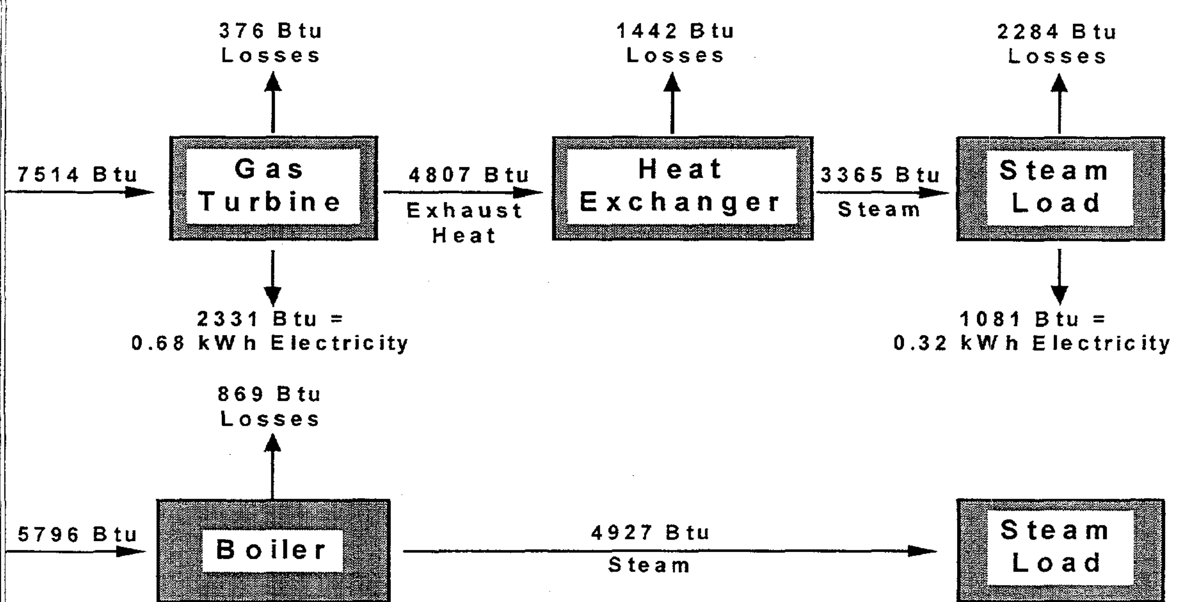


Figure 4-15b illustrates a boiler that produces the same steam output as the cogeneration system and a 1 kW combined cycle system. The boiler's efficiency is about 85 percent. Thus, the overall industrial process is less efficient than the original boiler; however, when the electricity output is taken into account, the process is more efficient. The boiler plus the combined cycle unit have a total heat input of 13,310 Btu, for an overall efficiency of 63 percent.

Exhibit 4-15b. Separate Boiler and Electric Generation Systems



Cogeneration may also be used in commercial buildings (e.g., hospitals and hotels). In the U.S., however, cogeneration has been used more successfully in industrial facilities than in commercial buildings for a variety of reasons: (1) industrial facilities tend to operate 24 hours a day, seven days a week and are, consequently, able to utilize cogeneration units to their fullest capacity, and (2) industrial facilities tend to have higher energy requirements than commercial buildings, implying that they can exploit scale economies associated with cogeneration units (larger units also tend to be more reliable). Therefore, the discussion that follows focuses on the use of industrial cogeneration.

4.4.2.1 Evaluating Cogeneration as a GHG Mitigation Option

The suitability, potential, and costs of cogeneration as a GHG mitigation option for a country or region will depend on a number of factors, including the steam and electricity requirements of the industries in the region; the cost and reliability of existing power supply; current demand and supply situation for power and expected future growth in demand; and the cost of cogeneration systems.

In evaluating the cogeneration option, the first step is to define the option and the baseline- what would have occurred in its absence. For example, without the cogeneration system, the industrial facility would have perhaps replaced its boiler with a new boiler with a 20 year life and purchased electricity from the power system over this time period. However, with the cogeneration facility in place (1) the boiler is not constructed, (2) a cogenerator sized to meet thermal loads is constructed, and (3) on-site electricity demand is met by the cogenerator, displacing generation from the power sector. Excess electricity may be generated and sold back to the grid, displacing some other source of less efficient generation. The emissions and cost effects of all these impacts must be considered in the analysis.

Industry Profile. In order to assess the potential for industrial cogeneration in a country, a first step would be to assess the nature of its domestic industry. Such an assessment would also help determine whether the boiler technology used in domestic industries can be easily retrofitted with cogeneration units. Because cogeneration produces electric energy and thermal energy simultaneously, it is most suited to industrial facilities and processes that have significant electricity and steam loads. Examples of industries that use thermal energy in their production processes include iron and steel, paper and forest products, textiles, and chemicals. In the absence of cogeneration, such industries are likely to operate boilers to meet their steam requirements and purchase electric power from power generation facilities.

Reliability of existing power supply. Another factor that would influence the attractiveness of cogeneration is the reliability of the existing power supply to domestic industry and the production losses resulting from load shedding. For example, countries where the power system is unable to maintain a reliable supply of power would be strong candidates for industrial cogeneration. Improved operational reliability alone could provide adequate economic justification for cogeneration.

Energy Demand and Supply. Cogeneration is a long-term investment. For the investment to be a profitable one, the industrial facility should be able to use all the power and steam generated by the unit. Therefore, industrial cogeneration will be more successful in countries with a growing industrial sector. The level and timing of electricity demand versus steam demand are also important in assessing the cost and cost-effectiveness of carbon reductions.

Cogeneration will also be easier to promote in countries where the power sector is having difficulty meeting power demands. In such situations, the power sector is more likely to be willing to help industries be self-sufficient in their power requirements. However, in some countries, the government may be providing power to the agricultural and residential sectors at a highly subsidized rate. In such countries, even if power shortages exist, the power sector may resist the promotion of industrial cogeneration because industrial customers may be the sector's only remunerative customers.

Cogeneration may also have a role in regions where district heating systems supplied by "heat only boilers" (HOB) are the predominant form of space heating. These "combined heat and power" (CHP) applications can be cost-effective upgrades to existing district heating plants.

Cost of Cogeneration. The costs of a cogeneration system includes capital costs (including engineering, equipment, and installation), fuel-related capital costs, and auxiliary equipment and controls. If excess electricity will be sold to the electric power system, then there may be additional costs to interconnect the unit to the system. Cogeneration can require a substantial upfront investment, which will vary across applications. Operation and maintenance costs and fuel costs are also important considerations.

Defining what would happen in the absence of the cogeneration project is important to assessing the cost of the option. If the boiler was slated for retirement or replacement with a new boiler, the relevant capital costs are the incremental costs - the difference in costs between: (1) the new boiler and the utility capital cost, if any, and (2) the cogeneration unit. However, if the boiler is being replaced early, relevant costs are the total capital cost of the cogeneration unit less any salvage value of the existing boiler.

Relative fuel prices are important in determining total costs if the cogeneration system results in the use of a different fuel mix. Cogeneration will result in fuel cost savings for the country as a whole because cogeneration systems use fuel more efficiently. Cogeneration costs will also be influenced by whether the unit defers capacity. Cogeneration systems operated in an integrated manner with the power system may also influence the dispatch of the power system, displacing older, less efficient plants.

Impact on GHG Emissions. Because cogeneration uses fuel inputs more efficiently than a combination of boiler and generating units that would operate in its absence, it results in lower GHG emissions. Different types of cogeneration units have different efficiency levels and will have varying effects on GHG emissions. In general, as the proportion of electric output increases, the efficiency of the unit falls and the unit begins to look increasingly like a pure electric power production unit. In addition, the use of different manufacturers' components in very similar cogeneration systems has implications for efficiency. Certain turbines — for example, aero-derivative combustion turbines — have higher efficiencies. The cogeneration unit that has the lowest GHG emissions associated with it is the natural gas fuel cell, which uses an electrochemical process similar to that used in an automobile battery. The fuel cell, however, is the most expensive type of cogeneration unit available. Therefore, in evaluating the GHG emissions impact of different cogeneration scenarios, the analyst should be cognizant of the various trade-offs that exist.

If cogeneration results in the use of a less carbon-intensive fuel (e.g., gas instead of coal), GHG emissions can be further reduced. Emissions reductions will also depend on the carbon emissions associated with the electricity generation that is displaced by the unit. A gas-fired cogeneration unit displacing coal-fired generation on the margin (assuming no change in service levels) will produce greater carbon reductions than a gas-fired cogenerator displacing oil-fired generation on the margin. An understanding of the marginal fuel source of the power sector during the hours of the cogeneration unit's output is important for evaluating the GHG impacts of this option.

Finally, in countries where the power distribution system is plagued by high transmission and distribution losses, installing cogeneration units for on-site use at industrial facilities eliminates such losses. This additional efficiency increase can further reduce GHG emissions.

The net carbon emissions reductions from cogeneration are equal to the difference in emissions of (1) the boiler and purchased electricity and (2) the cogenerator, as shown below.

Emissions Reductions = [Boiler Emissions + Emissions from Displaced Generation - Emissions from Cogeneration]

Note that the generation displaced at the utility site is greater than the electricity generated by the cogeneration unit because of T&D losses. Therefore, the generation levels underlying this calculation should reflect the appropriate level of losses incurred to meet demand.

Replicability of Project. An analysis of cogeneration for a country may reveal a number of opportunities that are cost-effective without considering the carbon reductions that would occur. Therefore, GEF funding may not be required for such projects. GEF funding could, however, help spur some initial investments in cogeneration and help overcome market inertia. Successful projects can then be more easily replicated in other industrial settings and other countries. Exhibit 4-16 presents information on the potential effects of a cogeneration project in China.

Exhibit 4-16. Cogeneration in China's Paper Industry

The paper industry in China is a large consumer of both electricity and steam. Most paper mills generate their own steam in boilers which operate at low pressures and moderate efficiencies. Some of the larger enterprises generate their own electricity, also using boilers to produce steam at relatively low pressure and at efficiencies of 50 to 60 percent. Increased adoption of cogeneration systems in the paper industry will permit much higher generation efficiencies for both steam and electricity, partly through the application of a process that is inherently more efficient than separate generation and partly by the effect of replacing old and outdated equipment.

Total Cogeneration Potential and CO_2 Emissions Reductions in China Under Alternative Scenarios:

	Without cogeneration (10^6 tpy pulping capacity)	With cogeneration (10^6 tpy pulping capacity)	CO_2 Savings (10^3 tpy)
BAU	1.9	0.5	11
Accelerated	1.4	1.0	21

Source: *Energy Efficiency in China: Technical and Sectoral Analysis*, Subreport Number 3, Edited by Barry G. Tunnah, Wang Shumao, and Liu Feng, August 1994, p. 76.

4.4.3 *Alternative New Electric Capacity Decisions*

4.4.3.1 Overview of Option

The amount and timing of requirements for new power plant capacity is affected by current power shortages, the rate of growth in demand for electricity, and the planned retirement of power plants currently on-line and operating. Selecting technologies that use lower carbon or no-carbon fuels will result in overall reduction in GHGs relative to the projected Reference or Business-as-Usual Case. Further, more efficient generation means less fuel consumed (and thus even further reductions in GHG emissions) per kWh of electric output.

Alternative capacity choices may include more efficient technology choices, fossil fuel alternatives, renewable energy technologies, and nuclear generation. A decision to build an alternative technology or alternative fueled generating unit could be made in conjunction with a broader strategy to develop an underdeveloped resource in a country or region. Increased use of indigenous natural gas supplies or renewable resources (such as hydro or biomass) are two such strategies. The decision to shift to alternative capacity alternatives would also be consistent with a decision to pursue dispersed resources.

Illustrative Alternative Capacity Choices

- Alternative coal fired technologies (AFBC in place of conventional pulverized coal technology, advanced combined cycle technologies in place of combustion turbines).
- Oil or natural gas-fired generation in place of coal-fired generation.
- Renewable energy (hydroelectric power, photovoltaics, wind power, geothermal energy, biomass, solar thermal energy and nuclear energy) in place of fossil fueled systems in central station or dispersed applications.

Most of the alternative fossil-fuel technologies are proven, commercially available options and include constructing an advanced pulverized coal system - such as atmospheric or pressurized fluidized bed combustion (FBC); constructing an advanced combustion turbine system - such as integrated steam injected gas turbines (ISTIG) and constructing an integrated gasification combined cycle (IGCC). Many of the renewable energy technologies (with the exception of hydroelectric power) have been used much less frequently and are newer technologies. The extent to which the capital costs and efficiencies of renewable energy technologies improve as the technologies mature will have a major effect on their cost-effectiveness. Renewable energy technologies also have a wide range of performance characteristics, from intermittent to fully dispatchable.

Many of these options are suitable for dispersed application. Photovoltaics, solar thermal, wind energy, or small generation systems ("gensets") can be installed at the end-use site, eliminating the need for construction of transmission lines to connect the load centers to the central grid.

4.4.3.2 Evaluating New Capacity Choices as GHG Mitigation Options

Evaluating new capacity choices requires defining the Reform Scenario and the mitigation option. For example, the Reform Case may be the construction of a new 200 MW coal-fired power plant. The GHG mitigation option may be to construct instead a 200 MW natural gas-fired combined cycle plant. Another example would be to construct a 200 MW hydroelectric plant. It is important that the cases be constructed so that they are truly comparable and provide the same level of capacity and energy services. Exhibit 4-17 illustrates how the comparisons should be constructed in two cases.

A screening-level analysis is not sufficiently detailed to evaluate impacts where dispatch may be affected (as would be the case in the examples illustrated above). In analyzing the potential cost-effectiveness of new capacity choices, it is necessary to consider future system dispatch. In a screening analysis, estimates of the marginal generating source (i.e., the last unit to be operated) can be used to assess system dispatch impacts.

Exhibit 4-17. Illustration of Constructing Reform/Mitigation Scenario Comparisons

Reform Scenario	Mitigation Scenario	Comment
200 MW coal plant with a capacity factor of 75 percent	200 MW gas fired combined cycle unit with a capacity factor of 65 % and make up generation of 175 GWh (200 MW * (75-65%) * 8760 hours/year)	The capacity factor of the combined cycle unit may be lower than the coal plant and additional generation from other units on the system will be required.
50 MW oil steam plant which operates at 60 percent and generates 263 GWh per year.	50 MW(ave) hydroelectric unit (219 GWh) plus 25 MW combustion turbine (0 GWh). Generation from existing units (44 GWh) is required to provide the equivalent energy	The hydro plant provides only 25 MW at peak. Therefore under the Reform case, an additional 25 MW peaking capacity is required in a capacity constrained system. The energy output of the hydro plant is lower and makeup energy is required.

In evaluating the feasibility of alternative new capacity options as a GHG mitigation option for a country, the analyst should also assess the following factors:

- Suitability of the option to a country, including whether there is an indigenous renewable resource or adequate supplies of lower carbon fuels.
- Current demand and supply situation with respect to power and expected future growth in demand.
- The total lifetime cost of the option relative to the costs of alternatives.
- Impact of the option on GHG emissions, both within the country and outside the country.
- Replicability of the project within the country and in other countries.

These are discussed in more detail below.

Suitability of the Option. Of primary importance in assessing new capacity options is the suitability of the technology to the region or country, and power system. The resources required for economic use of renewable technologies, such as wind, water, sun, and biomass, are not uniformly distributed geographically throughout the world or even within a country. The successful use of a renewable technology in a given country or situation may not be replicable to other countries or even other areas within the same country. Thus, when considering a renewable energy resource, it is important to conduct a careful analysis of the technology's performance characteristics relative to a country's needs, including the measurement and inventory of renewable resources in the country.

In the case of intermittent renewable resource technologies, it will be important to consider the energy profile of the option as compared to the load profile. For example, photovoltaics may provide peak amounts of energy at the time of a system's peak. This may make the option a more economic choice than non-dispatchable renewable options with an energy output that does not closely follow demand levels (e.g., run-of-river hydro). The analysis of intermittent renewable options should consider the timing of energy production relative to demand levels.

For other options, the appropriateness of the technology's duty cycle (e.g., peaking, intermediate, base load) to the system, as well as its development status (e.g., commercial, demonstration), must be considered.

Energy Demand and Supply. The existing demand and supply situation for a given country can affect the adoption of alternative energy projects. In countries where the power sector is unable to meet the power needs of remote rural areas, small scale renewable energy projects can help overcome this limitation. For example, solar photovoltaic systems have been promoted as a means to supplement conventional energy supplies and meet the decentralized energy needs of rural areas. Therefore, depending on the energy requirements of a given country, a smaller or larger project may be more appropriate.

Renewable projects that have to be tried first on an experimental basis may be better suited to countries or regions where acute power shortages do not exist and there is no pressing need to channel investments into projects that can increase power supply quickly.

Cost of the Option. Costs of the option include capital costs, fixed and variable O&M, and fuel costs. Because incremental costs are important, the analysis may be conducted on a full cost basis and differences compared, or on an incremental costs basis. The components include:

- *Capital Costs:* Capital costs should include the plant construction and all fuel handling and delivery equipment.
- *Transmission and Distribution Costs:* Dispersed generation technologies may eliminate the need for costly T&D system upgrades and result in lower energy losses.
- *Fixed and Variable O&M:* Fixed and variable O&M costs may be lower for the alternative, for example, due to lower maintenance, the absence of consumables (e.g., in scrubbers), lower fuel handling and treatment costs, and reduced waste disposal requirements. Some renewable energy projects may require high upfront costs, but may have operating costs that are lower than conventional power facilities.
- *Fuel Costs:* Incremental fuel costs of the alternatives are important.

Impact on GHG Emissions. The impact on GHG emissions will depend on the relative efficiency of the new and displaced generating technologies, the fuels used in the Reform and Mitigation Scenarios, and the characteristics of the incremental generation displaced (or make-up generation used).

Advanced fossil capacity options (including advanced pulverized coal systems, advanced combustion turbine systems, integrated gasification combined cycle) can reduce carbon emissions relative to conventional alternatives up to 40 percent in some cases. Exhibit 4-18 summarizes the range of reductions that may be expected from these advanced fossil technologies. Renewable technologies have the potential to reduce emissions by up to 100 percent. Hybrid technologies (e.g., solar thermal with fossil backup) reduce emissions by lower levels.

Exhibit 4-18. Carbon Emissions Reductions for Advanced Fossil Technolo

Conventional Alternative	Advanced Technology	% Carbon Reduction
Pulverized Coal (PC)	AFBC	5%
PC	PFBC/Combined cycle	12%
PC	Advanced Pulverized Coal	11%
PC	IGCC	0% - 21%
Natural Gas Turbine	ISTIG	36%
PC	Fuel Cells (Molten carbonate)	24% - 30%
PC	Solid Oxide	32% - 39%

In some cases, emissions per kWh from an IGCC are higher than from a conventional coal unit

Source: LBL, 1995

The total potential reductions from alternative new capacity decisions will depend not only on the level of planned additions and their emissions characteristics, but also the types and characteristics of capacity additions that are planned in the Reform Scenario. A country planning to add predominantly natural gas-fired resources would have fewer potential reductions than a country or region planning to add coal-fired units.

Replicability of Projects. Renewable energy technologies, as noted above, tend to be newer and less proven than fossil fuel technologies. If they can be successfully promoted, these projects can act as catalysts in developing a commercial, broad-based market for renewable technologies. Wider commercial applications will likely lower the cost of such technologies and accelerate their adoption within a country or region. Before trying to replicate a given project, however, the analyst should be careful to assess the suitability of the technology to different settings.

4.4.4 Electricity Transmission and Distribution (T&D) Efficiency Improvements

Transmission systems connect generating stations and major load centers. Distribution systems provide the link between the transmission grid and the end-user. In industrialized nations, the level of losses in transmission and distribution (T&D) systems are in the range of 5 to 10 percent. In developing countries, the loss rate can be substantially higher, as much as 20 to 35 percent. These losses can be attributed to inadequate investment in system expansion and maintenance, overloaded systems, inadequate billing and collection systems, and theft.

Improvements in the efficiency of the electricity T&D system reduce the amount of energy that is "lost" between the point of generation and the point of end-use. A decrease in energy losses leads to a reduction in generation to meet the same end-use demands. This decrease in generation in turn reduces GHG emissions.

There are many different ways to improve the efficiency of the T&D system. In general, these involve either: (1) replacing the existing stock of T&D equipment with more efficient equipment, (2) implementing more efficient system management techniques, or (3) modifying operations, including billing practices, and security. Each option that reduces system energy losses will have the effect of reducing GHG emissions.

T&D Losses in China

A study supported by GEF examined the main sources of T&D losses in China. These included:

(1) High loads on old distribution systems.
(2) Expanded generation facilities not accompanied by increased distribution systems.
(3) Inadequate power factor compensation leading to high line losses.
(4) Little or no spare capacity on networks resulting in inflexible distribution management; long transmission distances with no alternative routings.
(5) Changes in electricity demand patterns (e.g., increased urban usage) with no concomitant changes in distribution capacity.

Source: " China – Issues and Options in Greenhouse Gas Control", August 1994.

Examples of transmission efficiency improvements include the following:

- *Higher capacity transmission systems,* including High Voltage Direct Current (HVDC) systems. Switching to HVDC can reduce transmission losses by 50 percent (relative to the losses associated with an alternating current line of the same power transfer capability).

- *Improved control of transmission line power flows.* Incorporating new electronic controls helps generating facilities increase transmission system capacity while reducing susceptibility to power disturbances. Through improved control, facilities can optimize their transmission systems, reduce backup reserve requirements, and potentially integrate renewable energy more effectively.

- *Replacement of existing conductors* with conductors that offer less resistance, either because of their size or their type of material. Reducing resistance leads to reduced power losses.
- *Increased transmission line voltage* decreases the current flowing through a conductor (for the same amount of power), thereby reducing energy losses.
- *Use of capacitors and synchronous condensers* to correct system power factors.
- *Construction of new transmission lines* to optimize transmission efficiency to distribution points.

Distribution efficiency improvements include the following:

- *Automation of the distribution system* such that generating facilities can more efficiently monitor and operate distribution from remote locations.
- *Use of voltage-regulating equipment controls* that maintain the voltage of the electricity provided to the customer within prescribed limits, thereby controlling losses.
- *Dispersed energy storage* improves the asset utilization of the distribution system, and facilitates the integration of "dispersed generation," particularly intermittent renewable energy technologies. Improved storage capability also allows the existing generation system to operate more efficiently.
- *Improved billing and collection procedures* to increase payments.
- *More rigorous security* to prevent theft of electricity.
- *Use of lower loss transformers* reduces generating requirements and, hence, emissions.

A 1992 study sponsored by the Bank estimated the annual T&D losses in India to be equal to 20 percent of net generation. The study found that investments in T&D have been generally insufficient. With the exception of the first plan period, investments have been biased towards generation capacity. Exhibit 4-19 summarizes the investments in T&D as a percent of investments in generation. As indicated, these have declined dramatically in recent years.

Exhibit 4-19. T&D Investments in India

Plan Period	T&D/Gen. (%)
1951-55	126
1955-60	46
1960-65	39
1965-68	40
1968-74	52
1974-79	41
1979-80	51
1980-85	46
1985-90	37

Source: *India, Long Term Issues in the Power Sector*, The World Bank, July 1991.

4.4.4.1 Evaluating T&D Efficiency Improvements as a GHG Mitigation Option

In evaluating the suitability of T&D efficiency improvements as a GHG mitigation option for a country, the analyst should assess the following factors:

- Relevance of the option to a country;
- Cost of the option;
- Impact of the option on GHG emissions, both within the country and outside the country; and
- Replicability of the project within the country and in other countries.

Suitability of the Option. A certain amount of T&D losses are considered normal for any power system. Consequently, T&D options are relevant for only those countries where T&D losses are in excess of the range considered normal (e.g., greater than about 10 percent). The greater the loss percentage, the more likely there are to be cost-effective measures to reduce costs and GHG emissions. Such countries not only incur the direct loss of energy that is wasted, but also incur costs of owning and operating additional capacity to support loads that are inefficiently served by the T&D system. T&D losses are most serious for countries that currently face power shortages. In some countries, the problem is exacerbated by a chronic imbalance of investment in favor of generation with the result that T&D projects are seriously underfunded.

Cost of the Option. As noted above, T&D improvements generally involve either replacing the existing stock of T&D equipment with more efficient units or modifying system management techniques or operations. The cost of these options is essentially the capital cost of improving the system (e.g., the cost of replacing existing conductors, the cost of improved transformers), or the cost of using improved system management techniques. The benefits, or cost savings, associated with such options include the costs savings associated with electricity not generated (or the economic benefits of additional load served in the case of a system with shortages) and the avoided cost of additional generating capacity to offset the losses.

One estimate developed for an Asian Development Bank-financed project in Pakistan revealed that rehabilitating the distribution system could provide power at an investment cost of US$135 per kW. Another study indicated power factor improvements resulting from distribution system rehabilitation range from US$100-200 per kW.[17]

Impact on GHG Emissions. T&D options can lower GHG emissions per unit of energy consumed by end-users by improving the overall efficiency of the T&D system and thereby reducing power losses. More of the power generated will actually reach end-users and less overall capacity will be needed to meet the same level of demand. In the case of countries that are not faced with power shortages, T&D improvements have the potential to defer future capacity. T&D improvements aimed at improving billings and collection systems and reducing theft will not reduce GHG emissions unless energy demand changes as a result (i.e., through income effects), a possible occurrence in some cases.

The Bank's study on GHG options in China, cited above, assessed the ability of technological changes to reduce T&D losses and mitigate GHG emissions from a 315 kVA system. The specific technological change involved replacing the transformer and trunk lines. Two alternatives were examined: (1) a case in which the capacitors are installed at the end user's side of the line (Case 1) and (2) a case in which the capacitors are installed along the line just below the transformer (Case 2). Annual power sales increase from 401.63 MWh under the base case to 430.45 MWh under Case 1 and 418.16 MWh under Case 2. The expected annual savings and GHG impacts of the change are shown in Exhibit 4-20.

Exhibit 4-20. Results of T&D Assessment For a 315 kVA System in China

Item	Case 1	Case 2
Annual power savings	39.43 MWh	23.46 MWh
Coal savings	15.38 tce*	9.15 tce
CO_2 reductions	11.43 t	6.80 t
SO_2 reductions	0.39 t	0.23 t
TSP reductions	0.43 t	0.26 t

* tce = metric tons of coal equivalent

Source: *China, Issues and Options in Greenhouse Gas Control, Subreport Number 4*, December 1994, page 156.

4.4.5 Fuel Switching at Electric Power Plants

Fuel switching refers to converting an existing generating unit so that it is capable of burning another fuel. It may be desirable to retain the capability to burn the original fuel. Fuel switching to lower carbon content fuels can produce significant reductions in GHG emissions. The most common shift and the one which may produce the largest reductions in carbon are from coal to natural gas. Shifts from coal to oil, or from oil to natural gas, will also reduce carbon emissions. Shifts may be complete (a 100 percent shift to the alternate fuel) or partial, where a lower carbon content fuel is co-fired with the primary fuel. Biomass and natural gas co-firing with coal have been successfully adopted in the U.S. Fuel switches may be adopted year round, or on a seasonal basis, varying with fuel or delivery constraints.

The costs of achieving carbon reductions from fuel switching are a function of the cost of capital improvements, differential fuel prices, and impacts on efficiency. Carbon reductions will depend on the relative carbon contents of the pre- and post-fuels, and efficiency impacts.

4.4.5.1 Evaluating Fuel Switching as a GHG Mitigation Option

In evaluating the feasibility of fuel switching as a GHG mitigation option for a country, the analyst should assess the following factors:

- Availability and prices of different fuels;
- Capital investments (in plant and fuel delivery) required to effect the switch;
- Incremental O&M cost impacts; and
- Impact of the option on GHG emissions, both within the country and outside the country.

Availability and Prices of Different Fuels. The ability to fuel switch will depend first on the availability of alternative fuels. Countries or regions with undeveloped natural gas supplies may be able to pursue a limited strategy of fuel switching. Other countries may be able to import natural gas from neighboring countries. Eastern European countries may be able to increase their natural gas imports from the resource-rich former Soviet Union. A more practical alternative may be the use of biomass resources to co-fire an existing plant.

There are a number of practical and political issues that should be addressed with a potential fuel switch. Because of the critical nature of power, a country may prefer to remain self-sufficient to avoid a power crisis in the event of rising prices for the imported fuel or changing political dynamics between itself and the country it is importing from. The country may not have the necessary infrastructure to transport locally produced or imported alternative natural gas.

Cost of the Option. The key factor that determines the cost of a fuel switching option is the price differential between the current fuel and the alternative fuel. Relative coal, oil and natural gas prices are likely to be of most concern, although biomass may be a potential alternative. Future natural gas prices, and their uncertainty, need to be considered. In contrast, coal prices may be less volatile.

Fuel switching may also require some capital investment to adapt boilers to an alternative fuel and to deliver the alternative fuel to power facilities. In the instance of fuel switching to natural gas, infrastructure costs generally involve construction of gas pipelines or pipeline spurs and the installation of gas burners. Biomass may require special fuel handling equipment (e.g., dryers) and transportation infrastructure (e.g., rail spurs).

Fixed and variable operation and maintenance costs may change as a result of a fuel switch. Fixed and variable O&M costs are likely to decrease when fuel switching from coal to natural gas. For example, natural gas has fewer ancillary requirements than coal - fuel handling and treatment costs are lower, and pollution control costs may be reduced or eliminated. The extent of the impact on O&M will depend on whether their is a full or partial fuel switch. With a partial fuel switch from coal to natural gas, the coal pile would still need to be maintained, and therefore O&M costs would be less affected than under a full fuel switch.

Finally, cost will be influenced by the extent to which overall efficiency is changed by the switch. When switching from coal to natural gas, small efficiency losses may occur. Due to the moisture content of the fuel, biomass may cause efficiency losses.

Impact on GHG Emissions. The carbon content of fossil fuels is the most important determinant of the GHG emissions rate of alternative generating options. Therefore, switching to fuels with lower carbon content can directly lower GHG emissions. Although fuel switching may involve a slight loss in efficiency, the increase in emissions from the greater fuel use is generally more than offset by the lower carbon emission rate of fuels such as natural gas.

The IPCC Guidelines contain a fairly exhaustive list of carbon emissions factors for primary and secondary fuels. Factors for selected fossil fuels were summarized in Chapter 4.2. It is important to note that different coal types have different carbon contents. Peat is the most carbon-intensive, with a carbon content of 28.9 metric tons of carbon per TJ, while bituminous coal has the lowest carbon content, at 25.8 metric tons per TJ, a range of about 10 percent.

In considering the GHG impacts of fuel switching options, the analyst should also factor in the full fuel cycle impacts of the decision. For example, coal and natural gas have different emissions associated with the production and transportation of the fuels. If a country needs to import the alternative fuel, the analysis should include the GHG impacts of increasing fuel production in the exporting country, as well as the emissions associated with transport from the selling region.

4.4.6 Power Plant Efficiency Improvements

The efficiency of electricity generation in developing countries is generally lower than in industrialized countries. For example, in China in 1990 the average net coal consumption for thermal plants above 6 MW in size was 427 gce/kWh, a figure that is about 25 percent higher than industrialized nations.[18] Part of the difference can be explained by differences in coal. The remaining is due to high plant service loads (e.g., pumps, fans and motor loads and losses). For example, in China service loads average 8 to 9 percent, 1 to 2 percent higher than industrialized countries.

One solution is to shut down older, small, and medium-sized units and replace them with newer, more efficient plants. However, there are improvements that can be made at existing plants to improve their performance and reduce GHG emissions. Improvements affect efficiency in one of two ways: (1) reducing the amount of fuel required to generate a kWh, or (2) reducing the service loads of the unit, thereby making more electricity available to meet electricity demands.

Potential improvements include upgrading plant instrumentation and controls, upgrading plant equipment, and improving coal preparation and handling practices. Methods of improving conversion efficiency that involve capital investments include the upgrading of plant equipment by turbine reblading or improvements in controls, valves, or generators. Upgrading of plant equipment can reduce energy consumption and maintenance costs, extend equipment life, improve power plant performance, and, ultimately, decrease GHG emissions. In the U.S., efficiency improvement projects generally increase efficiency by approximately 0.5 percent to 2 percent, but increases can be as high as 5 percent. Efficiency improvements tend to be very unit-specific. Many individual factors affect the level of reductions and cost-effectiveness, including capital costs, O&M costs, and fuel costs. In addition, efficiency improvements are more likely to be cost-effective at units with lower efficiencies (e.g., older units).

4.4.6.1 Evaluating Power Plant Efficiency Improvements as a GHG Mitigation Option

In evaluating the feasibility of conversion efficiency improvement options as a GHG mitigation option for a country, the analyst should assess the cost of the options and the impacts on GHG emissions, both within and outside the country. Issues to consider are discussed in more detail below.

Cost of the Option. Conversion efficiency options generally involve capital improvements to infrastructure to achieve efficiency improvements. Capital costs may be one time in nature, or periodic investments required to maintain the higher efficiency level. Improvements in efficiency may reduce maintenance requirements and O&M costs. O&M costs will also be lower because consumable costs (e.g., water and reagent) are a function of the amount of fuel consumed and less fuel will be required per kWh. Some efficiency improvements may, however, result in higher O&M costs (e.g., improving coal preparation and handling practices). Finally, fuel costs generally decrease following the efficiency improvement because less fuel is required to generate electricity. Specific components of the cost analysis are summarized below.

- *Utilization:* As mentioned in prior chapters, the capacity factor after an efficiency improvement (or any power sector GHG reduction option) may change. The improved efficiency might result in increased utilization.

- *Capital Costs:* These include the costs of the infrastructure to achieve efficiency reductions and/ or the costs of boiler modifications. Over the long term, periodic capital investments may be required to maintain improved efficiency. In the case of a retrofit it is necessary to consider the normal replacement cost of the option and any salvage value at the end of its life.

- *Fixed and Variable O&M:* Certain improvement measures require substantial capital costs, while others require higher O&M costs. Some efficiency improvements tend to lower variable O&M costs since consumable costs (e.g., water and reagent) may decline with reduced fuel consumption.

- *Replacement Energy Costs:* If a unit must be shut down during upgrading, costs for replacement power or the economic cost of the shutdown to customers (in the case of shortages) should be considered in the analysis.

- *Capacity:* Efficiency improvements may increase the capacity of a unit by reducing parasitic service loads. The value of this should be reflected in the economic analysis.

- *Other Costs:* Efficiency improvements may reduce emissions of other pollutants that may be assigned an economic value under the Bank's analyses.

Impact on GHG Emissions. Improvements in conversion efficiency (i.e., heat rate) will produce reductions in GHG emissions that are directly proportional to the decrease in heat rate, all else equal. Therefore, the emissions impact of efficiency improvements at a power plant can be calculated as a function of the change in total fuel consumption. In some cases, there may also be a change in the mix of fuels consumed. For example, some improvements may allow increased use of coal at ignition, with corresponding increase in GHG emissions. The net effect on GHG emissions will depend on the specifics of the efficiency project.

In the China study, several types of upgrades were evaluated. These included renovating burners, installing a tube preheater, and installing a variable speed motor on a water pump. Exhibit 4-21 describes these projects and their impacts in more detail.

Exhibit 4-21. Power Plant Efficiency Improvements		
Project	**Description**	**Impacts and Efficiency Gain**
Renovated Multi-Function Burner	Coal plants used for peaking required oil to stabilize combustion, renovating burners to use smaller burner nozzles	Oil savings, increased use of coal during ignition, increased combustion efficiency of 0.5 percent.
Heat Tube Preheater	Install a heat tube air preheater to prevent condensation in the tubes, which leads to corrosion and restricted airflow.	Raises boiler efficiency by 1 to 1.5 percent.
Variable Speed Water Pump	The continuous water requirements of a boiler are fed with a pump. If a variable speed pump is used to match output of the boilers, service loads can be reduced.	Energy savings of 6 percent of the motor's energy use.

4.4.7 End-Use Efficiency Improvements

Programs that increase end-use energy efficiency can significantly reduce GHG emissions. Energy efficiency measures will likely have a positive impact on any developing country because manufacturing equipment, home appliances, and lighting fixtures used in these countries tend to be outdated and energy inefficient. The set of measures that is most relevant to a given country will, however, depend on factors such as the nature of its industry and climatic conditions.

Energy efficiency may involve simply increasing the efficiency of an application with a more efficient and advanced version of the technology (e.g., motors or lighting). GHG reductions will depend simply on the relative efficiencies of the two technologies. Energy efficiency may also involve conversion of processes or equipment from one fuel to another (e.g., from one fossil fuel to another, from electricity to fossil fuel, from fossil fuel to electricity, or from a fossil to a renewable resource). The most common form of fuel switching is the application of electrotechnologies.

Electrotechnologies can be used in many different types of industrial, commercial, and residential processes in place of the direct use of fossil fuel. In most electrotechnologies, electromagnetic, electrochemical, and/or electrothermal effects are inherent parts of the process. Electrotechnologies are currently gaining widespread acceptance primarily due to their high efficiencies, but also because they offer precise energy control capabilities, high processing and production rates, cleanliness, more efficient use of production floor space, lower cost, and, in some cases, increased speed.

In some sectors, switching from electricity to natural gas may be economic in building applications, such as space and water heating. Resource availability and energy and fuel delivery constraints will be important considerations in determining the economics of fuel switching options.

When fuel switching results in greater efficiency, and/or a shift to a lower carbon content fuel, GHG emissions can be reduced. The extent of GHG emissions reductions, if any, depend on the relative "before" and "after" energy and carbon efficiencies. The extent of reductions in shifting to or from electric technologies will depend on the marginal fuel source used to service the new or displaced electricity demand.

The higher efficiencies associated with many electrotechnologies have the potential of reducing carbon emissions by decreasing energy use when compared with fossil-fueled processes. Since less energy is required to perform the same task, fossil fuel consumption can be reduced, decreasing the amount of combustion products, including CO_2 and other pollutants. Exhibit 4-22 lists the most common energy efficiency measures in the building (residential and commercial) and industrial sectors. Exhibit 4-23 lists a sample of fuel switching options, including electrotechnologies, that have the potential for reducing CO_2 emissions.

Exhibit 4-22. End-Use Efficiency Measures

Space Conditioning	**Refrigeration**
Thermal Storage	Defrost Control
Duct Sealing and Balancing	Multi-Stage Compressors
Improved Efficiency	Insulation/Weatherization
Water Heating	High-Efficiency Refrigeration Cases
Insulation Blankets	**Lighting**
Heat Pump Water Heater	High-Efficiency Ballasts and Reflector Systems
Variable-Speed Compressors	Lighting Controls and Occupancy Sensors
Flow Restrictors	Daylight Dimmers/Switches
High-Efficiency Water Heaters	Compact Fluorescents
Building Envelope	Efficient Fluorescent Lamps
Insulating Glass	High-Intensity Discharge Lamps
Low Emissivity Glass	**Process Improvements**
Insulation	Drying/Curing Efficiency
Controls	Economizers in Recovery in Steam Systems
Energy Management Systems (EMS)	Waste Heat Recovery
Motors	Boiler and Furnace Maintenance
Variable-Speed Drives	Air Compressor Efficiency
Improved Motor Rewinding	Repairing Leaks and Insulating Tanks and Pipes
High Efficiency Motors	**Industrial Housekeeping**
Ventilation	Scheduling Energy Intensive Operations
Improved Efficiency	
Variable Air Volume	
Multi-Speed or Variable-Speed Motor	

The costs and availability of end-use efficiency options will vary widely across countries and sectors. Many cost-effective measures will be found in industry, although the many different industrial processes are likely to require site specific design and evaluation. Examining those technologies that can be applied broadly across the entire sector will represent only a fraction of the full range of energy efficiency opportunities available in industry. In contrast, the building sector has a more limited range of options that can be applied more universally.

Energy efficiency improvements can encompass more than simply installing more efficient equipment. Some include major modifications to existing plants and the addition of new production capacity using state of the art technology. The range of measures may include:

- More efficient equipment displacing outdated, less efficient, equipment;
- Adoption of large scale processing facilities in place of multiple units of subeconomic scale;

Exhibit 4-23. Electric to Fossil Fuel Switching Options

Electric to Gas Water Heating or Gas Space Heating

Gas Engine Heat Pump

Driven Vapor Compression Chiller Gas-Absorption Chiller

Desiccant Cooling System

Heat Pump replacement of natural gas or oil furnaces

Electric Arc Furnace replacing a basic oxygen furnace

Induction Heating of metals

Electric Glass Melting, Annealing, Conditioning replacing natural gas furnace

Infrared Heating for curing and drying in place of natural gas heating

Freeze Concentration (electric motor-driven refrigeration cycle) to solidify liquid fractions at lower temperatures

- Changes to more efficient industrial processes;
- Waste heat recovery and reuse;
- Recycling of industrial waste; and
- Changes in location, closer to raw materials.

Improvements in specific industries include:

- Shifts to electric arc furnaces (in place of open hearth furnaces) and continuous casting in the iron and steel industry in place of ingot casting;
- Recovery of blast furnace top gas;
- Replacement of outdated copper, lead, aluminum, and zinc smelting facilities with new facilities in appropriate locations;
- Installation of pre-calcination in the cement industry; use of fly ash and coal washing wastes as feed to cement kilns;
- Black liquor recovery and cogeneration in the paper industry; increased use of bark, chips, and sawdust for energy generation;
- Cogeneration in textile and paper; and
- Down- and right-sizing of equipment (e.g., motors, boilers), variable speed motors, updating ventilator fans, and water pumps (and associated motors), improved steam traps and recycling of scrap and wastes in most industries.

Many options that improve efficiency and reduce GHG reduction options may be economic regardless of their energy impacts. Energy efficiency programs, however, need to be promoted through information and technical assistance programs that demonstrate the benefits of energy efficiency improvements, and provide economic analysis and implementation skills. Pricing policies that reflect the long-run marginal costs for electricity and fuels and which reduce or eliminate subsidies will improve the adoption rate of energy efficiency measures.

4.4.7.1 Evaluating Energy Efficiency Options

In evaluating the suitability of end-use efficiency improvements as GHG mitigation options for a country, the analyst should assess the following factors:

- Current demand and supply situation and expected future growth in demand;
- Cost of the option;
- Impact of the option on GHG emissions, both within the country and outside the country; and
- Demonstration value of the project and replicability within the country and in other countries.

Energy Demand and Supply. Countries where the demand for power is growing rapidly and/or supply shortages exist are likely to be the best candidates for implementing energy efficiency programs. Many developing countries are experiencing rapid growth in demand for energy services, driven by both increased population and increased consumption per capita. Such countries would probably be receptive to the idea of using measures to control the demand for energy so that the existing supply can be used most effectively.

Forecasts of total projected consumption of each energy type by sector are required. This may have been performed as part of an energy data collection process or GHG emissions inventory. Understanding the makeup of energy demand and energy demand growth is also important. In the building sector, information requirements include the number of pieces of equipment (or the floor area for space conditioning or lighting) and some measure of intensity (kWh or Btu/unit). Information on the types of technologies currently in place, their average lifetimes, energy efficiency, and utilization are also required.

Information required on the alternative new technologies includes the costs, efficiency, and equipment lifetime. Although the residential and commercial sectors have different types of buildings, many of the same types of measures can be applied to both. For end-use analyses, the IPCC commissioned the development of a database of energy efficient technologies for the buildings sector.[19]

For industrial improvements, of particular importance will be forecasts of production in each sector of industry. Being able to characterize the industry in terms of the age of its equipment, current product quality, and energy intensity (relative to international comparisons) will also be useful.

End-uses and sectors with the most rapid growth will offer great potential for energy and GHG emissions savings. The building and industrial sectors in rapidly growing developing nations will offer significant opportunities for energy and emissions savings by implementing more efficient technologies, equipment, and processes. Similarly, new buildings are likely to offer greater opportunities for cost-effective energy efficiency improvements than existing buildings. Retrofits tend to be more costly and difficult to implement.

Definition of the Baseline and Scope of Analysis. When evaluating end-use efficiency measures two analytic issues must be carefully addressed: (1) defining the baseline for the analysis and (2) identifying indirect effects.

As described earlier, the baseline is what would be expected to happen in the absence of the GHG mitigation option. It is relative to this baseline that a project's emission impacts and costs are measured. In the case of energy efficiency improvements, this can be particularly difficult. In many cases, energy efficiency technologies would eventually be adopted over time, and the effect of the program is to accelerate the placement of the technology by a few years. In other cases, it is possible that the technology would not be adopted, due to high upfront costs or marginal economics. The project may be pursued to overcome these hurdles and the effect of the project is the full impact of the technology.

The baseline will need to be defined on a case-by-case basis, depending on the technology, the sector, and what is included in the Reform or Reference Scenario defined in the Bank's sector work. In some cases, no specific assumption will have been made about the penetration of end-use technologies in these scenarios, and assumptions will need to be made.

A second analytic issue is the scope of analysis - specifically, what are the total direct and indirect effects of the project. Energy efficiency measures will reduce GHG emissions directly by increasing efficiency or through the use of a lower carbon content fuel. For example, residential and commercial buildings will use less energy for lighting and space heating, while industry will use less fuel for motors, steel making, etc.

However, energy efficiency projects could also have indirect effects that need to be accounted for in evaluating cost and emissions impacts. For example, lower energy bills could increase the demand for energy service (longer use of lighting, more light plugs, higher temperatures). In these cases it is necessary to correct cost and emissions impact numbers for these effects.

Similarly, GHG reduction projects in industry could involve output effects along with increased energy efficiency per unit of output. When output effects outweigh efficiency gains, total energy use and GHG emissions at the facility may increase with the project compared to without the project.

When evaluating the cost-effectiveness of energy efficiency measures, it is necessary to correct the results for these output effects. One approach is to assume that the increased output with the project will be used in substituting for less efficient production that would have occurred elsewhere in industry without the project. The simplest assumption is that the displaced production would have relied on equipment of equivalent efficiency to that replaced in the project. Therefore, the "with" and "without" cases are assumed to have equivalent output levels.

In addition to output impacts, energy efficiency projects may have other effects that may be considered in the analysis. These include "enterprise" effects, such as increased profitability, economic effects, and local environmental effects. The first two are evaluated in the macroeconomic analysis, while the latter can be included in the screening analysis to the extent there are agreed upon values for monetizing environmental impacts. Finally, energy efficiency improvements may also have a value effect in the form of improved product quality. These also may be included in the calculations and valued appropriately.

Cost of the Option. Many energy technologies and programs are economically viable regardless of the desire to reduce GHG emissions. Market inertia, aversion to risk, an orientation toward maximizing output rather than profitability with little concern for cost or efficiency, improper economic analyses, and lack of information make the process of change extremely slow. One of the main barriers in the case of energy efficiency programs is the high initial investment that may be required. In industry, capital is often directed to increasing output rather than efficiency.

Often the most significant costs of energy efficiency options are the capital costs of the option. In cases where a more efficient option is being installed a the time of retirement, it is the incremental costs of the option (relative to what would have been installed) that is important. For retrofit situations, one must consider the total cost of the new equipment less any salvage value of the existing equipment being retired early.

In the case of fuel switching options, replacement of an electric technology with fossil fuel technology involves investment in new equipment, conversion costs (e.g., flue and gas line connections), and changes in fuel and operation and maintenance costs. Switching to an electrotechnology may involve investment in metering and interconnection equipment.

The costs of energy efficiency options also include any incremental operation and maintenance costs, including fuel and labor savings. Administrative costs of large-scale programs (e.g., lighting retrofits) should also be considered. For some relatively low-tech program (e.g., compact fluorescents in the residential sector), administrative costs can be a significant part of total project costs.

Costs of energy efficiency programs may be offset by *cost savings*, including avoided energy costs. Avoided costs of electricity (and some other fuels) will depend on the pattern of energy savings across the day and year. Measures for saving energy during peak periods will typically have higher energy savings than measures saving energy year round (on a normalized basis). Other savings may also result from efficiency measures including reduced O&M and pollution prevention costs. Ancillary benefits may include reduced emissions of other pollutants.

In industry, the use of generic cost data is not possible given the diversity and uniqueness of processes and applications. Therefore, detailed information on the cost structure for an industry within a country is required. In the absence of comprehensive sector data, these may be based on a few representative plants or installations in the country.

Impact on GHG Emissions. For energy efficiency options, reductions in CO_2 emissions are a function of improvements in primary energy efficiency. For options that change the input fuel mix, the reduction in carbon content of input fuels is also important. In either case, carbon reductions per unit of output are calculated in a three step process: (1) determine carbon emissions associated with producing a given level of service (e.g., producing x metric tons of steel, building heating load of 2,100 MMBtu/year) without the project, (2) determine carbon emissions for same level of service with the project (i.e., higher efficiency, different process, alternative fuel), and (3) calculate the net reduction of carbon emissions from the project. The potential range of measures and applications is too large to review in detail here, so selected examples are given. For example, fluorescent light bulbs require only about 25 percent of the energy needed by incandescent bulbs to produce the same lighting level and last up to 13 times longer. As shown in Exhibit 4-24, a World Bank assessment of improved lighting options in India revealed significant opportunities for energy savings.

Exhibit 4-24. Efficiency Improvements From Improved Lighting Options in India

Option	Unit Reduction in Consumption (%)
Screw-in fluorescent tube	60
Compact fluorescent tube	75
New fluorescent fixtures	90
TLD fluorescent tubes	10
Electronic ballasts in fluorescent lamps	20
High-power factor ballasts	33
Improved mercury vapor lamps	40

Source: *India, Long Term Issues in the Power Sector, Volume II,* The World Bank, July 23, 1991, p. 173.

The greater the end-use inefficiencies that presently exist in a particular sector or industrial segment of a country, the higher are the potential GHG benefits of energy efficiency programs. Savings should reflect:

- Total energy consumption change at the target facility. The mix of fuels may change as a result of the improvements.

- Electricity savings. Electric energy efficiency programs that are successfully implemented can reduce generation requirements and eliminate or delay the need for new power plants. In such cases, an estimate of emissions reduced should reflect the mix of generation that is eliminated or deferred at the margin. Electricity savings also should include T&D losses that are also eliminated as a result of the measures.

- Reduced energy consumption in the sector generally, as a result of output increases at the target facility. This assumed energy consumption per unit output can match the industry average efficiency, the energy efficiency at the worst facility in the sector, or the efficiency of the facility being targeted before the energy efficiency improvements.

- Carbon emissions factors for the displaced fuel. In the case of electricity savings, the carbon emissions factors will depend on the annual and diurnal pattern of electricity savings. For electric system impacts, a marginal carbon emission rate that reflects the load characteristics of the affected portion of the system is required.

Demonstration Value and Replicability of Projects. Because energy efficiency programs tend to be economically viable, they should be easy to replicate within or outside a country once their benefits have been proven and techniques and methods have been provided to firms to assist in the evaluation process.

Moreover, within a country, a successful program can stimulate the production and purchase of energy efficient equipment. Increased production of such equipment can help lower the price and further stimulate consumption. Energy efficiency programs can also be replicated outside a country. Successful programs in one country can help make other countries more receptive towards them.

4.4.8 Coal Preparation

Coal cleaning (beneficiation) offers the potential to marginally reduce GHG emissions in addition to significantly reducing other air pollutants and coal combustion by-products. Coal beneficiation removes impurities such as ash forming minerals and sulfur and improves the combustion characteristics of the coal. Three alternative approaches can be used: (1) physical beneficiation which is commercially available, (2) chemical cleaning which is under development, and (3) biological cleaning which is also under development.

Physical cleaning involves crushing the coal and screening it into different sized particles to separate out impurities that are not chemically bound to the coal. Most techniques rely on specific gravity differences to separate the coal from other constituents such as ash, while the coal "fines" may be discarded or cleaned using froth flotation.

Coal briquetting is another coal preparation option being promoted in some countries to increase the efficiency of coal use. In China, over 1000 kilns for coal briquetting have been constructed.

4.4.8.1 Evaluating Coal Preparation Projects

Cost Impacts. The cost of coal beneficiation depends on the feedstock and the degree of cleaning. Capital costs range from US$25,000 to US$100,000 per metric ton/hour of cleaning capacity. Related O&M costs range from US$1 to US$5 per metric ton of cleaned coal.[20]

In addition to these direct costs of coal cleaning, it is necessary to consider secondary impacts. These include the value of reduced emissions of SO_2, the value of reduced waste disposal requirements (e.g., ash), and the value of increased heat content of the coal (increased generation per metric ton of coal).

Any financial analysis should also include the impact of beneficiation on the value of the coal. For example, in China it is estimated that unprocessed coal has a value of about $US5.05 per metric ton.[21] Processed medium grade coal has a price of about $US8.45 per metric ton. The sulfur content of this coal is reduced by two-thirds and heating value is increased by about 10 percent. Exhibit 4-25 illustrates the impacts of coal washing on ash, sulfur, heat content and price, based on an analysis of a facility in China. For coal briquettes, costs include the capital and O&M costs of the facility. User costs include decreased costs due to increased fuel efficiency, about double the relative efficiency of conventional coal - 30 versus 15 percent. The increased fuel efficiency offsets the higher price and lower heat value per unit weight. These fuel savings are offset by the cost for a briquette stove and repair costs.

Impact on GHG Emissions. The use of beneficiated coal improves boiler availability, reduces maintenance, reduces SO_2 and particulate emissions, and increases the heat content of the coal. The **improved energy efficiency resulting from smoother system operation** would result in marginally lower CO_2 emissions per kWh of electricity generated. The CO_2 benefits would depend on the net impacts of these effects, for a fixed level of output from a facility.

On average, fuel savings from briquetting amounts to 10 to 20 percent for furnaces, 10 to 15 percent for steam engines, and 20 to 25 percent for residential stoves and cooking. Ancillary benefits are significant and include ash reductions (about 70 percent for furnaces and stove) and sulfur reductions.

Exhibit 4-25. Impact of Coal Washing in China					
Item	Total %	Ash	Sulfur	Heat Value (kcal/kg)	Price (US$/ton)
1. Total Feeder	100	16.86	1.38	6000	5.05
2. Total Products	90.65	10.61	0.88	6435	
a. Lump	9.72	6.40	0.46	6600	8.27
b. Medium	20.15	6.40	0.46	6600	9.11
c. Small	11.91	10.82	0.46	6600	7.98
d. Powder	37.75	13.38	1.27	6300	5.22
e. Fine Slime	8	13.87	1.10	6300	3.27
f. Compressed Slime	3.10	17.66	1.27	6200	2.96

Note: Price evaluated at 5.5 yuan per U.S. dollar.

Source: See *Energy Efficiency in China: Case Studies and Economic Analysis.*

4.4.9 Natural Gas Supply System Options

Methane (CH_4) is the main component of natural gas. The majority of natural gas system methane leaks occur from the production, transmission, and distribution stages, with lesser quantities from storage and processing. There are also non-methane GHG emissions in the gas engines used in all stages of the natural gas system. These sources include:

- Fugitive emissions from wellsite equipment as a result of damaged seals or corrosion leading to a leak in a pipeline.
- Fugitive emissions from high bleed pneumatics used on gathering lines, heaters, separators, and dehydrators as valve controllers, valve acuators, pressure regulators, and pressure transmitters. Most high bleed pneumatic devices use significant amounts of pipeline gas for pressure, which is then emitted to the atmosphere.
- Emissions from dehydrators, which are used in natural gas production to remove water vapor and liquids from natural gas. The process involves bringing gas into contact with a desiccant (glycol) which absorbs the water and some methane. The desiccant is regenerated through heating which releases the water as steam and any absorbed methane.
- Methane from processing and storing natural gas.
- Fugitive emissions from the transmission system compressor stations (through joints, leaking seals), through pneumatic devices, and maintenance practices.
- Fugitive emissions from the distribution system from failed seals in failed cast iron and steel pipe, and from gate station components and joints.
- Emissions from compressor engines' exhaust due to incomplete combustion of natural gas.

There are many cost-effective technologies and practices that can be used to reduce methane emissions from natural gas system production, transmission, and distribution processes (see Exhibit 4-26). The techniques discussed here are based on U.S. experience and estimates.

Exhibit 4-26. Methods to Reduce Methane Emissions in Natural Gas Systems

Replacing high bleed pneumatics with low bleed devices in the production and transmission stages of the natural gas system. Reductions of about 85 to 98 percent are possible.

Install flash tank separators in the production process to collect methane and use the methane to fuel the dehydrator heater. Reductions of 90 percent are estimated.

Directed inspection and maintenance programs at production wells and treatment facilities, at compressor stations, and gate stations, requiring leak screening and repairs. Reductions of about 70 percent are estimated.

Replace reciprocating engines with gas turbines in the transmission system. Reductions of 98 percent are possible.

Emerging technologies including "Smart" regulators, metallic coated seals, catalytic converters on reciprocating engines, sealant and cleaner injections for valves, and composite wraps for pipeline repair.

Source: USEPA, 1993 Opportunities to Reduce Anthropogenic Methane Emissions in the United States, Report to Congress, EPA 430-R-93-012.

Evaluating Natural Gas System GHG Mitigation Options. A range of currently available technologies and techniques to reduce emissions in the natural gas industry are described below. Many of these options are labor intensive options and their costs will depend on local conditions. The following describes the available options and potential impacts on emissions based on experience in the U.S.

Replacing High Bleed Pneumatics. Natural gas operated pneumatic devices are used on gathering lines, heaters and separators to monitor and control gas flow. These devices control valves and actuators, pressure regulators and transmitters, flow computers, and gas samplers. These devices use pressurized gas to drive their operating mechanisms. Most devices use pipeline gas as their source of pressurized gas. This gas is eventually emitted to the atmosphere.

One option to reduce emissions is to use an alternative source of pressurized gas. However, this is usually not cost-effective. There are also alternative designs that would reduce methane emissions, including lower bleed designs that emit significantly less gas, or no gas at all. Moving from a high to low bleed device reduces emissions from 85 to 98 percent depending on the device on which it is used.[22] Not all devices can be replaced, as some operations require high bleed devices. Studies in the U.S. indicate that about 80 percent of high bleed devices can be replaced with lower bleed models.

These replacements could be done at the end of the life of the high bleed model (about seven years). Assuming a rate of 77 MCF/year of gas emitted by a high bleed device, a reduction of about 70 percent, and a well head gas price of US$1.60, the saved gas would have a value of about US$86. Installed on transmission systems, the value of the saved gas would be even higher. The average costs of a low or no bleed version of a pneumatic device costs about US$1000, or about 20 percent higher than a high bleed version of the same devices, for an additional capital expense of US$167 per device. The carbon equivalent of the annual methane reductions may be estimated as follows:[23]

$$CH_4 \text{ emissions(Mcf) x } \frac{0.0175 \text{ tons } CH_4}{\text{Mcf}} = CH_4 \text{ emissions(tons)}$$

$$CH_4 \text{ emissions(tons) x 24.5 GWP x} \frac{CO_2}{CH_4} = \text{Global Warming Equiv. tons of } CO_2$$

$$\text{Global Warming Equiv. tons of } CO_2 \text{ x } \frac{12 \text{ lbs } C}{44 \text{ lbs } CO_2} = \text{Global Warming Equiv. tons of Carbon}$$

The net costs after savings would total about US$81 per device with a lifetime cost effectiveness of about US$3.5 per metric ton of CO_2 equivalent emissions reduced. Given the higher costs of delivered gas, improvements on the transmission system would result in lower cost per metric ton of CO_2-equivalent saved.

Installing Flash Tank Separators. Dehydrators remove water from natural gas in order to prevent the formation of hydrate slugs in pipes and to reduce corrosion. In the process of heating the desiccant that absorbs water, methane is driven off and vented to the atmosphere. The most effective mitigation option here is to install flash tank separators (FTS) on the glycol line to prevent the methane and other hydrocarbons from reaching the regenerating units. Reductions of 90 percent are possible at incremental initial costs of about US$4,200 and incremental annual maintenance costs of about US$60 per year over a lifetime of 15 years.[24] U.S. EPA has determined that many applications of flash tank separators can be profitable based on the value of gas savings.[25]

Directed Inspection and Maintenance Programs at Well Sites, Transmission and Distribution Systems. Inspection and maintenance (I&M) programs at compressor stations, transmission lines and gate stations can reduce methane losses. I&M programs use a hydrocarbon analyzer such as an organic vapor analyzer (OVA) to measure concentrations of hydrocarbons at the component. A reading over some threshold value indicates a leak. Re-inspection after repair would be required to verify that the leak had been stopped.

At transmission facilities, leaks may develop around packing seals of the moving parts of compressors and values. At gas well sites, valves, flanges, and instruments that control and monitor gas flow may eventually leak. Directed I&M programs can reduce these emissions from 40 to 70 percent.

Costs of I&M equipment can be substantial, ranging from US$4,000 to US$9,000 per unit. In addition, equipment maintenance costs, screening program costs (e.g., recordkeeping, labor costs), and repair costs must be considered in evaluating the cost-effectiveness of an I&M program. The program savings result from the value of the saved gas (valued at the appropriate point-wellhead, pipeline, or distribution system).

Analyses conducted by the U.S. EPA indicate that directed I&M programs at gas well sites are not profitable. However, at compressor and gate stations, these programs were profitable. These analyses are based on conditions in the U.S. and may not be representative of conditions in other countries, depending on the value of the gas, the cost of equipment and labor, and the current leakage rate.

Rehabilitating Leaky Pipe. Leaks in underground distribution pipes are an important source of fugitive methane emissions. These pipes (typically constructed of steel, cast iron, or copper) lead to corrosion, joint failures and fractures. Rehabilitation involves complete replacement or by inserting new pipe inside existing pipe. In the U.S. the costs of such replacements typically exceed the value of the saved gas. However, replacements are often justified on the basis of safety concerns.

Installing Catalytic Converters on Reciprocating Engines. The compressors used to maintain gas pressure in the natural gas system are driven by reciprocating engines or turbines. The use of turbines in place of reciprocating engines can reduce methane emissions.

Capturing Gas Released During Pipeline Repairs in Transmission Systems. Leakages occur in transmission pipeline systems during normal repairs when gas must be removed from the chapter under repair to ensure safe welding conditions. Given that shut-off valves can be considerable distances apart (e.g., 15 miles in the U.S.), the volume of gas released during these repairs can be considerable. Portable evaluation compressors (PEC) can be used to evaluate the pipe chapter under repair and reduce the amount of vented gas by up to 80 percent. PEC units are used in the U.S. and Canada. The systems are costly and tend not to be profitable investments in the U.S., as measured by the value of the gas saved. Typical investment requirements are in excess of US$5 million and costs per operation are in excess of US$5,000.

Emerging Technologies. Emerging technologies for reducing methane leaks in natural gas systems include Smart regulators, metallic coated seals, catalytic converters on reciprocating engines, sealant and cleaner injectors for valves, and composite wraps for pipeline repair. For example, Smart regulators reduce the leakage from the distribution pipe by reducing the overall pressure in the pipe. Leakage from distribution pipe is related to the system pressure. Pressure in the system is maintained to meet peak demand; however, this pressure is too high during non-peak periods. Smart regulators are under development that will enable the pressure to fluctuate with demand. By having the pressure better match demand conditions, the time-average pressure can be reduced and leaks can be reduced.

4.4.10 Methane Recapture Projects

Two primary types of methane recovery projects are discussed here: (1) landfill gas recovery and (2) coal mine methane.

4.4.10.1 Overview of Landfill Gas

Methane is produced in sanitary landfills as a direct result of the natural decomposition of solid waste. The organic matter in the refuse is decomposed by bacteria under anaerobic conditions in a process that yields mainly methane, carbon dioxide, and trace amounts of hydrogen sulfide and volatile organic compounds (VOCs). Unless trapped by a collection system, landfill gas will migrate through the waste and may eventually diffuse through the soil cover of the landfill and into the atmosphere. Not only is the released methane a potent GHG, but also because methane is flammable, the possible migration of gas into nearby enclosed structures is a serious safety concern.

Landfill gas recovery and utilization projects result in GHG emission reduction benefits in two ways. First, recovery projects directly reduce emissions of methane, a potent GHG. Recovery and utilization projects also can reduce emissions indirectly by displacing other fossil fuels used in generating electricity or at the end use.

Because landfill gas is about 40 percent to 60 percent methane, it can be recovered and used as a fuel, thereby reducing emissions of methane to the atmosphere. Landfill gas can be collected using a relatively simple system of vertical wells drilled into the landfill at selected points, with each of the wells connected by piping to a central point where a motor/blower provides a vacuum to remove the gas from the landfill. In a well-designed and constructed system, methane recovery rates in excess of 85 percent can be achieved. In the U.S., these recovery systems usually are operated as part of an overall landfill gas control system required for safety reasons.

Once collected, the gas can be used in several ways: (1) to generate electricity; (2) as a medium-Btu fuel to fire industrial boilers, chillers, or similar equipment; (3) as a high-Btu, pipeline quality gas, after upgrading; or (4) as an input to the production of liquid fuels and industrial chemicals. In addition, landfill gas can simply be flared if a cost-effective utilization option cannot be developed. In each of these options, the methane contained in the recovered landfill gas is consumed, either through combustion (i.e., use as a fuel, including upgrading, and flaring) or conversion to a non-GHG (i.e., production of industrial chemicals), thereby reducing emissions of methane to the atmosphere. These options are discussed in more detail below.

Electricity Generation. For landfills that generate large amounts of landfill gas, electric power generation may be a viable method of utilization. Options for producing electric power including:

- *Internal combustion,* reciprocating engines where small sizes are necessary (smaller landfills). Although nitrogen oxide (NO_x) emissions from IC engines can be a problem in some areas, newer lean-burn IC engines produce less NO_x than previous engines.

- *Combustion turbines* are used at landfills that generate large amounts of methane gas with an output per turbine of about 3 MW - 4 MW. NO_x emissions are considerably lower than in IC engines.

- *Rankine Cycle (Steam) Turbines* are used in rare cases where gas flow rates are extremely high-on the order of 10 MW of power. If the scale of the operation will support a Rankine cycle turbine, electrical efficiencies similar to other methods of power generation can be achieved (30 percent to 40 percent), generally with lower emissions of air pollutants and lower costs per kWh of output. They also offer large amounts of high temperature water that can be easily utilized for thermal cogeneration activities.

Gas Sales. Recaptured methane can also be processed so that it can be sold as a gaseous fuel. Pipelines are used to deliver the fuel directly to a customer, or to the natural gas system network. In areas where industry is located near the landfill, medium-Btu gas can be transported via pipelines to one or more industrial facilities.

If the landfill gas is processed to pipeline specifications, it can be sold directly to natural gas companies, where it is injected directly into the distribution system. The cost to upgrade the gas to high-Btu standards is generally very high. Upgrading the gas to pipeline quality specification requires the removal of water, CO_2, hydrogen sulfide, hydrocarbons, and, on some occasions, nitrogen.

Flaring. Flaring is the least costly method to safely eliminate landfill gas. In some cases flaring may be the preferred option from an air quality perspective. However, while the capital cost is small compared to energy recovery systems, flaring does not generate income and produces fewer carbon reductions because it does not displace an alternative fuel and produces CO_2 in the process.

Emerging Utilization Options. Other less conventional utilization options are available or may become available. Some of these options, such as fuel cells, are being demonstrated at a number of landfills to determine their operational and economic viability. Other options such as the production of mobile diesel fuel are promising technically but are not economically justifiable at this time. Recently, a small number of landfills have used recovered gas in the incineration of soil contaminated with hazardous waste (GAA 1994).

4.4.10.2 Evaluating Landfill Gas Recovery as a Mitigation Option

Costs Associated with Landfill Gas Recovery. Costs associated with landfill gas recovery include capital and annual O&M costs, offset by revenues from electricity or gas sales. Capital and O&M costs will include the costs associated with the gas collection equipment, utilization equipment, and standby flare capacity (if required). Capital costs associated with the collection system include the vertical extraction wells, the well header system and horizontal well connections, the gas compressor or blower, and the condensate handling system. Capital costs for the utilization equipment depend on the particular option. For a typical electricity generation project, this would include the installed cost of an on-site engine generator, engine controls, gas-processing equipment, and electrical grid interconnection equipment. The major capital costs for direct gas sales are typically the construction of a gas pipeline from the landfill to the user, additional compressors, and any required gas processing equipment or end-user equipment modification. Annual O&M costs are comprised of direct cost, primarily labor costs, and indirect costs including insurance, overhead, and administration.

Exhibit 4-27 contains representative cost data for a range of landfill and project sizes. These cost data were derived from statistical analyses of existing projects (U.S. EPA 1993). Detailed project analysis should use engineering cost estimates based on the site characteristics and project configuration. These costs are offset by the cost savings from avoided electricity or natural gas use, depending on the utilization options. The avoided electricity cost will be used to determine the incremental value to the electricity system of electricity generated from landfill gas. The project may also provide a capacity value to the electric generating system.

Exhibit 4-27
Representative Landfill Energy Recovery System

Land-fill Size	Max. Gas Flow[a]	Engine Cap.[b]	Collection System ('000 US$)		Flare System ('000 US$)		Generator System ('000 US$)		Total ('000 US$)	
(10^6 metric tons)	(m^3/ min)	(MW)	Capital	Annual O&M	Capital	Annual O&M	Capital[c]	Annual O&M	Capital	Annual O&M
0.25	1.6	0.3	155	55	68	4	360	34	583	93
0.5	3.2	0.6	269	60	72	4	720	67	1,061	131
1	6.3	1.1	468	68	79	4	1,320	123	1,867	195
5	29.4	5.2	1,698	117	130	7	6,240	581	8,068	705
10	51.8	9.1	2,956	167	180	10	10,920	1,016	14,056	1,193
20	96.6	17.1	5,146	255	280	15	20,520	1,910	25,946	2,180

[a]Estimated using a statistical model based on existing landfills that recover methane, assuming a collection efficiency of 85 percent.
[b]Engine capacity must be sufficient to utilize the estimated peak sustainable gas flow.
[c]Assuming engine generator cost of US$1,200,000 per MW of installed capacity.
[d]Assuming engine generator O&M rate of US$0.015 per kWh.

Source: Reproduced from "Opportunities to Reduce Anthropogenic Methane Emissions in the United States", Report to Congress, October 1993.

The electricity generated by a landfill gas recovery project may be estimated from the installed capacity by applying a suitable capacity factor (85 percent is used here as a default value) and multiplying by 8,760 hours per year. The installed capacity can be estimated from the landfill gas flow using an estimate of the generating equipment heat rate (in Btu/kWh) and the heat content of the gas (in Btu per volume). For an internal combustion engine, a typical heat rate would be 12,000 Btu/kWh. Landfill gas has an average energy content of 500 Btu per cubic foot.

Similarly, for projects involving gas sales, the cost of the gas sold into the pipeline or to the end user will be the effective "avoided cost" depending on the utilization of the gas.

Impact on GHG Emissions. The level of (equivalent) carbon dioxide reductions resulting from landfill gas recovery and utilization and the associated costs of these reductions is a function of several factors. The most important are the quantity of methane recovered, the GWP of methane, and the displaced CO_2 emissions resulting from utilization.

The most important aspect of a landfill gas recovery and utilization project is the amount of gas produced in the landfill, its methane concentration, and the amount that may be technically and economically recoverable. Methane production typically begins one or two years after waste placement and may last for decades.

Emissions reductions are the sum of: (1) the carbon equivalent of the methane recovered that would otherwise have been emitted; and (2) the carbon dioxide emission reductions associated with fuel displacement. The relative impact of these methane reductions are expressed as a Global Warming Potential (GWP), as described earlier. An appropriate GWP value for methane is still the subject of scientific debate. However, the most recent value assigned by the IPCC is 24.5 over a 100-year time horizon. The impact on emissions will also depend on the emission rate of the displaced fossil fuel. However, most of the GHG emission reduction benefits result from the recovery and combustion of the methane, not the displaced fossil fuel generation. At a GWP of 24.5, displaced generation will account for less than ten percent of the total benefits.[26]

4.4.10.3 Overview of Coal Mine Methane

Methane and coal are formed together during coalification, a process in which biomass is converted by biological and geological forces into coal. Methane is stored within coal seams and also within the rock strata surrounding the seams. Methane is released when pressure within a coalbed is reduced, either through natural erosion, faulting, or mining. Deep coal seams have a substantially higher methane content than shallow coal seams, because geological pressure intensifies with depth and prevents increasingly larger amounts of methane from escaping. Accordingly, per metric ton of coal extracted, underground mines release substantially more methane than surface mines.

Several well-established methods may be used to recover methane from underground mines. These methods have been developed primarily in order to supplement mine ventilation systems to ensure that methane concentrations in underground mines remain within safe tolerances (methane is explosive in concentrations of 5 percent to 15 percent in air). While these degasification systems are currently used for safety reasons, they can also recover methane that may then be utilized as an energy source. How the methane can be used is a function of its purity which, in turn, is partially dependent on the recovery method. Recovery methods include:

- *Advance (Pre-Mining) Degasification:* With this method, vertical wells similar to typical natural gas wells are drilled into the coal seams several years in advance of mining. When wells are drilled at least five years prior to mining, the majority of the methane that would otherwise be emitted to the atmosphere during mining can be recovered before mining begins.

- *Gob Wells:* The fractured zone caused by the collapse of the strata surrounding a mined coal seam in an underground longwall mine is known as a "gob" area. This area is a significant source of methane. Gob wells are drilled from the surface to a point just above the coal seam. As mining advances under the well, the methane-charged coal and strata around the well fractures. The methane emitted from this fractured area flows into the gob well and up to the surface.

- *In-Mine Horizontal Boreholes*: Horizontal boreholes are drilled inside the mine directly into the coal seam, draining methane from the coal seam shortly before mining. The recovery efficiency of this technique is low—approximately 10 percent to 20 percent of methane that would otherwise be emitted—and it is frequently used in conjunction with other recovery methods. However, the methane produced is typically over 95 percent pure.

Once the methane has been recovered, there are a number of methods by which the gas may be utilized, rather than emitted to the atmosphere. Options for utilizing recovered methane include:

- *Selling the Methane*: This option requires that nearly pure methane is recovered. Gas processing/treatment facilities, compressors, and gathering lines (from the mine to a commercial pipeline) and interconnection facilities must be installed.

- *Utilizing Methane as a Fuel in a Turbine or Engine:* Under this option, recovered methane is fed into an on-site generator. The electricity generated may be used to meet the potentially significant electricity requirements of the mine. Power generation is a technically viable option for methane concentrations as low as 30 percent.

- *Local Use*: In addition to pipeline injection and power generation, coal mine methane may be used as a fuel in on-site coal preparation plants, transported to a nearby coal-fired power plant for co-firing, or piped to other industrial or institutional facilities for direct use.

- *Flaring*: It is conceivable that methane recovered from coal mines could be burned at the mine site with no productive use, so that carbon dioxide rather than methane would be emitted to the atmosphere.

4.4.10.4 Evaluating Coal Mine Methane GHG Mitigation Options

There are a number of steps to evaluating coal mine methane opportunities. These include (1) identifying potential sites, (2) calculating costs, and (3) calculating emissions impacts. These are described below.

Identify Potential Sites. An initial screening of underground mines to determine potential candidates may be performed with a limited amount of data: methane emissions from ventilation systems, annual coal production, current degasification system, mining method, and life expectancy. The emissions and coal production may be used to calculate the amount of methane emitted per metric ton of coal mined, which is another critical factor in identifying potentially attractive projects. Exhibit 4-28 summarizes the types of data and information required to identify candidate mines for methane recovery projects.

Exhibit 4-28. Coal Mine Methane Recovery — Mine Selection Criteria

Data Needed	Description
Annual Emissions from Ventilation Systems	In the U.S., the gassiest mines typically emit more than 1 million cf/day from ventilation systems.
Annual Coal Production	Larger mines (annual production > 1 million metric tons) are likely to be better candidates.
Current degasification methods, if any, and estimated methane recovered	Pre-mining degasification (vertical wells), gob wells, or in-mine boreholes. Mines with systems in place are particularly good candidates. Emissions from degasification systems generally represent from 35 - 65 percent of total emissions.
Calculate emissions per metric ton of coal mined	Add annual ventilation emissions and degasification emissions, then divide by annual coal production. As a rough estimate, mines with emissions per metric ton greater than 500 cf/ton may be considered gassy
Mining Method	Longwall mines tend to be the gassiest.
Mine Life Expectancy	Mine will need to be in operation for several years in order to see a positive return on the large capital investments required for methane utilization.

Calculate Project Costs. Cost calculations are comprised primarily of capital costs for recovery wells, utilization equipment (compressors, gathering lines, generator, etc.), utilization system capital, and O&M costs, the value of gas or electricity produced, and other costs. Offsetting these costs are revenues from the price at which produced gas will be sold (for pipeline injection projects and local use) and the avoided cost of utility generation (for power projects).

- ***Recovery System Costs:*** The recovery system costs are the capital and operating costs of drilling and maintaining the degasification wells. In the case of gob wells and in-mine boreholes, drilling occurs every year over the duration of the project, based on the rate of mining. In the case of pre-mining degasification wells, wells will be drilled several years in advance of mining. A field of wells may be drilled at one time, so that drilling would represent an up-front capital cost, as opposed to an annual drilling cost, as with gob wells and in-mine boreholes. In the U.S., per well costs for gob wells typically range from US$50,000 to US$200,000 per well. Costs for vertical wells are higher — typically US$100,000 to US$300,000 per well, but the cost of some wells may be over US$500,000 in some basins. The number of wells needed would be about one well for every 250,000 metric tons to 1,000,000 metric tons of coal produced.

In examining recovery system costs, it is important to note that some underground mines may already use degasification systems as a supplement to their ventilation system even though the recovered methane is vented to the atmosphere. In such cases, only the additional wells drilled in order to increase total gas recovery for an offset project would be included in a cost evaluation.

Finally, water disposal represents an additional recovery cost for pre-mining degasification. Large amounts of water are produced during the first few months after a well is drilled, but production declines significantly after the first year.

- *Gas Utilization Costs*: Gas utilization costs vary significantly depending on mine-specific factors and upon the utilization approach selected. Costs for pipeline projects include costs of gathering lines, compressors, and processing/treatment equipment. In the U.S., these costs are in the range of US$200 per thousand cubic feet of gas produced per day. A principal factor in determining the economic feasibility of a pipeline project is the distance from the mine to a pipeline that can accommodate the mine's methane production. Costs for installing pipelines can span a broad range and depend on terrain and other site-specific factors. For power generation projects, capital costs include obtaining and installing all necessary generator equipment. Additionally, projects that sell electricity generated at the mine to a local utility may incur interconnection costs. For local use projects, costs would be similar to pipeline projects, although costs for compression and gathering lines are not likely to be as high since the end-user should be located close to the mine. Additional costs may be incurred to convert an existing boiler system to recovered coal mine methane. For flaring projects, compressor and gathering lines would be needed, as well as operating costs for a flare line and flare.

- *Value of Gas/Electricity Production:* In estimating revenues from sales as natural gas, multiply total gas recovered by an estimated 90 percent to account for fuel use during compression and transmission of the gas. For on-site uses, the value of the methane is equal to the value of the coal or electricity displaced. The value received for local use projects will vary, depending on the quality of the gas produced and the value of the gas.

- *Value of Electricity*: The value of on-site electricity production is the difference between the cost of on-site generation and the cost of displaced utility generation.

- *Ventilation Savings Realized Due to Installation of Additional Wells*: For those mines that install additional gob wells as a result of an offset project, costs for ventilating the mine will be reduced. Reduced ventilation costs may result because substantial quantities of methane will flow into the wells as opposed to the mine working areas where the gas would need to be diluted with large quantities of air.

Calculate Emissions Reductions. For each option, estimate the amount of methane that can be recovered. In addition, for electricity generation projects located at mines, calculate the reduced carbon emissions from fuel displacement based on estimates of the displaced utility generation.

The emission reduction realized is the amount of methane that is recovered and utilized rather than emitted to the atmosphere. If the methane goes into a pipeline, no additional calculations are required because any emissions associated with its use are offset by reduced emissions from the natural gas it displaces.

Note that an additional step may be necessary to estimate total carbon reductions in cases in which a coal mine uses recovered methane to generate power for on-site use or for sale to the grid. In such cases, if electricity generated by the coal mine methane project displaced coal- or oil-fired generation, the net reduction in emissions from fuel switching would also need to be taken into account. Additionally, if the recovered gas were flared, rather than utilized for energy purposes, the CO_2 emissions from combusting the methane and the CH_4 emissions resulting from incomplete combustion would need to be included in the overall GHG impact assessment.

Because reducing a metric ton of methane emissions has a much greater effect than reducing a metric ton of CO_2 emissions (i.e., CH_4 has 24.5 times the global warming potential of CO_2), it is helpful for analytic purposes to convert potential methane emission reductions to carbon equivalents using the appropriate GWP value. The carbon equivalent of the annual methane reductions may be estimated as follows:

$$\text{CH}_4 \text{ emissions (Mcf) x } \frac{0.0193 \text{ tons CH}_4}{\text{Mcf}} = \text{CH}_4 \text{ emissions (tons)}$$

$$\text{CH}_4 \text{ emissions(tons) } 24.5 \text{ GWP x } \frac{\text{CO}_2}{\text{CH}_4} = \text{Global Warming Equiv. tons of CO}_2$$

$$\text{Global Warming Equiv. tons of CO}_2 \text{ x } \frac{12 \text{ lbs C}}{44 \text{ lbs CO}_2} = \text{Global Warming Equiv. tons of Carbon}$$

4.5 Mitigation Scenario Formulation

The previous chapter described the process of identifying and screening a broad range of GHG mitigation options in the energy sector. Options were screened on the basis of a single, consistent criterion (e.g., US$/ metric ton of CO_2-equivalent or IRR). This process is necessary to identify the characteristics of a broad range of options or strategies in a quick and efficient manner. This chapter describes how to use the information developed in the screening analysis of GHG mitigation options to develop GHG Mitigation Scenarios.

The goal of the Mitigation Scenario is to allow analysis of adoption of specific policy changes and their effects, or adoption of a specific set of mitigation options. A Mitigation Scenario can be formulated based upon the screening of GHG mitigation options and strategies that have been evaluated using the framework and guidelines described in Chapters 4.3 and 4.4. The Mitigation Scenario may represent a specific strategy (e.g., increase use of natural gas, increase end-use efficiency), or it may represent a collection of specific options that are designed to reach a specific target (e.g., reduction of GHG emissions by 20 percent by 2000) or other goal (adopt all cost-effective GHG emission mitigation options below a certain cost or meeting a certain IRR criteria).

4.5.1 GHG Mitigation Options Supply Curves

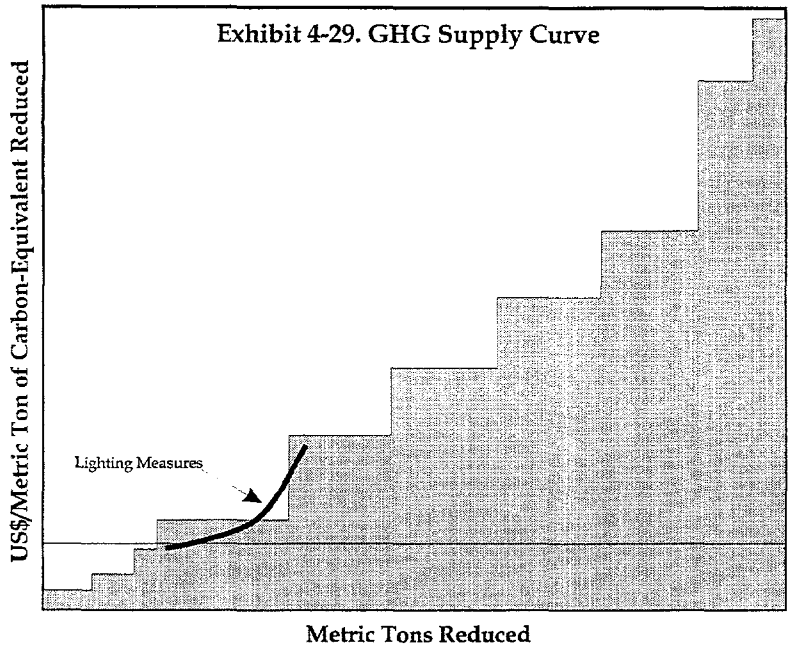
The result of this screening is a GHG reduction curve, as shown in Exhibit 4-29.

The objective of creating a cost curve is to show the relationship between the level of reductions achievable and the costs of those reductions. The curve may contain a broad range of measures. Each step on the curve may represent a single option or broad categories of options or strategies. This curve represents the starting point for developing a Mitigation Scenario, but is not sufficiently detailed to use in estimating the costs of specific GHG emission reduction scenarios or goals.

First, the curve and the underlying screening analysis do not provide very precise estimates of the costs of achieving specific emissions reductions. In examining the curve, it is important to distinguish between the *average* and the *marginal* cost per ton of CO_2 removed. The simple, discrete curve shown in Exhibit 4-

29 illustrates a series of estimates of the *average* cost per metric ton of CO_2 removed for each of the options. For example, in this illustrative curve, the *average* cost of CO_2 removed as a result of lighting programs is shown to be US$10/metric ton, an illustrative value. A detailed analysis may reveal that there is a range of costs for lighting programs, perhaps from a negative cost per metric ton to a much higher level, for example, up to US$50/metric ton (which would be the marginal cost of lighting programs). A more accurate representation of a supply curve would distinguish between these costs for each broad category of programs, and might look like the lighting measures curve shown in Exhibit 4-29.

Exhibit 4-29. GHG Supply Curve



Using a cost curve to develop a Mitigation Scenario has other problems. As noted previously, screening GHG emission mitigation options in isolation is not always appropriate. Developing a Mitigation Scenario allows the consideration of interactions between options as well as the impact of individual options on a country's energy sector. For example, power sector options, such as fuel switching, may result in system dispatch changes. A similar interaction may occur with efficiency improvements where a power generating unit's merit order increases as a result of efficiency change. These interactions may require more detailed assessments. In the power sector some of these interactions include:

- ***Options That Target the Same Source or Sink:*** The most easily recognized interaction between GHG reduction options occurs when two or more options target the same emissions source or sink. For example, a single generating unit may be under consideration for one or more GHG reduction options, including a fuel switch, efficiency improvements, or repowering. Different options may be planned for the same time frame or at different times. Options planned for the same time frame may be mutually exclusive or complementary. A supply curve does not capture these overlaps.

- ***Generating Unit Dispatch Impacts:*** Impacts on the dispatch of the system may occur as the unit's dispatch price rises or falls as a result of the action taken. Dispatch costs may rise as the result of a fuel switch, or fall with efficiency improvements. It may be the case that the power sector decides to maintain the utilization of the unit to maximize carbon reductions.

- *System Dispatch Impacts:* Interactions may occur when options change the dispatch of the system and, as a result, change the marginal emissions or cost used to evaluate another option. In the screening analysis, each option is evaluated at the margin, i.e., assuming system marginal costs and marginal emissions rates without any GHG reduction options in place. Adopting many GHG reduction options may have an impact on cost and emissions rates at the margin. For example, a group of DSM programs evaluated at the margin may generate a considerable level of reductions, due to the assumptions that coal is the predominant fuel displaced at the margin. However, where a DSM program is coupled with a fuel switch, the marginal mix of resources may change (e.g., to a mix of coal and gas), in which case the reductions associated with the gas-fired unit are lower and cost per metric ton is higher.

- *Resource Planning Impacts:* Some options, in particular DSM and cogeneration, may reduce or defer the requirements for new resource additions. This may have the effect of eliminating from consideration some of the reduction options that target new resources (e.g., building renewable resources in place of fossil generation).

In addition, the cost of any one GHG reduction option may change over time. These costs are also influenced by the year being examined, other options implemented earlier, and the cumulative effects of prior options. For example, if electric generation fuel switching options are implemented prior to electric energy efficiency options, the cost-effectiveness of these programs is likely to change. Cumulative effects of decisions may influence cost-effectiveness. For example, increased use of natural gas resources may increase the cost of options that rely on natural gas, as increased demand increases gas prices.

4.5.2 Criteria for Selecting Options to Include in Mitigation Scenario

Given these considerations and complications, it is necessary to select a range of strategies or options to incorporate into a Mitigation Scenario. As described earlier, the cost-effectiveness measure of US$/metric ton of CO_2-equivalent reduced provides a consistent yardstick by which options can be compared. However, there may be many alternative or additional criteria by which options are selected for inclusion in the Mitigation Scenario. These include:

- *Level of Cost-Effectiveness.* There may be some threshold US$/metric ton level over which options are considered too costly to pursue.

- *Level of Reductions Required.* A Mitigation Scenario may be formulated to reach a total level of reductions (e.g., 20 percent reduction relative to year 2000 levels projected in the Reform Scenario). The number and type of options selected will depend on the level of reductions required and the range of options available. For example, an effort to stabilize emissions may require targeting those options that achieve large reductions.

- ***Consistency with broader national economic development goals and policies.*** Some GHG emission mitigation options will be consistent with policies and strategies proposed for the Reform Scenario. These might include pursuing natural gas end-use options in combination with a policy to develop indigenous gas resources. Policies may complement reform strategies by mitigating increased GHG emissions relative to a Reference Scenario. Pursuing high efficiency coal options could mitigate GHG emissions increases associated with a strategy to develop indigenous coal resources in place of imported natural gas.

- ***Ancillary impacts, including local environmental and economic benefits (and costs).*** Consistency with other national environmental goals (such as the reduction of particulates, SO_2 and NO_x) could make some options more attractive than others. For example, options that target the power sector may be more attractive than methane recapture programs for this reason.

- ***Political, social, and technical feasibility.*** Some options may be more feasible than others in terms of their political, social, or technical feasibility.

- *Demonstration Capability.* In some cases, an option will be attractive simply because it offers an opportunity to demonstrate a technology or application. This might be the case for emerging end-use and power sector technologies that may have potential wide scale application in the future. An option with limited applicability may be an unattractive option, unless it provides large reductions at low cost.
- *National and multiplier effects.* Some projects may be highly valued for the national level and multiplier effects they may produce. For example, a program targeting energy efficiency in industry may have potential impacts on export capability.

Options may be selected based upon one or more criteria described above. Developing a systematic approach to this multi-criteria assessment may be helpful when the number of options and criteria are large. One approach is to identify for each option its relative ranking on the basis of a range of selection criteria. Rankings could be "high," "medium," or "low," indicating how an option meets the stated criteria. Numeric values could also be assigned, e.g., ranging from 10 (meets the criteria fully) to 0 (fails to meet the criteria). Weights could be assigned to each of these selection criteria in order to develop a single rating for each mitigation option. Exhibit 4-30 illustrates one approach to ranking two mitigation options.

Exhibit 4-30 .Illustration of Approach for Ranking Competing Mitigation Options

Selection Criteria	Relative Weight	Repowering	End-Use Efficiency Residential Lighting Program
Reductions			
Level	10	10	5
Certainty	8	10	5
Cost-Effectiveness	7	5	10
Capital Required	5	8	5
Consistency with National Goals	9	9	8
Feasibility			
Technical	10	8	9
Political	10	8	6
Social	10	5	8
Ease of Implementation	6	8	4
Sustainability	8	10	6
Data Availability for Detailed Evaluation	5	10	6

It is more likely that a subjective assessment of the available options and screening results will lead to the selection of the options to be included in the Mitigation Scenario analysis. In some cases, there will be only a few options with sufficient data and information to include in more detailed sector level analysis. The experience to date with certain programs, technologies, or policies may lead to consideration of other options. More detailed and impartial analysis may be required when a larger number of disparate options are available.

4.5.3 Methodological Considerations

Most Bank energy sector work is conducted using detailed energy system models. The model may be specific to only one subsector of the energy economy, for example a power sector optimization model such as WASP, or may cover the entire energy sector in some detail, such as the MARKAL model.

Methodologies that have the potential to account for the system interactions described above are most useful in evaluating the cost and reduction potential of Mitigation Scenarios. Optimization models often used in the power sector studies conducted by the Bank are ideally suited to assessing portfolios of GHG emission mitigation options. Flexible models allow detailed analysis of the power system (e.g., unit retrofit, alternative capacity expansion decisions), and may have the capability of modeling energy efficiency decisions on a level playing field with supply side options while capturing detailed information on load shape costs impacts. Other models are capable of performing detailed evaluations of alternative end use technologies.[27]

It may not be possible to incorporate some options directly into the modeling framework used in the sector work. For example, power sector models may not have the capability to model GHG offsets such as coal mine methane reductions. These and other similar options may be included in the analysis by adjusting emissions limits to be evaluated by the model to reflect the availability of off-system models. The emissions constraints to be evaluated can be reduced by the equivalent emissions reductions associated with these options. The remaining reductions will be met by on-system options. Similarly, several tools may need to be combined in evaluating GHG reduction targets for the entire energy sector (e.g., including the power sector and end-use fuel consumption).

The exact requirements for modeling individual options will depend on the framework being used. Some may require detailed information on the performance and cost characteristics of an option (e.g., capital, O&M, and administrative cost per piece of equipment, energy savings or electric load shape impacts, penetration rates). In any case, it will be important to capture expected changes in cost over time (e.g., due to real cost increases or decreases) and changes in performance over time (e.g., due to technological advances).

Another important consideration in modeling GHG mitigation options in a Mitigation Scenario is the ability to capture the time dependence of GHG emissions decisions. With the costs and performance of technologies changing over time, and changing energy supply prices, intertemporal tradeoffs become important.

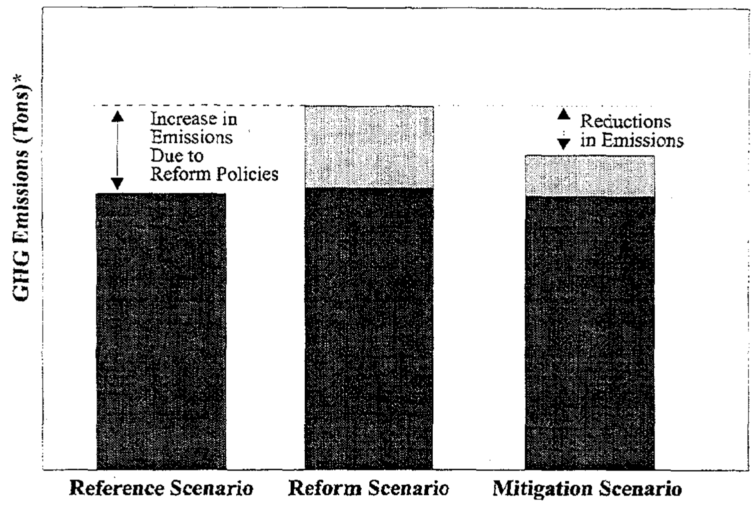
4.5.3.1 Measuring Impact

Measuring impacts requires comparing the costs and emissions of the Mitigation Scenario to the Reform Scenario. As illustrated in Exhibit 4-31, the difference in costs and emissions between the Reform and Mitigation Scenario reflect the mitigating impacts of the chosen options.

Costs may be measured in total net present value of costs, or levelized annual costs. Emissions may be total emissions over the study horizon, annual emissions in the year of analysis, or annual average emissions.

The marginal cost of reductions on a system (e.g., a country or a region) is the cost of decreasing GHG emissions (through reductions, offsets, or sequestration) by one additional metric ton. In an optimization framework, the marginal cost is equivalent to the shadow prices of the imposed emissions constraint. The results of a series of analyses using an integrated model containing all possible GHG emission mitigation options, each with a slightly more stringent constraint, could be used to construct a marginal cost curve of GHG emission reductions.

Exhibit 4-31 Comparison of Alternative Scenarios



*The Reform Scenario will not necessarily increase emissions. In many situations, the GHG impacts of improved resource utilization efficiency will outweigh the overall effect of increased levels of economic activity.

4.5.3.2 Evaluating Ancillary Impacts

The cost of a Mitigation Scenario may include the consideration of direct costs only (e.g., the net cost of the measures). In some cases, it may be desirable to include ancillary benefits of the options and scenario. Most important will be the ancillary environmental benefits. Reductions in SO_2, NO_x, and particulate matter can be evaluated as is done in other Bank sector and project analysis, using Bank-approved monetary values for these pollutants. These benefits will offset the increased cost of the scenario.

There may be social and economic benefits as well. Employment and direct and indirect income effects should be considered as discussed in Chapter 6 (Macroeconomic Analysis), which describes approaches to estimating these macroeconomic effects.

End Notes

1 In some sense, estimating fuel consumption for each sector of the energy economy could be viewed as a bottom-up approach. However, in these discussions, the term "top-down" refers to those approaches based on total fuel consumption (in a sector or region/country) without regard for how the fuel is used. The term "bottom-up" refers to approaches that build up estimates of energy consumption from end-use/technology specific information (e.g., at the generating unit, boiler, or furnace level).

2 The approach illustrated here does not include information on international bunker fuels, as illustrated in the IPCC Reference approach.

3 The IEA generally reports data in terms of net caloric values. The difference between the net and gross calorific value (NCV) of a fuel is the heat of condensation of moisture in the fuel during combustion. Typically, IEA assumes the NCV are about 5 percent lower than gross calorific values for oil and coal, and 10 percent lower for natural gas.

4 UNEP/OECD/IEA/IPPC. 1995. *IPCC Guidelines for National GHG Inventories, Volume 3: GHG Inventory Reference Manual,* UNEP/OECD/IEA/IPCC; Bracknell, United Kingdom., p. I.25.

5 UNEP/OECD/IEA/IPCC. 1995. *IPCC Guidelines for National GHG Inventories, Volume 3, p. I.25.*

6 UNEP/OECD/IEA/IPCC (1955) *IPCC Guidelines for National GHG Inventories, Volume 3,* p. 1.39-1.41.

7 UNEP/OECD/IEA/IPCC. 1995. *IPCC Guidelines for National GHG Inventories, Volume 3,* p. I.95.

8 UNEP/OECD/IEA/IPCC. 1995. *IPCC Guidelines for National GHG Inventories, Volume 3,* p. I.98.

9 UNEP/OECD/IEA/IPCC. 1995. *IPCC Guidelines for National GHG Inventories, Volume 3,* p. 1.111.

10 For example, as noted earlier, the Ukraine currently imports significant natural gas resources from Russia. Under some Reform Scenario, it might decrease its reliance on natural gas imports and increase its use of domestic coal reserves. In this case, emissions of GHGs would increase in the Ukraine due to (1) the use of coal in place of natural gas in electricity generation and at the end-use and (2) from increased coal mining and related activities. The increase in GHG emissions would reflect the difference in coal and gas CO_2 emission rates, adjusted for any demand effects. At the same time, emissions outside of the Ukraine may be influenced by the Ukraine's shift to domestic coal reserves. For example, if natural gas production in Russia is supply-constrained, than the natural gas previously sold to the Ukraine may be resold to another party, displacing another resource. If this resource is coal, then the net effect of the Ukraine's action on global CO_2 emissions may be very small. If natural gas production is demand-limited and no such market exists, then less gas may be produced in Russia, reducing GHG emissions associated with gas production activities, offsetting only a small part of the increased emissions in the Ukraine. Given the potential for offsetting emissions changes outside the country, the *net global* effect of the action should be considered.

11 For more information on shadow pricing applications, see Ward, W.A. and B. J. Deren, *The Economics of Project Analysis: A Practitioner's Guide,* The Economic Development Institute of the World Bank, EDI Technical Manuals, Washington, D.C., 1991; Munasinghe, Mohan, *Environmental Economics and Sustainable Development,* World Bank Environment Paper No. 3, Washington, D.C. 1993; and *Handbook on Economic Analysis of Investment Operations,* Operations Policy Department and Learning and Leadership Center, The World Bank,Washington, D.C., forthcoming.

12 For example, see the Staff Appraisal Report on the Ertan II Hydroelectric Project, July 7, 1995. Report No. 14072-CHA.

13 Although the NPV is the criterion the bank uses to evaluate projects, many Bank staff use the IRR. The IRR is the discount rate that results in a zero NPV for a project. If the IRR is equal to or greater than the chosen discount rate, then a project's NPV will not be negative and the project will be acceptable from an NPV perspective as well.

14 Lawrence Berkeley Laboratory, *Guidance for Mitigation Assessments: Version 2.0,* prepared by the Country Studies Management Team, March 1995. (LBL 1995).

15 It is possible that increased electric energy could displace consumption of fossil fuels at the end-use and decrease GHG emissions.

16 Higher electrical output is possible at a lower overall efficiency. Depending on the value of capacity and energy a different overall configuration may be desirable.

17 Burrel, A.D. 1991. "Coal, the Environment and Development: Technologies to Reduce Greenhouse Gas Emissions". In :*Proceedings of International Conference on Coal, The Environment and Development: Technologies to Reduce Greenhouse Gas Emissions,* Sydney, Australia, 18-21 November 1991.

18 See *China: Issues and Options in GHG Control, Subreport Number 4, Energy Efficiency in China: Case Studies and Economic Analysis,* Prepared by Clemson University and Energy Research Institute, Supported by Global Environment Facility.

19 Koomey, Jonathan, et al., *Buildings Sector Demand Side Efficiency Technology Summaries,* Lawrence Berkeley Laboratory, 1994. Prepared for the Technology Characterization Database of the Intergovernmental Panel on Climate Change. LBL-33887.

20 *The IPCC Technology Characterization Inventory, Phase II Report, Volume 1,* Prepared for the Intergovernmental Panel on Climate Change, 1993 as cited in *Guidance for Mitigation Assessments: Version 2.0,* Prepared by the U.S. Country Studies Program, Lawrence Berkeley Laboratory, March 1995.

21 Based on *Energy Efficiency in China: Case Studies and Economic Analysis,* Subreport Number 4, World Bank, December 1994. Translated at 5.5 yuan per $US dollar.

22 U.S. EPA, Report to Congress on Opportunities to Reduce Methane Emissions in the U.S. (U.S. EPA, 1993)

23 A GWP of 24.5 is used for methane based on a hundred year lifetime. This is based on the most recent research conducted and reported by the IPCC. See Exhibit 3-2 for a more detailed discussion of GWPs.

24 Estimates of potential costs reported in this chapter are based on three reports prepared for the US EPA, October 1993 *Report to Congress on Opportunities to Reduce Methane Emissions in the U.S.* See Radian. 1992a. *Estimate of U.S. Methane Emissions - Production Segment (Draft Peer Review Report),* Radian; Austin, TX; Radian. 1992b. *U.S. Natural Gas Industry Methane Emissions Mitigation and Cost Benefit Analysis,* Radian, Austin, TX; Radian. 1992c. *Venting and Flaring Emissions from Production, Processing, and Storage in the U.S. Natural Gas Industry,* Updated Draft Report prepared for the U.S. EPA and the Gas Research Institute.

25 USEPA 1993.

26 The actual contribution will depend on a large number of factors, particularly the displaced generation fuel type (e.g., coal, oil) and technology, as well as the heat rate and load factor of the landfill gas-fired generation equipment.

27 For a detailed description of the models available, see *Interagency Joint Project on Databases and Methodologies for Comparative Assessments of Different Energy Sources for Electricity Generation,* DECADES Project Working Paper No. 5, March 1995.

5 Forest Sector

5.1 Introduction

Forest sector policies can be important components of an overall strategy to reduce greenhouse gas (GHG) emissions. Trees absorb carbon dioxide from the atmosphere while growing and sequestering (storing) it as carbon in trunks, limbs, leaves, and roots. Globally, forests hold two-thirds of terrestrial carbon. When forest lands are harvested or converted to other uses, the stored carbon is released to the atmosphere in the form of GHG. This may happen immediately if the timber is burned, or more slowly over time if the timber is left to decay or is converted into timber products that are eventually discarded. The annual release of carbon into the atmosphere from deforestation was estimated at 1 to 3 billion metric tons in 1980; the rate is higher now as deforestation proceeds.[1] In contrast, the annual release of carbon from combustion of fossil fuels is about 5.6 billion metric tons.

Approximately half the dry weight of wood is carbon. Thus, expanding, maintaining, or improving the management of forested lands can increase carbon or reduce emissions of GHGs. Options to alter GHG flows between forests and the atmosphere can sequester significant amounts of additional carbon, particularly in tropical countries where deforestation is occurring and biomass can grow rapidly. Mitigation options, such as plantation forestry, sustainable harvest techniques, forest protection, and agroforestry to meet demands for forest products, can increase carbon storage and reduce GHG emissions in the forest sector. Sustainably grown biomass energy projects can offset non-renewable sources of GHG emissions, such as fossil fuel consumption or depletable biomass fuel sources, and thereby reduce GHG emissions.

Many of the factors that influence the choice of forest sector policies in the Reform Scenario – such as land availability or the demand for forest products – also influence the mitigation options appropriate to a particular country. Such policies can supplement or align with strategies being considered in the Reform Scenario to meet economic, development, and other goals. As part of a long-term climate change mitigation strategy, however, forest sector policies are far more controversial than emission reduction options in the energy or transportation sectors. Timing is one important factor. Sequestering carbon by forestation or natural regeneration produces benefits only slowly over time as biomass matures. In contrast, forest preservation projects that reduce deforestation, or projects that replace fossil fuel combustion with biomass fuel – like projects that reduce emissions in the energy sector – result in a rapid reduction in GHG emissions.

Permanence is also an important consideration. Because the carbon contained in biomass will eventually return to the atmosphere upon decay or burning, the carbon is not stored indefinitely. Both natural disturbances, such as fire, pests, and disease, and anthropogenic causes of forest loss can reduce carbon stocks. Thus, much of the focus in designing and analyzing forest sector mitigation projects is on minimizing the loss of carbon benefits over time due to market and non-market forces that produce pressures to deforest or harvest project and adjacent lands.

This section of the report focuses on identifying and analyzing technical and policy options that maintain or expand the carbon stored in forests and wood products or use biomass energy to offset other energy sources. The remainder of this section of the report is divided into five sub-sections:

- *Section 5.2* introduces the processes governing carbon sequestration in forests and the concepts of carbon stocks and flows;
- *Section 5.3* identifies technical mitigation options using forestry and briefly discusses policy options both inside and outside the forest sector that influence forest carbon;
- *Section 5.4* presents criteria for screening technical and policy options on the basis of costs, GHG sequestration, country characteristics, and other relevant factors;
- *Section 5.5* focuses on methods for assessing the technical options on the key criteria of costs and GHG sequestration; and
- *Section 5.6* describes alternative strategies for developing and analyzing Mitigation Scenarios.

5.2 GHG Emissions and Forests

Carbon is a major constituent of forest ecosystem components, which include living biomass (e.g., trees and undergrowth), dead standing biomass, decaying biomass on the forest floor, and soil. In forest ecosystems, carbon dioxide (CO_2), which is a key GHG, is removed from the atmosphere and stored by vegetation during the process of photosynthesis, resulting in the accumulation of carbon in growing biomass. This accumulation of carbon during biomass growth results in the movement of carbon from the atmosphere to the ecosystem components. Carbon removed from the atmosphere in this way can be stored (sequestered) for considerable periods of time.

The carbon sequestered in forest ecosystem components is released when biomass oxidizes (i.e., is burned) or decays. The carbon is released both as CO_2 and as other GHGs, depending on the mechanism of release. A forest is considered to be a carbon "sink" if more carbon is accumulated in the forest soils and biomass than is released by other processes. A forest is considered to be a "source" of emissions when the rate of carbon accumulation is less than the rate of loss, and there is a net movement of carbon from the forested area to the atmosphere.

In the absence of any disturbance, a balance exists between the carbon stored and the carbon emitted by mature forest ecosystems. In the absence of significant natural disturbances, such as wildfire, there is generally little net change in the amount of carbon stored because emissions from trees that die and decay are balanced by the carbon uptake in new biomass growth and regrowth. Human activities, however, can have a significant impact on forest ecosystems. These anthropogenic forest-related activities, such as afforestation, reforestation, and deforestation, may change the amount of biomass on land area, the area of forested land, or the age and other characteristics of forests. The associated changes in amount of biomass and rates of regrowth in forests affect the amount of carbon released from or stored in the forest.

In addition to changes in forest biomass, human activities have long-term and sometimes delayed impacts on GHG emissions. For example, harvesting trees not only reduces the amount of biomass on site, but also results in the accumulation of dead biomass on the forest floor which decays over time and results in GHG emissions after the actual time of the harvest. Similarly, land use change can disturb soils causing the long-term release of stored carbon.

Forest sector GHG mitigation options are designed either to augment the storage and accumulation of carbon in forest ecosystem components, or to reduce the release of stored carbon. In both cases, options seek to shift the dynamic balance of carbon flows in favor of forests acting as net sinks. This section discusses various measurement concepts for estimating the magnitude of carbon storage in forest ecosystem components and the net movement of carbon resulting from implementing mitigation options and other human activity.

5.2.1 *Carbon Storage on Forested and Other Lands*

Land areas influenced by human activities may be broadly grouped into four categories:

- savannas (e.g., grasslands including pasture lands);
- agricultural lands (e.g., lands on which crops are grown and harvested);
- forests (e.g., timberlands, plantations); and
- built-up/urban areas (e.g., city parks, perimeter and roadside trees).

Forests are generally able to store the most carbon per unit of land area of any of these land-use types. However, it is important to recognize that in many countries (e.g., Pakistan, Kenya, Uganda), forests represent less than 30-35% of standing wood stock. Therefore, while GHG estimation methods focus on estimating forest carbon storage, mitigation options very often include other changes in land use on a given area.

Within forests, there is great natural and anthropogenically influenced variation in carbon storage. Forest ecosystems range from dense tropical forests to arid land with few trees. The quantity of carbon stored or GHGs emitted by these forests depends on ecosystem characteristics, which are regulated by climatic and geographic factors such as annual precipitation, soil type, elevation, and slope. Forest ecosystem characteristics are also affected by past and ongoing human activities, particularly land use conversion and wood use. As these factors vary across forest types, so do biomass density, tree species, growth rates of trees, and the ability of soils to store carbon, each of which affects carbon storage.

Forest productivity and the related rates of carbon accumulation and amounts of carbon stored per unit of land area depend on a number of country- and region-specific factors. In order to estimate the carbon storage characteristics, forest types can be categorized at various levels of detail (e.g., global, national, or regional). For example, at a broad level of definition, forests can be defined as tropical, temporal, and boreal. Tropical forests typically have higher rates of biomass growth and amounts of biomass per unit area than boreal forests.[2] Forests may also be categorized according to other characteristics, often the result of human influence, including whether the forest cover is closed or open, primary or secondary forest, degraded or protected. Exhibit 5-1 illustrates the range of carbon storage both within and across several general forest ecosystem categories.

Exhibit 5-1. Variation in Carbon Storage Across Forest Types

The amount of dry matter (dm) and soil carbon per hectare (ha) depends on the forest ecosystem type and climate. Even within these classifications, there is considerable variation.

Tropical Forests:
Moist: 150-300 t dm/ha; 115 t C/ha (soil)
Seasonal: 95 - 190 t dm/ha; 100 t C/ha (soil)
Dry: 16 - 60 t dm/ha; 60 t C/ha (soil)

Temperate Forests:
Evergreen: 220 - 295 t dm/ha; 120-134 t C/ha (soil)
Deciduous: 175- 250 t dm/ha; 120-134 t C/ha (soil)

Boreal Forests: 120 - 165 t dm/ha; 185 - 206 t C/ha (soil)

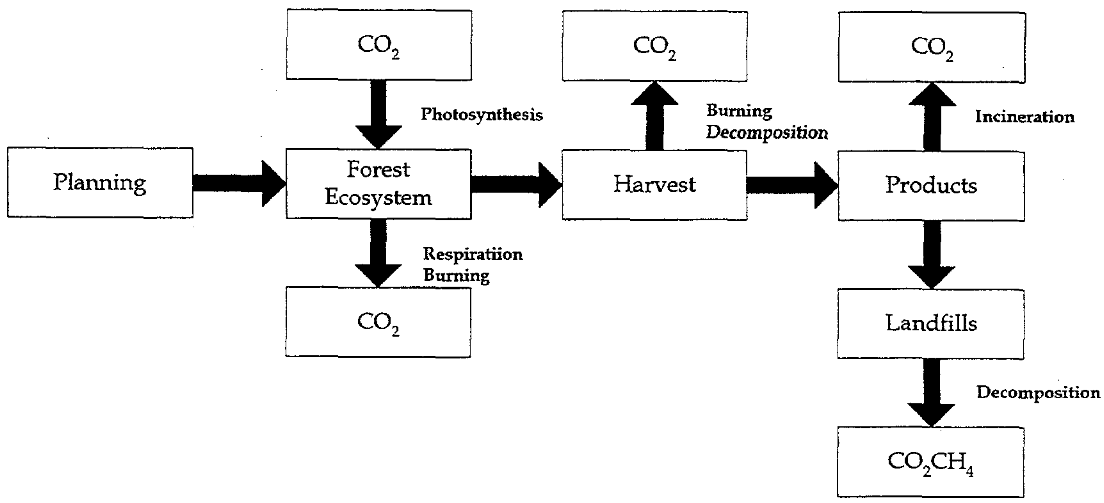
Grasslands: A default value of 10 metric tons of dry matter/ha may be adopted for grasslands although there may be significant differences in this value depending on the characteristics of that land area. Very general default values for soil carbon in grasslands are 60 (tropical) and 70 (temperate) metric tons/ha.

Because no two forests are the same, carbon storage will always vary even within detailed forest ecosystem classifications. Because of differences in factors affecting forest productivity - such as biomass density and soil types - different tropical forest ecosystems may not store the same amount of carbon. Thus, although default values are available to aid in calculating carbon stocks, local, and preferably, site-specific data should be used whenever possible to account for these variations.

A carbon budget is a bookkeeping system for tracking the amount of carbon in various reservoirs ("pools") and the amount of carbon transferred among the reservoirs and the atmosphere ("flows"). The forest sector carbon budget has three pools:

- the organic matter of forest ecosystems;
- the products derived from forests; and
- products that are landfilled, incinerated, or otherwise discarded (see Exhibit 5-2).

Exhibit 5-2. The Forest Sector Carbon Budget



Source: Adapted from Turner, D.P. et al. 1993. *The Forest Sector Carbon Budget of the United States: Carbon Pools and Flux Under Alternative Policy Options*. Report No. EPA/600/3-93/093. USEPA: Washington, DC.

Anthropogenic influences on carbon stored in these pools can be assessed using methods that account for stocks and flows of carbon between pools. These methods can be used to evaluate the carbon benefits of mitigation projects, and incorporate various economic and biophysical factors as well as social and cultural considerations. In conducting forest sector studies, the World Bank already gathers and evaluates much of the information - such as land use and forest inventory - that is necessary to assess the GHG implications of projects and policies. However, when evaluating emission mitigation projects, data such as forest productivity, mean annual increment of growth, and tree species do not alone determine the value of a mitigation project.

For the purposes of GHG mitigation options assessment, it is not usually necessary to include carbon pools contained in forest products (lumber, furniture, paper, etc.) in the analysis. It is only relevant in the case of very large forest projects which inject such large product volumes onto the market that they disturb local or national wood consumption patterns. The level and mix of national wood product consumption is determined by many factors, and the sale of harvested wood from a relatively small plantation would do little or nothing to alter that consumption pattern, but would rather simply displace production from other supply sources.

5.2.2 *Carbon Storage (Stocks)*

Estimating the amount of carbon stored in the forest ecosystem components under consideration is a basic approach to GHG assessment. Tracking the stored carbon (carbon stock) in each component is a convenient tool, particularly because many of the components are affected differently by forest sector activities. For example, different amounts of carbon are stored in various tree species and stand ages. Forest types under different management conditions have varying amounts of dead biomass and litter. Soil carbon varies with current as well as past land use (e.g., primary forest soils hold more carbon than secondary forest soils).[3]

Biomass and soil carbon stocks may change over time due to anthropogenic activities in the forest. Policies and activities affecting land use will determine whether a particular forest is a carbon source or sink. By estimating the carbon stocks over time, the net changes can be calculated and used to evaluate proposed land-use changes for their GHG impacts (see Exhibit 5-3).

In addition to carbon stocks found in a forest ecosystem, wood products made from harvested timber exist in "carbon pools" outside of the forest. Harvested forest biomass is used for a variety of commercial purposes including construction, paper production, and furniture manufacture. These wood products can have a long lifespan before they are disposed of and can continue to store carbon for decades or even centuries before the carbon is released to the atmosphere. It has been estimated that as much as 30-40 percent of stored carbon can be found in wood products.[4]

Exhibit 5-3. Data Availability

As part of their commitments under the Framework Convention on Climate Change (FCCC) countries are currently in the process of preparing national GHG emission inventories. These inventory data can be adapted to evaluate mitigation projects within the country. If inventory data are not available, other forms of national data may be used such as national timber land areas and commercial harvest statistics.

The IPCC Guidelines, an internationally accepted methodology for estimating emissions from and sequestration in forests, bases calculations of carbon on units of dry matter. These calculations also include, for example, the growth rate of biomass in an area (in dry matter), the fraction of harvested wood that is burned off and on site and left to decay, and storage in or emissions from soils. Various default factors are available to convert information related to forest management into the appropriate units of measure for calculation of carbon changes.

The method by which the product is eventually disposed also influences when and which types of gases are emitted. For example, if the product is burned, emissions, primarily in the form of CO_2, are immediate at the time of disposal. Depending on the type of burning and the properties of the product, other GHGs may be emitted in trace quantities. If a product is landfilled, emissions are further delayed as the material decomposes slowly. Moreover, significant portions of the carbon may be emitted as CH_4, a more potent GHG.

The impacts of proposed land-use changes can be evaluated by measuring and comparing the carbon stocks before and after a land-use change. The incremental change in carbon stocks must be evaluated in order to consider the net difference in carbon stored due to a land-use change. Consider the example of one hectare (ha) of forest being cleared for pasture land. If the forest is known to have a total carbon stock of 300 metric tons, and pasture land has a carbon stock of 20 metric tons, then the net loss of carbon associated with this land use change is 280 metric tons of carbon per hectare.

This concept may be stylistically represented by: $C_1/\text{ha} - C_2/\text{ha} = C_{change}/\text{ha}$. C_1 is the carbon stock before conversion, and C_2 is the carbon stock after conversion. A negative change indicates increased carbon storage, and a positive change indicates carbon emissions. In this example, the carbon stock is estimated for the forest as a whole. A more detailed analysis would consider the forest ecosystem components as separate stocks.

The calculation of carbon stock changes may become very complex. For example, a land-use change from forests to commercial tree plantations harvested on 20-year rotation cycles must account for the carbon stored in the soils and biomass before and after conversion, the carbon stock of the plantation over time, and the emissions due to tree harvest.

5.2.3 *Carbon Flows*

Carbon flows are the incremental changes in carbon stocks that occur as the result of natural factors and human activities. Tracking flows of carbon is critical because flows, rather than stocks, directly determine the concentrations of GHGs in the atmosphere. Moreover, flows are comparable with the types of emission impacts estimated in the energy and other sectors. The concept of carbon flows is also useful to evaluate both the immediate and delayed effects of anthropogenic activities. Past activities can have considerable effects on current emissions and, in the same way, current activities will have long term effects on future emissions.

Because of this delay in cause and effect, past activities can affect current year emissions. For example, aboveground biomass that remains on site after clearing decays over time; thus, past forest clearing continues to generate emissions from decay long after clearing occurs. Soil disturbance also has long-term consequences. Based on the assumption that soils lose approximately 50 percent of stored carbon in 50 years (the majority of carbon being lost in the first 25 years), the IPCC methodology recommends using the average land-use change over the past 25 years in order to account for emissions from soils disturbed by land-use changes.[5]

Assumptions about flows can be used to track changes in the underlying stocks. A typical flow is the accumulation of carbon in new biomass growth. Different forest types will have different rates of accumulation. Rather than estimating the carbon stocks at different time periods, data may be used for the annual accumulation itself. Exhibit 5-4 presents typical ranges of carbon accumulation for different forest types that could be used in GHG assessments.

For example, consider a project that establishes a tree plantation on 10 ha of existing grasslands. The plantations will be harvested on a 20-year rotation for the indefinite future. If the original carbon storage is estimated to be 10 tC/ha, then the original carbon stock is 100 tC. The soil accumulates 1 tC/ha/yr for 10 years, and then does not accumulate additional carbon. The accumulation from annual tree growth averages 2 tC/ha/yr. The carbon flow is therefore 3 tC/ha/yr for the first ten years. Note that the final stock can be estimated after ten years, 400 tC, but is not crucial to evaluating the impact of the project (see Exhibit 5-5).

Exhibit 5-4. Carbon Flows By Forest Type

Average Annual Uptake (t dm/ha)

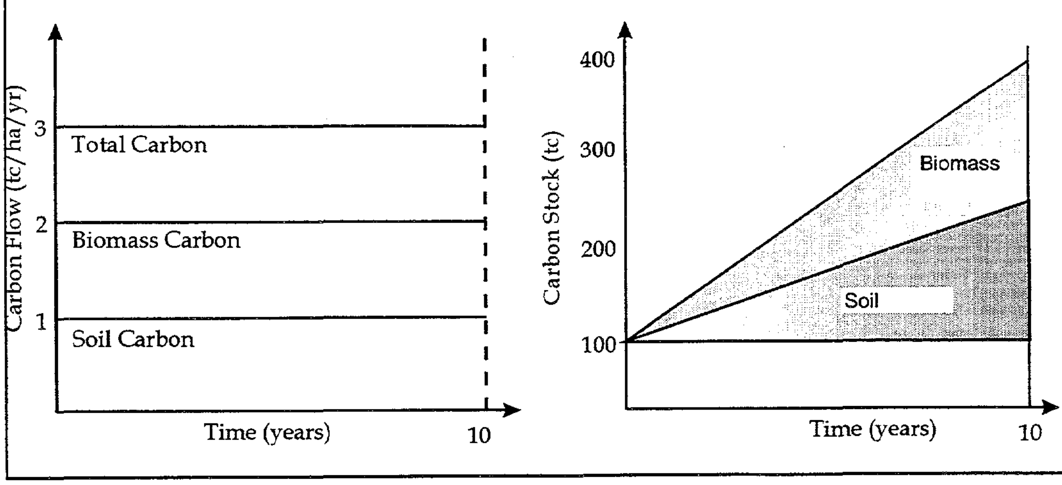
Forest Type	**0-20 years**	**20-100 years**
Temperate	2-3	2-3
Boreal	1	1
Tropical	4-11	0.25-1

Note: Forest ecosystems include various types of forest (i.e., moist, seasonal, dry) as well as primary and secondary forests.

Source: UNEP/OECD/IEA/IPCC. *IPCC Guidelines for National GHG Inventories, Volume 3.*

The rate at which carbon is stored is influenced by both anthropogenic and natural factors. Insects or wildfires that damage or destroy trees may slow the rate at which carbon is stored, or release carbon and other GHGs to the atmosphere.[6] In addition to natural occurrences, policies and activities affecting land use will determine whether a particular forest is a carbon

Exhibit 5-5. Stock and Flows on a 10 Hectare site



source or sink. Deforestation, for example, results in the destruction of the forest; if the timber is harvested, carbon may continue to be stored in products such as furniture or may, if the timber is burned to clear land for pasture or agriculture, be released immediately.

Human influences on forests can be broadly grouped into two categories: (1) changes in forests and other woody biomass stocks; and (2) land-use changes.[7] The first category, changes in forests and other woody biomass stocks, includes anthropogenic activities such as establishment and harvest of plantations, commercial forest management, and harvesting and fuelwood gathering. Forest conversion and abandonment of managed lands are included in the second category, land use change. Forest may be converted for agricultural purposes such as crop production or to create pasture land for domestic animals. Land that was used for pasture, or to grow agricultural crops, may be abandoned and allowed to regrow naturally. Land conversion from one use to another affects not only the amount of carbon stored in aboveground biomass but also the amount of carbon stored in the soil.

The function of a forest as a carbon "sink" may be enhanced through programs or activities that reduce the baseline level of GHG emissions or that increase the rate at which carbon is stored over baseline levels. For example, GHG emissions may be reduced by more efficient burning of biomass fuels (e.g., use of a stove for cooking), or more efficient harvesting techniques resulting in less burning or decay of biomass. The amount of carbon sequestered may be increased by increasing the amount of forested lands and the rate at which carbon is sequestered. Programs that increase both the rate at which carbon is stored and the amount of carbon stored per unit of land area might include reforestation and afforestation programs which result in an increase in the number of trees over present stocks. The following section describes potential mitigation options and broad policies.

5.3 Identifying Mitigation Options: Projects and Policies

Crafting a Mitigation Scenario requires understanding the technical options for increasing carbon sequestration. These options are defined at the project level and derive from the ability of forest ecosystems and wood product pools to accumulate and store carbon over relatively long time-frames. For example, options such as tree planting and improved forest management techniques can expand total biomass and, hence, the carbon sequestered. Implementing these options, however, requires adopting broader policy options such as regulations, taxes, institutional changes, and other policies.

Although assessing GHG and cost impacts of enhanced carbon sequestration in the forest sector is more easily understood at the project level, designing a Mitigation Scenario must also take into account feasible policy options in the country and synergies (or conflicts) between and among technical options and policies. Thus, both project level and policy options are described in this section. Moreover, although mitigating carbon emissions in the forest sector involves management techniques and policy instruments familiar to forest sector analysts, such options and policies have different implications when forests are managed for carbon as well as for economic gain, biodiversity, or other goals.

5.3.1 *Project-Level Options to Promote Carbon Storage*

There are two primary types of technical mitigation options for the forest sector. One type involves expanding the pools of carbon stored in vegetation, soils, and products manufactured from wood. For example, options that expand forested areas remove additional CO_2 from the atmosphere and store it as carbon. The second type of mitigation option maintains existing carbon pools, which may otherwise decrease. For example, maintaining existing stands - by avoiding deforestation or converting standing timber into wood products more efficiently - maintains baseline carbon pools and prevents carbon emissions. Both types of projects typically use standard forest sector management techniques to meet the twin goals of increased storage and reduced emissions of carbon.

Net carbon emissions can also be reduced by substituting the wood obtained from forest plantations and other sources for non-renewable sources of GHG emissions, such as fossil fuels. This activity results in a permanent reduction in emissions because less fossil fuel is burned. Wood derived from sustainable sources, rather than woodfuel derived from depletable forest activities, also slows the carbon emissions from the non-sustainable source. Forest sector mitigation options are described below, and a number of these options are summarized in Exhibit 5-6.

Exhibit 5-6. Land-use and Forestry Practices to Manage Carbon

Practice	MAJOR OBJECTIVES: Increase C Storage	Maintain C Storage/Avoid C Emissions	Reduce Energy C Emissions
Afforestation	X		
Agroforestry	X	X	X
Breeding/genetics	X	X	
Biomass for energy			
Disease control		X	
Drainage	X		
Fertilization	X		
Fire control		X	
Herbivore control		X	
Improved regeneration	X		
Increased forest products	X	X	
Insect control		X	
Irrigation	X		
Longer rotation	X	X	
Preservation		X	
Recycling		X	
Reduced impact logging		X	
Reforestation	X		
Salvage dead biomass		X	
Shade trees			X
Shelterbelts		X	X
Soil management	X	X	
Stocking control			
thinnings	X		
enrichment plantings	X		

Source: Richards, K.R. et al. 1995. Consideration of Country and Forestry/Land-use Characteristics in Choosing Forestry Instruments to Achieve Climate Mitigation Goals. In Sampson R.N. et al., eds., *Economics of Carbon Sequestration in Forestry*, Proceedings of Workshop held in Bergendal, Sweden, 15-19 May, 1995, American Forests: Washington, DC.

5.3.1.1 Expanding Forested Areas and Carbon Storage

The principle carbon benefit of these projects is the accumulation of carbon in new-growth biomass. Described below are several different types of projects that can increase carbon stocks, each with unique aspects to be considered when selecting and designing mitigation options.

Afforestation. Afforestation involves establishing forest cover on land that currently contains no substantive woody crops. More specifically, it is the conversion to forest of land that was previously managed in another capacity, such as agricultural land or range land. This mitigation project results in an increase in biomass and, therefore, a carbon sink.

Reforestation. Reforestation includes planting trees on deforested lands or allowing natural regeneration of forests on land previously deforested. Reforestation involves the natural or enhanced regeneration of forest land whose tree cover has been diminished due to natural or anthropogenic causes, such as natural disasters, fire, or timber harvesting. It differs from afforestation in that the land to be reforested is degraded forest land, rather than land previously converted to non-forest uses.

Plantation Forestry. Plantation forestry, which is a subset of reforestation, or afforestation, establishes single or multiple species stands on previously bare, denuded, degenerated, or clear cut lands. Short rotation woody biomass (SRWB) plantations produce a dedicated biomass energy source, which is specifically used to displace fossil fuel in energy production. Plantations can also be established for commercial harvesting, either for wood products or energy applications.

Improved Forest Management Techniques. Forest management projects seek to apply new management techniques to existing forests in an effort to increase carbon storage by enhancing tree growth or increasing the sustainability of the forest ecosystem. For example, enrichment planting increases the biomass density of forests that are currently under-stocked or degraded. Other technologies include improved seedling stock and genetic improvements. Alternatively, projects may reduce carbon loss by increasing the efficiency with which forest products are processed. Because these projects maintain existing stocks, they are discussed in more detail below.

Agroforestry and Multiple-Use. Agroforestry involves integrating trees into existing or modified agricultural land use patterns in order to enhance positive ecological and economic interactions. Examples include planting windbreaks and shelterbelts, establishing multiple use species (e.g., orchards) on agricultural land, planting live hedges, alley cropping, and multi-layer tree gardens. Agroforestry involves the storage of carbon in new tree growth, as well as the preservation of forest land by addressing demand pressures for new agricultural land. Thus, agroforestry projects may also reduce carbon emissions by reducing deforestation.

5.3.1.2 Maintaining Forested Areas and Carbon Stocks

Carbon emissions can be reduced or delayed by policies and projects that provide incentives for currently forested areas to remain forested.

Protection and Conservation. Preservation projects protect an existing forest area which is in danger of being cut down or degraded. Preserved land can be designated as parks, wildlife preserves and refuges, and/or sustainable forestry areas. Protecting forests prevents existing carbon stocks from being released to the atmosphere, and may also result in additional growth. Credible preservation projects not only protect forests but also address the underlying resource pressures and provide for economically sustainable uses of the preserved areas.

Increased Efficiency in Harvest and Products. A number of measures can be implemented to increase the efficiency of forest harvests and reduce biomass loss. These measures include the use of selective harvesting in natural forests, reduced impact logging, harvesting for multiple end-uses, more efficient use of biomass being cleared during land conversion, and improved sawmill technology. Other technologies that increase the efficiency of forest utilization include fire protection and pest control. In the end-use sector, improved efficiency includes promoting production and use of wood products with longer durability and recycling used biomass materials, both of which may reduce the demand for new harvest.

5.3.1.3 Other Mitigation Options

Other mitigation options in the forest sector involve the use of renewable bioenergy and urban forestry.

Bioenergy. Mitigation options for bioenergy are generally designed to reduce the use of biomass (as well as the need to harvest additional fuel) and thereby reduce the associated GHG emissions while maintaining carbon stocks. Options include more efficient technologies for the use of biomass for burning and charcoal production (e.g., better kilns for charcoal production, charcoal packaging, woodfuel stoves, use of charcoal for industry and agriculture).

The use of wood from renewable resources such as dedicated plantations as a substitute for non-renewable energy resources is another option for reducing net carbon emissions. The non-renewable sources may include fossil fuels or woodfuel from natural forests.

Urban Forestry. In urban forestry projects, trees are planted as residential shade trees, on the roadside, and as demarcation trees. Urban tree planting reduces energy consumption for heating and cooling of buildings. The primary GHG benefit of urban forestry is the reduced fossil fuel emissions that result from reduced heating and cooling loads, rather than carbon sequestered in new biomass growth. These benefits are unrelated to forest sector calculations, and require analyzing the energy requirements of the targeted area. Carbon sequestration benefits can be accounted for using the methodologies discussed in this section of the report.

5.3.1.4 Managing Forests for Carbon Sequestration

Nearly all forest management options have been used to maintain carbon stocks (see Exhibit 5-7). Although the technical options all seek to expand or maintain carbon stocks, they differ in several critical respects. First, the timing of emission reductions may be very different across project types. Agroforestry projects that reduce deforestation by providing alternative sources of food and fuelwood in order to reduce demand pressures on forested lands generate carbon benefits rapidly. Because the primary GHG impacts are the reduced emissions of carbon associated with slowed deforestation, avoided emissions accrue immediately. In contrast, afforestation and reforestation projects sequester carbon slowly over decades as trees mature and soil carbon is restored (except in the case of short rotation five-to-six year plantations, which can sequester carbon very rapidly).

Exhibit 5-7. Joint Implementation Projects

As part of the FCCC pilot program on activities implemented jointly, a number of industrialized countries are pursing GHG reduction projects in developing countries and those with economies in transition. Four forestry projects covering a range of activities, were approved during the first round of proposals submitted to the USIJI.

Ecoland: Esquinas National Park, Costa Rica. This project is designed to protect the carbon storage and sequestration capacity of an area of tropical forest in the Esquinas National Park in southwestern Costa Rica. This forest land is threatened by logging and conversion to agricultural and pastoral lands. The project will also protect an area of land no longer forested, thus enhancing carbon sequestration as the forest regenerates. The forest land will be placed under the jurisdiction of the Ministry of Natural Resources and Energy (MINAE) in Costa Rica and will be managed by the National Park Service.

Rio Bravo Conservation and Management Project, Belize. This project is designed to develop carbon sinks through the acquisition, management, and preservation of forest lands over a forty year period. The project involves both the protection of 6,000 hectares of forest land (broadleaf forest and seasonally inundated scrub) and the development of a conservation and a sustainable forestry management program on additional land. The project will attempt to demonstrate economically viable sustainable land uses that retain the forest cover.

RUSAFOR: Saratov Afforestation Project. This project is designed to evaluate the biological, operational, and institutional opportunities to manage a Russian forest plantation as a carbon sink. This project will reforest 50 hectares of burned pine plantation with pine seedlings and afforest 450 hectares of marginal agricultural lands with broadleaf (i.e., Green Ash, Maple and Elm) seedlings. The lands are situated in the Saratov Oblast, 440 miles to the southeast of Moscow.

FUNDECOR: Project Carfix in Costa Rica. This project is designed to stabilize existing forested areas in the national parks and expand forest cover in the surrounding buffer zone through reforestation, sustainable management of natural forest, and natural forest regeneration. This project will protect approximately 72,000 hectares of natural forests in the national parks. In addition to 36,700 hectares of lands in the buffer zone, landowners and farmers will be encouraged to adopt sustainable forestry practices, reforestation, and natural regeneration by outreach and education programs and monetary incentives.

Second, projects differ in the permanence of the carbon sequestered. For example, plantation forestry results in periodic harvest and conversion of timber into fuelwood or timber products. If the plantation consists of an infinite series of rotations, then the total amount of carbon sequestered by the project equals the amount sequestered during one rotation. If the project does not continue in perpetuity, then all carbon is ultimately emitted back into the atmosphere if the lands do not remain forested. A successful preservation project that maintains carbon stocks represents a permanent store of carbon unless the land is eventually harvested. However, as described below, such a project has other uncertainties. Bioenergy projects, which offset emissions associated with combustion of fossil fuels or enhance combustion efficiency, may offer the most permanent emission reductions among the forest sector projects.

Third, because forest carbon is transitory relative to the emission reductions achieved by projects in the energy sector, both the likelihood of success and careful project design are critical components of forest sector mitigation plans. Forestry projects are subject to natural disturbances such as fire and pests and to climatic influences such as drought, any of which may result in a loss of forest carbon. Projects are also subject to anthropogenic pressures that may result in a loss of forest carbon. For example, the demand for forest products often contributes to deforestation. Thus, effective forest protection may require measures to replace the forest products that would otherwise have been supplied by deforestation, in order to reduce the likelihood of renewed deforestation occurring inside and outside the project boundaries.

Finally, mitigation options designed to maximize carbon storage may differ from options designed to maximize economic gain, preserve biodiversity, or meet development or other goals. For example, the rotation length before harvest that maximizes carbon storage will exceed that which maximizes the economic returns of a plantation or managed natural forest.

Although these concerns have been described thus far at the project level, they are also relevant to the policy instruments used to implement the technical options. Policies that set aside and protect tracts of land as parks or designated wilderness areas, for example, must take into account the impacts on carbon emissions that occur if pressures to deforest remain unabated in contiguous and accessible areas. As described in Section 5.6.2, assessing carbon impacts at the national level can quantify some forms of leakage. However, policies that encourage plantation forestry, or require alternative harvest practices, must nonetheless take into account the long term incentives created by the policy. They must also consider the consequent long term impacts on the permanence of the forest inventory and carbon storage.

5.3.2 *Policy Instruments to Promote Carbon Storage*

Technical mitigation options are actions that expand or maintain the carbon stored in vegetation, land, and wood products. Implementing the technical, or project-level, options requires putting government plans and policies in place that affect land use practices and the extent of forest cover. Such policies, many of which are typically considered as part of forest sector studies, may involve direct government action in the form of tree planting or regulation. Alternatively, government actions can indirectly affect land use and carbon storage by, for example, providing financial incentives using subsidies or by changing institutions that affect tenure. Moreover, policies initiated outside the forest sector can also influence carbon storage. For example, policies to expand agricultural production and the extent of agricultural lands may reduce forest cover and carbon storage. Similarly, policies that change the production of wood products - such as import-export policies and paper recycling programs - can also alter carbon flows.

5.3.2.1 *Direct Policy Instruments*

Direct government policies focus specifically on controlling actions to produce outcomes in line with the technical options. With direct control policies, the government either regulates specific targeted activities that affect carbon or directly promotes carbon storage through government-sponsored activities. Such policies include:

- limits on timber production on government-owned land;
- limits on timber production on private land where the owner is compensated for the opportunity cost of the land (e.g., leasing);
- afforestation on government-owned or leased lands;
- regulations requiring management actions, such as reforestation after harvest, or guidelines on allowable logging techniques; and
- establishing parks and designated wilderness areas.

Direct government control typically allows for greater specificity and certainty of outcome. More general requirements, such as legislation requiring sustainable management techniques, can result in greater discretion in compliance and a range of activities that vary widely in carbon consequences. The more specific regulation is, the more it can be designed to target activities that enhance carbon storage. Further, compliance with more specific requirements, such as banning certain logging techniques, may be easier to monitor and verify. Such requirements, however, reduce the flexibility and discretion with which the regulation can be implemented, by both the government and private sector agents.

5.3.2.2 *Indirect Policy Instruments*

The government can also indirectly implement the technical options by providing incentives for landowners and other entities to undertake actions that increase carbon storage. Such incentives can be financial (in the form of taxes, subsidies, or the establishment of markets for carbon), or institutional (changing property rights or providing education). Indirect policies may be the most effective means of accomplishing broad structural change in the country's forest sector. Because it is difficult to predict the extent to which indirect policies change land use decisions, the carbon outcome of these policies can be more difficult to quantify and, perhaps, less certain. Moreover, such policies are often part of a broader strategy of reform inside and outside the forest sector and, consequently, may be designed to meet a variety of objectives, of which carbon sequestration is only one.

In countries with well-functioning markets and a clear assignment of property rights, economic incentives can be used to encourage activities that enhance carbon storage. These incentives can be general - such as subsidies for commercial forest plantations, or they may be GHG specific - such as taxes on the carbon released by harvest, subsidies to extend rotation periods and increase the carbon sequestered between harvests, or a domestic emissions trading program.

Institutional incentives can encourage landowners to manage forests for both economic gain and carbon storage. For example, resolving land title claims and protecting property rights may reduce the uncertainty surrounding management decisions, encouraging longer-term planning that may have GHG benefits. Community-based forestry, which emphasizes local government ownership of timberland, can be used to encourage sustainable land management activities, which in turn will encourage carbon sequestration. Examples of this approach are seen in India[8] and Thailand.[9] Some institutional and infrastructure policies, such as road building or the ability to claim title through "improvements," may encourage conversion to forests. Indirect policies also include research and development of new management techniques and providing technical assistance to private forest owners.

5.3.2.3 *Policy Instruments Outside the Forest Sector*

Both direct and indirect policies outside the forest sector can also have carbon implications. Agriculture policies, in particular, can affect forests. In general, agricultural policies that seek to improve production efficiency will tend to reduce pressures for available land, and either reduce deforestation pressures or reduce the cost of land (i.e., make more land available) for forest sector mitigation measures. Economic development goals and population policies will be important drivers in the medium- and long-term demand for forest products and in land availability.

More general macroeconomic policies can also have implications for carbon sequestration. For example, policies that affect the attractiveness of forest sector investments relative to other sectors - such as the tax treatment of capital gains and depreciation - will alter incentives in the forest sector. Policies such as subsidies that affect the prices of wood products or of outputs (i.e., agricultural products) generated from competing land uses will change the forest inventory and forest carbon. Thus, tax and subsidy policies, restrictions or tariffs on imports and exports, and changes in income and the standard of living in the country can all alter carbon storage.

5.3.3 *Combining Technical Options and Policy Instruments*

No one policy instrument will be appropriate for all technical options or all countries. Across countries, appropriate policy tools will depend on common forestry practices, the level of technical expertise, and country characteristics such as the land tenure history, the prevalence of markets, or legal constraints. Similarly, the appropriateness of a given technical option will depend on land availability and the natural type of vegetation in a country, as well as on institutional considerations. Last, a particular policy tool such as direct control may be more suited to options that require implementing readily identified activities (e.g., using specified harvest practices), particularly if lands are within the control of the government. These issues are discussed in more detail in Sections 5.4 and 5.5.

5.4 Screening Technical Options and Policy Instruments

The first step in constructing a Mitigation Scenario is to screen -- roughly assess and rank -- potential mitigation approaches for suitability to the forest sector in the country under study. This step is designed to screen out options that are clearly unsuitable, given the climate and physical characteristics of the country and political and institutional considerations. The criteria described here are important both for screening and for in-depth analysis of the options.

Screening out non-promising options can proceed using different types of criteria. The first type involves broad criteria that could be used for any technical option independent of its GHG impacts or the sector involved. These criteria include macroeconomic impacts (see Section 6, Macroeconomic Analysis), such as increases in domestic employment or improving the balance of payments, and consistency with national development goals. For policy options, criteria would also include ease of implementation and consistency with existing legal arrangements and institutions.

The second type of criteria is more specific to the global overlay concept and the focus on GHG mitigation. Such criteria include expected reductions in GHG emissions, total costs and costs per unit of emissions reduced, and the long term sustainability of the option in terms of generating or maintaining carbon sequestration over time. Also included in this set would be consistency with options and policies generated in the Reform Scenario and broad consistency with national environmental and natural resource goals and land use practices.

The screening process should also focus on criteria specific to the forestry sector. In particular, biophysical considerations such as climate or soil may result in some projects being less promising. For example, short rotation forestry in a dry area without the possibility of irrigation will not produce large increases in biomass and, hence, can be screened out. Forestry also raises specific political considerations. For example, a measure requiring physical removal of large numbers of forest dwellers for resettlement may be politically infeasible.

Screening out non-promising options may require collecting preliminary data on land availability, costs, GHG impacts, and other characteristics of the options. These data can be used to construct a matrix similar to that illustrated in Exhibit 5-8 where options are arrayed and roughly evaluated against key criteria. Such a screening should consider not only current country characteristics and economic, development, and environmental goals, but also likely future conditions. For example, if deforestation is increasing because of drought and adverse economic conditions, alleviating future pressures on existing forests by providing alternative revenues through harvest or ecotourism, or providing forest products sustainably, can be important options.

Exhibit 5-8. Criteria Matrix for Screening Options

	Mitigation Option 1	Mitigation Option 2
Potential for large impact on GHG emissions	High	Medium
Favorable macro-economic impacts on:		
Employment	Low	High
Income	Low	Low
Growth	Low	Low
Trade	Low	Negative
Consistency with national environmental or natural resource goals	Low	High
Consistency with development goals	Medium	Medium
Ease of implementation	Medium	High
Compatibility with biophysical characteristics	High	High
Total costs of technical option	High	Low
Compatibility with Reform Scenario	High	Low

5.5 Analyzing Technical Options in the Forest Sector

Assessing technical mitigation and policy options requires analyzing and, where possible, quantifying impacts using multiple criteria. Of these criteria, several are critical from the perspective of the forest sector, including:

- land availability and country suitability;
- GHG impacts;
- incremental costs and cost-effectiveness; and
- other criteria, such as environmental or development effects.

Each of these criteria is discussed in turn below.

5.5.1 Suitability and Land Availability

The availability of land shapes the mitigation options in the forest sector. Forests, range and grasslands, and agricultural lands together comprise most of a country's vegetative area. Changes in the land-use pattern in one sector directly influence the magnitude of land available for other sectors. In particular, land conversion from forests to agriculture or pasture lands is a common feature in many developing countries. Moreover, the regulations governing the distribution of land in one sector are often connected to those for other sectors. Because of these interactions, it is important that the availability of land and its distribution for alternative activities be evaluated in a comprehensive manner.

Characterizing the currently available land is the first step in screening and analyzing mitigation options in the forest sector. Relevant characterizations include:

- *forest land*—which may include rangelands, grasslands, or wastelands with sufficient forest cover;
- *protected land*—including wildlife sanctuaries and national parks;
- *crop land*—including both land currently cultivated and currently fallow land; and
- *other land*—including urban areas, dams, roads, and mines.

Not only the type of land, but also biophysical factors such as soil productivity, topography, and climate will affect the productivity of the land and so are relevant to the choice of mitigation option. The type and intensity of land use, such as whether agriculture is shifting or permanent, or forests are clear-cut or selectively harvested, may suggest the potential carbon sequestration gains of different options.

Evaluating mitigation options requires not only analyzing current land uses, but also tracking land use changes over several decades. In turn, qualitative or quantitative estimates of future land use activity and product demand and supply depend on demographic and economic forecasts. Demographic variables, such as human population and growth rates, rural/urban migration trends, and dependence on land resources, will determine land use over time. Economic factors - such as income level, technological developments, dependence on exports of land-based products, and rates of economic growth - will also be important. Demographic and economic information collected during the course of the forest sector study can be used also to evaluate potential mitigation options.

Most commonly, carbon sequestration will be an important by-product of other land-use goals such as timber production, soil preservation, and environmental protection. The policies that will be most useful in expanding carbon sinks must be consistent with larger land use goals. Thus, choosing relevant policy instruments involves considering the policy tools already available in the country, current carbon sequestration and land use practices, and characteristics of the particular country (see Exhibit 5-9). Instruments must be carefully matched with the types of land-use practices that are meant to be encouraged, as well as make use of existing technical capabilities and infrastructure and the resources that are available to support implementation.

Exhibit 5-9. Key Country Characteristics

Policy Variables
- Agricultural Policy
- Economic Policy
- Forest Policy

Forest/Land Use Variables
- Competing Land Uses
- Land Degradation
- Structure of Existing Forests
- Timber Production
- Physical Infrastructure and Road Access

Institutional Variables
- Legal Infrastructure
- Land Ownership
- Market Systems
- Technical Capabilities

Source: Adapted from Richards, K.R. et al. 1995. *Consideration of Country and Forestry/Land-use Characteristics.*

5.5.2 *GHG Impacts Assessment*

The GHG impact of a mitigation option is a key criterion for ranking options and subsequently incorporating them in a Mitigation Scenario. The benefit of an option is also an input into calculating cost-effectiveness. Moreover, the GHG impact under specific conditions will be important data to be used in assessing the overall effects of any national
scenario.

From the perspective of GHG mitigation policy, the net flow of carbon from the atmosphere is critical. The benefit of a mitigation option is the incremental carbon flow that occurs as a result of implementing the option. This benefit is the increase in carbon flows above that which would have occurred in the absence of the mitigation option (the Reference Scenario). This is important to consider because carbon stocks may change significantly with the ongoing land use activities. In fact, for some mitigation options such as preservation, averting these likely changes is the basis for the GHG benefit. Thus, for the purposes of analyzing a mitigation option, the assessment must be performed relative to some land use reference case that defines the expected natural and anthropogenic changes over the period of the analysis.

5.5.2.1 *Definition of the Reference Case*

The reference case for the option can be based on conditions anticipated under either the Reference (Business-as-Usual) Scenario or the Reform Scenario. The choice between these two scenarios depends in large part on the way in which the Mitigation Scenario is constructed, as discussed in more detail in Section 5.6. There is, however, no fundamental difference in terms of the methodological approaches to the analysis of a specific option. Whatever scenario is reflected in the Reference Scenario, the analysis estimates the incremental increase in carbon storage.

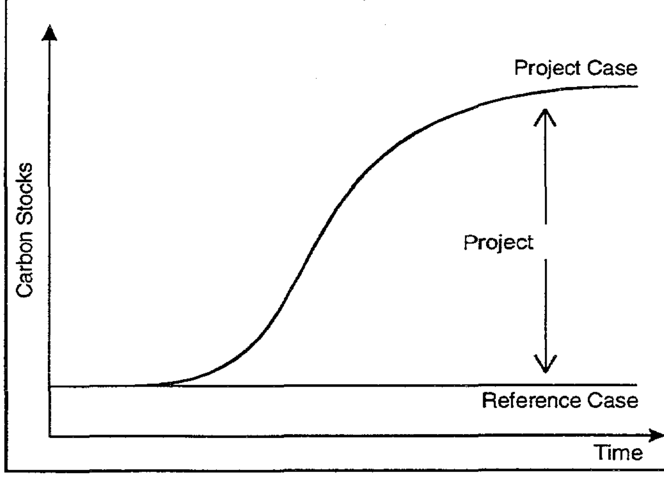
The Reference Scenario must define the specific land use management practices that will occur, as well as the necessary biophysical data required to estimate carbon storage and flows. This is the same information that is required in describing the mitigation options. Note that the Reference Scenario and the option definition will have the same initial conditions.

As part of defining the conditions of the Reference Scenario and the Mitigation Scenario, the boundary of the analysis must be defined. At this stage of the global overlay analysis, the mitigation options are typically considered at a significantly smaller scale than the national level. For example, project-level options might be analyzed on a per-hectare basis, which then allows easy application to the national assessment. However, the boundaries are not only geographic but also determine which GHG effects are captured (e.g., end-use and disposal). Defining the project boundary is particularly important for forest activities because resource demand pressures are geographically fluid and can reduce the carbon benefits of a mitigation option. These types of effects must either be accounted for in the screening analysis, or in the scenario assessment.

5.5.2.2 *GHG Assessment: Overview*

The ultimate goal of the analysis is to estimate the net flows of carbon under the project and reference cases, and to compare these to derive the incremental benefit of the mitigation option. In some cases, the flow over the time frame of the analysis may be known directly from available data. More commonly, flows are derived from estimates of the amount of carbon storage at different points in time. In both approaches, the trajectories of carbon storage under the reference and project cases are determined, with the project benefits at any point in time being the difference between the two trajectories (see Exhibit 5-10).

Exhibit 5-10. Project Benefits



Whether the analysis is based on stocks or flows, an important element is the time interval over which changes are estimated. In cases where there is little data available, or where only a scoping assessment is being conducted, a time interval of a decade or longer might be used. Intermediate storage estimates can then be derived by simple interpolation. Increasing the time intervals that are analyzed will reduce the precision, but may be sufficient for most purposes and will also greatly reduce the analytical effort required.

The stock and flow approaches differ primarily in their use of available data. Both approaches could be used to estimate different stocks in the same assessment of a mitigation option. For example, in assessing the impact of a tree plantation, the biomass growth could be assessed using known growth rates (flow approach), while the soil carbon accumulation is estimated from data obtained from sampling a mature plantation site (i.e., a measured stock at some time period). Thus, soil carbon and vegetation carbon would be estimated differently, but the results would be combined.

GHG analysis can account for carbon storage in each of the significant carbon stocks, including vegetation (biomass) stocks, soil, and end-use product pools. In addition, the analysis can account for the end-use of harvested material in energy applications, in which case fossil fuel emissions are displaced. The impact on these stocks of the various actions and occurrences under a mitigation option (and reference case) should be accounted for, including biomass growth, harvest, associated on-site decomposition and end-use of forest products (in the case of very large forest projects), and land use conversion and other disturbances.

The estimation of these stocks and flows of carbon can often rely on accepted default data (see Exhibit 5-11). However, these data are based on very general assumptions that capture average regional characteristics. Although regional default data may be useful for screening analyses, as well as for assessments that are limited in detail, greater detail may be appropriate for analyses of national policy options within a country such as Bank sector work and global overlays. More detailed information can often be obtained from experts at national and local forest management agencies, research centers, and universities. In addition to available data on carbon storage and accumulation, GHG estimates can be derived from other forest management data that may be available.

Exhibit 5-11. Default Data on Stocks and Flows

The carbon stored in a given land area is referred to as the carbon density, and is expressed in metric tons of carbon per hectare (tC/ha). Flows of carbon are also expressed in tC/ha, but are specified over some time period, typically annually (i.e., tC/ha/yr). Carbon density can refer to all carbon stocks on a given area, or a subset of these stocks. Carbon density for a given type and characteristic of forest is related to the amount of biomass contained in the forest ecosystem (biomass density).

The literature provides default values for the carbon density for many different forest ecosystems. For example, Appendix 5-A presents examples of some default data used to prepare national GHG inventory assessments (IPCC 1995). These data include information on carbon accumulation in plantations and under natural conditions, carbon storage in aboveground biomass, and soil carbon storage. These data are based on a comprehensive synthesis of currently available research.

The remainder of this section discusses important issues in the use and derivation of carbon storage estimates for each of the major stocks (e.g., vegetation, and soil). The section also discusses bioenergy projects, the estimation of GHG emissions other than CO_2, and other analytical issues such as the estimation of stocks that fluctuate over time.

5.5.2.3 Vegetation

Vegetation is the most important stock in performing GHG estimations. Credible default data are likely to be available from a number of sources. In the absence of suitable default information, the carbon density can be derived from data on biomass densities. The dry biomass density (and carbon density) is a directly measurable entity. If a particularly detailed assessment is being conducted, then direct measurement of the site-specific biomass and carbon density is often performed. Such an assessment can prove very revealing. Woody biomass inventories in Pakistan, Kenya, and Uganda have indicated that standing wood stock — including trees outside the forest, branches and twigs, brush and shrubs — has been found to be roughly 3-4 times greater than that estimated by Forest Departments for conventional "forests"[10].

In practice, biomass density estimates can often be derived from commonly available timber management data, such as stemwood volume (e.g., m^3/ha). This allows the use of existing timber inventory techniques that have been developed for commercial timber management, and also allows the use of existing research and data (e.g., yield tables). Timber volume estimates are converted to total biomass through the combination of the following factors:

- *Total (wet) biomass: timber volume ratio*-timber volume estimates that are derived from forest management information include only a portion of the total biomass present in forest vegetation. A conversion factor is applied to timber volume to account for non-commercial components, including non-recoverable tree volume, branches, and foliage.
- *Biomass density (metric tons/m3)*-timber volume must be converted to mass using biomass density information. Biomass density varies greatly by tree species, ranging from 0.31 - 0.86 g/cm^3. First order default values of 0.65 metric tons dry biomass/m^3 (deciduous) and 0.45 t/m^3 (coniferous) may be used.[11] However, if specific species are known then more detailed density information should be applied.
- *Dry biomass: wet biomass ratio*-timber management estimates are based on "wet" biomass, which is simply the biomass in its natural state. Care must be taken to ensure that data and conversion factors are consistent in their assumptions of wet and dry biomass.
- *Carbon ratio*-estimating the carbon density requires applying the carbon ratio of the dry biomass. The carbon ratio is the percentage of the total biomass weight that is accounted for by the carbon content (i.e., metric tons carbon/metric tons dry biomass). A default value of 0.45 tC/t dry biomass can be used, although this value will vary by tree species.[12]

5.5.2.4 Soil Carbon

Forest ecosystems can accumulate large quantities of carbon in the soil. Soil carbon loss is particularly important when considering land use conversion from existing forest to pasture and agricultural use. For example, large portions of the carbon stored in the soil can be released when the soil is significantly disturbed by subsequent cultivation and tilling.

Soil carbon dynamics are relatively poorly understood, particularly for tropical forests. As a result, accounting for changes in soil carbon that result from human forest sector activities can be highly uncertain. Many estimates of GHG impacts do not include soil carbon stocks for this reason, and following this approach is recommended as a conservative assumption.[13]

If soil carbon is included in the analysis, the loss of carbon is estimated as the difference between storage in the existing forest soils and that in the subsequent land use. Default information is provided in Appendix 5-A. However, the release of soil carbon occurs over a period of decades. The actual emissions in any given year may be estimated as the average release over 25 years (i.e., total carbon difference divided by 25).[14]

5.5.2.5 End-Use Pools and Bioenergy Projects

When forests are logged or harvested, carbon is removed from the stocks that represent storage in living biomass. The carbon contained in the biomass is not necessarily emitted to the atmosphere at the time of harvest, but is instead transferred to one or more separate stocks, some of which may continue to store carbon for significant periods of time. Thus, in assessing the GHG impact of land use activities that involve the harvesting of trees, it may be important (in the case of very large forest projects)to track the end-uses or other disposition of the harvested biomass.

For example, timber and other durable wood products may store carbon intact for decades or even centuries. Paper products have a shorter lifetime and decay faster, but even paper may store carbon for decades if it is disposed of in modern landfills or recycled. During harvest, considerable quantities of biomass are typically either left as slash or as dead below-ground biomass on the site. This biomass may be burned, in which case emissions will occur immediately, or it may decay over some longer time period. The decay rate of dead biomass is highly variable and depends on the climate and other physical conditions. A default decay period of 10 years for aboveground biomass has been suggested.[15] Similarly, waste wood is created during processing, and may be burned or left to decay.

When forests are logged or harvested, carbon is removed from the stocks that represent storage in living biomass. This carbon is not necessarily emitted to the atmosphere. Rather, it is transferred to a number of separate stocks, some of which may continue to store carbon for significant periods of time. This is particularly true of material that is transferred into durable wood products (although one ought to account also for transfer of carbon out of durable wood product pools as these products reach the end of their useful life). It is also true for the decay of material that does not go into wood products, but is left on-site to decay. Thus, in assessing the GHG impacts of land use activities that involve the harvesting of trees, it may be important to track the end-uses or other disposition of the harvested biomass. For example, omitting product carbon in evaluating a scenario involving a plantation or forest managed sustainably in rotations may result in underestimating carbon benefits and, hence, overestimating the unit costs of carbon sequestration.

The assessment then consists of two factors. First, the amount of the harvested material that is transferred into each particular end-use category may be determined. For the purposes of GHG mitigation options assessment, it is not usually necessary to include carbon pools contained in forest products (lumber, furniture, paper, etc.) in the analysis. It is only relevant in the case of very large forest projects which inject such large product volumes onto the market that they disturb local or national wood consumption patterns. The level and mix of national wood product consumption is determined by many factors, and the sale of harvested wood from a relatively small plantation would do little or nothing to alter that consumption pattern, but would rather simply displace production from other supply sources.

Second, the analysis must assign a typical or average duration of storage that is characteristic to each category. These data are combined to derive a trajectory of carbon storage and release in a similar manner as tracking other carbon stocks.

Bioenergy projects that displace fossil-fuel generated energy or electricity result in avoided net GHG emissions. Thus, when trees are planted for the purpose of harvesting biomass to be used for energy applications, it introduces several analytical issues. The net emissions from bioenergy projects have three components: (1) net uptake of carbon in stocks; (2) release of carbon from harvested material; and (3) avoided emissions from displaced energy production.

The uptake and release of carbon from forest carbon stocks during the growth and harvest of trees can be assessed in the same manner as other mitigation options. One important difference is that the harvested material results in practically instantaneous carbon release because it is burned, whereas other types of plantations may have long term end-use product storage as described previously. The third component, avoided emissions, depends on the energy supply sources that would have been used to generate the energy now supplied by bioenergy. Determining the displaced emissions can be accomplished following the techniques described in Section 4 (Energy Chapter).

5.5.2.6 Non-CO_2 Emissions

When biomass is burned, not all the carbon released is released as CO_2. Depending on the conditions under which it is burned, some of the carbon is released as methane, carbon monoxide, or other carbon-containing compounds. Because methane is one of the more potent GHGs, this may have a significant impact on overall GHG emissions. In addition, burning can produce emissions of nitrous oxide and oxides of nitrogen. The emissions of these non-CO_2 trace gases can be calculated using ratios based on the total amount of carbon and nitrogen released (see Exhibit 5-12).

Exhibit 5-12. Emission Ratios for Open Burning of Cleared Forests	
Compound	Ratios
CH_4	0.012 (0.009 - 0.015)
CO	0.06 (0.04 - 0.08)
N_2O	0.007 (0.005 - 0.0098)
NO_x	0.121 (0.094 - 0.148)

Note: Ratios for carbon compounds (i.e., CH_4 and CO) are mass of carbon compound released (in units of C) relative to mass of total carbon released from burning. Those for the nitrogen compounds are expressed as the ratios of emission (in units of N) relative to total nitrogen released from the fuel.
Source: UNEP/OECD/IEA/IPCC. *IPCC Guidelines for National GHG Inventories, Volume 3*

The concept of Global Warming Potential (GWP) has been developed to compare the ability of each GHG to trap heat in the atmosphere relative to another gas. As discussed in Section 3, the convention is to use CO_2 as the "reference" gas. The GWP of a GHG is the ratio of radiative forcing (both direct and indirect), from one kilogram of a GHG to one kilogram of CO_2 over a period of time (see Section 3).

5.5.2.7 Issues in GHG Estimation

As a result of the way in which carbon is accumulated and stored.in forest carbon stocks, forest sector GHG mitigation options present unique analytical challenges. In the forest sector, GHG emissions are never truly "avoided" or reduced as they are when implementing energy efficiency options. Rather, carbon is transferred to a stock, to be released in subsequent years. Thus, the analysis is often complicated by several factors, including changes in management over time, and non-permanent storage of carbon. For example, plantations managed on a rotation have fluctuating carbon storage over time that can be analytically challenging. In resolving the assessment of these issues, there are two basic choices.

One method is to track the change of each stock and future emissions. For example, in tracking the carbon in vegetation, one can account for the annual growth in each year of the rotation, and then account for the harvest at the end of the rotation. This approach is most accurate in terms of representing the physical flows of carbon. However, accounting for all the stocks and emissions from actions initiated in different regions and at different times can be computationally complicated, and accurate tracking may require data and assumptions that are not available. Moreover, because carbon storage fluctuates over time for some options, such as plantations, the GHG mitigation benefits of these options can be difficult to rank.

An alternative method that can simplify assessment is to assume instantaneous emissions resulting from certain stock changes that in reality are delayed or spread out over many years.[16] The analyst must balance the increased accuracy against the additional effort and data requirements. Assuming that emissions are instantaneous is a conservative assumption for the assessment of storage, but, if used to assess a Reference case, will lead to an overestimate of incremental benefits (or will measure benefits sooner than they actually occur).

The foregoing methods focus on carbon flows. Because the cumulative flow of carbon over time will be affected by the time frame of the study period, some analysts focus on stock measures in estimating GHG impacts. One approach is to estimate the carbon stock by the amount accumulated in tree biomass, soil, litter, and understory over a period of time, typically one or more rotations. This approach implicitly assumes that trees will be planted for carbon benefits and will not be harvested. The advantage of focusing on stocks is that the analysis is not artificially truncated at the end of the time frame for the analysis, which may occur in the middle of a rotation and thus not capture the effects of harvest. The disadvantage is that stock approaches do not provide annual flow data that can be compared with flow data in the energy sector.

Provided carbon storage in post-harvest products is not a significant fraction of total project carbon storage, the mean carbon storage approach can be used to assess stored biomass carbon, particularly for plantations or other forests that are harvested sustainably and in perpetuity. This approach calculates the average amount of carbon on-site over one full rotation. It can be calculated by summing the carbon standing crop for every year prior to harvest and dividing by the rotation length:

$$Mean\ C\ Storage = \frac{\sum_{1}^{n-1} C\ standing\ crop}{n},$$

where n equals the rotation length (i.e., the year in which harvest occurs). The mean carbon storage calculation then gives the total carbon benefit of a given project over an infinite number of rotations. This benefit is the amount of carbon which, on average, is removed from the atmosphere and stored in biomass over an indefinite period. The advantage of mean carbon storage is that it accounts for harvest, as well as carbon accumulation, in measuring carbon stock. The disadvantage is that stock measures fail to capture fluctuations in emissions or sequestration over time, or pre harvest production, e.g. thinnings. These GHG flows, however, determine the rate and timing of climate change.

5.5.3 *Cost Screening and Analysis*

Costs—both total cost and cost-effectiveness—are key criteria on which to screen mitigation options and broader policies to implement the options. Once mitigation options have been identified, analyzing the costs of these options consists of several steps:

- estimating the direct costs of any investment projects or programs associated with the option and estimating analogous costs for the Baseline or Reference case;
- estimating non-GHG benefits of the options and calculating net costs (costs minus benefits) for the baseline and scenario;
- summarizing net costs in present value or annualized terms;
- calculating incremental costs of the scenario (i.e., the net costs of the scenario over net costs in the baseline); and
- calculating cost-effectiveness measures (based on incremental cost and carbon impacts) and comparing mitigation options.

These steps are described below.

5.5.3.1 Components of Costs

Mitigation options can be thought of as a series of projects designed to expand or maintain the carbon sink or reduce emissions associated with fossil fuel use. Cost calculations should include both initial costs and the costs necessary to cover each project's development and continuing expenses and incentives for its ongoing operation. Although any cost analysis will be conducted in conformance with World Bank procedures, studies of the costs of carbon sequestration typically include a range of initial and recurring unit costs. These costs cover both direct project costs and program costs of administration and implementation:

- *opportunity costs*—measure of the value of the land in alternative uses; in its simplest form, the value of the land;

- *establishment costs* — costs of seeds or seedlings and other materials; labor costs for site preparation, planting and building access roads; and material and labor for replanting trees that do not survive the first year;
- *management costs* — cost of overall administration, technical assistance, and training;
- *maintenance costs* — recurring costs to weed and thin stocks, maintain roads, protect against fire and pests, and other operating costs over the life of the project;
- *monitoring costs* — monitoring both project activities and inventory and carbon measures, such as site surveys, before and after soil testing, and destructive tree measurements; and
- *incentive costs* — other payments, such as equipment loans or advanced harvest revenues, necessary to ensure project success.

Different cost components will be more significant for different project types, suggesting that more attention should be paid to capturing costs that are likely to be a significant portion of total costs.[17] For example, training costs may be critical in the long term success of an agroforestry project. Establishment costs will be highest for afforestation and reforestation projects and lowest for agroforestry projects. Management costs tend to be higher for projects that involve agroforestry or small-holder plantations. Maintenance costs will be higher for projects that involve long-term protection of mature or growing forests. While costs are most straightforward to measure at the project level, analyzing mitigation options may also require sector-level analyses to capture interactions between and among projects and other activities in the sector, as discussed in Section 5.6.2.

In calculating both carbon and cost impacts, it is important to define the system boundary within which impacts will be evaluated. The boundaries may be slightly different for carbon than for costs. For example, one option is to calculate costs and revenues within fairly narrowly defined boundaries; a typical boundary is the roadside.[18] Roadside costs include direct project costs on and near the site (including harvest costs) and forest-road construction costs. Excluded from the forest sector calculation, however, may be the costs associated with transporting products to the market. In contrast, carbon calculations may include the store of carbon in forest products and its fate, but exclude emissions associated with sawmills or other materials processing. Although excluded emissions and costs may be captured in analyses in other sectors, such differences can affect both the qualitative and quantitative assessment of the options.

5.5.3.2 Cost Benefit Analysis: Calculating Net Costs

Steps in Calculating Cost-effectiveness

1. Calculate annual "net costs" for each year.
2. Convert annual net costs to discounted net present value or annualized costs.
3. Derive incremental net costs between scenarios.
4. Divide incremental net costs by incre mental emission reductions.

The focus in calculating costs for a global overlay is on screening and analyzing mitigation options that produce GHG benefits. To facilitate comparing costs across options, costs should be calculated net of other accrued benefits. If the project results in revenue-producing outputs, such as timber or crops for export, the market value of these outputs should be included. For example, an agroforestry project may provide fuelwood, or a preservation project provide tourism or recreational opportunities. Any revenues generated are deducted from costs to produce a *net cost* (cost minus benefit) measure of the project. In some cases, while products are valuable to inhabitants, they are not traded in markets. Thus, some costs may be difficult to monetize and include in a net cost calculation.

Mitigation options may similarly have other benefits, such as positive non-GHG environmental impacts or beneficial development effects, which can be difficult to quantify and measure in dollar terms. Projects may provide employment and training for local inhabitants, or develop infrastructure such as roads or hospitals. From an environmental perspective, projects may protect biodiversity, provide air pollution and micro-climate control, protect watersheds, or reduce erosion. In addition, the forest has a value derived from its stock as a resource, providing a future source of timber and forest products as well as less tangible, indirect benefits for future generations.

Where possible, the values of these non-GHG, or ancillary, benefits should be included in the net cost calculations. Although techniques such as restoration cost, damage assessment, and willingness-to-pay measures are available, in many cases monetizing these benefits is difficult. Thus, for the most part, the monetary value of these services will be excluded from calculations of cost and benefits. However, they are important in selecting options for the Mitigation Scenario. Where a strict net cost calculation is impossible, such benefits can be considered qualitatively in screening and analyzing options and constructing the Mitigation Scenario. Alternatively, costs can be roughly attributed across the various benefits the project provides, thereby allocating only a portion of the costs to carbon reduction.

5.5.3.3 Present Value and Annualized Levelized Costs

In order to compare the costs of mitigation options in the forestry sector across projects, or against projects that reduce GHG emissions in other sectors - such as improved energy efficiency in the energy sector - a consistent measure of total costs and cost-effectiveness is required. The most common total cost measure is the net present value of the project, in which net costs (costs minus monetized benefits) in each year of the project are discounted and then summed over the project lifetime or the lifetime of the analysis. The discount rate chosen should be that which is relevant to Bank forest sector studies in the country of analysis. Real discount rates between 10% and 12% are commonly used by the World Bank for economic analysis of projects in developing countries. Net present value costs can also be converted to annualized (or levelized) costs using an annuity factor, for comparability with energy and other sector work, and to calculate cost-effectiveness measures.

Net present value provides a direct indicator of the benefits of the project. If costs are calculated net of harvest revenue and other benefits, present value measures of cost may be negative (i.e., the option appears profitable), although the carbon benefits are excluded. For projects involving plantations and managed forests in particular, present value net costs may be negative at reasonable discount rates.[19] For options such as forest protection, the present value indicator may also be negative if indirect benefits and forest value are included, although the evaluation of these benefits is controversial.

Some projects, such as plantations, involve multiple rotations. Maintaining the carbon stock on plantation lands requires incurring both initial and recurring annual costs over all rotations. Thus, an alternative method of viewing present value net costs is as the present value of costs incurred in perpetuity, rather than over the life of the analysis or another lifetime, such as rotation length (see Exhibit 5-13). In some sense, this measure of present value costs is a more accurate representation of the real costs of carbon storage. In reality, however, most cost analyses operate either on an annualized basis or using total discounted costs over a finite period. Thus, considerations of carbon permanence and other factors — which are pertinent to evaluating not only plantations but all forest sector mitigation options — are best dealt with by appropriate and careful design at the project level, by incorporating risk considerations into the decisions of what role the forest sector should play in an overall mitigation strategy, and how much mitigation a country should pursue in the forest sector.

Exhibit 5-13. Illustration of Net Cost Calculations

Suppose that an afforestation project has a rotation length of T years. For year t, annual costs are given by C_t and harvest revenues are R_t. If the discount rate is r, the net costs of this project can be summarized in several ways.

$$Net\ present\ value\ (NPV) = \frac{\sum_1^T (C_t - R_t)}{(1+r)^t}, \text{ or}$$

$$Annualized\ value\ (AV) = \frac{NPV}{annuity\ factor} = \frac{NPV}{\frac{1}{r} - \frac{1}{r(1+r)^T}}.$$

Both these values have been calculated for one rotation length. If the project will be managed for perpetual rotations on the plot, the annualized value can be converted into a perpetuity value:

5.5.3.4 Incremental Cost Analysis

As in estimating carbon, costs should be calculated on an incremental basis. Thus, incremental costs of mitigation options are the costs for the projects or policies over and above costs that would have otherwise occurred. Incremental costs are usually calculated as the net project and programmatic costs minus the net costs that would have occurred under the Baseline or Reference Case (see Exhibit 5-14). For the Reform Scenario, the Reference Case is the business-as-usual situation in the country. For the Mitigation Scenario, either the Business-as-Usual or the Reform Scenario can be used as the Reference Case. Incremental costs can be calculated annually (i.e., year-by-year) or using present value or annualized measures of net costs for the Mitigation and Reference Cases.

Exhibit 5-14. Incremental Net Costs

Incremental costs represent the difference in net costs between the project and the baseline. For the first year of a project, incremental costs can be expressed as:

$$I = P_i - B_i + P_R - B_R - P_B + B_B$$

where I = incremental costs
P_i = initial project costs
B_i = initial baseline costs
P_R = recurring project costs
B_R = recurring baseline costs
P_B = monetized project benefits
B_B = monetized baseline benefits

Incremental net costs can be calculated annually for each year of the project, then summarized using net present value or annualized measures. Incremental costs can also be calculated directly from net present value or annualized measures for the Mitigation and Reference Scenarios.

In a forest sector study, data limitations can affect the extent to which incremental costs can be calculated. First, data on many components of net costs can be difficult to obtain. In particular, environmental and development benefits to the environment are difficult to monetize. Even more elemental data, such as land or labor costs, may be difficult to estimate because of ownership issues or imperfect or non-existent markets. Estimates of programmatic costs, which often rely on data available from similar programs, may be difficult to compile if the option involves very different practices from those typically used in the country. For consistency, comparable measures and types of costs should be calculated for both the Reference and Mitigation Scenarios.

Further, it may be difficult to identify which costs are truly incremental. For example, because part of the opportunity cost of a project to preserve natural forest is the revenue that could have been earned if harvests had been permitted, net incremental cost tends to be lower for plantations and other projects than for preservation projects.[20]

5.5.3.5 Calculating Cost-effectiveness

Cost-effectiveness analysis is often used for environmental projects where impacts (in this case GHG impacts) cannot easily be valued. Because GHG impacts are generally measured in physical rather than dollar terms, cost-effectiveness, which measures the cost per metric ton of GHG emissions reduced, provides a common metric — dollars per metric ton — by which diverse options can be compared both within the forest sector and across sectors.

Cost-effectiveness measures are constructed by dividing some measure of incremental costs by some measure of incremental metric tons of GHGs reduced. Cost-effectiveness is calculated for the project as a whole over the lifetime of the project. In some cases, present value (discounted) costs are divided by total GHG reductions, where GHG reductions may either be discounted or simply summed. Frequently, however, cost-effectiveness is calculated by dividing annualized costs by either annualized or average annual incremental carbon benefits (flows). The annualized cost-effectiveness measure provides a means by which projects with different lifetimes — such as those in the energy sector — can be compared (see Exhibit 5-15).

Exhibit 5-15. Calculating Cost-Effectiveness

A project with a lifetime of T years has incremental *net* costs (as described in Exhibit 5-13) and incremental carbon sequestration benefits of E in each year t. Cost effectiveness can be calculated in several ways:

For the project as a whole:

$$\frac{NPV}{cumulative\ carbon} = \frac{NPV}{\sum_{1}^{T} E_t}$$

On an annualized basis:

$$\frac{AV}{average\ carbon} = \frac{AV}{\frac{1}{T}\sum_{1}^{T} E_t}$$

As a perpetuity value:

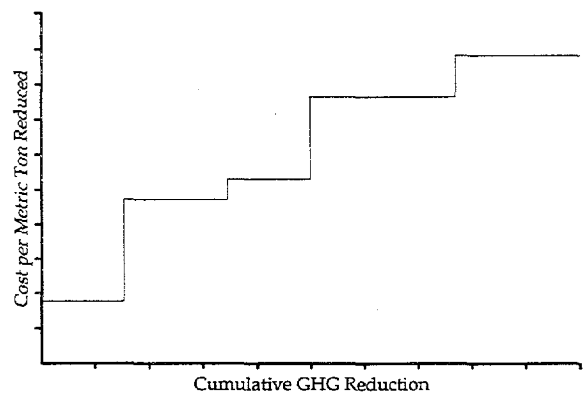
$$\frac{PeV}{mean\ carbon\ storage}$$

In most calculations of the cost-effectiveness of GHG mitigation measures in the forest sector, emissions impacts — the denominator of the cost-effectiveness measure — are not discounted but simply summed or averaged over the project life. By not discounting emissions, these measures of cost-effectiveness suggest that the timing of emissions reductions is irrelevant; projects that sequester carbon over the first few years of the project are equivalent to projects that sequester the same amount of carbon many years or decades in the future.[21] Thus, unlike measures of cost-effectiveness constructed for other types of projects, this measure provides no incentive to choose projects that provide benefits, in the form of sequestered carbon or reduced emissions, quickly. An alternative viewpoint, however, is that GHG emissions are simply a proxy for future potential damages caused by climate change. If damages were to rise at approximately the discount rate, then this measure of cost-effectiveness would be a proxy for a measure calculated by discounting rising emissions.

5.5.3.6 Cost Curves of GHG Mitigation Options

The cost-effectiveness calculations and information on the availability of land in the country for undertaking different mitigation options can be combined and summarized in a GHG reduction cost curve, sometimes referred to as a supply curve of carbon opportunities. This curve relates the quantity of GHGs that can be reduced or sequestered by different mitigation options to the cost per unit of emissions reduced or sequestered. In Exhibit 5-16, each "step" on the curve represents a different mitigation option.

Exhibit 5-16. GHG Reduction Cost Curve



The supply curve is a series of steps. Each step represents a discrete option, and options are displayed in decreasing order of cost-effectiveness, i.e., increasing order of cost per metric ton. The height of each step is the cost per metric ton of emission reduced for a given mitigation option, and the width is the quantity of emission reductions that are possible using that option. Since costs are calculated incrementally (relative to a baseline), the supply curve illustrates how expensive each additional step becomes per unit of extra GHG emission reduced.

The supply curve can be used simply to screen and rank options according to one criterion. Alternatively, depending on how the supply curve is constructed, it can provide the basis for constructing the Mitigation Scenario, as described in Section 5.6.1. For example, the supply curve described above provides the basis for determining the total financial resources required to achieve a given total reduction scenario at the lowest cost. Alternatively, options could be ordered based not on cost-effectiveness but using another criteria, such as feasibility or compatibility with the Reform Scenario. In this case, the supply curve provides information on the cost and carbon potential of different combinations of options. Depending on the adequacy and comprehensiveness of underlying cost information, the supply curve may be more or less important in the final selection of options.

Other cost measures, such as economic or financial cost estimates, can also provide useful information. Financial analysis is closely related to net incremental cost analysis, but is confined to the direct financial costs and benefits of a project, excluding broader social impacts. A financial analysis can be useful in providing a range of indicators of project feasibility such as rates of return, cash flow, and *pro forma* income and balance sheets. Economic costs estimated using welfare measures such as consumer and producer surplus changes provide information on the distribution of gains and losses when the primary impact of a mitigation option occurs in markets that are well-defined. Supply curves can be constructed using cost-effectiveness measures that incorporate these types of costs as well.

5.5.3.7 Overview of Existing Cost Estimates

A few studies have calculated cost-effectiveness measures for selected countries or projects.[22] Available estimates suggest that costs per metric ton of carbon sequestered can be as low as a few cents or dollars per metric ton, particularly in tropical areas. If so, then forest sector mitigation options appear relatively cost-effective in comparison with some options in the energy and transportation sectors. Cost estimates, however, are highly specific to the country and mitigation options being considered. Wide variation in estimated cost across the limited data available reflect not only differences in land and labor costs and carbon sequestration potential across countries, but also differences in the types of costs included and the method used to calculate cost-effectiveness.

Cost-effectiveness calculations are extremely sensitive to the methods used.[23] On the cost side, studies that do not include land costs will underestimate the cost per metric tons of emission reduction. Alternatively, excluding revenues generated from the sale of forest products and timber will overestimate cost per metric ton. Studies of forestry options differ in the discount rates used to evaluate financial outlays, which range from 4% to 10%. Finally, studies differ in the methods used to calculate carbon. Some studies sum undiscounted carbon in calculating cost-effectiveness, while others discount or annualize carbon and so find a higher cost per metric ton reduced. Yet other studies calculate mean carbon storage, which also yields a higher estimated cost per metric ton than a simple summation of carbon flows (if annualized costs are used in the numerator). Moreover, studies differ in the components of forest ecosystem carbon that are included in the calculations. Some studies include the carbon in soil, understory, and litter, whereas other studies include only above- and below-ground biomass.

One study has calculated cost-effectiveness for several mitigation options and 94 nations worldwide.[24] This study is based on a global database containing information on land availability, carbon sequestration potential, and implementation costs for several different forest mitigation options. The database was constructed by assessing published technical information and surveying professionals in the forestry sector of the nations. Cost-effectiveness is calculated using initial establishment costs (including site preparation, stocking, and labor) and mean carbon storage over a 50 year period. Revenues generated from harvest (which tend to reduce costs) and land and recurring maintenance costs (both of which would increase costs) are excluded.

Dixon et al. found that afforestation, reforestation and natural regeneration were the most cost-effective forest practices in the countries studied—costing less than US$10 per metric ton of carbon sequestered. Cost-effectiveness estimates for these practices, grouped by broad ecoregion, are reported in Exhibit 5-17. This table presents both the median value and the interquartile range (the range of the estimates in the middle 25 percent of observations). The median cost-effectiveness across *all* practices and nations was about US$5 per metric ton of carbon, with an interquartile range of US$1 to US$19. Because of differences across countries and limitations in the methods used, these estimates should be considered illustrative. Even within this study, results reflect differences in responses and methods across countries.

Exhibit 5-17. Cost-Effectiveness of Forest Options

	Median	Interquartile Range
	Dollars per tC	
Boreal		
Natural regeneration	5	4-11
Reforestation	8	3-27
Temperate		
Natural regeneration	1	0.01 - 0.43
Afforestation	2	0.22 - 5
Reforestation	6	3 - 29
Tropical		
Natural regeneration	0.90	0.54 -2
Agroforestry	5	2 - 11
Reforestation	7	3 - 26

Source: Dixon, R.K. et al. *Assessment of Promising Forest Management Practices.*

Many studies do not include land cost, which may or may not have a significant impact on the estimated cost-effectiveness of forest practices in sequestering carbon. In Thailand, the present value of the opportunity cost of land was estimated to be US$44 to US$89 per hectare.[25] In India, the cost of degraded lands suitable for reforestation was estimated to be US$20 per hectare.[26] In China, the opportunity cost of those lands which are already allocated for forestry use may be close to zero.[27] Since median initial establishment costs in the Dixon et al. study range from approximately US$250 to US$2,500 per hectare in tropical regions for reforestation and afforestation respectively, land costs could be an important cost component in some countries.

5.5.4 Assessing Against Other Criteria

While evaluating mitigation costs and emission impacts may be the principal focus of assessment, forest sector mitigation options may produce positive and negative ancillary impacts as well. Key impacts include environment and development impacts. To the extent that forest sector mitigation options modify typical forest sector policies considered in constructing the Reform Scenario, these impacts will already be considered in the forest sector study, and so they are only discussed briefly below.

Forest sector mitigation options may have a variety of environmental impacts. Tree planting, for example, can contribute to biodiversity by re-introducing native species to enhance species composition, or by reducing sedimentation of tributaries and lakes that provide habitat for fish and other species. Forest sector projects can also have negative impacts. For example, road construction to support new plantations can cause soil erosion and increase air pollution.

Economic, social, and cultural impacts may also be positive or negative as a consequence of the mitigation options. Forest preservation, for example, may increase local income from tourism but also restricts current uses of the forest. Projects may provide training and increase the local skill base or, alternatively, may divert scarce resources or skilled individuals from other useful employment. Mitigation policies may also have distribution impacts, if the supply or prices of timber are affected.

5.6 Constructing and Assessing Scenarios for the Forest Sector

Developing a forest sector mitigation strategy requires identifying and analyzing different actions that could be taken to reduce emissions of GHGs. Based on the results of this analysis, Mitigation Scenarios can be constructed that not only satisfy specific policy objectives, but also fall within institutional, political, and budgetary constraints. Assessing the GHG and cost impacts of those scenarios can be used to redefine scenarios as part of an iterative process.

5.6.1 Defining Mitigation Scenarios

Forest sector Mitigation Scenarios, which combine technical and policy options, can be constructed in any of several ways. They can be constructed to achieve carbon sequestration goals, such as maximizing achievable emissions reduction potential. Alternatively, they can be constructed following a particular strategy, such as adopting win-win options. Either way, both the technical options and the policy instruments should be chosen keeping in mind both the baseline conditions in the country and the components of the Reform Scenario.

5.6.1.1 Setting Basic Parameters

In constructing and assessing scenarios, basic underlying parameters must be specified and treated consistently. Timeframe is one critical parameter. Because of the length of time over which impacts associated with climate change are projected to occur, the time frame for GHG analysis is often quite long, extending from 50 to 100 years. Many Mitigation Scenarios rely on projections of land-use changes and economic and demographic variables, and thus may employ a shorter time-frame. Where forestry is concerned, however, long rotation tree plantations may need to be evaluated over a longer time frame.

The baseline must also be constructed carefully. The baseline represents a future in which no additional policies are put into place that are designed to encourage actions to reduce GHG emissions or increase carbon sequestration. Thus, from the perspective of the sector study, two baselines are relevant: the Reference Case (against which the GHG and other impacts of the Reform Scenario can be assessed), and the Reform Scenario itself (against which the incremental GHG and other impacts of the Mitigation Scenario(s) can be assessed).

Specifying a baseline requires judgments about future likely trends in economic, demographic, and land use conditions. In order to estimate GHG impacts, in particular, these scenarios must be fairly quantitative and specific in terms of land uses, forest cover, and projected forest inventories. Consequently, it can be difficult to select one view of the future as more likely than others. It may be helpful to define more than one Reference Scenario, reflecting low or high assumptions about key variables, such as population growth or deforestation.

5.6.1.1 Defining Mitigation Scenario Goals and Strategies

For analytical purposes, it is useful to consider several scenarios that bracket a range of technically, economically, and politically feasible outcomes. The most basic is the *technical potential scenario*. This scenario sets the upper bound of the analysis by estimating the amount of carbon sequestration possible if all technically available land area were used for mitigation options. This scenario includes virtually all options beyond the Reference and Reform Scenarios. Because it ignores many crucial economic, legal, and institutional factors limiting the realizable potential of different options, a more realistic scenario is the *achievable scenario*. Constructing this scenario requires recognizing two types of constraints.

First, the amount of carbon sequestration that can be achieved in a given country must consider the end-use needs for forest products and land in the country. In tropical countries, forests are the source of many timber and non-timber products. Designing a scenario that maintains the forest stock in perpetuity requires considering the end-use needs of inhabitants and designing a strategy that provides not only for carbon, but also for diverse financial and product benefits. End-use scenarios of this form can be analyzed at varying levels of complexity, an approach that was recently applied to evaluate forest sector mitigation options for India.[28]

Second, whether or not a scenario is achievable depends also on land tenure arrangements and on legal constraints, technical capabilities, and resource availability in the country. Constraints may limit the rate of implementation, the magnitude of overall project scale and the policy mechanisms that are selected. In choosing policy instruments as well, the Mitigation Scenario should recognize existing institutions and legal arrangements, as well as the changes recommended in the Reform Scenario.

The foregoing scenarios are relatively comprehensive mitigation strategies. Mitigation plans can also be designed to choose among technical options by following alternative selection strategies such as:

- adopting low-cost technical options or technical options that are "win-win" from the perspective of the country Reference or Reform Scenario;
- focusing on preservation, tree planting, or another technical option that seems most promising in the country; or
- incorporating options that minimize conflicts or institutional changes relative to existing Reference or recommended Reform Scenario land use policies.

A final strategy is to design the scenario to be incremental relative to the Reform Scenario. In general, there are two ways in which the Reform Scenario can be adapted to produce a Mitigation Scenario. The first is by adding options that are fundamentally different from those potentially included in the Reform Scenario, although they may or may not compete or conflict with Reform Scenario goals and policies. For example, the Reform Scenario may include forest preservation and protection; the Mitigation Scenario could also include fuelwood farms to abate the demand for cut trees. The second way is to employ technical options that expand or slightly modify programs contained in the Reform Scenario. For example, the Reform Scenario may include plantation forestry; one Mitigation Scenario may expand the area of plantations, or modify harvest rules.

The difficulty in constructing scenarios incrementally, or in using limited selection criteria, is that they may not account for interactions in the forest sector as a whole. As in the design of the Reform Scenario itself, the Mitigation Scenario should be sensitive to current and projected needs for forest products and land, how these demands will be met, and the extent to which the Mitigation Scenario can provide for them directly. Moreover, a mitigation strategy that focuses on one criterion, such as costs, may not consistently account for non-monetized, but important, impacts. Regardless of how the scenario is constructed, it should bound the technically achievable scenario with assumptions concerning the technical, institutional, economic, and sociocultural realities of the country.

5.6.2 *Assessing the Reference, Reform, and Mitigation Scenarios*

There are several challenges in assessing the Reference, Reform, and Mitigation Scenarios. One challenge is accounting for the dynamics of economic growth and change. Rapid economic structural changes occurring in many developing countries and countries with economies in transition make forecasting economic performance, land use, and other important variables difficult. Ancillary costs and benefits of the options (both positive and negative), including short- and long-term social and political costs and impacts, can be difficult to quantify. From the perspective of the global overlay, the most critical challenge is estimating the incremental costs and GHG impacts of the Mitigation and Reform Scenarios, given data and budget constraints in the forest sector study.

Developing a Mitigation Scenario that can be assessed requires defining the types and levels of activities associated with the mitigation options that are undertaken in detail sufficient for the analysis. A variety of levels of detail and depth in both scenario construction and analysis are available. In general, the method for assessment should be matched to the objective and the resources available for the assessment process. Available methods vary in terms of sophistication, and it may be difficult to obtain the data required to use a specific method.

The simplest approach is to estimate impacts at the level of the mitigation option, and then aggregate these estimates to produce an overall estimate of the impacts of the scenario. If the technical options are fairly modest in scale, this approach will be adequate. In some cases individual projects may be sufficiently large, or there may be multiple projects that collectively can affect markets, prices, or producer behavior. In these and other cases, impacts may be more widespread. For example:

- *Land prices.* If the mitigation options include afforesting significant amounts of marginal agricultural lands, then a broader level of analysis may be required to account for impacts on land prices. Changing land prices would alter not only the costs of the mitigation option, but could alter the effectiveness of financial incentives or policies used to implement the option.
- *Timber prices.* If the options involve significant amounts of new harvestable timber, then resulting price declines may discourage some producers from continuing to plant trees or manage forest land. There may also be resulting impacts on imports and exports of timber and forest products, and on the distribution of income within the forest sector.
- *Competing land uses.* If technical options compete for the same land, then an integrated model can choose the most productive uses of the land, from a carbon perspective, or otherwise constrain the feasible option set.
- *Combined policies.* Some combinations of options may have competing or synergistic effects that are difficult to analyze using a bottom-up approach that analyzes the options independently. For example, combining forest protection with more efficient wood stoves may enhance the effectiveness of the forest protection policy. Alternatively, combining plantations with policies to

reduce the demand for timber products may reduce the financial attractiveness of the plantation option.

- *Complex policies.* Some individual policies may be difficult to analyze in a piecemeal manner. For example, a paper recycling policy may have competing effects on carbon storage, depending on how the timing and magnitude of planting decisions and of the demand for virgin timber are affected.

Thus, depending on the nature, scale, and number of mitigation options comprising a scenario, in some cases it may be necessary to account, qualitatively or quantitatively, for broader sectoral and national level impacts.

Where models do not already exist, constructing sector level or national models to assess the cost and carbon implications can be extremely resource intensive. However, such models have the advantage of capturing not only interactions and synergies between options, but also implicitly account for leakage or indirect impacts on forest carbon. In particular, carbon inventories estimated and forecast at the national rather than project level can account for impacts of end-use demand on rates of deforestation.

Even where broad socio-economic models are not used, the carbon and cost assessment methods can be more or less complex. For example, although the time frame of the assessment is determined early on, within this constraint the assessment can be conducted annually, at specified intervals (e.g., decades), or for a specified endpoint. Where data and resources for modeling are limited, the approach of estimating total costs and incremental carbon at the endpoint of the options' full implementation provides information that can be used to rank and assess the options based on either overall, or average annual, impacts. This approach is particularly useful when the timing of carbon is dynamic (each consecutive time period is linked to the others over the entire time horizon). Such changes are difficult to model and assess, as in the case of a plantation forestry project.

Similarly, the resources devoted to estimating the components of cost and carbon can vary depending on the Mitigation Scenario. For options that focus on modifying end uses of harvest timber, tracking and quantifying GHG emissions post-harvest may be crucial. For other projects, such as a preservation project, assuming instantaneous emission upon harvest alters only the timing, but not the long-term consequences, of the project.

Because the focus of the sector study is on broad policies as well as on specific investment projects, assessing the GHG (and cost) impacts of the policy requires two steps: (1) estimating the effectiveness of policies in achieving the mitigation options, and (2) assessing the technical impacts of the options. For example, assessing the GHG impacts and costs of a policy providing financial incentives to encourage commercial plantations requires determining the regions in which plantations will be established. Other factors to be addressed include what types of species and management regimes will be selected as a result of the policy and estimating the GHG impacts of the plantations. Thus, a key step in analyzing broad policies is to relate them to specific, project-level actions.

The analyst has some discretion over the introduction of policy mechanisms into the analysis. If the global overlay analysis is primarily a scoping assessment to begin to understand the potential for GHG mitigation, then the analysis does not require the specification of policy implementation mechanisms. At the least, the policy mechanisms can be reviewed independently of the identification and assessment of mitigation options. However, in almost all cases, the Reform Scenario will contain national policy level recommendations, the effects of which must be assessed in terms that feed into the GHG and cost assessments. Thus, in more applied/advanced applications of the global overlay, the analysis will be conducted within the context of broad policies that will result in structural changes in the forest sector that are deemed necessary for economic development and other purposes.

APPENDIX 5.A: DEFAULT DATA

Regional default estimates may be used as an initial starting point or for comparison purposes. However, in any country for which forest conversion or regrowth is a significant source or sink, local experts and measurements should be consulted to develop more accurate values reflecting local conditions.

TABLE 5.A-1

ANNUAL AVERAGE ABOVEGROUND BIOMASS UPTAKE BY NATURAL REGENERATION
(metric tons dm/ha)

	Forest Types					
	Moist Forests		Seasonal Forests		Dry Forests	
	0-20 Years	20-100 Years	0-20 Years	20-100 Years	0-20 Years	20-100 Years
Tropical Regions						
America	8.0	0.9	5.0	0.5	4.0	0.25
Africa	11	1.0	7.0	0.7	4.0	0.25
Asia	11	1.0	7.0	0.7	4.0	0.25

Note: Growth rates are derived by assuming that tropical forests regrow to 70% of undisturbed forest biomass in the first twenty years. All forests are assumed to regrow to 100% of undisturbed forest biomass in 100 years. Undisturbed forest biomass values are from Table 5-3. Assumptions on the rates of growth in different time periods are derived from Brown and Lugo, 1990.

	0-20 Years	20-100 Years
Temperate Forests		
Evergreen	3.0	3.0
Deciduous	2.0	2.0
Boreal Forests	1.0	1.0

Note: Temperate and boreal forests actually require considerably longer than 100 years to reach the biomass density of a fully mature system. Harmon et al. (1990), for example, report carefully designed simulations indicating that a 100-year old stand of Douglas fir would contain only a little over half the biomass of a 450-year old growth stand of the same species. There is also evidence that growth rates in temperate and boreal systems are more nearly linear over different age periods than is the case in tropical systems. Nabuurs and Mohren (1993) suggest that growth rates for several different species in temperate and boreal zones rise slowly to peak at ages of 30-55 years and decline slowly thereafter. This suggests that using the same default values for 0-20 year and 20-100 years may be a reasonable first approximation. Naburrs and Mohren (1990) also illustrate that growth rates may vary as much as a factor of ten for stands of the same species and age, depending on site-specific conditions. The table values are very general representative global values from Houghton et al. (1983 and 1987).

TABLE 5.A-2
AVERAGE ANNUAL ACCUMULATION OF DRY MATTER AS BIOMASS IN PLANTATIONS

Forest Type	Annual Increment in Biomass (metric tons dm/hectare/year)
Tropical	
Acacia spp.	15.0
Eucalyptus spp.	14.5
Tactona grandis	8.0
Pinus spp.	11.5
Pinus caribaea	10.0
Mixed Hardwoods	6.8
Mixed Fast-Growing Hardwoods	12.5
Mixed Softwoods	14.5
Temperate	
Douglas fir	6.0
Loblolly pine	4.0

Note: These are average accumulation rates over expected plantation lifetimes; actual rates will vary depending on the age of the plantation. The data for the temperate species are based on measurements in the US. Data on other species, and from other regions, should be supplied and by individual countries (as available). Additional temperate estimates by species and by country can be derived from data in ECE/FAO (1992), assuming that country averages of net annual increment for managed and unmanaged stands are reasonable approximations for plantations.

Sources: Derived from Brown et al., 1986. Farnum et al., 1983

TABLE 5.A-3
DRY MATTER IN ABOVEGROUND BIOMASS IN TROPICAL FORESTS
(metric tons dm/ha)

	Seasonal Forests		Moist Forests		Dry Forests (or Woody Savannas)	
	Primary	Secondary	Primary	Secondary	Primary	Degraded
America	230	190	140	120	60	25
Africa	300	240	190	150	36	16
Asia	300	150	190	95	60	20

Sources: These average regional values are presented for illustrative and comparison purposes. They are volume-based estimates derived from a variety of sources. Recent revised estimates for aboveground biomass in undisturbed moist forests were taken from Brown and Lugo (1992) for Tropical America, Brown et al. (in press) for Asia, and Brown (1993) for Africa. Corresponding values for secondary forests were derived on the basis of the ratios of these biomass densities to the biomass density for undisturbed forests as reported in Brown et al. (1989). For seasonal forests, the ratios of the densities for tropical moist and seasonal forests for Asia, reported in Houghton and Hackler (1994), was applied to the regional values for moist forests, to obtain regional estimates for seasonal forests. Values for dry forests are "open forest" values from Brown and Lugo (1984) and multiplied by 0.77 to obtain the aboveground portion only.

TABLE 5.A-4

DRY MATTER IN ABOVEGROUND BIOMASS IN TEMPERATE AND BOREAL FORESTS (metric tons dm/ha)

	Temperate Forests		
	Evergreen	Deciduous	Boreal Forests
Primary	295	250	165
Secondary	220	175	120

Source: Primary forest estimates from Whittaker and Likens (1973); secondary forest estimates from Houghton et al. (1983). Total biomass estimates were converted to aboveground biomass by multiplying by 0.83 (Leith and Whittaker, 1975). Alternative estimates of aboveground biomass per hectare, by country, for coniferous species and non-coniferous species, can be derived using statistics provided in ECE/FAO (1992). Data are provided for 37 countries.

TABLE 5.A-5

CARBON IN SOILS IN TROPICAL FORESTS (metric tons carbon/ha)

	Moist	Seasonal	Dry
America	115	100	60
Africa	115	100	60
Asia	115	100	60

Note: The forest categories presented here are different from those presented in Tables 5-A2 and 5-A3. The average of the values for moist and seasonal forests presented above can be used for both closed forest types (broad-leaved and coniferous); the values for dry forests presented above can be used for open forests.

Source: Post, W.M., et al., 1982.

TABLE 5.A-6

CARBON IN SOILS IN TEMPERATE AND BOREAL FORESTS (metric tons carbon/ha)

	Temperate Forests		
	Evergreen	Deciduous	Boreal Forests
Primary	134	134	206
Secondary	120	120	185

Note: Alternate values for soil carbon in tropical, temperate, and boreal forests, by continent, are available in Zinke et al. (1984). However, care must be taken when choosing appropriate soil carbon values in Zinke et al. (1984). Ecosystem types in this reference may not match the ecosystem types for which clearing data and biomass estimates are available.

Source: Schlesinger, 1977, as cited in Houghton et al., 1983; and Houghton et al., 1987.

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21 Moreover, as discussed in Section 4 (Energy Sector), there is considerable debate about whether, and at what rate, long-term or "non-monetized" benefits should be discounted.

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6 Macroeconomic Analysis

6.1 Introduction

Evaluating the relationship between greenhouse gas (GHG) emissions and macroeconomic activity is necessary for two major reasons. First, the Framework Convention on Climate Change (FCCC), signed in 1992, asks its Parties to "take climate change into account, to the extent feasible, in their relevant social, economic, and environmental policies and actions....with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment..." (Article 4.1.f). The agreement also stipulates that provisions be made for assisting developing countries in identifying and communicating the technical and financial needs associated with proposed projects and response measures (Article 4.3). Upon receipt of the necessary financial and technical assistance, a developing country would then have three years to submit a communication to the FCCC. Other developing countries may submit communications at their discretion (Article 12.5). Developed countries (Annex I, including OECD and Economies-in-Transition) are required to submit communications by December 31, 1998.

The second reason is the World Bank's Operational Directive 10.04 (September, 1994), which states:

"A project's global externalities — normally identified in the Bank's sector work or in the environmental assessment process — are considered in the economic analysis when (a) payments related to the project are made under an international agreement, or (b) projects or project components are financed by the Global Environment Facility. Otherwise, global externalities are fully assessed (to the extent tools are available) as part of the environmental assessment process and taken into account in project design and selection."

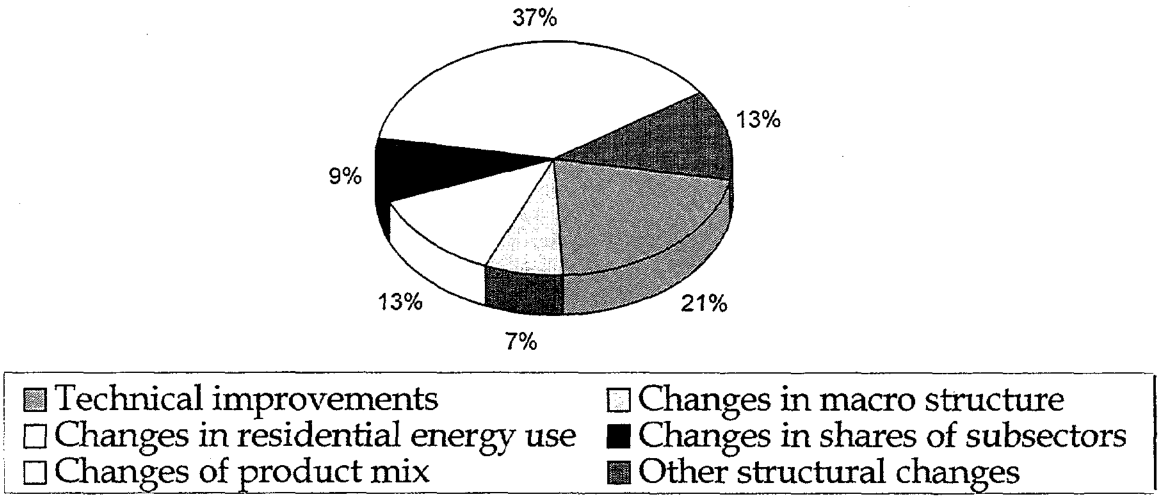
Macroeconomic and structural reforms are a centerpiece of Bank advice to many of its client countries and will contribute a large fraction of future carbon savings. A wide range of studies and the IPCC findings indicate that macroeconomic policies that effect structural change and promote efficient resource allocation are the single most important source of GHG emission savings.

First, energy subsidies add to the potential for global warming. Many countries, both in the developed and the developing world, subsidize the use of fossil fuels. A World Bank study[1] has shown that such subsidies are substantial for some countries and reach as much as 10% of their GDP. Worldwide fossil fuel subsidies are in excess of $210 billion per annum, or 20-25% of the value of global fossil fuel consumption at world prices. Phasing them out would not only save scarce public resources, but reduce GHG emissions at the same time. The study estimates that a removal of fossil fuel subsidies would reduce global carbon emissions by almost 7% and in some countries by more than 20% assuming no change in world fuel prices.

Second, evidence is growing that changes in economic structure affect the future path of GHG emissions more than any other factor. A joint study of the Chinese Environmental Protection Agency, the State Planning Commission, the United Nations Development Programme (UNDP), and the World Bank emphasizes the importance of structural change for energy intensity, energy demand and the associated GHG emission reductions. The study isolates different factors that are responsible for reducing the energy intensity of the Chinese economy below the level that would be reached with static production technologies.

Exhibit 6-1 shows that only 21% of the total expected decline in energy intensity results from technical efficiency gains at the project level such as industrial modernization, improvement in industrial equipment and energy conservation. The remaining 79% is the consequence of different types of structural change at sectoral and sub-sectoral levels. The most important one is the shift in the product mix within subsectors, which contributes 37% of the total decline. This change represents movement up the product quality ladder and a shift into higher value added products, mainly in the chemical, machinery, building materials and light industry sectors. These findings indicate the enormous effects that structural changes have on energy intensity, and consequently on energy consumption and associated CO_2 emissions. Macroeconomic and other policies can therefore have a larger impact on GHG emissions than any explicit mitigation option at the project level.

Figure 6.1. Sources of Projected Energy Intensity Decline in China, 1990-2020



Source: China: Issues and Options in GHG Emissions Control, December 1994

This finding is consistent with recent research in OECD countries. An extensive ongoing research study at the Lawrence Berkeley Laboratory analyzed the impacts of various factors on CO_2 emissions in the manufacturing industries in major OECD economies. Structural change within the manufacturing sector since 1973 alone reduced CO_2 emissions in that sector by about 20% in Germany, the U.S., and Japan. More striking, reductions in energy intensity cut emissions by 25-35% in these and most other OECD countries. Without this evolution of both structure and intensity, CO_2 emissions from manufacturing in the early 1990s would have been twice their actual level.

At the project level, although the macroeconomic impacts are likely to be small (especially for GEF-assisted projects) project expenditures will have a ripple effect on the economy, because each good purchased requires inputs for production. The short-term consequences of different patterns of investment on the host economy and GHG emissions can be estimated using input-output or general equilibrium techniques. The long-term impacts from different investment strategies and projects result from the impact of the projects on the patterns of energy consumption.

For example, a project mentioned in the Bank's study of options for reducing Ukrainian GHG emissions reduction options would install natural gas meters. The purpose of this project would be to allow the government to collect an amount closer to the full market value of actual natural gas sales. Currently, the government charges a flat monthly fee for gas, resulting in severe overconsumption of gas, and therefore a large government deficit. Metering would lead to an increase in the price of gas to households, which will profoundly affect their pattern of consumption for all goods, yielding a substantial impact on the macroeconomy.

A development strategy for a particular sector will also have an impact on both the pattern of energy consumption, and the contribution of the industry to the country's long-term economic development. Sector reports and sector development strategy papers must take these changes into account. For example, the aforementioned Bank study of possible scenarios for reducing China's GHG emissions accounts for changes in energy use assuming alternative levels of fuel efficiency improvement by sector. The study also accounts for changes in each sector's share of total output, which in turn leads to changes in energy intensity and, hence, carbon emissions.

Medium-term macroeconomic analysis and country assistance strategies, reported in the Country Economic Memoranda (CEM), project levels of GDP, inflation, investment, and other key macroeconomic variables. In accordance with the Bank's Operational Directive 2.00, the CEM also integrate the analyses and policy recommendations from sector work. Computable general equilibrium models, hybrid top-down/bottom-up models, and other techniques (such as dynamic input-output modeling), are options for evaluating macro-economic impacts. Generally, Bank-driven macroeconomic policies will result in greater economic growth. While this usually results in greater carbon use per se, carbon released per unit of energy should decrease because of increased efficiency.

This section provides guidance for incorporating the economic impacts of different mitigation strategies in ESW. The global, or climate change, overlay is one technique for assisting developing and transitional economies in accounting for global externalities and contributing to the completion of an FCCC communication. Overlays provide a bridge between the Bank's country and economic and sector work (ESW) and the need for adequate assessment of GHG mitigation options by developing countries. The incorporation of global externality concerns will also allow sector economists to become familiar with mitigation options which potentially offer a "win-win" opportunity for countries to reduce GHG emissions while enjoying substantial domestic benefits.

These guidelines highlight the significant concerns that economists should be aware of when evaluating different scenarios. They are designed to be applicable to a wide range of analyses, from comparison of specific carbon dioxide mitigation and adaptation options, to the impacts of a broad-based policy reform scenario for specific sectors. The most significant reductions in carbon emissions will occur due to changes in each industry's, or sector's, change in energy consumption. The energy sector will be affected either directly, or indirectly, by every policy or investment option. The key to the analysis is understanding how the different options affect the pattern and level of fuel consumption that ultimately lead to changes in carbon emissions.

Measuring the short-run economic impacts of an investment project can be simulated using input-output analysis, with modifications for approximating the effects on net, short-term global carbon emissions. This analysis would represent an extension of techniques used in previous Bank economic and sector work (ESW) completed for China and the Ukraine as examples. These studies both utilize input-output analysis for projecting baseline industry output levels. In the case of China, the input-output framework is also used to analyze the impact on carbon emissions of different technological scenarios.

The input-output framework can be extended to assess the impacts of project expenditures on the host country's economy. A method for extending this analysis to cover the broad range of developing nations' economies and project types will be discussed in Section 6.3. This analysis will provide the project evaluator with a general indication of the short-term economic and carbon emission impacts resulting from the initial stimulus. An input-output framework can also be adapted to extend the Bank's ESW and other macroeconomic work to account for changes in carbon emissions from structural change and economic growth.

The long-term consequences of GHG abatement projects stem from their impact on energy consumption and investment in the host country's economy. While the short-term economic impacts lend themselves to a straightforward, empirical analysis, the long-term consequences are difficult to determine from an analytical standpoint, let alone empirical estimation. This problem is acutely highlighted by the conflicting results for carbon abatement investments from studies on the Egyptian economy.[2] The same model was utilized, but due to differing assumptions (primarily about the availability of financing), Blitzer projected large, negative consequences for the economy, while El Mahgary projected positive impacts on the economy which were equal to the Blitzer estimates in magnitude. Jorgenson and Wilcoxen (1990)[3] analyze the economic impact of environmental regulations on the U.S. economy. This is done by simulating long term growth with and without environmental regulations. The model is dynamic, and runs between 1974 and 1985. The share of abatement costs in total cost is estimated for each industry, as well as the share of investment in emissions control equipment. The model is run with and without these costs, to estimate the economic impacts. The results include the finding that the coal industry is among the hardest hit by environmental regulations, at the same time that real GNP and consumption rise in the country.

In order to provide project evaluators with some guidance, a discussion regarding the potential long-term, macroeconomic consequences of GEF investments on developing economies, organized by project type, is also included in this report. These concerns will be broad-based, and will highlight some of the key factors that will need to be examined by the evaluator when assessing different projects for a specific country. By focusing on broad-based, macroeconomic consequences, several key development issues will be muted that may be of importance to a specific country's development goals - such as regional development (i.e., rural vs. urban), income distribution, and capital ownership. The ownership and control of the energy sector is also critical, and will vary widely from country to country. Other unpredictable factors include the monetary and fiscal response of the host government, as well as the political and economic structure of the economy. All of these factors will have an impact on the response of the economy to improved fuel efficiency, or to a change in fuel prices from changes in taxation and subsidies.

The remainder of Section 6 discusses the issues outlined above in more detail. It is divided into the following three subsections:

- *Section 6.2* attempts to group projects in order to facilitate a more focused analytical discussion of macroeconomic consequences.
- *Section 6.3* provides a general discussion of short and medium term consequences of GHG abatement investments and how to apply input-output for policy analysis and technological and economic forecasting.
- *Section 6.4* discusses the long-term macroeconomic consequences of GHG abatement investments on developing economies.

6.2 Major Categories of Current and Future GEF Projects

The GEF has participated in a broad range of programs to date. Exhibit 6-2 contains a list of the projects GEF funded in which the World Bank is currently involved. The projects range from the promotion of alternative energy by making financing options more affordable in India, to the subsidization of energy-efficient light bulbs in Poland. A useful categorization for the macroeconomic analysis of projects would be to rank them by the principal mechanism used to implement the option. Three major categories emerge using this option:

- **Energy conservation/fuel-switching projects.** This category includes projects which change a given industry's (or sector's) pattern or level of energy consumption. Project expenditures lead to a short-term increase in carbon emissions. However, as conservation measures are completed, the use of energy in production or consumption is altered. Changes in consumption affect the demand and price of energy in the economy, causing changes in the fuel choices made by all agents in the economy.

Exhibit 6-2. Current World Bank Project Involvement Under GEF*

Country	Project Description	Duration	Total Cost (Million US$)
Africa			
Mali	Household Energy[1]	4 years	$11.10
Mauritius	Sugar Bio-Energy[1]	5 years	$11.10
Asia & Pacific			
China	Sichuan Gas Transmission & Distribution Rehabilitation[1]	6 years	$122.70
India	Alternate Energy[1]	7 years	$186.00
Pakistan	Waste-to-Energy: Lahore Landfill Gas Recovery & Use[1]	5 years	$76.00
Philippines	Leyte-Luzon Geothermal[1]	5 years	$1,333.00
Thailand	Promotion of Electricity Energy Efficiency[1]	5 years	$89.00
Indonesia	Solar Home Systems (SHS)[2]	5 years	$74.30
Indonesia	Renewable Energy Small Power (RESP)[2]	4 years	$168.00
Europe			
Poland	Coal-to-Gas Conversion[1]	6 years	$48.32
Russian Federation	Gas Distribution Rehabilitation and Energy Efficiency[1]	5 years	$200.70
Lithuania	Klaipeda Geothermal Demonstration[2]	3 years	$18.02
Latin America & the Caribbean			
Jamaica	Demand Side Management Demonstration[1]	5 years	$12.50
Mexico	High Efficiency Lighting Project[1]	3 years	$23.00
Middle East & North Africa			
Iran	Tehran Transport Emissions Reduction[1]	3 years	$4.00
Morocco	Repowering of Power Plant[1]	3 years	$45.70
Tunisia	Solar Water Heating[1]	10 years	$20.90

*Table only includes projects classified as "Climate Change" by the GEF.

[1]Project included in Pilot Phase.

[2]Project included in GEF1.

Source: Global Environment Facility Operational Report, December, 1995

- **Agroforestry, afforestation, and other sequestration projects.** Sequestration and biodiversity projects will have a limited, short-term economic impact and a one-time effect on carbon emissions. The long-term structure of production and energy use in the economy remains unchanged, resulting in no long-term carbon emissions from economic activity, although there are long-term effects in terms of carbon absorption. Agroforestry and other biomass development will lead to the long-term development of a new sector, alter the pattern of fuel consumption, and create new economic linkages (see Section 5, Forest Sector).

- **Pricing options.** Energy pricing options will alter both short- and long-term fuel choices through changes in taxes and subsidies on energy and energy- related goods. The price of goods which require the use of energy (complementary goods), such as autos, could also be increased through similar mechanisms. In the short-run, energy-users will have less ability to substitute a given fuel type for other inputs. In the medium-term, flexibility of fuel choice will be much greater.

After categorizing the options by the principal mechanism used to implement the option, the next concern is how the option affects the choice(s) of the targeted economic group(s) or sector(s) in the economy (i.e., by changing the fuel choice in the electric industry, changing the expenditure patterns of households, rural economic development from an agroforestry option, etc.).

6.3 Short and Medium Term Consequences of GHG Abatement: An Input-Output Framework for Extending Bank Economic and Sector Work

Two ESW studies done by the Bank have used an input-output framework to analyze the impact of different macroeconomic scenarios on energy use. Both studies start by using either an explicit macroeconomic model, or assumptions about how the macroeconomy will evolve, to project changes in the *level* of final expenditures (or "final demand") by households, business investment, the government, and exports. Changes in the *patterns* of these expenditures across the sectors in the economy are also determined. The projected levels of final demand are then used to calculate the output of each sector based on assumptions about the structure of production in the economy. Both models manipulate production assumptions to account for changes (over time) in energy efficiency, the mix of capital equipment, and the process used by industry. Once industry outputs are known, energy consumption by fuel type is calculated, and an estimate of total carbon emissions can be made.

The first ESW study, done for the Ukraine, examined three possible Reform Scenarios: (1) most plausible, (2) slow reform, and (3) accelerated reform scenarios.[4] Each case was based on a different forecast of GDP growth, technology adoption, investment, and energy efficiency improvements. All cases used the same assumption about changes in the pattern of consumption, while each case assumed different long-run aggregate price elasticities of energy. These forecasts were then used to generate the levels of final demand facing each industry in future periods. Using an input-output model, total industry outputs and energy consumption were predicted. However, the Ukraine study did not calculate emissions.

The second study was the result of ESW for China.[5] The analysis of China utilized a macroeconomic model to determine dynamic changes in the pattern of expenditures by consumers, government, investment, and exports (i.e., changes in final demand). Alternative scenarios are calculated based on different assumptions about the level of energy efficiency and process/technological advancement in each sector. The outputs are then used to calculate energy consumption by fuel type, which is then converted into carbon emissions by sector. Similar emissions calculations are done for household and government energy consumption (see Box 1).

Most of the investment opportunities of interest to the GEF decrease energy consumption through energy efficiency improvements, or through substitution of low- and non-carbon-based fossil fuels. Projects which improve energy efficiency will have three primary impacts on the economy:

- A short-term increase in emissions which occurs as a result of the initial project expenditures.

Box 1. China Greenhouse Gas Model

The China Greenhouse Gas (GHG) Model was constructed specifically to assess the relationship between economic growth and greenhouse gas emissions. Because the majority of China's GHG emissions come from energy consumption (an estimated 82% in 1990), a major focus of the study was to estimate the amount of energy needed by the Chinese economy under various scenarios. The time period of interest is the coming 2-3 decades, since there is likely to be a large addition to China's capital stock during this period as a result of economic growth. In addition to growth of the economy and the consequent investment in new capital equipment, other factors that were presumed to have a large effect on GHG emissions and were therefore evaluated within the model include: (i) the structure of the economy, (ii) the energy efficiency of various sectors, particularly industry, and (iii) the mix of fuels (including renewables). The objective was to identify the key variables affecting GHG emissions in China under various scenarios, and to assess what measures could be taken to limit GHG emissions.

The Model combines a macroeconomic regression model with an 18-sector input-output (IO) table of the Chinese economy. The macro model "drives" the model by estimating the demand for goods and services. The technical efficiency of the economy is reflected in the I-O coefficients. GHG emissions from energy production and consumption are calculated by sector and by fuel from the input-output table as are the non-energy related GHG emissions, including CO_2 from cement manufacture, methane from rice fields, and methane from ruminant animals. Increases in the share of non-carbon fuels in the economy is handled by changes in fuel mix of the energy sectors and by changes in the emission coefficients. To avoid criticisms regarding the inadequacy of utilizing energy-output ratios without an accompanying description of the final demand for commodities by sector, the specific new energy-efficiency technologies employed, and the accompanying monetary requirements, the China GHG Model was designed to provide both a top-down and bottom-up perspective.

The macroeconomic analysis makes it possible to (i) estimate future GHG emissions in China and assess changes in the sources of emissions over time; (ii) examine the environmental implications of increased energy consumption; and (iii) identify the key options for reducing GHG emissions and assess the potential magnitude of emissions reduction. The analysis concludes that China's strategy for reducing GHG emissions should be based on the following principles:

- Continue and expand the economic reform program to improve the efficiency of resource use;
- Accelerate the implementation of win-win projects over the short to medium term; and
- Enlarge and improve the program to develop low-carbon-intensive energy technologies for the longer term.

- A change in the long-term efficiency or conservation of carbon-based fuel consumption.
- An alteration of the projected, long-term growth path of the host economy.

The impact of the longer-term changes significantly outweighs the impact of the initial increase in emissions.

Currently, projects are ranked on a cost-per-dollar of carbon abated basis based on post-installation, engineering estimates. However, two alternative projects, although costing the same amount, may have different input requirements necessary for installation. The result is that the two projects may have different impacts on GHG emissions in the short-term which will have an effect on the cost-per-dollar estimates that do not take the differences into account. Adequately accounting for expenditure impacts may in some cases affect the ranking of options and, therefore, the investment strategy for a sector.

By changing the pattern of fuel consumption in an economy, energy-related projects often lead to improvements in long-term economic performance while simultaneously decreasing GHG emissions. Efficiency improvements allow the economy to either produce the same product with lower energy requirements (improving the country's competitiveness), or allow households to shift expenditures from energy to other goods. Biomass and other renewable energy projects decrease the country's dependence on traditional fossil fuels, yielding improvements in the government and trade sectors of the economy. Agro-forestry options lead to economic development directly while leading to a net decrease in emissions. Overall, the result is a shift towards sustainable economic growth in the long term, both for the host economy directly, and for the global community due to lessened emissions. The long-term impacts are discussed at greater length in Section 6.4

6.3.1 Accounting for Economic Inter-linkages: A Simplified Example

The basis for input-output analysis lies in the estimated structure of economic inter-linkages in an economy. The macroeconomic impacts of both economy-wide reforms and individual projects are both implemented in an input-output framework through the same two mechanisms: changes in final demand and changes in the structure of production to meet final demand. This section focuses on changes in final demand at the project level in order to facilitate a clear introduction to input-output modeling and the key issues involved. Analysis of the impacts of a *change* in final demand due to a project or due to an economy-wide policy are applied to an input-output model in the same way. Section 6.3.2 deals with special concerns about adapting this framework to economy-wide issues. In Section 6.4, issues pertaining to changes in the structure of production will be discussed.

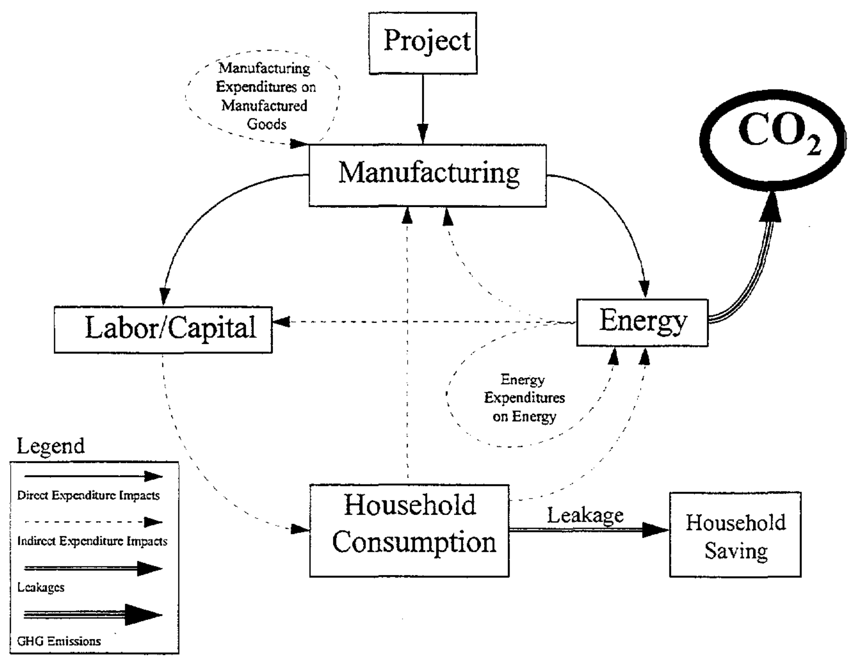
A very simplified example of how project expenditures may affect emissions in the short-run is presented in Exhibit 6-3. The sample economy consists of a manufacturing sector and an energy producing sector. The economy is also assumed to be closed with respect to foreign trade, and there is no governmental body present. The initial funds from a GEF project are assumed to be spent entirely on the manufactured goods sector. In order to fill this order, the manufacturing sector needs to utilize labor, capital, energy, and manufactured goods during production. These expenditures are referred to as the *direct* impacts of the initial investment. Since energy is required to produce the goods demanded by the investment, there will be an effect on carbon emissions, which in turn depends on the mix of energy used by the manufacturing sector.

The economic linkages can be exemplified more clearly by examining a specific industry. For example, the construction industry is an industry which will be utilized for installing facilities and will lead economic development. Construction activity uses inputs such as concrete products, fuel, labor, and imported materials to produce its output. If the assumption is made that the construction sector uses these inputs following a fixed pattern of production, then an exogenous increase in the demand for construction services will result in an increase in the demand for the goods and services needed to support the new construction activity. The four major input classifications listed above serve as useful illustrations. As the direct use of energy products by the construction sector increases, so too do carbon emissions. The energy sector now faces new demand, which it will supply using a production process that uses a broad pattern of goods and services, including construction services, resulting in an indirect increase in carbon emissions. Similar "feedback" effects will occur for the other sectors in the economy as well.

To the extent that these potential short-term pathways for increased carbon emissions appear to be of any significance, they may need to be addressed when assessing the overall net reduction in carbon emissions stemming from a marginal investment in carbon efficiency improvements. A standard input-output table of economic flows is a useful tool for assessing these impacts. An input-output table represents a double-entry accounting system which records the purchases made by each industry from other sectors (including labor, capital, imports, and indirect business taxes) in the columns, and the sales by an industry to other sectors (including consumers, investment demand, government, and exports) in the rows. Input-output multipliers[6] can be derived from the input-output system which measure the extent of direct and indirect increases in economic activity that occur as a result of an increase in the exogenous demand for a given sector.

Although providing a rough estimate of the short-term economic impacts, the multipliers alone are not

Exhibit 6-3. Economic Linkages and Carbon Emissions from a GHG Abatement Project in a Simple Economy

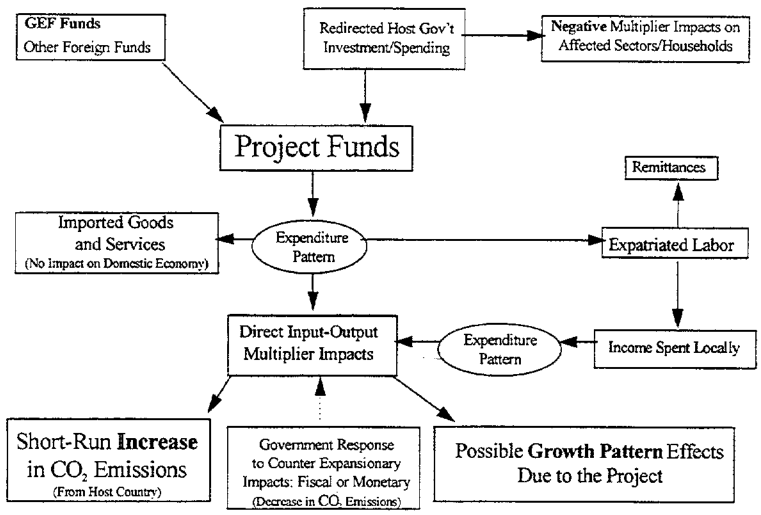


enough to demonstrate the impact on carbon emissions. In order to make such an estimate, another set of numbers is necessary which converts dollars of output by industry into carbon emissions.
Simply multiplying the change in overall output by a single indicator of carbon emissions to GDP will mask important pattern effects which result from the underlying structure of the target economy, including fuel choice, fuel efficiency, and the depth of economic inter-linkages between sectors. Carbon emission discrepancies may also result from differences in the initial expenditure pattern of the project and the source of funding. The source of funding is important, because if a large quantity of funds are reallocated by the local government to assist in project development, the change in the pattern of government expenditures may have an impact on sectoral growth patterns, and, hence, carbon emissions.

For example, two projects may be under consideration which apparently have the same overall impact on output. The first project is shown to cause a sizable increase in the use of concrete because of a focus on the construction industry, which has a comparatively high carbon emission factor for a given increase in output. The second project may cause large impacts for a service sector because of a focus on education activities, with a low emissions factor. Although resulting in the same change in GDP, the latter project will cause a much smaller impact on short-term emissions than will the former project because of the difference in emissions factors.

To finalize the analysis with respect to the current ESW framework, the impacts on general economic growth, and the corresponding changes in the pattern and level of final demands, should be taken into account when estimating the long-run impacts of a project. Exhibit 6-4 illustrates the flows that need to be accounted for, and how the flows translate into carbon emission impacts.

Exhibit 6-4. Short-term Evaluation of the Direct Impacts of GHG Abatement Projects



6.3.2 *Economy-Wide Analysis: Special Concerns*

Analyzing the emissions impacts from alternative policies or projected growth paths represents an extension of project analysis. In the short-term, the analysis will focus primarily on changes in the final demand facing each industry as a result of the policy.

Government fiscal policies may result in a change in the purchases of goods and services, resulting in a change in the pattern of expenditures. If a redistribution program decreases direct investment spending that affects industry A, there will be impacts on the economy. Simultaneously, the funds diverted from investment spending are reallocated to consumers, who purchase goods following a set pattern of expenditure (which will include some or all industries in the economy, including imports). The net change in final demand facing each industry can then be calculated.

Applying the changes in final demand by industry to input-output coefficients will provide an estimate of the change in each industry's output. The changes in output can be multiplied by coefficients relating carbon output per dollar of output for each industry. These coefficients can be derived from energy statistics for the country on fuel consumption by type for each industry. The total BTU consumption by fuel type could be derived next, followed by a calculation of carbon per BTU by fuel type. The level of carbon produced by an industry can then be divided by its output to obtain the level of carbon emissions per unit of output. Since each industry is characterized by a unique mix of fuels, a change in the pattern of final demand, without altering the level, can result in significant changes in overall carbon emissions (as in the project comparison given earlier).

For preliminary analysis, an economy-level carbon coefficient could be calculated to obtain an estimate of carbon emissions from different levels of growth. Care must be taken to ensure that comparable units are used. For example, if 1987 data are used, and the currency is valued in 1987 dollars, an estimate of emissions in year 2000 will only be valid if the economic projections are also in constant 1987 dollars. Finally, if an ESW study results in projected energy use at the economy-wide level by fuel type, calculations similar to the ones used to calculate the coefficients could be made to estimate total carbon emissions in future years. The results of ESW are likely to project trends in energy efficiency and process selection for each major industry in a given country. Changes in the pattern of expenditures by socio-economic group, exports, government expenditures, and investment may also be projected. The latter changes can be used in conjunction with projected GDP growth estimates, or with a macroeconomic model, to predict the level of final demand in future time periods. For example, the Ukrainian study assumed that Ukrainian expenditure patterns would generally tend towards European patterns.[7]

For example, the impacts from changes in the production process will require changes in the technical coefficients. Substitution can occur among capital, labor, energy, materials, imports, and other goods and services. A new process projected to be implemented by the manufacturing sector may decrease the input share of metal into production while the use of plastic inputs is increased. A change in energy efficiency may lead to an increase in the share of rent payments in the value of output. Dynamic input-output modeling overcomes this type of intertemporal problem by adjusting the input-output coefficients to reflect the use of particular technologies in each sector, as well as fundamental shifts across all sectors due to normal technological development. In the analysis of China's future emissions performed for the World Bank, the historical progress captured by input-output tables from Japan and other developing, East Asian countries was studied to assist in projecting these general shifts.[8] The Ukrainian study made explicit distinctions between new and old capital's effect on the use of energy by industry.

Similarly, changes in the mix of fuels used in an economy, as well as the level used by each industry, can be integrated into the matrix of carbon coefficients. Historical trends in other countries can be combined with specific industry energy consumption estimates in future years to specify preliminary estimates of future emissions. In general, a simple estimation of projected carbon outputs for an economy can be made if the following resources are available: (1) a matrix of input-output coefficients, (2) projected GDP, and (3) current (and projected, if available) fuel consumption statistics. Furthermore, standardized input-output and carbon coefficient tables by country type would facilitate back-of-the-envelope calculations of policy impacts on carbon emissions for developing countries.

6.4 Long-term, Macroeconomic Consequences of GHG Abatement Investments on Developing Economies

6.4.1 A Computable General Equilibrium Framework for Extending Bank Economic and Sector Work

Changes in the energy policies of developing and transitional economies aim towards market determination of energy prices (by eliminating subsidies or improving energy metering). Energy taxes may also be included in long-term energy policies. Pricing measures affect the long-term economic choices made by individual firms, households, and the government. Substitution will occur between higher priced energy and conservation or other energy-efficiency investments. Firms will face a higher cost of production, while households will have less to spend on other consumer goods. The government will have more revenue available. How these, and other responses, combine to affect the macroeconomy has been hotly debated. However, guidance can be given on the critical interactions which must be taken account of by any analysis or modeling effort.

6.4.1.1 Model Selection

In order to assess the long term macroeconomic impacts of GHG mitigating policies, a computable general equilibrium (CGE) model could be used. The development and application of general equilibrium models to climate change policies is a relatively recent occurrence. Thus far, the competing models have served to highlight the issues most critical to any macroeconomic analysis. The concerns elaborated below need to be addressed, whether a complicated model is being developed, or whether an analyst is simply summarizing potential short- and long-term impacts.

General equilibrium models are driven by prices that lead to the clearing of all goods markets in the economy. At equilibrium prices, no economic agent will have an unsatisfied, or excess, demand for any good in the economy. If this were not true, the agent requiring more of a particular good will bid up the

price in order to induce someone else to sell part of their supply. This process continues until a set of prices is reached at which no agent is willing to pay a higher price for any good in the economy.
Economic agents must make choices between different goods. Therefore, only the price of a good in relation to other goods (the "relative price") matters, and not the absolute price level. Changes in the relative price of energy, compared to other consumer goods and production inputs, occur through several mechanisms including:

- Elimination of direct subsidies;
- Imposition of carbon (or energy) taxes/marketable permits;
- Ending a system of cross-subsidization among energy types; and/or
- Reduction in the demand for energy due to conservation or fuel-switching projects.

Recent analyses of energy taxation have led to widely different conclusions about the impacts on sectoral and macroeconomic variables. These differences are the result of inconsistencies in the choices and assumptions made by modelers.

The main advantage of CGE models is the consistent modeling of economic inter-relationships between different types of agents (i.e., households, producers, government, and other institutions), each of which optimizes a production or consumption function. The result is a set of consistent prices that account for all the substitution options available and clear all markets for each good. CGE models also offer considerable flexibility in choosing functional forms to represent optimizing behavior. This flexibility allows for straightforward inclusion of several types of substitution based on price.

The disadvantage of CGE models is that they generally assume that markets function smoothly, and that energy consumption is efficient. This problem may lead to conclusions that overstate the cost of mitigation by not including options that may be available at negative cost, which could be identified if bottom-up, or engineering, cost approaches were used. Other problems are more practical, including data limitations and the length of time needed to organize, run and interpret a CGE model.

6.4.1.2 Substitution Effects

The economy will adapt to a change in relative energy prices through numerous substitution possibilities. For example, a carbon tax may cause the price of coal to increase relative to natural gas due to differences in carbon per Btu between the two fossil fuels. Some producers will find it advantageous to utilize natural gas, rather than coal. Although a large number of substitution possibilities exists, they generally fall into four major categories.[9]

- **Intra-fossil fuel substitution** (IFFS): Lower carbon fossil fuels are substituted for more carbon fossil fuels.
- **Non-fossil fuel substitution** (NFFS): Renewable, non-fossil fuel based energy sources (such as solar and biomass) are substituted for traditional fossil fuels.
- **Other factor energy substitution** (OFES): Capital, labor, and other factors are substituted for energy in the production process.
- **Product substitution** (PS): Less energy-intensive products substituted for more energy-intensive products in consumption.

CGE models generally contain an explicit treatment of energy substitution due to price changes for each industry in the model. The models also incorporate a mechanism for converting the changes in energy consumption occurring under a Reform Scenario into changes in overall carbon emissions.

Other types of substitution will also occur in market supply and demand choices. Most developing countries will not be able to influence the prices of goods on the international market. Therefore, the "small country" assumption generally holds, which means that countries face a fixed price on the international market. As the cost of supplying goods using domestic sources increases, suppliers will try to substitute less expensive foreign goods for domestic goods. The degree to which this type of substitution is possible will depend on quality differences between domestic and foreign goods. Modelers must also deal with the issue of industry aggregation (i.e., if steel and textiles are included in the model as a single "manufacturing" industry, substitution from changes in the price of one good will be diluted because of aggregation). The easier producers and consumers can substitute foreign goods for domestic as prices increase will critically affect projected GDP.

6.4.1.3 Scope

An important factor for many countries is how a policy will affect specific regions, such as rural vs. urban. For example, an increase in the price of diesel fuel will cause the cost of traditional, rural-based agricultural production to increase. As a result, domestic agricultural production will be less competitive with foreign production. This may lead to negative macroeconomic consequences in the rural region. Had a national outlook or model been selected, this critical impact may have been overlooked. Models are either regional or multi-regional, where the scope of the model ranges from global, global with regions, multi-national, national, regional, or multi-regional in scope.

6.4.1.4 Policy Implementation

How a price mechanism is implemented is important to evaluating macroeconomic impacts. The most obvious questions concern the level and timing, how the mechanism enters the system or model (e.g., an excise tax on gasoline), and whether or not the policy is unilateral, multilateral, or global. The government's response also plays a significant role. The government's budget will increase in response to the ending of subsidies or the imposition of taxes. The most critical concern is how the increase in the budget of the host country is "recycled", or disbursed, back into the economy. Several methods exist for recycling revenues, focusing primarily on returning the funds to households via changes in marginal or average labor taxes, or via lower capital taxes. Other options include using the funds to cut the budget deficit, accomplish income re-distribution goals, or improve economic development through project investment. The government may also invoke a monetary response if the price mechanism leads to a higher rate of inflation.

6.4.1.5 Level of Sectoral Detail

If a model is limited to a small number of industries, it may fail to account for critical substitution and growth patterns in specific industries. On the other hand, the inclusion of too many industries leads to a model that is difficult to estimate due to lack of data, time constraints, and model complexity. Selection of industries to be disaggregated in a model must be done carefully with the objectives of the analysis in mind. Industries which are expected to undergo substantial changes in the structure of production, or will be affected by a specific policy, should be included as a separate sector. For example, if the steel industry is expected to undergo substantial changes in its production process, resulting in lower energy intensity, the industry should be included explicitly in the model. If the policy involves a specific tax on coal products, then the coal sector should be disaggregated.

6.4.1.6 Dynamic Elements

Some models are short-term in nature, projecting only a static, one-period adjustment by comparing a "base-case" scenario with an experimental scenario. Longer-term models attempt to overcome this limitation by building in assumptions on investment and saving behavior, the effect of prices on technical change, and factor malleability/mobility through the use of closure rules. Exogenous changes resulting from population growth, autonomous energy efficiency improvements, and other factors are also built into the model. Other possible issues that might be incorporated into the CGE framework are the presence of market imperfections and exogenous limitations to the market's ability to respond and grow over time. These include the presence of market power, political instability, and investment and foreign exchange constraints. The government may also intervene during policy implementation by changing its fiscal or monetary policies

6.4.2 *Target Sector and Induced Impacts*

The long-term impacts of projects differs according to the sector in which the project originates. This section discusses how projects in the following sectors affect energy consumption and the technical relationships in the economy: power and other energy industries, residential, commercial/industrial, transportation, forestry and agriculture, and government. Although this section focuses on how different types of projects affect the macroeconomy, the analysis also has cross-applications to how expected technical improvements detected by ESW will affect future input-output and other economic relations.

6.4.2.1 Power and Other Energy Industries

Projects in the energy producing sectors (excluding metering and efficient pricing options) reduce emissions by two main routes: (1) increasing the efficiency of energy production and delivery from carbon-based energy sources, or (2) fuel-switching to fuels with lower carbon-to-Btu ratios such as natural gas, or a renewable/alternative fuel option. Assuming that the production of energy for final consumption is now possible at a lower cost, the principle result of the project is an outward shift in the supply curve for energy producing industries. Depending on the elasticity of energy demand in the economy, this shift will cause an increase in the quantity demanded. One adverse result is that industries and consumers not affected by the project may actually become more energy-intensive. However, the lower cost fuel allows domestic firms to be more competitive internationally.

The pattern of ownership in the power and energy producing sectors is a critical variable in determining the extent of price changes, and the distribution of any increase in profits occurring as a result of the project. In many developing countries, the government owns and operates the energy sector, or a monopoly situation exists, where the government imposes performance regulations. These institutional structures may prevent savings from being passed on to consumers. The increase in profits will be disbursed to either the government or investors. If the profits flow to the government, two results will occur. First, the new funds may displace foreign borrowing, but leave domestic expenditures unaffected, resulting in no new emissions of carbon. Second, the funds may be used to increase the amount of government spending beyond the current level, resulting in further economic expansion and carbon emissions which will partially offset the carbon reductions from the project. If the profits accrue to investors, the economic impact will depend on the distribution of ownership and the pattern of savings and investment in the local economy. The government will also earn tax revenue from the flow of profits to investors.

The project may offset the need on the part of the government or energy sector to invest in new capacity in the short-term, allowing critical foreign exchange to be used for other development purposes. This is also a benefit which would result from an energy conservation program, which decreases future levels of demand, thus diminishing the need for more facilities. This is a critical concern for a developing country which may have to import the labor and capital for production of new resources.

Projects which attempt to develop agricultural value-added activities (e.g., domestic biomass utilization projects) will result in a shift in industrial structure. First, a new (or strengthened) linkage will occur between the domestic energy production and agriculture sectors. Second, if the biomass resource will be produced from a specific agricultural development, then a new sector will be present in the economy with a unique production function. The economic impact depends on both the impact of a viable new industry, and the extent to which traditional fossil fuels are displaced. For example, a decrease in imports of oil will lead to a direct increase in available foreign exchange. An alternative path results if the project competes for the output of a traditional agricultural sector. The price of the agricultural product may be bid up, crowding out other domestic consumption.

It is difficult to make an a priori statement about the economywide effects of projects that enhance the production capability of the energy producing sectors. Whereas these projects at a minimum do not cause a decline in the level of energy sales, conservation projects in other sectors which decrease the demand for energy products may result in a decline in the energy sector. As the energy sector decreases its purchases of intermediate goods from other industries, the domestic economy might experience negative economic pressure. The degree to which the energy sector purchases its inputs domestically, in addition to its structure of production, will determine the magnitude of the downward pressure. This pressure will be offset by the extent to which other sectors adjust their spending due to increased profits or income available to spend on goods other than energy. In fact, if other sectors become more efficient due to increased energy efficiency, they lower their costs and will probably increase production as long as it is profitable to do so. As production increases, employment in the economy as a whole should benefit from more efficient resource utilization. If intermediary inputs into the energy sector are tradeable goods, any surplus could be exported. If not, the input sectors would indeed contract, freeing labor and capital, and increasing production in other sectors because of lower factor prices.

Another class of projects involves improvements in the utilization of traditional biomass fuels for cooking and heating. Reductions in the consumption of these fuels will result in a decline in biomass consumption and deforestation activities (with respect to GHG emissions). If a market-based biomass fuel industry exists, conservation efforts will cause a general economic decline in production activities of these resources (unless the biomass is exported instead). However, these declines will be partially or fully offset by increased expenditures by households on all goods due to an increase in household incomes from the conservation activity. If biomass is collected by households, i.e., through non-market mechanisms, households will experience an increase in time available for other activities, including paid labor. Forestry activity and biodiversity may also improve, resulting in improved economic growth.

6.4.2.2 Residential

As suggested in the previous section, the main impact of residential conservation will come from the increase in income resulting from the decrease in energy expenditures. This may be the result of either conservation through education or new equipment, or through fuel-switching (e.g., switching from charcoal to natural gas in cooking). These savings stem directly from the resulting change in the pattern of final demand expenditures. The portion of each household's income made available due to the project will either be saved or spent on a mix of other goods, including imports and energy. The end result is a change in the mix of final demand expenditures that leads to a change in the pattern and levels of sectoral outputs in the economy. Problems typically associated with demand-side management (DSM) efforts should also be expected, such as snap-back, which could lead to an increase in the amount of energy consumed.

6.4.2.3 Industrial/Commercial

The main result in the industrial sector is a change in the matrix of technical coefficients-that is, the share of each energy type in a dollar of an industry's output will shift both between fuels and between energy and other inputs, including profits. Changes will also occur if operation and maintenance schedules change. These changes are net of changes in the technical coefficients matrix resulting from the autonomous improvements in energy use over time. The changes will be greatest for supply-side power projects, which cause direct shifts in the pattern of energy consumption by utilities and refineries. Changes in energy efficiency will improve the competitiveness of the country's export goods, which will further boost growth. Changes in the pattern of material inputs into production may also change. If materials with a lower energy intensity (in production) are substituted for materials with higher energy intensities, both sectoral development and carbon emissions will be affected.

Certain studies point out that the distribution of savings from energy conservation is also important.[10] If a firm undertakes an efficiency improvement and the cost savings are passed on to downstream industrial customers through a lower price, it may lead to a shift towards more energy-intensive materials in production. If the savings continue to be passed through the economy in successive rounds of activity, the overall price level in the economy may decline, improving the overall international competitiveness of all affected industries. The mix of final demand may shift as well. If savings are distributed via corporate profits, then further impacts will depend on the ownership patterns of firms (i.e., if more is spent on corporate investment, or if profits are distributed to owners, who either invest or consume the revenues). If savings are used to increase wages, there may be inflationary impacts, as well as changes in the level of final demand.

6.4.2.4 *Transportation*

Efforts to improve the fuel economy of a country will change both the technical coefficients matrix and the pattern of final demand because all agents in the economy will be affected. Indirect improvements in the economy may occur in congested areas if efforts result in decreased air pollution. Air quality improvement could lead to health-related benefits that increase the productivity of the labor force. Transportation options include improving the efficiency of the transportation system (to reduce traffic congestion/idling), increasing fuel-efficiency standards, using alternative fuels, improvements in public transit, or creating opportunity costs to driving (e.g., high-occupancy-vehicle (HOV) lanes, restricted access roads, tolls) or owning a vehicle (e.g., increase the cost of parking).

If the project attempts to improve the efficiency of the transportation system by decreasing congestion or improving the quality of the roads, the opportunity costs associated with automotive and trucking transportation decrease. More people can be expected to choose automotive means of transportation over public transit and alternative methods, and increase the number of miles they travel. This will result in increased demand for cars and trucks, which are often imported, and an increase in gasoline sales to offset the gains from the infrastructure improvements. Industries will experience lower costs of transportation, which will improve profits and cause a lower price for each industry's output. Conversely, options which increase the opportunity costs to driving and owning a vehicle will have the opposite effect, roughly speaking.

Options that focus on improving fuel efficiency will cause a decline in energy demand per unit (as discussed in Section 6.4.2.1), and will most likely lead to increased vehicle maintenance and purchase costs (to both households and industries). The impacts of alternative fuel options will depend on the alternative fuel and its source. If the fuel selected is ethanol produced from domestically grown biomass, there will be impacts similar to those associated with other biomass projects described in Section 6.4.2.1. However, if the alternative fuel is natural gas, or biomass derivatives produced in other countries, the impact on the host economy may be minimal because the project results in substitution between imported oil and other imported fuels. Fuel switching in motor vehicles may result in conversion and an increase in maintenance costs over time. If a price-per-mile difference results, then price-induced economic impacts will also result.

6.4.2.5 *Forestry and Agriculture*

If a forestry or other sequestration policy is chosen, there will be numerous long-term impacts depending on the initial option. If an agroforestry option is selected, there will be a long-term structural change in final demand and the technical coefficients of the agricultural sector. The resulting product will either be sold domestically or exported, which will alter the pattern of final demand in the economy. If the forestry products compete as an energy source in the domestic economy, other carbon-based energy sources may be displaced, resulting in net carbon emission reductions. If imported energy sources are being displaced, overall final demand in the economy would increase, resulting in multiplier impacts on the economy. If the wood products are exported, final demand will increase as well.

The development of a competitive agricultural product will fall between two extremes, in terms of the impact on the structure of production and final demand. One extreme would be the complete displacement of other agricultural activity. The other extreme would occur if an adequate stock of land, labor, and capital is available to support the beginning of a new enterprise, without displacing or altering the prices of inputs utilized by other industries. The former case would result in little change in the overall level of final demand, and a shift in the pattern of agricultural production, with little consequence on the domestic economy. The latter case would result in an economic improvement by utilizing surplus resources, causing a sustainable improvement in the economy. The greater the economic growth induced by a forestry option, the greater the increase in energy consumption in the economy, which will dampen the goal of decreased emissions from the forestry option. Other options, such as converting corn or sugar to energy, may also lead to permanent changes in the structure of both technical coefficients and final demand for both the agricultural and energy producing industries, as well as strengthening industrial linkages through the development of value-added activity.

6.4.2.6 Government

Tax revenues will grow or decline depending on economic growth (corporate and household income taxes, ad valorem sales taxes, etc.). The main decrease in government revenues will result from energy taxes. The biggest concern with respect to long-term growth in the economy stems from the question of what the government does with the revenues. As demonstrated by studies which examine revenue recycling, potentially large differences exist depending on how funds are rerouted by the government.

6.4.3 Combining the Bottom-Up and Top-Down Approaches: The MARKAL-MACRO Model

The MARKAL-MACRO model is the most advanced effort to date for considering how changes in the structure of energy production and energy prices interact with the macroeconomy. The model represents a combination of the bottom-up and top-down modeling paradigms. MARKAL is a dynamic linear programming model that optimizes a network representation of an energy system, from extraction to transport to end use. The model minimizes the cost of supplying energy services to the economy, accounting for a large number of demand- and supply-side options, environmental constraints, and technology characteristics. MACRO is a single producer/consumer neoclassical macroeconomic growth model that creates an endogenous feedback mechanism between the energy supply system and the overall economy.

An examination of the MACRO module provides useful insights into concerns critical to long-term energy-economy interactions. The MACRO module was developed by Alan Manne to support his ETA-MACRO global model for analyzing the imposition of international carbon constraints.[11] The following interactions are accounted for by MACRO:

- The trade-off between energy expenditures and investment.
- The dynamic impacts of different levels of capital accumulation over time.
- Inter-energy service substitution in production.
- Inter-factor substitution in production between energy services and capital/labor.
- Substitution between capital and labor.
- Autonomous conservation.
- Consumer utility maximization and the trade-off between consumption and investment.
- Rates of market penetration by different supply technologies.
- Time lags of demand in response to changing prices.

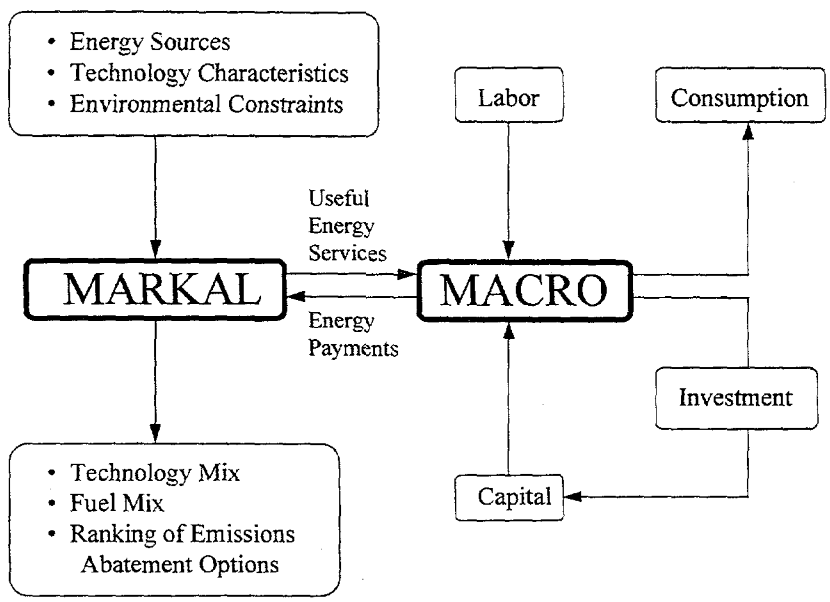
One of the principal advantages of the MACRO module is the need for only a limited set of socioeconomic data, which may already be available as a result of ESW. The standard overview of the MARKAL-MACRO system provided by the Brookhaven Institute is reproduced in Exhibit 6-5.

Aggregate output (Y) is allocated between, or balanced by, inter-industry payments for energy services (ES) and "final demands" for current consumption (C) and investment (I):

$$Y = C + I + ES$$

According to this specification, an increase in the cost of energy services will result in less funds for consumption and investment. Investment drives the accumulation of capital available for future time periods in the model. Therefore, the productive capacity of the economy will be lower in the future than if energy costs had not increased.

Exhibit 6-5. Overview of the MARKAL-MACRO Modeling System



Source: U.S. Dept. of Energy, Country Studies Management Team. 1995. Guidance for Mitigation Assessments: Version 2.0. March, Springfield, VA.: U.S. Dept. of Commerce - National Technical Information Service.

In addition to being a claim on the economy's output, energy services are also an input into the economy's production structure. In order to accommodate this interaction, an economy-wide production function is specified which allows for several levels of substitution in production. The first level of substitution concerns the competition between capital and labor versus energy service inputs in production. If the cost of energy services rises, then firms are assumed to substitute towards more capital and labor inputs to partially offset the energy cost increase. The second level of substitution occurs between capital and labor, and also between the various types of energy services. The model also contains a parameter that explicitly allows for autonomous energy efficiency improvements (AEI) due to changes in government policies and the structure of the economy, which lowers the amount of energy needed in production.

Consumption and investment decisions are based on the utility maximization of a single consumer. Savings and investment decisions are determined so as to maximize the discounted utility of consumption. Conservatism on the part of consumers is reflected in hurdle rates, which reflect a combination of lack of information, lack of ready cash or available credit, risk aversion, and other factors which may lead consumers not to purchase the technologies prescribed by the bottom-up approach. Other modifications are currently under development that will allow for the inclusion of stochastic variables (such as world energy prices) and the incorporation of MARKAL-MACRO into a world trading system.

APPENDIX 6.A: LITERATURE REVIEW

A limited number of studies have been done on the short- and long-term general equilibrium impacts of investment flows and energy efficiency projects. This appendix presents a summary of the relevant studies reviewed for this analysis as background material for project evaluators. One problem with conducting this analysis has been the dearth of studies which examine the macroeconomic impacts of energy/carbon efficiency improving projects in general. Studies that have been done examine the issue from the perspective of an economy-wide improvement in energy efficiency, rather than the impact of specific policies or programs. Other studies examine the direct costs and benefits of a category of projects, but do not analyze the impact on the macroeconomy. Despite these difficulties, some tentative conclusions are drawn and presented at the end of the section.

Carbon and other energy taxation policies have been examined to a larger extent compared to direct investment options, especially for the developed economies. A substantial number of studies have been done over a broad enough range of economies that the macroeconomic impacts of pricing policies, and the associated impact on carbon emissions, can be roughly stated for a range of circumstances. The impacts of ending cross-subsidization policies and the potential impacts of efficient pricing of energy, which is of particular importance for former Soviet Union countries, have received comparatively little coverage in the literature. However, a recent study (discussed later in this appendix) has been done concerning the elimination of energy-related subsidies on the U.S. economy. Furthermore, an attempt to understand the macroeconomic consequences of correcting these policies may be discussed in the context of energy taxation (price increases), as efficient pricing policies would lead to a reduction of energy expenditures by the government. A review of the studies done to date are presented in Section 6.A.2, which suggests a bounded range into which these impacts will fall. Several, critical issues that modelers must deal with when constructing models are also presented throughout the discussion, with an emphasis on the issue of revenue recycling.

6.A.1 *Summary of Selected Studies on the Macroeconomic Impacts of Direct Investment Projects*

Five studies were reviewed that dealt with the longer-term, macroeconomic consequences of direct investment with an emphasis on energy efficiency improvement projects. Although each study differs with respect to model formulation, study area, time frame, and a host of other concerns, the studies do begin to trace out a mapping of the potential impacts which may result from energy efficiency -related investments. Possible upper and lower bounds on the potential impacts are perhaps the most useful result of this review. The review also highlights critical concerns which will need to be adequately dealt with by future modeling efforts.

Semboja used a simple, static computable general equilibrium (CGE) model to analyze the impacts of significant energy efficiency improvements on the Kenyan economy.[12] An approximately 25% improvement in efficiency across most of the sectors in the Kenyan economy resulted in a small increase of 0.5% in GDP, and an improvement in the balance of trade of 44.7%, caused by a 1.9% increase in exports and a 1.7% decrease in imports. Because of the static, short-term nature of the model, there was a significant energy rebound effect, causing an increase in energy consumption of 1.7%, despite a 0.54% reduction in the energy intensity of production.

A study undertaken by El Mahgary, et al. examined the impact of energy efficiency improvements on the Egyptian economy.[13] Options were ranked based on a bottom-up, engineering model, which ranked options by cost-effectiveness. In stark contrast to an earlier study by Blitzer, et al., a substantial improvement in GDP was projected (about 1% per annum for a 10% decrease in projected 2020 emissions, 2% for a 20% improvement, and about 4% for a 40% improvement).[14] The assumption is made that a 10%, 20%, or 40% reduction leads to a 10%, 20%, or 40% decrease in emissions, respectively. Overall investment and welfare improved significantly, and at an increasing rate for the three levels of carbon reduction. They argue that these savings are in line with other work done on the macroeconomic impacts of conservation measures done on the U.S. economy. The three levels of improvements are based on projected costs and benefits associated with approximately 30 different efficiency measures, including fuel-switching, efficient lighting, and other demand-side management measures.

According to the authors, Egypt, like many developing countries, has substantial opportunities for profitable, very low-cost energy efficiency improvements (often said to be available at negative or zero marginal cost). This large range means that there is substantial growth potential to be gained from implementing energy conservation measures. This study highlights the problems inherent in the non-dynamic nature of the Semboja study (i.e., the rebound effect may be important in the very short-run), but as the production and consumption structures are altered due to the conservation activity, increased growth occurs concurrently with declining emissions. Unlike the Blitzer model, the assumption is made that all of the conservation measures are economical from a cost-effective perspective (even including a 25% increase in cost to account for unforeseen implementation costs). Because the measures are not as technology oriented and do not have high net positive costs as in Blitzer, the financial constraints were considered to be non-binding, contributing to the reversal of Blitzer's results.

Blitzer, et al. (1992), predicts that forced emissions reduction constraints will act like a tax on energy with respect to the impacts on growth. The study reports that annual growth rates range from 2% to -4% (for 20% to 40% reductions in carbon dioxide emissions) in the tenth year of adjustment, compared to the baseline of about 4%. However, by the fifteenth year of adjustment, all of the annual growth rates are positive, and by the twentieth year and beyond, the rates are equal to or exceed the baseline growth rates. This type of convergence is associated with taxation measures, and indicate that the principal effect of the forced conservation measures were short-term in nature.

A recent study of the impact of conservation measures on the U.S. economy calculated the impact of a 12.8% decrease in the consumption of fossil fuels across industries, including utilities, using a static, computable general equilibrium model.[15] The result was an overall decrease of 1.44% in GDP and a 4.41% drop in employment from the improvement in conservation. Investment fell by 4.41%, while exports increased 2.75% and imports decreased by 3.63%. The energy industries fare well, despite the sharp increase in conservation, because the fall in consumption leads to a decrease in the relative price of energy products, causing substitution towards energy in production. The energy sectors only decline by 1% to 4% as a result of the improvement in conservation. Overall, the improvements in purchasing power, international competitiveness, and multiplier effects were not great enough to offset the economic declines in the energy industries. The most notable result of this study is that a 12.8% improvement in conservation only led to a 3.32% decrease in carbon dioxide emissions. The authors conclude that, as a rule of thumb, energy conservation may need to be several times higher than the overall carbon dioxide mitigation goal in order to meet the target level of emissions.

Yamaji examines the impacts of "free" conservation projects on the Japanese economy.[16] The projects are free in that the costs of financing the grants to businesses and households are not considered. The analysis assumes different lead-times for the introduction of new facilities, and accounts for a bottom-up model of marginal costs of conservation rising (i.e., as the amount of the subsidy rises, the decrease in carbon emissions begins to level off). The study estimates that the multiplier impacts on carbon dioxide emissions from the exogenous flow of funds is quite small. They estimate that a 20,000 yen per metric ton subsidy would be required to reduce carbon dioxide emissions by 40 million metric tons in 2005, and that at this level of subsidy, the economic impact on the economy from the increased expenditures would be less than 0.1% of baseline GDP. They further estimate that real GDP improves by 0.05%, and carbon dioxide reductions of 9.4% in 2005 are achieved as a result of the expenditures.

Lolos and Zonzilos examine the impacts of Community Support Framework (CSF) transfers from the European Community to Greece over the 1989-1993 time period using a dynamic CGE model.[17] The transfers were equal to roughly 2% of GDP and 6-7% of investment during this time period. These transfers are relevant to this analysis as the funds were earmarked for improvements in infrastructure, human resource training, vocational training, and restructuring productive capacity, where the latter focused on technical progress in industry, energy, and tourism. The study separated the effects into supply- and demand-side effects. The supply-side effects occurred due to technical progress. The total effect on GDP was 0.2% in the first year, snowballing to 0.5% by 1995, two years after the funds ended. Other variables were positively affected by the improvements by 1995 (Inflation: -0.04%; budget deficit as a share of GDP: -0.14; Investment: +0.20%; and Private Consumption: +0.54%). The demand-side effect on GDP was 0.7% per year on average, indicating significant leakages from the original 2% share of GDP. Combining the supply- and demand-side impacts, GDP was 0.84% greater than the baseline, while unemployment was down 1%, and private consumption was up 2%, while the real exchange rate appreciated and inflation increased slightly. After the program ended, the demand effect exerted a downward effect on GDP of about 0.5% per year over the baseline level. The article assumed non-accelerating technical change and surplus labor, which may have indicated more significant impacts from the CSF than predicted by the model.

The studies described above provide little empirical consensus as to either the direction or magnitude of the impacts of projects to improve energy efficiency. Overall, the studies seem to suggest that incremental changes in energy efficiency are not likely to have significant impacts on the overall growth rate of the economy. Most of the studies examined a high level of efficiency improvement within the target economy, which is not likely to be the case with most GEF direct investment projects. Even if large projects are undertaken, the studies indicate that the effects on the macroeconomy will be relatively small, as the examination of CSF funds indicated (a 7% increase in investment funds causing only a 0.84% improvement in GDP). Blitzer, et al., provides a lower bound on the economic growth impacts of projects to reduce carbon emissions, which, in the case of a 10% decline in emissions yielded a GDP growth rate which is only 1% lower that the baseline. El Mahgary, et al., eased the investment constraints on the Egyptian economy (and other constraints), similar to the effects of GEF funding, to show that positive economic growth rates and decreases in carbon emissions will occur simultaneously over the range of "costless" reduction options. Rose and Lin impeach the zero-cost viewpoint by including a full assessment of conservation's impact on the energy sector. However, as suggested above, assessing efficiency improvements in the context of a developed economy such as that of the U.S. will differ from the situation in most developing countries and less-developed countries. Therefore, the 1.44% decline in GDP (for a 12.8% efficiency improvement in industrial production only) projected using a model for the U.S. economy could be viewed as a further lower bound on conservation's economic impact.

6.A.2 *Summary of Studies on the Macroeconomic Impacts of Efficient Energy Pricing Policies*

A number of studies have been carried out which attempt to assess the macroeconomic consequences of energy taxation and subsidies on a target economy. Cline conducted a useful survey of the most prominent economic assessment models as of 1991, which attempts to summarize the impacts reported by other modelers.[18] The result is a "rule of thumb" for calculating the impact of a given percentage reduction in carbon emissions on GDP. Several studies have been recently published which assess the impacts of energy taxation policies on a range of countries and policies. However, policies designed to end energy subsidies have not been as extensively analyzed as energy taxation. Two studies were found to be relevant to policies aimed at ending energy subsidies, one for the U.S., and one for oil exporting nations are discussed. The inferences from these studies are reported, with special emphasis given to the role of revenue recycling on the macroeconomic results.

Since the objective of this work is to find broad-based standards, little attention is given to the structure of the economic models reported. The flaws of computable general equilibrium and other modeling approaches are well known, and repeating them here would mask the objective. Instead, the focus will be on the type of policy being modeled in each study, and the reported results for that policy. The structure of a model will be discussed only if the results deviate substantially from the expected range of impacts, based largely on the conclusions of Cline.

Cline attempts to synthesize the results from the most important studies of carbon reduction policies up to early 1992. Several studies are included in this synthesis.[19] Each study utilizes disparate measures of the percentage changes in emissions necessary to maintain emissions at a specified, benchmark level, usually assumed to be the 1990 level. Furthermore, the models differ substantially on key points, such as the types and degrees of substitution allowed in the model, the dynamic elements of the model (GNP and population growth, investment, technological change, etc.), scope (global, national, regional, multi-regional), the level of disaggregation, the type of model selected, how the tax is implemented (timing and level of taxes), revenue recycling, and so on. One feature common to all of the models is that they implicitly incorporate the impacts of GDP changes in the final calculations of carbon reductions. The work by Cline tries to create a standard of comparison by aligning the different studies on the basis of percentage change in reductions for a given year, and the impact of the forced reduction on GDP. Comparison is not possible for all of the studies because the CBO-DRI and Department of Energy only examined the short-term impacts.

Cline's analysis makes use of an econometric model based on model results which have been standardized and transformed into observations. The negative change in output, or GDP, predicted by each model is regressed on the percentage change in output, time, and a constant. The results show that there is a considerable range for "free" improvement, which is indicated by the negative constant value of -1.25. The most important finding is that a 10% decrease in the amount of carbon emitted will result in a 0.9% drop in GDP per annum over the baseline. He also shows that there is a significant time factor of 0.025% per year, i.e., carbon emission reductions undertaken 10 years in the future will result in a rate of GDP growth which is 0.25% higher than if the same action were taken in the current period. This is a result of the future availability of cheaper backstop technologies assumed by most of the models. Cline also notes that despite the potentially high required emission reductions required by some models, all of the models generally estimate GDP impacts in the range of 1-3.5% of baseline economic growth per annum. These results are mainly applicable to long-term impacts on growth (2025+). Furthermore, these estimates do not explicitly include estimates of potential price-induced efficiency improvements in the use of fossil fuels, which may indicate that the estimates are too low.

The short-term impacts of carbon taxes have been addressed recently in an updated version of the DRI model for the United States, sponsored by EPRI.[20] Their model uses an explicit macroeconomic module which explicitly models international trade, monetary policy, and investment, final demands, and the energy sectors. The results of this model are applied to a 105 sector input-output table to obtain sectoral outputs, which in turn fuel a regional analysis module. The model shows that GDP falls by 0.7% by 2000 and by 2.3% by 2010 for a US$100 increase in carbon taxes starting in 1995. The GDP price deflator increases by 2.3% and 3.9%, the net effective capital stock decreases by 1.1% and 4.3%, and potential GDP falls by 0.5% and 1.9%, in 2000 and 2010, respectively. The model recycles revenues via a constraint that hold deficit spending constant. Some of the tax revenues are therefore given back to households in a lump sum manner, and the rest is used to maintain baseline deficit levels to offset revenue losses from decreased growth. Revenue recycling will be discussed further below.

Several studies have now been done which examine the impacts of various energy taxation policies on the macroeconomies of selected countries. Numerous studies have been done for the United Kingdom,[21] while others have been done for Norway[22], Kenya[23], Belgium[24], and the Philippines.[25] The studies done for the UK, as well as recent work by Jorgenson, et al., highlight the importance of revenue recycling options in macroeconomic assessments.[26]

Revenue recycling is a critical issue in the current debate over the impacts of carbon taxes, and refers to how the revenues from the carbon tax are utilized by the government. The argument is that potential economic gains are possible if the revenues from a carbon tax are used to decrease the amount of some other distortionary tax in the economy. Options range from deficit reduction, which will cause the most severe impacts, to decreasing other taxes, such as value-added taxes (VAT) on non-energy products, average or marginal wage taxes, or property and capital gains taxes, which will generally produce negative, and, possibly, small positive impacts on growth. Expansionary impacts could occur if the government used the revenues to finance large-scale, non-fossil fuel research and development projects, resulting in macroeconomic imbalance and inflation.[27]

Two studies have been done on the economic impacts of various carbon reduction agreements on the economy of the United Kingdom.[28] Both studies explicitly examine revenue recycling as a factor in reducing the economic impacts of energy taxation. Barker, et al., examines the proposal by the Commission of the European Communities (CEC) to implement a European carbon tax. The proposed tax would start at US$3 per barrel oil equivalent in 1993, rising US$1 per year until the tax reached US$10 per barrel in 2000. The carbon tax would be implemented as an increase in the ad valorem tax rate allocated across different energy carriers. The rates would be allocated across fuel consumption, 50% based on calorific value, and 50% based on carbon content. The model explicitly allows for the CEC proposal to exempt certain, energy-intensive industries so that the overall competitiveness of the UK economy is not diminished substantially as a result of the tax. OPEC is assumed to reduce production to maintain stable world prices for oil. The exempted industries are assumed to behave as though they had to pay the new tax, as the policy would likely include measures requiring firms to improve their energy efficiency. The model demonstrates that the impact of this measure would be minimal on the UK economy, resulting in a 0.09% decrease in GDP in 1995, reaching 0.19% in 2000, and gradually diminishing to 0.17% by 2005. Total primary energy use declines from -1.2% in 1995 to -5.6% compared to the base case scenario, but when fuel switching is accounted for, the latter figure translates into a 12% reduction in baseline carbon dioxide emissions.

The examination by Ekins provides a summary of other studies' predictions for the year 2005 of a US$10 per barrel oil equivalent tax on various OECD countries, starting in 1990.[29] For the more developed countries in the European Union (West Germany, France, Italy, and the UK) the results show that GDP drops by about 0.53% on average assuming revenue recycling through a cut in direct taxes on household income. Other revenue recycling options are considered, and, not surprisingly, the GDP losses are considerably greater when tax revenues are used to pay down public debt (from -0.92% to -2.19%), and considerably less if used to offset other VATs (from slightly negative, to +2.69% for the UK). The employment effect is significant in that energy price increases relative to the price of labor cause employment to improve by +0.01% for the four countries on average. The price level is reported to be 2-5% higher than in the baseline case. A study by Sondheimer[30] placed the inflationary impact at under 1% for the UK over the 1991-2000 period, while the study by Barker actually predicts lower price levels initially, and only eventually becoming slightly higher by the year 2005.

The results of studies done for four smaller European countries are also discussed, including Belgium,[31] Denmark,[32] Portugal,[33] and Ireland.[34] A similar tax is assumed to be enacted in 1991, and the impacts in the year 2000 are reported. The impact on GDP ranges from -0.69% to -2.62% with no revenue recycling (deficit reduction) and from -1.65% to +1.12% if a VAT reduction is used to recycle the revenues. The changes in employment are approximately equal to the changes in GDP.

The impacts on international competitiveness for various sectors are also assessed with respect to the position of the UK among the G-7 countries (USA, Japan, Germany, France, Italy, Spain, and the UK). The iron and steel, chemical, non-ferrous metal, and non-metallic metal industries experience the largest declines (about 4.5% for each) in trade intensity (percentage ratio of exports plus imports to production, indicating that these industries have the highest carbon intensities). However, if tax revenue is rebated to the carbon intensive industries, the impacts on trade intensity are lessened by 1 to 4% for the carbon intensive industries, and cause the non-carbon-intensive industries to experience a cost improvement.

As referenced previously, other studies on the effects of carbon taxation in developed nations include Proost and Regemorter (1992), Glomsrod (1992), and Yamaji, et al. (1993), for Belgium, Norway, and Japan, respectively. The study by Proost and Regemorter for Belgium projects the impacts of excise taxes on energy necessary to yield a 30% reduction in 2005 baseline carbon emissions using a general equilibrium model. All tax revenue is recycled to consumers in lump sum fashion. This policy results in drops of 1.8% in GDP, 8.1% in investment, 2.3% and 2.6% in exports and imports, and 0.4% in terms of trade compared to the baseline by 2005.

The study by Glomsrod uses a computable general equilibrium model to examine the impacts of a carbon emission stabilization policy (starting in 2000) in 2010. The price of carbon-based fuels climbs to over twice the baseline level in order to achieve this objective. The Norwegian energy market is unique because all electricity is generated from hydroelectric sources, and Norway is a net exporter of carbon-based energy. The results indicate that GDP is 2.7% lower than the baseline in 2010, investment is 1.3% lower, and imports and exports fall by 4.1% and 6.8%, respectively. No account is given of how the tax revenues are disbursed.

Yamaji, et al., utilize a general equilibrium framework to estimate the impact of cutting carbon emissions by 36% in 2005 compared to the baseline emissions projections. The goal of the policy is to maintain emissions at the 1988 level. The results indicated a 6% decline in GDP from the baseline. Even incorporating revenue recycling, the results still indicate a 5% decline in GDP. This is a surprisingly high value in comparison to the other studies done to date, especially Jorgenson and Wilcoxen, who project only a 1% decline in GDP over baseline from a 27% reduction in carbon emissions in the year 2005 for the U.S.[35] The model contains an inter-fuel competition sub-model, an energy conversion block which determines the price of secondary energy goods, and allows for non-clearing markets. These features are unique to this model and may be the reason for the sharper decrease in the GDP compared to other models. The options for fuel-switching and conservation available to Japan may also not be as diverse as those for the United States, which implies higher costs for achieving a given percentage decline.

Two studies were found that analyzed the impact of energy taxes on developing economies. The reason for the small number is that little work to date has focused on the impacts of these policies on developing countries. Cline makes a similar comment in his chapter on macroeconomic models. The first study was done by Semboja, which estimates the impact of a substantial increase in the Kenyan energy sales tax (48.6%) over the original tax levels to maintain a constant balance of payments condition.[36] The model used was a static, computable general equilibrium model for Kenya. GDP and imports both decline by 5.3%, while exports increase by 0.6%, and total energy use declines by 4.8%.

As a result of the lower economic activity, government and household revenues declined overall. Since the tax was applied uniformly to all energy commodities, the tax is not indicative of the effects of a carbon tax, which recognizes the differences among fuels. Since fuel substitution is not explicitly modeled in this study, the effects of carbon taxation measures are likely to be overstated. However, the model stands alone as one of the few studies done on the effects of energy taxation on less developed countries in general. Only 25% of fuel use in Kenya comes from oil-based fuels, with the other 70% coming from biomass. Semboja also notes that most of the technologies used for production of goods are energy-intensive, meaning that any attempt to reduce oil use will incur economic losses, especially since the country has no domestic supplies.

The study done for the Philippines by Uri and Boyd examined the possible effects of eliminating the tax on petroleum products (48% on premium products, and 24% on other types of refined products) using a computable general equilibrium framework, which is similar to examining the impact the energy taxes have had on the economy.[37] The results will be a worst-case scenario, as the loss of tax revenue is not replaced. The producing sectors' output is 3.7% lower under the energy tax. The less energy-intensive sectors are stronger than they would be without the tax by roughly 2-4%. Consumption by households is 13% lower than it would be without the energy tax, and net government revenues are 62.4% higher.

The elimination of subsidies in developing countries could result in substantial benefits for developing countries. The debate over the definition, measurement, and macroeconomic impacts of energy subsidies is beginning to heat up due to recognition of the impact of the subsidies on energy use and, hence, carbon emissions. Since many energy subsidies distort the pricing mechanism to favor carbon-based energy, the subsidies lead to inefficiently high consumption. By ending the subsidies and allowing the price mechanism to operate, governments have more money to either save or recycle to consumers, using recycling methods similar to those discussed above.

One of the primary objectives for offering subsidies, including cross-subsidizing various energy types, is to accomplish distributional goals. However, as Birol, et al., have noted, these goals are more appropriately accomplished through direct government transfers to the target socioeconomic group.[38] One reason for this is that there are no adverse substitution impacts due to the artificially low energy price. In production, industries will become more energy-intensive, making labor and capital more expensive which could lead to unemployment and underinvestment, which will eventually lead to a potentially energy-inefficient resource base. Households will alter both the mix and level of their consumption pattern in response to a decrease in prices. Another reason is that energy subsidies often flow to the upper-income classes, rather than the rural and urban poor.

The macroeconomic impacts of subsidies primarily stem from the effects on the balance of payments and government revenues. Even though the amount of output produced by the energy sector remains the same, based on the world price of oil, a domestic subsidy increases the quantity demanded domestically, reducing the quantity available for export (or increases the level of imports in the case of a net-importer of oil). This has a negative impact on the balance of payments. Furthermore, energy subsidies are a drain on government finances. If the government operates the energy distribution and production, the government will experience drains from both decreased oil revenues, and having to supply more oil at a lower price domestically.

Although the Birol, et al., study examined the impacts of subsidy elimination on the domestic demand for energy, it did not address the macroeconomic impacts. However, a study was recently completed which analyzes the macroeconomic impacts of direct subsidy elimination in the United States. The Jorgenson-Wilcoxen-Slesnick model, developed by Dale Jorgenson Associates for the EPA, and reported in Shelby, et al., applies a computable general equilibrium model of the U.S. economy to a policy entailing the elimination of US$15.4 billion in direct energy subsidies (about 3% of total energy expenditures), including subsidies to non-carbon energy sources.[39] Carbon emissions drop by 4% annually over the base case for the period 1990-2050. Removing the subsidies contributes 30% of the total reduction in emissions required to achieve stabilization of emissions from the U.S. overall. If the revenues are recycled via a decrease in capital income taxes, GNP will improve by 0.2% over the base case due to the favorable impacts of increased investment on the economy. If recycling occurs through a reduction in marginal labor taxes, growth increases, but only gradually, to 0.1%, as the opportunity cost of consuming leisure increases, causing workers to supply more labor and produce more output. Finally, a change in the average tax rate results in an increase in consumption, and no increase in labor supplied, resulting in a -0.3% change in growth. The model is not capable of analyzing the impacts of a change in the budget deficit as a result of the decrease in subsidies, so no "worst case scenario" is available.

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Environment Department
The World Bank
1818 H Street, N.W.
Washington, D.C. 20433
202 473 3641 202 477 0565 FAX